Australian National University

A Thirst for Change: Can Irrigation Technologies Reach Nepal's Poorest?

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Declaration

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Manita Raut
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Abstract

In this thesis, I ask a deceptively simple question: Who is able to irrigate, and on what terms, in a landscape shaped by agrarian inequality? Grounded in mixed-methods fieldwork, conducted between April 2023 and January 2024, in two wards of Shambhunath Municipality in Nepal's *Madhesh* plains, I approach groundwater irrigation not as a neutral technical input but as a socio-material field shaped by land relations, institutional practice, and everyday power. Drawing on political ecology, science and technology studies, I develop the concept of a bundled architecture of access to theorise irrigation as a layered achievement rather than a discrete act of 'adoption'.

Combining a 401-household survey with prolonged ethnographic immersion, in-depth interviews, and visual methods, I show that irrigation unfolds through sequential thresholds. Secure land enables fixed infrastructure. Tubewells condition access to electric pumps as material devices. Electric pumping becomes affordable, stable, and institutionally recognised where enrolment in the electricity system, via a subsidised electric meter, is possible. Each layer presumes the previous. Multivariate analysis reveals that landholding scale is the strongest predictor of access to fixed groundwater infrastructure, particularly tubewells, yet land operates differently across technologies. For tubewells, land serves as both a gateway and a gradient. For electric pumps, infrastructural alignment and social position outweigh land size among landowners. Diesel pumps concentrate where electrification is absent, clustering among socially marginal households as a costly technology of coping rather than a step toward inclusion. Access accumulates rather than diffuses.

I find that households cultivating small or insecure plots irrigate through borrowing, renting, and negotiation, assembling water through relations and labour rather than ownership. Women in migrant households increasingly manage electric pumps and fields in practice, while constrained by norms of asset control and institutional recognition. Irrigation support programmes intended to expand access are frequently reinterpreted and captured by locally powerful actors, concentrating infrastructure in areas where land, capital, and institutional visibility already exist.

I reframe groundwater irrigation as a lived politics of access. What appears as non-adoption is often structural misalignment rather than individual reluctance. Technology does not travel freely. It settles

along lines of property, recognition, and power, reproducing agrarian difference even as it promises transformation.

By situating irrigation within everyday relations of land, labour, and recognition, this research points toward a different future for water governance. In an era of climatic uncertainty, the challenge is not only to extend infrastructure but to redesign the socio-technical systems through which groundwater becomes available. Equity will depend on whether irrigation can be organised as a shared livelihood foundation through tenure, electrification, and institutional recognition that accommodate mobility, informality, and collective use, rather than as a privilege secured through position.

List of Abbreviations

ACIAR	Australian Centre of International Agricultural Research
ADB	Asian Development Bank
ADS	Agriculture Development Strategy
AEPC	Alternative Energy Promotion Centre
AKC	Agricultural Knowledge Centre
AMPP	Agricultural Mechanization Promotion Policy
ANU	Australian National University
B.S.	Bikram Sambhat
CDO	Chief District Office
CGIAR	Consortium of International Agricultural Research Centres,
CIMMYT	The International Maize and Wheat Improvement Centre
DADO	District Agriculture Development Office
DoWRI	Department of Water Resources and Irrigation
DTW	Deep Tube Wells
FAO	Food and Agriculture Organization of the United Nations
FHH	Female Headed Household
FMIS	Farmer Managed Irrigation Systems
FPE	Feminist Political Ecology
GESI	Gender Equality and Social Inclusion
GWRDB	Groundwater Resources Development Board
H1	Hypothesis 1
H2	Hypothesis 2

H3	Hypothesis 3
HHs	Households
HP	Horsepower
HREC	Human Research Ethics Committee
iDE	International Development Enterprises
IDS	Institute of Development Studies
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
IMP	Irrigation Master Plan
IMT	Irrigation Management Transfer
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
JAF	John Allwright Fellowship
JLO	Joint Land Ownership
kVA	kilo-volt-ampere
kW	Kilowatt
MHH	Male Headed Household
MoAD	Ministry of Agricultural Development
MoALD	Ministry of Agriculture and Livestock Development
MoEWRI	Ministry of Energy, Water Resources and Irrigation
MS	Mild Steel
N	Number
NSO	National Statistics Office

NEA	Nepal Electricity Authority
NGO	National Government Organization
NPR	Nepalese Rupee
NWP	National Water Plan
NWRS	National Water Resources Strategy
OBC	Other Backward Classes
ODI	Overseas Development Institute
OR	Odds Ratios
PAN	Permanent Account Number
PhD	Doctor of Philosophy
PM	Post Meridiem
PMAMP	Prime Minister Agriculture Modernization Project
PVC	Polyvinyl Chloride
RAID	Researchers in Agriculture for International Development
SCOT	Social Construction of Technology
SE	Standard Errors
SHG	Self-Help Group
SLC	School Leaving Certificate
S.N.	Serial Number
STS	Science and Technology Studies
STW	Shallow Tubewells
TAFSSA	Transforming Agrifood Systems in South Asia
UPVS	Unplasticised Polyvinyl Chloride

USD	United States Dollar
USQ	University of Southern Queensland
VAT	Value Added Tax
VDC	Village Development Committee
WRA	Water Resources Act
WUAs	Water User Associations

Glossary

Access (to irrigation technology): The ability to use a technology, whether through ownership, rental, sharing, or informal arrangements. It is used consistently to capture both formal and informal modes of use.

Adoption (of Irrigation Technology): Refers to awareness, take-up, and continued use of technologies over time. This thesis includes both initial acquisition and sustained use of the technologies. Those discussed are tubewells, pumps (mostly electric, diesel, and solar-powered where relevant), and subsidised government-issued electric meters at a discounted price. This definition applies primarily to smallholder and marginal farmers, for whom technology investment represents a substantial and largely fixed commitment. Larger landholding households may engage in more flexible, moving into and out of specific technologies seasonally in response to water availability, input costs. The adaptive pattern is distinct from the sustained adoption trajectory that the definition captures for resource-constrained farmers.

Bundled Architecture of Access: A conceptual framework developed in this thesis to describe irrigation access as a cumulative alignment of land, infrastructure, social position, and institutional recognition. Access emerges through layered thresholds rather than discrete adoption decisions.

Caste: A system of social stratification shaping access to land, labour, authority, and infrastructure. In this thesis, caste is operationalised primarily as Dalit and non-Dalit.

Dalit: Historically oppressed caste groups subject to systemic exclusion from land ownership, public institutions, and infrastructure. Dalit households face layered barriers to irrigation access.

Diesel Pump: A mobile pump powered by diesel fuel. Diesel pumps require no grid connection but are costly to operate and labour-intensive. They are commonly used where electrification is absent or inaccessible.

Electric Pump: A motorised pump powered by grid electricity, used to lift groundwater from a tubewell. Electric pumps are considered transitional technologies that depend on both physical and institutional infrastructure.

Farmers: In this thesis, farmers refers to agricultural households engaged in cultivation under a range of land ownership and land-use arrangements, consistent with the Agriculture Knowledge

Centre (AKC) landholding categories used in Nepal's Terai. This includes landless households farming as tenants or sharecroppers; marginal farmers (owning less than 0.5 ha, approximately less than 15 *kattha*); small farmers (owning 0.5-2 ha, approximately 15-60 *kattha*); and farmers owning landholdings larger than these categories. The terms large, largehold, and large-scale are used in a relative sense to denote farmers with more land compared to marginal and small landholders, and do not refer to large commercial, corporate, or plantation-scale farming.

Female-Headed Household (FHH): A household in which the household head is reported as female in survey or administrative records. In this thesis, female headship is treated as a descriptive indicator of formal headship, not as a direct proxy for women's authority, autonomy, or control over assets. In some cases, women are recorded as household heads due to male out-migration, while key decisions continue to be shaped by absent male members through remittances, instructions, or kinship relations. Female headship is therefore understood as relational and context-dependent, shaped by migration patterns, gender norms, and intra-household power dynamics.

Infrastructural Citizenship: The condition of being recognised by the state through infrastructure, such as electricity meters. This thesis examines how access to irrigation is mediated by bureaucratic eligibility.

Landless Farmer: A household that does not own agricultural land. Landless households rely on rental, sharecropping, or wage labour and are structurally excluded from many irrigation technologies.

Madhesh: The southern flat plains of Nepal along the Indian border, historically known as the Terai. It is a politically and socially distinct region shaped by agrarian livelihoods, caste hierarchies, cross-border mobility, and long-standing marginalisation within the Nepali state.

Male-Headed Household (MHH): A household in which the household head is reported as male in survey or administrative records. This category captures formal headship status and does not necessarily reflect the full distribution of labour, responsibility, or decision-making authority within the household, particularly in contexts where women undertake substantial agricultural and irrigation work.

Marginal Farmer: In this thesis, a marginal farmer refers to a household cultivating up to 3 *kattha* of land ($\leq$ 0.1 ha). More broadly, farmers owning less than 0.5 hectares are also considered

marginal, as they operate on very small, often fragmented plots. Marginal farmers face severe constraints on investing in fixed, capital-intensive irrigation infrastructure.

Migration: Migration refers to the out-migration of household members for labour, commonly to Indian cities, Gulf countries, or within Nepal. Such migration reshapes household labour availability, remittance flows, and investment capacity.

Non-Dalit: All caste groups other than Dalit.

Relational Bricolage: Everyday practices through which farmers assemble access by borrowing, renting, sharing, and negotiating across social relations, when formal infrastructure is unavailable.

Remittance: Income sent by migrant household members. Remittances may enable some investment in irrigation but can also weaken on-farm management capacity.

Subsidised Electric Meter (agricultural meter): A state-issued subsidised electricity connection for agricultural use. Meter access requires proximity to the grid, payment of fees, and land documentation, and signifies formal inclusion within the electricity system.

Tenant Farmer: A farmer cultivating land owned by others under informal or verbal agreements. Tenants typically lack the documentation required for fixed infrastructure and state programs.

Tubewell: A fixed groundwater extraction structure is drilled into the aquifer. In this thesis, tubewells represent land-embedded and capital-intensive irrigation infrastructure.

Water Market: An informal or semi-formal arrangement through which farmers buy, sell, rent, or share irrigation water, usually mediated by pump owners rather than state-regulated systems.

Units and Measures

***Kattha* (Nepal)**: A local unit of land measurement used in Madhesh. One Nepali *kattha* equals approximately 0.0338 hectares (ha).

***Bigha* (Nepal)**: A larger land unit equal to 20 *kattha* (approximately 0.677263 hectares).

Kattha* and *Bigha: India-Nepal Difference: Units with the same names differ across India and Nepal. All references in this thesis follow Nepali standards used in Madhesh.

Maan: A traditional local unit of weight used in rural Nepal, where 1 *maan* = approx. 40kg, commonly applied to grain in everyday exchange.

Kilogram (kg): The standard metric unit used in surveys and analysis. Local units, such as *maan*, are converted to kilograms as needed.

Quintal: A unit of weight equal to 100 kilograms, commonly used in South Asian agricultural contexts.

Currency and Numerical Terms

Crore: A unit of number used in South Asia, equal to ten million (10,000,000).

Lakh: A commonly used South Asian unit equal to NPR 100,000. For example, NPR 3 lakh = NPR 300,000 (approx. USD 2,200–2,300 during fieldwork).

Million (in local usage): Used only in analytical contexts. In everyday speech, farmers use "lakh".

1 million NPR = 10 lakhs (approximately USD 7,400–7,700 during fieldwork).

NPR (Nepalese Rupee): The national currency of Nepal. All monetary values are reported in NPR. During fieldwork, 1 USD equalled approximately 130-135 NPR.

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1 Chapter One: Introduction

1.1 The Groundwater Paradox: Promise and Exclusion

> *'The pump is there, standing right in front of us. The electricity pole is just outside our house. But the land under our feet is not ours. The pump belongs to the landlord. We can only use it if he permits us, and only after he has finished irrigating his own fields. When harvest comes, we must give most of what we have grown to him. Tell me, what good is a technology that we cannot control?' (Field interview, Saptari, August 2023).*

Over the past five decades, a quiet but profound transformation has reshaped the agrarian landscapes of South Asia. The state did not orchestrate this transformation through grand dam projects or extensive canal networks, but rather emerged from the ground up, driven by the individual decisions of millions of farmers to invest in private tubewells and motorised pumps. Scholars have aptly termed this phenomenon the "groundwater revolution", celebrating it as a paradigm shift that promised to liberate agriculture from the unpredictability of monsoon rains, and the chronic inefficiencies and inequities of state-managed surface irrigation systems (Shah, 2009; Mukherji, 2006; Pathak, 2018; Molle & Closas, 2020). For decades, development discourse positioned this technological surge as a foundation of the broader Green Revolution, framing it as a democratising force capable of intensifying cropping patterns, enabling diversification into high-value cash crops, and charting a direct pathway out of poverty for countless smallholder families across the region (Dhawan, 2017). The narrative was compelling in its simplicity and optimism: providing farmers with access to groundwater technology would inevitably trigger a cascade of positive outcomes (Kumar & Kumar, 2024).

This narrative of technological promise has been particularly compelling in Nepal's Terai plains, the nation's agricultural heartland and breadbasket. Here, where surface irrigation infrastructure has long been characterised of paramount importance but also exhibiting limited coverage, poor maintenance, and unreliable water delivery, the rapid expansion of groundwater irrigation over the past two decades is increasingly embraced, by both the state and its international development partners, as a critical solution to persistent food insecurity and rural poverty (ADB, 2011; Thapa et al., 2019; Urfels et al., 2020). National agricultural policies, most notably the ambitious Agriculture Development Strategy (ADS) and recent Irrigation Master Plan (IMP) 2019, positions groundwater development as one of

the instruments in tandem with surface irrigation[1] for achieving three development goals: ensuring food security for a growing population; alleviating entrenched rural poverty; and building resilience among farming communities to the increasingly severe shocks of climate change (Ministry of Agricultural Development, 2016; Thapa et al., 2019; Ministry of Energy, Water Resources and Irrigation Department of Water Resources and Irrigation, 2024). Despite the ambitious targets set by Nepal's ADS, the 2024 ADS review indicates that irrigation coverage remains limited: only 58% of cultivable land (2,640,000 ha) and 87% of irrigable land (1,760,000 ha) is irrigated, and of the total cultivated area (1,512,432 ha), just 48% receives irrigation, with only 33% benefiting from year-round water supply in the fiscal year 2022/23. These policy objectives rest on an implicitly techno-optimistic logic, traceable to Rogers's (2003) diffusion of innovations framework, which models technology uptake as spreading from innovators and early adopters through to late majority and laggards on the assumption that once access barriers such as credit constraints and information gaps are removed, adoption will proceed in a broadly inclusive direction (World Bank, 2018; Giordano et al., 2012). This thesis challenges that assumption, arguing that the barriers shaping differential irrigation access in Shambhunath municipality are not remediable market imperfections but structural properties of the agrarian system itself (Dillon, 2011; Giordano & de Fraiture, 2014). The underlying logic, deeply rooted in mainstream development assumption, is temptingly linear and techno-optimistic: equip farmers with access to irrigation infrastructures and pumps.

As I discovered during my extensive fieldwork in Shambhunath Municipality at Saptari district[2], the lived realities on the ground pose a profound, deeply troubling challenge to this sanitised, apolitical discourse. In Wards 2 and 4 of Shambhunath Municipality, where I conducted this research, the persistent buzz of diesel and electric pumps has indeed become an echo of agricultural intensification. However, it is also an echo of deepening social divisions and the entrenchment of historical inequalities. Through countless conversations with farmers across the social spectrum, I came to understand that the ability to command groundwater is not simply a function of market access, technical knowledge, or individual entrepreneurial spirit. Instead, it is fundamentally determined by a

[1] The ADS 2024 review shows that only 58% of cultivable land (2,640,000 ha) and 87% of irrigable land (1,760,000 ha) are irrigated. Of the total cultivated land (1,512,432 ha), 48% is irrigated, out of which only 33% had year-round irrigation in FY2022/23.

[2] District is a pre-federal Nepal administrative unit, which is bigger in landmass and comprised of multiple Village Development Committees. The municipality is a smaller landmass post-federal Nepal; it is part of the local government and a powerful unit post-2015. I refer to Saptari along with the Shambhunath Municipality because, in many data terms, Saptari is still referred to.

farmer's positionality, their specific location within a complex, deeply stratified, and historically sedimented agrarian order, structured by intersecting axes of land tenure, caste, gender, class, and migration (Nightingale, 2011; Zwarteveen & Boelens, 2014; Ribot & Peluso, 2003; Shrestha & Paudel, 2022).

The *Musahar* woman's words that open this chapter capture this disjuncture with painful clarity. The pump is visible. The electricity pole stands nearby. Infrastructure appears present. Yet, control remains elsewhere. Her question cuts to the heart of this dissertation's intellectual and political terrain. It lays bare what technocratic policy frameworks and market-based interventions systematically obscure: technologies do not operate in a social vacuum, and their transformative potential is never automatic (Winner, 1980; Joshi et al., 2025). Instead, the benefits of technology are crafted through pre-existing architectures of power that dictate not merely whether a farmer can physically access groundwater, but how they are positioned to do so, under what conditions of dependency or autonomy, with what degree of tenure security and control, and with what ultimate implications for their livelihood trajectories and social standing (Mehta et al., 2012; Hoogesteger & Wester, 2015).

In this dissertation, I therefore consciously reframe the central problematic away from the narrow instrumentalist policy question of 'How can we maximise adoption rates?' toward a more fundamental structural interrogation: How does a farmer's social position, configured at the intersection of multiple axes of difference and inequality, shape their ability to access, control, and benefit from groundwater irrigation technology? Through this reframing, I seek to understand why the much-celebrated groundwater revolution has, for so many farming households in Shambhunath Municipality, situated in Saptari district and Madhesh province, and beyond, remained perpetually overdue.

1.2 The Research Problem: Unpacking the Social Foundations of Technological Inequality

The central problem that animates my research is the persistent, socially embedded, and structurally reproduced stratification of access to groundwater irrigation technology. This is not, I argue, a problem of simple technological lag, temporary market friction, or inadequate information dissemination that will naturally resolve itself with time and better extension services. Instead, it is a fundamentally political problem, deeply rooted in the differential positioning of farmers within a profoundly unequal agrarian system (Razzaq et al., 2025). Through my fieldwork and analysis, I have identified three interwoven empirical dynamics that together constitute this problem. I approach these not as discrete,

isolated issues but as constitutive elements of a single, dynamic, and mutually reinforcing process of socio-technical and agrarian transformation.

Three analytical threads run through this dissertation, each addressing a distinct dimension of the central question. The first concerns the structural patterning of irrigation technology access: whether and how land tenure, landholding size, caste identity, gender, and migration status predict which households own or can access tubewells, pumps, and subsidised electric meters[3]. The quantitative analysis in Chapter Four examines these patterns systematically, and the concept of a bundled architecture of access, developed in Chapter Two, provides the theoretical frame for interpreting what the data show. The motivating puzzle is straightforward: if irrigation technologies are physically present across the study area and if subsidies and credit programmes nominally target smallholder and marginalised farmers, why does access remain so strongly structured by prior social and economic position? What mechanisms reproduce the stratification across successive rounds of programme support?

My findings reveal that tubewell access is structured by sharp land thresholds rather than by a smooth gradient. Fixed irrigation infrastructure only becomes viable once land reaches a scale that can absorb risk and justify sunk investment. Even among landowners, marginal holders remain largely excluded, while households cultivating modestly larger areas are far more likely to stabilise a tubewell. This pattern shows that irrigation is not simply a matter of 'having enough' land. Land ownership confers tenure security, collateral, and social legitimacy, and it is these attributes that enable entry into subsequent layers of technology.

In stark and painful contrast, tenant farmers working under insecure verbal agreements, Dalit households systematically excluded from land ownership, and marginal landholders struggling on tiny plots occupy structurally disadvantaged positions that sharply constrain their ability to harness irrigation infrastructure. Through my interviews, particularly with tenant farmers and landless Dalit groups, I came to understand how insecure tenure actively disincentivises long-term, fixed investments such as constructing a tubewell (Sugden et al., 2014). More critically, landlessness

[3] In this thesis, 'electric meter connection' refers specifically to the subsidised electricity meter for irrigation provided by the Nepal Electricity Authority (NEA). It does not denote a regular, non-subsidised household or commercial electricity meter. Holding this irrigation meter enables farmers to operate electric pumps at a highly subsidised tariff, commonly described in the study area as around NPR 2.5 per unit of electricity. Accessing this meter typically requires: applying at the local NEA office with a Ward or municipal recommendation; proof of land ownership or a formal land rental agreement; an upfront payment (often around NPR 5,000 – approx. USD 35); along with other administrative requirements.

becomes an insurmountable barrier when coupled with institutional requirements. Applications for electric meters require land ownership documents, transforming what appears to be a neutral bureaucratic procedure into a powerful mechanism of exclusion and powerlessness.

My research further reveals that access to irrigation infrastructure is not merely a matter of physical presence or affordability; it is deeply entangled in the socio-political terrains of caste hierarchies, gendered labour divisions, insecure tenancy arrangements, and selective institutional recognition. Different social groups interpret and experience the same technology in radically different ways. For instance, the growing preference for electric pumps among farmers in my study area reflects not only infrastructural improvements in electricity access but also the specific technological and socio-political affordances offered within a context of land fragmentation, economic marginality, and uneven entitlements. For wealthier farmers, electric pumps offer a cost-effective way to access water. For some women farmers who own land, even small plots, an electric meter can become a crucial means to maintain cheaper water access and assert autonomy in agricultural decision-making, as I document in a particularly revealing case study (Chapter Five). However, for landless Dalit farmers, the same electric pump technology and the electric meter that powers it becomes symbols of their exclusion, physically present in their landscape but legally and socially inaccessible (Chapter Six).

Furthermore, their marginalised social status, particularly acute for Dalit communities who face ongoing disguised caste-based discrimination, often excludes them from the dense informal networks through which technical knowledge and, crucially, access to state patronage and subsidy programmes are circulated (Gellner, 2007; Kafle et al., 2022; Suntharalingam, 2023). For these marginalised groups, ‘access’ to irrigation, when it exists, is rarely direct, secure, or autonomous. Instead, it is mediated through exploitative and dependent relationships, accessing land on lease with a tubewell at extortionate rates from a landlord who prefers to lease to farmers paying higher land rent, or relying on the uncertain and sometimes humiliating discretionary goodwill of a better-positioned neighbour (Pariyar et al., 2018). Critically, my research reveals that access is not merely about initial adoption but fundamentally about control and the capacity for long-term use, which ultimately determines who reaps sustained benefits and who is left behind or locked into dependency (Theis et al., 2018). The outcome, as my data clearly shows, is not a gradual, inclusive, and equitable process of technology diffusion (Rogers, 2003). Instead, it is the creation and active reinforcement of a structural reality between those who command technology as an instrument of empowerment and accumulation, and

those who are relegated to accessing it only on deeply subordinate terms that may deepen their dependency and vulnerability (Ribot & Peluso, 2003; Franks & Cleaver, 2007).

The second, thread concerns the lived experience of marginalised farmers navigating the structural conditions. Chapter Five moves beyond statistical patterns to examine how Dalit tenant farmers, women managing farms in male out-migrant households, and landless labourers actually experience, negotiate, and sometimes subvert the access constraints they face. This thread is motivated by a different kind of puzzle: given the structural barriers documented in Chapter Four, how do some marginalised farmers secure water access at all? What strategies, alliances, and forms of improvisation do they use? And what can these practices of navigation and resistance tell us about the specific points in the access architecture that are most amenable to change?

The question is not one of the programme failure but of how structural advantages in the wider agrarian system are systematically translated into institutional advantages with ostensibly inclusive programme spaces. Through my detailed case study of an irrigation project in Shambhunath Municipality in Saptari, I found that this entrenched stratification is not always amended and is sometimes paradoxically exacerbated during development interventions explicitly designed to promote inclusion and equity. Nepal's agricultural policy landscape, shaped significantly by international donors' priorities and funding, includes progressive language on social inclusion, gender equality, and pro-poor development (Nightingale et al., 2011; Nightingale, 2019). Subsidy schemes are carefully designed with specific numerical targets for poor and marginalised farmers, gender and caste quotas are mandated for the executive committees of water user associations and farmer cooperatives, and 'pro-poor' development is enshrined as a stated priority in virtually every planning document I examined (Ministry of Agricultural Development, 2016; Government of Nepal, 2019; Gajurel et al., 2024). However, despite these admirable stated intentions, my ethnographic research and interviews with farmers revealed a consistent and pervasive pattern of what the literature terms 'elite capture'[4] (Mukherji et al., 2009).

My analysis reveals three routes through which this elite capture operates. First, rural elites systematically exploit the interpretative flexibility of irrigation infrastructure support, a concept I borrow from Science and Technology Studies (STS), to shape its meaning and application in ways that consolidate their access to resources while marginalising less-connected farmers (Bijker, 2001;

[4] Elite capture refers to situations where powerful local actors use their social, economic, or political advantages to secure an unfair share of resources or benefits ((Bardhan et al., 2007)).

Pinch, 2010). For what counts as a ‘poor farmer’ eligible for subsidy, what constitutes ‘legitimate’ land tenure, and which farmers are deemed ‘capable’ of managing technology, these definitions are not fixed. However, these are actively negotiated and strategically manipulated by well-positioned actors to serve their interests. Second, these rural elites strategically mobilise overlapping identities, based on class, caste, political affiliation, kinship networks, and institutional positions, to maintain privileged access to irrigation support. A wealthy farmer may simultaneously position himself as a ‘progressive farmer’ deserving of support for commercialisation, as a ‘community leader’ trusted to manage group resources, and as a political broker connected to district-level authorities, thereby accessing multiple channels of benefit (a case explained in Chapter Six). Third, the appropriation of irrigation infrastructure support establishes powerful closure mechanisms that marginalise alternative perspectives and entrench socio-economic inequalities, effectively stabilising one configuration of technology access, private, individually owned pumps controlled by landed elites, as the "normal" and "natural" form, while foreclosing more equitable alternatives (Bijker, 2001).

Time and again in my fieldwork, I documented how better-positioned social actors – typically landowners of relatively larger areas, individuals with connections to local political parties, and those with relatives or friends working in the district administration – disproportionately appropriated the benefits of subsidy programmes and development projects. These well-positioned actors skilfully leveraged their superior economic resources to meet co-financing requirements that were prohibitive for genuinely poor farmers, mobilised their political connections to influence selection processes, deployed their social capital to dominate farmer groups, and utilised their bureaucratic literacy to navigate complex application procedures and documentation requirements. As I came to understand through my analysis, this pattern of elite capture is not merely an unfortunate "unintended consequence" or a minor implementation flaw that can be fixed with better monitoring (Lund & Saito-Jensen, 2013). Rather, it reflects a fundamental void in current policy design: a persistent failure or refusal to acknowledge that institutions are not neutral, technical arenas for resource allocation. Instead, they are inherently political sites of contestation where pre-existing power differentials are not neutralised but actively performed, negotiated, and ultimately reinforced (Mosse, 2004; Li, 2007; Jenkins, 2017). By conceptualising ‘farmers’ as a homogeneous, undifferentiated category and treating institutions as impartial, technocratic channels, well-meaning development interventions are almost inevitably absorbed into, rather than transforming, the existing architectures of inequality (Thuijsman et al., 2022; Rao et al., 2025).

An additional dimension that emerged powerfully from my research concerns the role of social networks in facilitating or constraining technology adoption and sustained use. My findings demonstrate that networks indeed facilitate technological access, but not all networks are equal in their effects or sustainability (Hoffmann & Villamayor-Tomas, 2023). Self-initiated networks, grounded in local trust relationships, shared interests, and accumulated social capital within specific communities, tend to sustain technology access, use, and control over time. These organic networks provide ongoing technical support, enable informal technology shared arrangements, facilitate water-sharing agreements, and create accountability mechanisms that persist beyond project cycles. In contrast, externally imposed networks, such as farmer groups formed by development projects to meet participation requirements, may sometimes falter, collapse, or restructure when external support is withdrawn, because they fail to integrate into existing social realities and may even cut across existing lines of trust and cooperation. This finding has crucial implications for understanding why so many well-intentioned participatory development interventions fail to achieve their stated goals of empowerment and inclusion.

The third thread concerns the role of formal institutions and development interventions in reproducing or potentially transforming these patterns of access. Chapters Six and Seven examine how government subsidy programmes and externally funded irrigation projects interact with the agrarian structures documented in Chapters Four and Five. The central puzzle here is one of persistent design failure: why do programmes explicitly designed to expand access for marginalised farmers so consistently produce outcomes in which better-positioned farmers capture the majority of benefits? What specific mechanisms accomplish this capture, and what programme design looks like if it were built from the outset to resist rather than accommodate existing hierarchies (Li, 2007; Ferguson, 1990; Platteau, 2004; Rao et al., 2025)?

Conversely, for poorly positioned farmers, the same technological shift often accelerates a downward spiral of marginalisation and dispossession. The improved productive potential of irrigated land drives up both market values and rental rates, making it increasingly difficult for cash-poor tenants and land-poor households to maintain their already tenuous access to land (Sugden et al., 2014). Simultaneously, the broader structural shift toward capital-intensive, input-heavy, high-risk commercial agriculture, particularly the cultivation of vegetables or adaption to mango farming, which reliable irrigation and long-term land access make possible, systematically advantages those farming households with the necessary capital, established connections, risk-bearing capacity, while marginalising those who lack

these resources and are confined to low-value subsistence production or forced to sell their labour (Birkenholtz, 2017). My research further reveals a duality of roles within this process: the same individuals and technologies can simultaneously represent power and empowerment in one context, while serving as instruments of subjugation in another. A woman farmer who uses her electric meter connection to assert control over irrigation scheduling and maintain autonomy from male Dalit farmers shows empowerment through technology. However, the very same technological system, with its requirement for land documents to secure an electric meter, becomes a tool of powerlessness for landless Dalit farmer groups who lack the legal credentials to access it. This duality hints at how technology and social position interact to create complex, sometimes contradictory, and dynamic patterns of winners and losers that cannot be understood through simple binary categories.

In this context, as my analysis reveals, technology ceases to be conceptualised as an external, apolitical input to agricultural production. Instead, it becomes an endogenous force actively embedded in and constitutive of social relations, continuously remaking class structures, deepening social contours, and scripting divergent livelihood trajectories across the rural landscape (Hajdu et al., 2024). Taken together, these three interlocking aspects highlight that accessing and benefiting from technology is not a straightforward technical act or simple economic transaction. It is a profoundly social and inherently political process, fundamentally governed by a farmer's specific position within a matrix of intersecting structures of power (Ribot & Peluso, 2003). This dissertation is dedicated to a rigorous, empirically grounded dissection and theoretical interpretation of this process, foregrounding positionality as the central analytical concept through which I seek to understand the complex, contradictory, and often unjust interplay of technology, power, and agrarian change.

1.3 Research Questions Guiding this Inquiry

Anchored in this understanding of the research problem, my dissertation is guided by a central research question that I develop and examine through four interconnected sub-questions. Together, these questions aim to probe technological access and inequality across multiple analytical scales and through different methodological registers, thereby building a multidimensional analysis.

My central research question is:

> How are farmers differentially positioned to access and benefit from groundwater irrigation technology within an agrarian system structured by the intersection of land tenure, caste, gender, class, and migration?

This question deliberately places the concept of position at its analytical core. Drawing on insights from feminist theory, critical race studies, and postcolonial scholarship, I use positionality to refer to the specific, situated location of individuals within multiple, overlapping, and mutually constitutive social structures and systems of power (Carley, 2022; Leder et al., 2024; Nepali & Baral, 2024). Position is not reducible to any single axis of identity or social stratification; it is not just about being a woman, or a Dalit, or a tenant farmer, or someone affected by migration. Instead, it is about how these different dimensions of social life intersect and interact in specific contexts to shape an individual's lived experience, opportunities, constraints, knowledge, and agency (Crenshaw, 1991). In asking this question, I seek not merely to document that access is unequal – this is already widely recognised in the literature – but to explain precisely how and through what mechanisms a farmer's unique, intersectionally-defined social position enables or forecloses their capacity to engage with, adopt, control, and ultimately derive benefits from groundwater irrigation technology (Ribot & Peluso, 2003).

To answer this central question, I have developed three specific sub-questions[5], each designed to answer a different dimension of the problem. My first sub-question asks: What are the relationships between a farmer's position through the axes of land tenure status, caste identity, gender, and household migration status, and their access to and ownership of irrigation technologies? (Chapter Four). Through rigorous quantitative analysis, I seek to identify which dimensions of social position are most predictive of technology access, and how these different axes interact to create advantage or disadvantage through the bundling process. This sub-question directly addresses my finding that irrigation technology adoption is shaped by a multi-layered process of social and technological bundling, wherein access is conditioned not only by social hierarchies but also by the sequential and interdependent configuration of technological systems themselves.

[5] These sub-questions address related but analytically distinct dimensions of access. Sub-question 1 asks about access to irrigation technologies while sub-question 2 asks about access to groundwater. These are analytically distinct. Ownership of or access to a tubewell and pump is a necessary but not sufficient condition for groundwater access, because the latter also depends on aquifer dynamics, seasonal water table levels, and the aggregate extraction behaviour of other users within the hydraulic catchment. Throughout the dissertation, pump and tubewell ownership is used as the primary empirical proxy for groundwater access, on the grounds that these technologies are the principal means through which groundwater is extracted for irrigation in the study context. This simplification is acknowledged as a limitation: the data capture technology ownership rather than actual water availability, and the two do not always coincide. Even when wells and pumps are individually owned, the aquifer itself is never privately owned, and the extraction behaviour of neighbours directly shapes the water available to any individual user.

My second sub-question shifts from statistical to ethnographic, asking: How do farmers from marginalised positions experience and negotiate groundwater access, and livelihood challenges, within unequal agrarian structures (Chapter Five)? Through this question, I aim to move beyond abstract patterns and quantitative numbers to understand the human dimension of inequality, the everyday practices, tactical social negotiations, and moments of resistance through which marginalised actors navigate a constrained and often intimidating landscape. I am interested in how people understand and explain their own situations, what strategies they develop to cope with or challenge their exclusion, how they interpret technology differently based on their social position, and how structures of constraint are experienced, internalised, or resisted in the spaces of daily life. This question addresses the interpretive flexibility of technology, exploring how different social groups ascribe radically different meanings and values to the same irrigation infrastructure, based on their positionality.

My third sub-question focuses analytical attention on formal institutions and development interventions, asking: Through what structural institutional, and social mechanisms do irrigation support programmes produce differential outcomes, and how do better positioned actors consolidate advantage within formally inclusive programme spaces (Chapters Six and Seven)? This question conceptualises irrigation institutions not as neutral or purely technical entities, but as political arenas where power is exercised, contested, and reconfigured (Cleaver, 2007). It examines the full range of mechanisms producing differential outcomes: regulatory requirements designed with good intent but failing marginalised groups in practice, administrative arrangements that presuppose formal land documentation, and the micro-practices through which better-positioned actors reshape ostensibly inclusive programmes to serve their own interests, including diesel pump rental, shared tubewell arrangements, and water purchase from neighbours: strategies that highlight the persistent effects of land insecurity and unequal access to formal institutional channels.

1.4 Constructing a Theoretical Framework: Synthesising Three Traditions

To construct an analytical framework capable of capturing the complexity of the relationship between social position and technological access, I have synthesised insights from three distinct but complementary scholarly traditions: political ecology; the study of agrarian change (also known as agrarian political economy); and the Social Construction of Technology (SCOT) from science and technology studies. While these fields have often developed in relative isolation from one another, pursuing separate intellectual trajectories and publishing in different journals, I argue that their

deliberate integration offers a uniquely powerful lens for understanding socio-technical change in contexts marked by deep and persistent inequality. I bring these traditions together through the organised bundle of architecture of access, a conceptual framework I develop in detail in Chapter Three and introduce briefly here. This framework is particularly well-suited to explain the layered progression of technology access that my empirical research has documented, while also accounting for interpretative flexibility, institutional mediation, and agrarian differentiation (see Figure 1 for a visual representation of the framework).

Political ecology provides the foundational premise of my framework. This interdisciplinary field, which emerged in the 1980s and 1990s, is centrally concerned with unmasking the political and economic forces that shape environmental outcomes and resource distribution (Blaikie & Brookfield, 2015). Political ecologists have consistently argued that environmental issues, including questions of resource access, environmental degradation, and conservation, cannot be understood through purely technical, ecological, or managerial lenses. Instead, they must be understood as fundamentally political, shaped by power relations, economic interests, historical legacies of colonialism and capitalism, and ongoing struggles between differently positioned social actors. Within this broader tradition, the 'hydro-social' approach has proven particularly valuable for my research. This perspective, articulated by scholars such as Budds et al. (2014) and Swyngedouw (2009), holds that water and society are not separate domains that interact; instead, they are co-constituted and mutually productive. Water, in this view, is never only a natural substance with inherent properties. Instead, it is always entangled with and inseparable from the technologies, infrastructures, institutions, property regimes, cultural meanings, and power relations through which it flows and is made available for human use (Bakker, 2002). An aquifer, from this perspective, is not merely a geological formation but a socio-natural entity, actively produced and continuously transformed by patterns of extraction, the distribution of pumping technologies, energy systems, legal frameworks of water rights, and state regulatory practices (or their conspicuous absence). This understanding is directly applicable to the Madhesh plains, where the shallow unconfined aquifer underlying the study area is simultaneously a shared resource and an individually exploited one. The commons structure of the aquifer, which no pump owner individually controls but from which all extract, creates a particular form of distributional injustice that private property frameworks systematically obscure: the decision of any individual pump owner to extract intensively reduces water availability for all users within the hydraulic catchment, with no institutional mechanism to compensate those who lose supply as a result. In the study villages,

where pumping capacity is highly unequal. This hydro-social perspective helps explain how the physical infrastructure of groundwater irrigation, tubewells, pumps, and electric meters becomes embedded within land relations and social hierarchies, as my statistical findings clearly demonstrate.

Feminist political ecology represents a crucial extension and deepening of these insights, that have been particularly important for shaping my approach to this research. Feminist political ecologists have powerfully demonstrated that all environmental relations and resource access processes are fundamentally gendered (Elmhirst, 2011). They have meticulously documented how irrigation institutions and even forms of ecological knowledge are shaped by and serve to reproduce patriarchal power relations, often burdening women with the invisible and undervalued labour of water collection, agricultural production, and household provisioning while systematically excluding them from spaces of decision-making, resource control, and technical training (Ahlers & Zwarteveen, 2009; Cleaver & Hamada, 2010; Zwarteveen, 1994). Nevertheless, my research also reveals more complex and sometimes contradictory dynamics: in specific contexts, such as when women own land and can access electric meters in their own names, irrigation technology can become a tool for asserting autonomy and challenging traditional gender constraints. This complexity underlines the need for an intersectional approach.

From this rich tradition, I adopt the analytical concept of intersectionality as a core organising principle for my research. Initially developed by Black feminist legal scholar, Crenshaw (1991), and expanded by scholars such as Collins (2009), intersectionality insists that systems of oppression and axes of social difference, such as race, class, gender, sexuality, and, in the South Asian context, caste, are not separate, independent variables that can be analysed in isolation or added together. Rather, they are interlocking, mutually constitutive, and fundamentally inseparable, creating unique configurations of privilege and oppression that cannot be understood by examining any single axis alone (Yuval-Davis, 2006; Cho et al., 2013; Carley, 2022). In the context of my research in Shambhunath Municipality, this means recognising that a Dalit woman tenant farmer does not simply face the sum of discrimination based on caste, plus discrimination based on gender, plus disadvantage based on tenure status. Rather, she occupies a unique social location produced by the intersection of these axes, and her lived experience and strategies for navigating access to irrigation must be understood in terms of this specific intersectional positionality (Nightingale, 2011; Sultana, 2011). My findings about the duality of technology, where the same infrastructure simultaneously empowers some while disempowering others, can only be adequately explained through this intersectional lens.

The second pillar of my theoretical framework comes from the rich tradition of scholarship on agrarian change, a field with deep roots in the Marxist political economy and the classical agrarian question debates of the late 19th and 20th centuries (Kautsky, 1899/1988; Byres, 1996; Bernstein, 2010). This tradition provides the essential class-analysis lens that informs me. Scholars of Agrarian change fundamentally challenge the undifferentiated, homogenising category of the "peasant" or "the farmer" that has long dominated both romanticised agrarian populism and technocratic development policy. Instead, they insist on understanding rural societies as internally differentiated, composed of distinct social classes with different relationships to the means of production, particularly land and capital, and therefore fundamentally different, often antagonistic, economic interests and political orientations. The central analytical concern of this tradition is the historical process of agrarian differentiation: the long-term, uneven, and often violent processes through which some rural households accumulate land, capital, and productive assets, transitioning into commercial farmers or rural capitalists, while other households lose access to land, are unable to sustain through farming alone, and are pushed into wage labour, debt dependency, or forced migration (Groth et al., 2021).

For my research, the crucial insight from this tradition is the recognition that technological change is not an external force acting upon a static agrarian structure, but rather a central mechanism through which differentiation occurs (Byres, 2009). New agricultural technologies, introduced into contexts already marked by inequality, rarely benefit all farmers equally. Instead, they tend to accelerate and deepen existing patterns of differentiation, providing powerful instruments of accumulation for those already well-positioned to adopt and control them, while simultaneously raising competitive pressures and costs for those who are poorly positioned, thereby squeezing their viability as independent producers (Bernstein, 2010). This agrarian perspective reveals how irrigation access drives divergent trajectories of accumulation and dispossession, and how different social groups experience fundamentally different long-term outcomes from the same technological shift. The concept of class differentiation helps explain why landholders significantly benefit from tubewell access, while marginal and landless farmers find themselves increasingly squeezed out, and why networks of accumulation emerge among propertied farmers while networks of survival characterise the landless.

The third pillar of my framework comes from science and technology studies, specifically the social construction of technology (SCOT) approach developed by scholars such as Bijker (2001), Pinch (2010), and Wajcman (2010). The SCOT framework provides an additional lens to examine technological determinism, the widespread but misleading assumption that technologies possess

inherent, fixed characteristics and effects that operate independently of social context (Winner, 1980). This framework introduces two concepts that have been particularly productive for my analysis and directly align with my empirical findings.

The first concept is interpretive flexibility, the recognition that any technological artefact is not a single, stable thing with one obvious meaning or use, but is fundamentally open to multiple, often conflicting interpretations by different 'relevant social groups' (Pinch, 2010). My research provides compelling empirical evidence of this interpretive flexibility in action. In the context of Saptari's irrigation landscape, a tubewell and pump system means radically different things to different actors positioned differently within the agrarian structure. For a landlord of a large-scale area, a tubewell symbolises modernity and progress, it increases agricultural productivity and rental income, reduces dependence on unpredictable tenant labour, enables control over production processes, and marks social status within the village hierarchy. For a tenant farmer working that same landlord's land, the pump may represent an instrument of intensified exploitation. This technology enables the landlord to demand higher rents or impose more onerous sharecropping terms, justifying increased extraction by pointing to improved yields. For the woman landowner I interviewed, who maintains control over her electric meter connection, the technology represents empowerment, autonomy, and the ability to resist pressure from male relatives. For landless Dalit farmer groups seeking to form cooperatives, the electric meter requirement for land documents transforms the technology into a symbol of institutional exclusion and structural violence. For a government hydrologist or environmental activist, the same tubewell may primarily signify a point of unsustainable groundwater extraction, a driver of aquifer depletion, and an ecological threat to long-term water security (Chandra & Brozović, 2024). This multiplicity of meanings is not a matter of misunderstanding or incomplete information; it reflects the fundamental reality that technology is experienced and understood through the lens of one's social position and material interests.

The second key concept from SCOT is closure, the social and political process through which the initial interpretive flexibility surrounding a technology gradually narrows, and one design, meaning, or configuration becomes stabilised and accepted as the "normal" or "natural" form (Bijker, 2001; Bijker et al., 2012). Crucially, SCOT scholars insist that closure is not a technical process of discovering the objectively "best" solution, but is a fundamentally social and political process in which one group's interpretation wins out over others, often reflecting the interests and power of dominant actors while foreclosing alternative technological pathways (Klein & Kleinman, 2002). My empirical

findings provide detailed evidence of how closure mechanisms operate in practice. In Shambhunath Municipality, I documented how rural elites' support for appropriate irrigation infrastructure helped establish closure around a particular configuration: individually owned electric pumps controlled by landed farmers were institutionalised as the legitimate, modern, and preferred form of irrigation technology. This closure marginalises alternative configurations, such as collectively managed systems, tenant-friendly rental arrangements, or public provision of pumping services. The stabilisation of this technological form is achieved through multiple reinforcing practices: bureaucratic requirements that favour landowners; subsidy structures that presuppose individual ownership; extension services that target "progressive" farmers and discursive framings that associate individual pump ownership with agricultural modernisation and entrepreneurship. Once closure is achieved, it becomes increasingly complex to challenge or reverse, as the entire supporting infrastructure, technical, institutional, financial, and ideological, becomes aligned around this stabilised form (Pinch & Bijker, 1984) .

I synthesise these three theoretical traditions through the organising concept of bundled architecture of access. This conceptualises a farmer's position as being determined by their location within multiple, layered, and mutually reinforcing structures or 'architectures': an economic architecture of land ownership, class relations, labour relations (drawn from agrarian change); a social architecture of caste hierarchies, gender relations, and social networks (drawn from Feminist political ecology); and a techno-institutional architecture of specific technology designs, energy infrastructures, property law regimes, water governance frameworks, and development programme rules. These layers are 'bundled' in the sense that they do not operate independently but are deeply interwoven, mutually constitutive, and reinforcing, which create the cumulative progression that my quantitative analysis has revealed. A farmer cannot: access an electric pump without first securing a tubewell; secure a tubewell without land tenure security; obtain land without navigating hierarchies stemming from caste hierarchies and land tenure; and effectively utilise irrigation technology without accessing knowledge networks and social connections. Each layer builds upon and requires the previous ones, creating compounded patterns of inclusion and exclusion.

A farmer's specific location within this complex, multidimensional, bundled architecture, which I term their position, fundamentally shapes and constrains their capacity to access, control, and benefit from irrigation technology. This bundled architecture of access framework enables an analysis that is simultaneously attentive to deep structural forces and constraints while also recognising human

agency, strategic action, interpretive processes, and the socially constructed nature of technology itself. It allows me to explain both the statistical patterns of inequality I document quantitatively and the lived experiences, tactical manoeuvres, and institutional play I observe ethnographically. Most importantly, it provides analytical tools to understand how technology, far from being neutral, becomes deeply implicated in the reproduction and transformation of agrarian social relations.

1.5 Saptari District as Research Site: Context and Rationale

This research was conducted in Wards 2 and 4 of Shambhunath Municipality, Saptari District, situated in the southeastern Terai along Nepal's border with Bihar, India. Saptari was purposively selected as a critical case embodying the intersection of groundwater dependence, agrarian inequality, technological change, and development interventions that is central to this study. The district's socio-economic configuration, marked by entrenched caste hierarchies, uneven technological diffusion, high male out-migration, and extensive donor engagement, renders it both theoretically strategic and empirically illustrative.

Saptari, located within Madhesh Province, has a population of 706,255, with 60.4% of households engaged in agriculture (National Statistics Office, 2024a). Out-migration is a defining demographic feature: 19.6% of households have members living abroad, and 6.8% have members who migrated domestically; 96.5% of international migrants[6] are male, reinforcing the feminisation of agriculture. However, only 13.1% of land is owned by women, revealing persistent gendered inequalities in property control (National Statistics Office, 2024b).

Despite the formal abolition of feudalism in the 1950s and several reform efforts, landlessness remains pervasive in Nepal, affecting 17.0% of households (National Statistics Office, 2024b). Overall, 26.1% of agricultural households lack cultivable land, and only 19.7% of women own land. Land inequality is deeply intertwined with caste, ethnicity, and gender, disproportionately affecting Dalits and indigenous groups (Nightingale, 2011). Among Dalits, landlessness reaches 36.7% in the Hill regions and 41.4% among *Madhesi*[7] Dalits, with those holding land confined to marginal plots. The National

[6] In this thesis, migrants, migration, or members from migrant households refer to household members who have migrated out for labour to other cities within Nepal, to neighbouring countries, or overseas. In Nepal and the study area, mostly men engage in migration.

[7] *Madhesi* refers to the historically marginalised and socially diverse communities of Nepal's Terai (Southern plains – Madhesh region), encompassing multiple caste, ethnic, linguistic, and religious groups. Their shared identity has emerged through long-standing exclusion from the hill-centric Nepali state, and struggles for political recognition and belonging.

Dalit Commission (2023) reports that 44.0% of *Madhesi* Dalits are severely landless, with 90.0% lacking agricultural land. These patterns are mirrored in Shambhunath Municipality in Saptari, where class, caste, and tenancy relations fundamentally shape agricultural livelihoods and access to irrigation technologies.

Madhesh Province exhibits a poverty incidence of 22.5%, among the higher side in Nepal, and continues to experience pronounced land concentration. Nationally, 5% of the population controls 37% of arable land (Sugden et al., 2016). Elite resistance, bureaucratic inertia, and weak policy enforcement have limited the effectiveness of the Land Act of 1964, perpetuating structural marginalisation. In Saptari, this translates into insecure tenancy, fragmented plots, and constrained investment in irrigation infrastructure.

Surface irrigation remains inadequate, covering less than 20% of cultivable land, and the other water source on which Terai agriculture has historically depended, monsoon rainfall, has become progressively less reliable as a foundational food production planning. Nepal recovers over 80% of its annual precipitation during the June to September monsoon season, and monsoon paddy is the dominant staple food crop across Terai plains, its cultivation calendar built around seasonal rainfall. But recent years have documented increasing variability and severity in monsoon patterns: the 2023 southwest monsoon fell below the seasonal average across most of Nepal, prompting agricultural scientists to recommend alternative cropping systems in drought-prone areas; the 2024 monsoon brought the heaviest recorded rainfall since 1970, triggering devastating floods across eastern Terai districts including Saptari (Nepal et al., 2024). For farmers in the study area, where surface canal infrastructure covers less than a fifth of cultivable land and monsoon variability has become a recurring production risk, groundwater irrigation has moved from a productivity growth to an essential buffer against seasonal food production failure. This shift has accelerated groundwater-based irrigation expansion (Foster et al., 2021; Adhikari et al., 2025). In Madhesh Province, groundwater now irrigates 56.2% of agricultural land, with Saptari contributing a significant share (National Agriculture Census, 2021). The past decade saw a 59.9% rise in Shallow Tubewells (STWs) and a 178.0% increase in deep tubewells (Chakraborty et al., 2023). Yet, unregulated expansion has reproduced inequalities and stressed shallow aquifers, with reports of drying wells across villages.

Energy access has become central to irrigation practices. While diesel pumps once dominated, electrification has driven a transition to electric pumps, aided by falling energy costs and infrastructure expansion. Over 90% of Madhesh households are now connected to the grid, and Saptari has received

significant upgrades, including new substations and transmission lines (Nepal Electricity Authority, 2024). Electricity for irrigation halved in cost in 2023 and is planned to become free, further incentivising adoption. However, capital barriers sustain uneven access, reinforcing informal water markets and class-based differentiation (Chakraborty et al., 2023).

High male out-migration has reconfigured rural labour and decision-making, with women increasingly managing farms under constrained tenure and limited support. Saptari's designation as food-insecure has prompted interventions from the Food and Agriculture Organization and Save the Children, often through subsidies, farmer cooperatives, and livelihood programmes (Ministry of Agricultural Development, 2016). These initiatives interact with entrenched inequalities, shaping who benefits from technological and infrastructural investments.

The social dynamics of technology access play out within a specific physical system whose characteristics shape who can reliably access water and when. The Madhesh plains are underlain by an extensive alluvial aquifer system recharged primarily by monsoon rainfall and Himalayan river systems. The shallow unconfined aquifer, accessible at depths of ten to thirty meters supports most of the tubewell extraction examined in this study. Seasonal fluctuations in water table levels are substantial: the table falls significantly during the dry pre-monsoon months of March to May, precisely when irrigation demand is highest. The equity implications of this seasonal cycle operate through pump technology type rather than through collective depth of the aquifer. Households with electric submersible pumps sustain extraction through the annual pre-monsoon drawdown; households dependent on shallow diesel suction pumps, limited to approximately four to six meters of suction head, face supply failure when the water table drops below that threshold. The CGAIR NEXUS Gains programme[8], which conducted field survey in Saptari and neighbouring Siraha districts, found that during the summer of 2015, farmers in Saptari specifically reported shallow tubewells drying up during the dry season, necessitating costly deepening (Neupane et al., 2024). This is seasonal water table drawdown exposing shallow infrastructure, a natural annual cycle, rather than permanent depletion driven by over-extraction. The eastern Nepal is distinct in that respect from the northwest Indo-Gangetic plains: current estimates suggest the Terai utilises approximately 22% of its dynamic groundwater recharge, well below the thresholds at which cumulative over-extraction becomes the dominant concern (Pandey et al., 2023). The pumps in this study area individually owned, but the

[8]The CGIAR NEXUS Gains initiative is a CGIAR research programme focused on advancing sustainable water, energy and food systems through research and innovation.

aquifer from which they draw is a shared resource governed as if it were private property, a governance gap with no mechanism to address the seasonal access differential or to monitor whether the trajectory of electrification-driven intensification moves the eastern Terai toward the depletion dynamics already experienced further west (Aryel, et al., 2025).

Overall, Saptari, where Wards 2 and 4 of Shambhunath Municipality are located, exemplifies a socio-technical landscape in which groundwater irrigation, energy infrastructure, agrarian inequality, and development interventions converge. The district provides a critical site for examining how class, caste, gender, and ethnicity mediate access to water and technology, offering broader insights into irrigation governance and equity across the Nepalese Terai and comparable agrarian frontiers in South Asia.

1.6 Research Design and Methodological Approach

To understand the complex relationships between social position and technological access, I applied a mixed-methods research strategy grounded in critical realist epistemology (Stutchbury, 2022). Critical realism's stratified ontology, distinguishing empirical observation, actual events, and underlying causal mechanisms, aligns with my goal of not merely describing inequality patterns but of explaining the deeper mechanisms that produce them. I deliberately adopted a mixed-methods design to leverage the complementary strengths of quantitative and qualitative methods. This approach uses broad quantitative mapping to identify patterns, followed by in-depth qualitative engagement to explain processes, culminating in systematic integration that produces more robust explanations than either method alone.

My research proceeded through three interconnected phases over nine months (April 2023 to January 2024). I started with a qualitative inquiry using multiple methods. I conducted 85 semi-structured interviews with farmers in diverse intersectional positions, purposively selected: Dalit tenants; women farmers; migrant and non-migrant households; landless labourers; large landowners; subsidy beneficiaries, and non-beneficiaries. Interviews lasting 1-2 hours explored life histories, irrigation experiences, institutional navigation strategies, social relationships around water, migration impacts, and network participation. I also conducted 20 key informant interviews with agricultural officers, National Government Organisation (NGO) staff, political leaders, pump drillers and dealers, and moneylenders, which provided institutional perspectives. Four focus group discussions were also facilitated to explore shared experiences and collective narratives.

I also conducted a quantitative household survey of 401 farming households across six village clusters in Shambhunath Municipality, Saptari. Working with trained local research enumerators, I implemented a stratified random sampling strategy, ensuring representation across four key positionality dimensions: land tenure status (landless/tenant, marginal <0.5ha, small 0.5-2.0ha, medium/large >2.0ha); caste/ethnic identity (Dalit, Tharu, *Madhesi* middle castes, and other caste groups); gender of head of household, and migration status. The structured questionnaire, refined through pre-testing, collected comprehensive data on: demographics; landholding and tenure; irrigation technology ownership and access; agricultural practices; subsidy programme participation; credit sources; migration experiences; network memberships, and livelihood strategies.

Quantitative analysis using Jamovi software proceeded through descriptive statistics, bivariate analyses, and binomial logistic regression models to examine how land tenure, social position, and infrastructure jointly shape irrigation access (Foxcroft, 2018). Rather than depicting adoption as a sequence of individual choices, the multivariate results point to irrigation as a cumulative and relational process. Fixed infrastructures such as tubewells and electric meters are closely tied to land ownership and tenure security, while access among landowners increases sharply beyond locally meaningful land thresholds. At the same time, irrigation technologies cluster rather than diffuse: households with tubewells are far more likely to use electric pumps and to hold subsidised electric meters, indicating that access builds through successive layers of material and institutional alignment. Subsidised electric meter ownership shows a clear threshold, with little differentiation by land size once it is crossed. Together, these patterns suggest that groundwater irrigation is governed by the alignment of land, infrastructure, and institutional recognition, laying the empirical foundation for the argument of this thesis that irrigation access is produced through bundled and stratified architectures rather than linear technological diffusion.

Beyond quantitative methods, I engaged in extensive participant observation, spending sustained periods living in two villages of Shambhunath Municipality, participating in agricultural work, attending meetings and festivals, and engaging in informal conversations, while maintaining detailed field notes (Emerson et al., 2011). I also employed visual documentation, capturing over 500 photographs and videos of irrigation infrastructure, labour practices, and (in)equality markers. A particularly crucial component was documenting farmers' irrigation practices, technologies, and farm experiences through videos to capture what it means to access water.

All qualitative data were analysed using thematic analysis (Merriam & Tisdell, 2016), beginning during data collection through the constant comparative method (Glaser & Strauss, 1967/2017). I developed theoretical concepts and research questions, identifying themes and tracing causal mechanisms through iterative reading, coding, and analytical memo-writing (Miles et al., 2014). I then integrated the data systematically, using qualitative data to explain quantitative patterns and quantitative data to assess qualitative case representativeness, treating contradictions as analytically productive (Macdonald et al., 2008). Throughout all phases, I maintained rigorous ethical practices, obtaining farmer permission, Australian National University (ANU) ethics approval and research permission, securing informed consent, ensuring confidentiality through pseudonyms, and practising reflexivity about my own positionality as an educated, urban-based researcher (Sultana, 2011).

1.7 Significance and Contributions

This dissertation makes several interconnected contributions spanning theoretical, empirical, methodological, and policy domains. Theoretically, my primary contribution is to develop and examine the bundled architecture of the access framework, a synthesis integrating political ecology, agrarian change theory, and science and technology studies. This framework spreads theory by examining intersectionality to understand how multiple axes (class, caste, gender, tenure, migration) combine to shape material access and challenge technological determinism, by revealing empirically how the same technology has radically different meanings and effects depending on farmers' positionality (Ribot & Peluso, 2003; Nightingale, 2011; Bernstein, 2010).

Empirically, this research provides a comprehensive, rigorous mixed-methods analysis of the social dimensions of groundwater irrigation, conducted in Nepal. Further, I produce a nuanced account of how multiple inequalities combine. I add to the insights of complex linkages between labour out-migration, agrarian change, and irrigation technology, show how out-migration reshapes demand and capacity for irrigation with highly differentiated effects depending on pre-migration position, and detail ethnographic cases of specific elite capture mechanisms. I move beyond observation that capture occurs to fine-grained analysis of how it is accomplished through strategic network mobilisation, bureaucratic manipulation, and discursive framing of deservingness.

Methodologically, I provide a transparent example of research methods applied to complex development problems in field contexts, offering a clear model of sampling strategies, analytical procedures, and integration techniques for other researchers (Creswell & Plano Clark, 2018). My

incorporation of visual methods alongside traditional ethnography also contributes to methodological discussions about capturing embodied, material, and spatial dimensions of resource access.

1.8 Roadmap of the Dissertation

This section sets out a roadmap for the dissertation, which is organised into seven chapters, building a cumulative argument from theoretical foundations to empirical analysis and conclusions. Chapter Two reviews four key bodies of literature: irrigation development and groundwater in South Asia; political ecology and hydro-social approaches; agrarian change and differentiation scholarship; and science and technology Studies, particularly SCOT. The chapter identifies research gaps and elaborates on the *bundled architecture of the access* framework, tracing its intellectual roots, explaining core concepts, and outlining empirical analysis. Chapter Three provides research context and methodology, detailing Saptari's historical, geographical, social, economic, and political setting. It describes research design, sampling, data collection, analytical strategies, and ethical procedures guiding fieldwork. Chapters Four to Seven form the empirical core, each ending with a discussion that synthesises findings and links them to theory. Chapter Four presents quantitative results from a 401-household survey, examining relationships between farmers' structural positions (land tenure, landholding size, caste/ethnicity, gender, migration) and access to irrigation technology. Descriptive, bivariate, and multivariate analyses reveal patterns of inequality and document the cumulative bundling of technological components. Chapter Five provides qualitative insights through narratives and case studies of marginalised farmers, especially Dalit tenant men and women affected by out-migration. Four video-documented cases and one photo-documented case highlight how these actors experience, navigate, and resist structural constraints, negotiate access to water, and contend with gender- and caste-based discrimination. The discussion connects these lived experiences to quantitative patterns and illustrates technology's interpretive flexibility. Chapter Six examines the role of institutions in shaping access to technology, analysing an irrigation project in Shambhunath Municipality, showing how benefits intended for marginalised farmers were captured by elites. Chapter Seven presents three case studies of elite farmers that explain the strategic use of networks, bureaucratic knowledge, and interpretive flexibility. The discussion synthesises how institutional mechanisms reinforce structural inequality.

Chapter Eight concludes by summarising key findings, discussing theoretical and methodological implications, and offering policy recommendations for equitable irrigation development. Through this progression from theory to multidimensional evidence to synthesis, the dissertation demonstrates how

social position shapes technological access, which in turn drives divergent patterns of agrarian change and rural livelihoods, contributing to both academic understanding and ongoing efforts for justice and equity in Nepal's agrarian society.

2 Chapter Two: Literature Review and Conceptual Framework

2.1 Introduction

The preceding chapter established that access to groundwater irrigation technology in Nepal's Terai is profoundly unequal, structured not by market mechanisms or technical considerations alone, but by farmers' differential positioning within intersecting systems of land tenure, caste hierarchy, gender relations, class structures, and migration dynamics. Understanding this complex socio-technical inequality requires moving beyond disciplinary silos that have historically characterised scholarship on irrigation, technology, and agrarian change. This chapter undertakes the theoretical work necessary to construct an analytical framework capable of capturing this complexity.

My central argument in this chapter is that explaining how and why social position shapes technological access requires synthesising insights from three distinct but complementary scholarly traditions that have rarely been brought into systematic dialogue: Political ecology (particularly feminist and hydro-social approaches); agrarian change scholarship (rooted in Marxist political economy); and science and technology studies (notably the social construction of technology framework). Each tradition offers crucial but cumulative insights. Political ecology illuminates how power relations and environmental processes co-constitute one another, revealing water not as a neutral resource but as deeply embedded in social and political struggles (Budds et al., 2014). Agrarian change scholarship provides the class analytic lens necessary for understanding how technological transformations drive processes of differentiation, accumulation, and dispossession within rural societies (Bernstein & Byres, 2001; Bernstein, 2010; Byres, 2009). Science and technology studies challenge technological determinism by demonstrating that technologies are socially constructed, interpretively flexible, and stabilised through political processes that advantage some actors while marginalising others (Bijker, 2001; Winner, 1980).

Together these traditions help examine my research contexts. Political ecologists analysing water governance often neglect class analysis and agrarian political economy. Agrarian change scholars examining technological transformation frequently treat technology as a black box, insufficiently interrogating how specific technological designs and configurations emerge and stabilise. Scholars investigating socio-technical systems in the Global South sometimes fail to adequately theorise the deep structural inequalities of class, caste, and gender of which interpretations matter and for which interests technological closure serves. This dissertation argues that their deliberate, systematic

integration, which I accomplish through the conceptual framework of bundled architecture of access, offers analytical power unavailable from any single tradition alone.

This chapter proceeds in three main sections. First, I conduct a comprehensive, critical review of four interconnected bodies of literature, organised thematically rather than strictly by discipline. I begin with scholarship on irrigation development and groundwater dynamics in South Asia, establishing the empirical and policy context within which my research is situated. Second, I turn to Political ecology and hydro-social approaches, which provide foundational insights into the co-production of water and society, and the centrality of power in resource access. Third, I engage in scholarship on agrarian change and differentiation, which offers essential analytical tools for understanding technology as a driver of class transformation. Fourth, I review science and technology studies, particularly SCOT, which reveal how technologies acquire meaning and stabilise in forms that reflect and reproduce social power. Through this review, I identify specific gaps and limitations that my research addresses.

Building on this critical engagement, I present a detailed elaboration of the bundled architecture of the access framework. I explain its intellectual lineages, define and interrelate its core concepts, demonstrate how it synthesises the three theoretical traditions, and show how it can be operationalised for empirical analysis. This framework conceptualises farmers' positions as determined by their location within multiple, layered, and mutually reinforcing structures: an economic architecture of land, labour, and capital; a social architecture of caste, gender, and networks; and a techno-institutional architecture of specific technologies, infrastructures, and institutional rules. These architectures ‘bundle’ in that each layer builds upon and requires previous ones, creating the cumulative, sequential process of exclusion and inclusion that my empirical research documents.

I conclude by articulating how this integrated framework addresses the identified gaps, provides a coherent analytical strategy for answering my research questions, and offers broader applicability beyond the specific case of groundwater irrigation in Nepal. Throughout this chapter, I maintain explicit connection to the empirical arguments previewed in Chapter One, the cumulative bundling process, interpretive flexibility across social groups, elite capture mechanisms, the duality of technology as simultaneously empowering and disempowering, and the differential role of networks, signifying how the theoretical framework is grounded in and responsive to empirical realities.

2.2 Irrigation Development and Groundwater Dynamics in South Asia: Promise, Inequality, and Sustainability Challenges

2.2.1 The Groundwater Revolution Narrative and its Critics

The dramatic expansion of private tubewell irrigation across South Asia over the past five decades has been one of the most significant transformations in the region's agrarian history. Beginning in the 1960s and 1970s in India's Punjab, and accelerating through the 1980s and 1990s across the Indo-Gangetic plains, Pakistan's Punjab, and parts of Bangladesh, the proliferation of millions of privately owned diesel and electric pumps fundamentally altered agricultural production possibilities, livelihood strategies, and rural economies (Shah, 2009; Molle et al., 2010; Medendorp et al., 2022). Scholars initially celebrated this transformation as a 'groundwater revolution', framing it as a largely spontaneous, farmer-driven response to the inadequacies of state-managed surface irrigation systems (Mukherji, 2006; Shah, 2022).

The dominant narrative, articulated most influentially by Tushaar Shah and colleagues at the International Water Management Institute (IWMI), positioned groundwater development as fundamentally different from and superior to surface irrigation, in several respects (Shah, 2009; Mukherji & Shah, 2005). First, groundwater irrigation was portrayed as inherently more flexible and reliable, allowing farmers to apply water precisely when needed rather than depending on unpredictable canal deliveries or monsoon timing. Second, it was characterised as more equitable than canal irrigation, which notoriously suffered from head-tail inequities, elite capture of water allocation, and corruption in water distribution (Wade, 1982; Shah et al., 2016). The private, individualised nature of tubewells seemingly bypassed these collective action problems and rent-seeking opportunities. Third, groundwater development was celebrated as a democratising, market-based process driven by farmers' initiative rather than state planning, representing a triumph of entrepreneurship over bureaucracy (Shah, 2009; Dhawan, 2017). Fourth, its contribution to food security and poverty reduction was emphasised, with econometric studies demonstrating strong positive correlations between irrigation access and agricultural productivity, household income, and nutritional outcomes (Dillon, 2011).

This optimistic narrative profoundly shaped development policy across South Asia. Governments and international development agencies invested heavily in promoting groundwater irrigation through subsidised electricity for agricultural pumping, credit schemes for pump purchase, drilling support

programmes, and extension services emphasising intensive, irrigated agriculture (Birkenholtz, 2017). In Nepal specifically, the 2015 Agriculture Development Strategy considered groundwater irrigation as one of the means to achieving food security, poverty reduction, and climate resilience goals, targeting 60% of irrigation coverage of cultivated land within 2025/26 (Ministry of Agricultural Development, 2016; Government of Nepal, 2016). The strategy planned to construct new tubewells to cover an estimated 75,000 ha, representing half of the 150,000 ha of identified potential. These investments have delivered substantial and well-documented productivity gains for many farming households across the region. Irrigated paddy yields in the eastern Indo-Gangetic Plains consistently exceed those under rainfed production, with the advantage becoming particularly pronounced during years of variable monsoon rainfall when groundwater provides a critical buffer against crop failure (Shah, 2009). Studies from comparable Terai and eastern Indo-Gangetic contexts similarly examine that reliable access to groundwater irrigation increases agricultural productivity, enables dry-season cropping and vegetable cultivation, and supports greater cropping intensity than rainfed agriculture alone (Urfels et al., 2020; Schmidt et al., 2019). These gains are real, and understanding them matters as much as understanding who does not access them: the conditions that enable successful adoption among some smallholder households illuminate the structural supports absent for others.

However, a substantial body of critical scholarship has emerged over the past two decades, challenging key elements of this narrative and documenting severe limitations, contradictions, and negative consequences of the groundwater revolution (Molle et al., 2010; Birkenholtz, 2017). Environmental sustainability concerns have received particular attention. Numerous studies document alarming rates of groundwater depletion across much of South Asia, with water tables falling by 0.5 to 3.0 meters annually in intensively irrigated regions of northwestern India, Pakistan's Punjab, and parts of Bangladesh and Nepal (Rodell et al., 2009; Tiwari et al., 2009; Aryal et al., 2020; Chandra & Brozović, 2024; Rahman et al., 2025). This unsustainable extraction threatens long-term agricultural viability and creates conditions for future crises as aquifers are depleted, pumping costs rise prohibitively, and millions of farmers face the collapse of irrigation-dependent livelihoods (Mukherji et al., 2009; Aryal et al., 2025). Groundwater quality degradation, through arsenic contamination, salinisation, and nitrate pollution from agricultural chemicals, poses additional public health and agricultural risks (Sultan et al., 2025).

Equity concerns have also received increasing scholarly attention, challenging the claim that groundwater irrigation is inherently more equitable than surface systems. A growing body of research

demonstrates that access to and benefits from groundwater technology are highly stratified along multiple axes of social difference (Janakarajan, 1993; Prakash, 2005; Kafle et al., 2022; Varshney et al., 2025). Studies from India document how larger landowners disproportionately own tubewells and pumps, while smaller farmers and the landless either lack access entirely or must purchase water at exploitative rates from neighbours, creating new forms of dependency and surplus extracted from the already marginalised (Shah, 2009, 2022; Birkenholtz, 2017; Chatterjee et al., 2024). Research on water markets, in which pump owners sell water to those without pumps, shows these markets often reinforce rather than ameliorate inequality, with prices not reflecting competitive market principles but local power relations and monopolistic control over water sources (Janakarajan, 1993; Saleth, 1998; Chatterjee et al., 2024). Gender dimensions of groundwater irrigation have been explored by feminist scholars, who document how new technologies sometimes intensify women's agricultural labour while excluding them from ownership of technology, decision-making authority, and capture of benefits. Recent national policy analysis shows that, although Nepal's agricultural and climate policies increasingly recognise climate risk, they remain largely silent on gender-specific impacts and on how inequality structures access to technology (Upadhyay & Bastola, 2024).

2.3 Nepal's Water Policies, Legal Frameworks, and Groundwater Governance

Understanding groundwater access in Nepal requires situating technology adoption within the country's evolving water policy landscape, legal frameworks, and governance institutions. Nepal's water governance has undergone significant transformations over recent decades, reflecting changing development paradigms, donor influences, and domestic political shifts. However, groundwater has remained relatively marginal within policy frameworks historically oriented toward surface irrigation megaprojects, creating regulatory gaps and governance challenges.

2.3.1 Evolution of Water Policy: From State Control to Participatory Management

Nepal's evolution of its water policy reflects broader global shifts in irrigation governance paradigms. The 1992 Water Resources Act (WRA) established a foundational legal framework, asserting state ownership of all water resources while recognising customary rights for domestic and traditional irrigation uses. However, as researchers document, this act prioritised hydropower and large-scale irrigation development, with limited attention to groundwater or to the needs of smallholder farmers (Pradhan, 2000; Khadka et al., 2022, 2024).

The 2002 National Water Plan (NWP) marked a significant shift toward integrated water resources management (IWRM) principles, emphasising basin-level planning, stakeholder participation, and environmental sustainability. However, subsequent policy analysis has demonstrated that, despite these formal commitments to IWRM, implementation has remained limited in practice, with central state agencies continuing to dominate decision-making and failing to institutionalise river-basin management or decentralised governance structures (Clement et al., 2017). These patterns reflect broader global water governance trends in which multilateral institutions such as the Asian Development Bank and the World Bank actively promote IWRM, decentralisation, cost recovery, and private sector participation, even as on-the-ground institutional change in many contexts remains constrained by entrenched sectoral practices (Hirji & Davis, 2009).

The 2014 Irrigation Policy represented another important milestone, explicitly promoting farmer-managed irrigation systems (FMIS) and groundwater development. This policy, analysed by Joshi et al. (2025), shifted the emphasis from state construction of new surface systems to the rehabilitation and transfer of existing systems for water user associations, alongside support for private groundwater development through subsidised wells and pumps. This policy reflected both fiscal constraints, the state lacked resources for continued significant irrigation investments, and ideological shifts toward farmer-led development and market-based approaches.

Most recently, the 2021 National Water Resources Strategy (NWRS) has attempted to integrate water governance across sectors, emphasising climate adaptation, groundwater management, and equity considerations. However, as Kulkarni et al. (2021) note, implementation remains nascent, and significant gaps persist between policy aspirations and field-level realities, particularly regarding groundwater regulation and the inclusion of marginalised groups.

Despite groundwater's critical importance for Nepal's agriculture, an estimated 42% of farmers in the Terai have access to its irrigation through shallow tubewells, underscoring its substantial role in dry seasonal crop production (Urfels et al., 2020). However, regulatory frameworks for groundwater remain underdeveloped compared to those for surface water. The WRA technically requires permits for groundwater extraction, but Pant (2011) documents that this requirement is rarely enforced for agricultural wells, creating a de facto open-access regime.

This regulatory gap has multiple implications. First, it enables unregulated expansion of groundwater extraction, raising sustainability concerns in areas experiencing aquifer depletion. Shrestha et al.

(2018) document declining water tables in parts of the Terai, attributing this to intensive shallow tubewell proliferation combined with reduced groundwater recharge due to changing land use. Second, the absence of regulation means there are no mechanisms to ensure equitable access or to prevent monopolisation by large landowners. Sugden et al. (2014) show that wealthier farmers drill deeper wells and install more powerful pumps, thereby accessing water denied to neighbours with shallow wells, without any regulatory constraints.

Third, regulatory ambiguity creates uncertainty for farmers considering tubewell investment. Without clear property rights to groundwater, farmers face risks that investments may be undermined by neighbours' drilling or future regulatory restrictions. Butterworth et al. (2010) argue that this uncertainty can paradoxically accelerate extraction, as farmers rush to capture groundwater before regulations are imposed or aquifers are depleted; a race to the bottom dynamic.

Some scholars advocate for clearer groundwater property rights and permitting systems. However, Molle and Closas (2020) caution that formal regulations are only effective where state capacity for monitoring and enforcement exists. Given Nepal's limited administrative capacity, particularly in rural areas, they suggest that regulatory approaches must be complemented by community-based management and incentive structures that align farmer behaviour with sustainability goals.

State and donor programmes promoting irrigation technology through subsidies have significantly shaped groundwater development patterns in Nepal. The Agricultural Mechanization Promotion Policy (AMPP) (2014) and various externally funded programmes provide subsidies covering 50%-75% of the costs of tubewells and pumps for targeted farmers. Presumably designed to expand irrigation access and increase agricultural productivity, these programmes raise important equity questions about who benefits.

Thapa et al. (2019) evaluated subsidy programmes in Nepal's Terai, finding that beneficiaries are disproportionately medium- and large-scale landowners with existing irrigation access, market connections, and bureaucratic literacy to navigate application processes. Marginal farmers, tenant farmers, and socially excluded groups rarely benefit due to targeting criteria (land-ownership requirements), information asymmetries (programmes advertised through channels accessible to elites), and implementation practices (officials collaborating with village elites in beneficiary selection) (Upreti et al., 2009; Kafle et al., 2022; Varshney et al., 2025). Upadhyay and Bastola (2024) show that even where gender inclusion is formally mandated, representation is weakly linked to

officials' performance and budgeting authority, leaving women marginal to programme design, resource allocation, and institutional power.

The patterns of subsidy capture reflect a broader structural shift in how irrigation services are organised across South Asia. Over the past three decades, state-led irrigation provision has been progressively replaced by market-based approaches under structural adjustment and new public management frameworks. In Nepal, this translated into the promotion of farmer-managed irrigation systems, cost-recovery requirements, and state withdrawal from direct infrastructure provision. In a market-led governance framework, equity tends to be operationalised as facilitated access as a right. The consequence, well documented in the Nepali literature, is that structural conditions advantaging larger, higher-caste, landowning households are not disrupter by market facilitation approaches; they are reproduced through them (Pradhan, 2019; Zwarteveen & Boelens, 2014; Joshi et al., 2025). The patterns of differential access documented in Chapters Four through Seven are therefore not deviations from a well-functioning system; they are products of how systems are organised.

Moreover, irrigation subsidy programmes in Nepal have often prioritised quantitative targets, such as the number of pumps or wells distributed, over qualitative outcomes related to equity and sustainable livelihoods. Analyses of Nepal's irrigation subsidy policies highlight significant gaps in implementation capacity and in mechanisms to ensure equitable access, with many policies lacking clear guidelines to translate technology delivery into inclusive development outcomes. In the case of solar irrigation pumps, applications have far exceeded available subsidies, and uptake has tended to favour relatively better-resourced farmers (Shrestha et al., 2022; Karki et al., 2023). At the same time, empirical evidence shows that many subsidised systems remain underused, thereby weakening their livelihood benefits and underlining the limits of technology-focused programmes that are not accompanied by broader institutional and livelihood support (Oziel et al., 2024).

Critically, some scholars question whether subsidy-driven technology promotion serves farmers' interests or external agendas. Birkenholtz (2017) argues that irrigation subsidies function as mechanisms of agricultural intensification that benefit input suppliers, equipment manufacturers, and the commercial agriculture sector, while creating dependencies and environmental externalities borne by farmers. In Nepal's context, scholars show how subsidy programmes align with donor and government commitments to agricultural growth and export promotion, sometimes conflicting with smallholder livelihood security and environmental sustainability priorities.

2.3.2 Water User Associations and Collective Action in Nepal

Water user associations (WUAs) have been central to Nepal's irrigation governance since the 1990s, promoted as vehicles for participatory management, cost recovery, and institutional sustainability. Understanding the functions of WUAs, their equity implications, and their relevance (or irrelevance) for groundwater governance is essential for analysing irrigation technology's institutional dimensions.

Nepal has a long history of FMIS, community-built and operated systems predating state involvement. Pradhan (2000) and Ostrom (2010) famously analysed these systems as examples of successful common-pool resource governance, explaining that farmers could self-organise effective institutions without state control. These studies challenged the belief that irrigation requires centralised bureaucratic management, helping inspire global shifts toward participatory irrigation management.

However, some scholarship has complicated these optimistic accounts of farmer-managed irrigation. Yoder (1994) demonstrates substantial variation in FMIS performance, showing that outcomes depend on resource characteristics, community social structure, and the degree of external support. Systems in relatively homogeneous hill communities (still diverse compared to the Terai), with clearly bounded water sources, tend to perform better than those in the Terai, where diverse users, uncertain hydrology, and stronger market pressures make collective management more difficult. Research in Nepal further shows that FMIS are not socially neutral institutions. Comparative studies document that water distribution rules and enforcement practices often reflect existing hierarchies, with advantages accruing to upstream, wealthier, or socially dominant farmers and weaker access for those at the tail end or lower in local social orders (Ostrom, Lam, & Lee, 1994; Pariyar, 2018). These findings challenge romanticised portrayals of indigenous irrigation institutions as inherently equitable and instead reveal how they can reproduce, and sometimes intensify, social and spatial inequalities, particularly in the Terai's complex agrarian landscape.

Critically, state intervention has transformed FMIS. The Irrigation Management Transfer (IMT) programme, initiated in the 1990s, transferred thousands of government-built systems to WUAs, ostensibly empowering farmers while reducing the state's fiscal burden (Regmi, 2008). However, as Gautam (2006) analyses, IMT often transferred systems in poor physical condition without adequate resources for rehabilitation, effectively shifting infrastructure costs to farmers. Moreover, WUA formation processes were often rushed and externally driven, creating formal organisations lacking genuine community ownership or capacity (Aubriot & Bruslé, 2023).

Research on WUA performance in Nepal reveals persistent challenges regarding elite capture, marginalised group exclusion, and limited accountability. Scholars examining WUA membership rules find that basing membership on landholding systematically excludes tenant farmers, sharecroppers, and landless agricultural workers who depend on irrigation but lack formal representation. Even when membership is nominally open, economic barriers (membership fees) and social norms (caste and gender restrictions on public participation) limit the involvement of poor and marginalised farmers. Upadhyay's (2005) cross-sectoral analysis shows that such exclusions are institutionally produced rather than culturally residual. Land-based membership rules, gender-blind extension systems, and programme designs that equate 'farmer' with 'male' systematically render women illegible as resource managers, even in contexts where they are the primary irrigators.

Shrestha and Clement (2019) analyse gender dynamics in Nepal's WUAs explicitly, documenting how patriarchal norms marginalise women despite formal policies mandating female participation. They find that while some WUAs have achieved nominal women's representation, often due to donor requirements, substantive participation remains limited. Women representatives often serve as tokens, attending meetings without speaking or deferring to male relatives. Moreover, WUA activities focus on infrastructure maintenance and water distribution for irrigated agriculture, domains culturally coded as masculine, while neglecting domestic water, livestock, and kitchen gardens, where women's water needs are concentrated.

Elite capture dynamics are well documented. WUA leadership positions are found to be monopolised by large-scale landowners, high caste members, and politically connected individuals who use these positions to secure favourable water allocations, influence infrastructure investments, and access state resources (Liebrand, 2010; Shunglu et al., 2022). Ordinary members and exceptionally marginalised farmers often view WUAs as captured institutions serving elite interests rather than collective farmer welfare, undermining cooperation and collective action.

However, some research identifies conditions enabling more equitable WUA performance. Lam (1998) finds that systems with clear rules, transparent decision-making, effective conflict resolution mechanisms, and regular monitoring of officials perform better and distribute water more equitably. Bardhan & Mookherjee (2002), Dhakal et al. (2018), and Parajuli et al. (2024) emphasise the importance of relative economic equality among members, arguing that high inequality makes collective action difficult as powerful actors opt out or dominate institutions. For Nepal, these findings

suggest that WUA effectiveness and equity depend significantly on broader social structures that policies may fail to address.

A critical question for the present research is whether WUA frameworks developed for surface irrigation systems are relevant for groundwater governance. Unlike surface systems, where water flows through shared canals that require collective maintenance and distribution rules, groundwater is accessed through individual wells on private land, creating fundamentally different governance challenges.

The institutional challenge, therefore, is to develop governance approaches appropriate to groundwater's hybrid character, neither purely private nor entirely shared, not an open-access resource, but one that involves complex layered institutional arrangements requiring both individual initiative and collective action. Central to this challenge is recognizing what the current legal framework obscured. Nepal's Water Resource Act (1992) treats groundwater as an adjunct of surface land rights, it is the landowner who applies for the tubewell permit, qualifies for the subsidy, and registers for the electric meter. The aquifer itself, however, is spatially heterogeneous: depth to water, saturated thickness, and seasonal recharge rates vary across short distances depending on proximity to river channels, local recharge zones, and the lateral fining gradient of alluvial sediments (Urfels et al., 2024). A farmer wo has secured land and installed a tubewell cannot know in advance whether the aquifer at that precise location will yield sufficient water at an affordable depth. This introduces a third, hydro geologically distinct stage in the conditionality of water access: land ownership enables institutional eligibility for technology; technology provides physical extraction capacity; but aquifer conditions, depth, yield, and seasonal water table level-determine whether extraction produces water in the quantities needed. The current institutional framework, which recognizes only the first two stages, leaves the third entirely to individual risk (Ostrom, 1990; Shah, 2009; Pant, 2011).

However, other scholars argue for the possibility of collective groundwater governance. Van Steenbergen and Shah (2003), and Matham et al. (2023), examine cases of community-managed aquifer recharge and the regulation of extraction in India, showing that collective action is possible when communities perceive shared threats from over-extraction. Mukherji and Shah (2005) and Razzaq et al. (2025) analyse informal water-sharing arrangements in Bangladesh, where shallow tubewell owners enter into reciprocal agreements with neighbours, creating quasi-collective governance despite individual well ownership.

For Nepal, research on groundwater's collective dimensions remains limited. Asian Development Bank (2001) notes that most tubewells operate independently, with minimal collective coordination. However, Sugden et al. (2021) document emerging water-sharing practices in some communities, particularly where remittance-funded tubewells are used by multiple family members or informally shared with neighbours. They suggest that groundwater governance exists along a spectrum, from purely individual to partially collective, depending on technology type, community social relations, and water availability.

Against this backdrop, groundwater irrigation has expanded rapidly in the Terai plains over the past two decades, driven by farmers seeking more reliable water sources, supported by development projects and subsidies, and enabled by expanding electricity infrastructure and declining pump costs. However, existing research on groundwater irrigation in Nepal has been limited in scope and depth compared to the extensive literature on India, Pakistan, and Bangladesh. Much of the Nepali literature consists of technical and hydrological studies documenting aquifer characteristics, recharge rates, and extraction volumes, providing essential baseline data but missing social dimensions (Shrestha et al., 2018; Dhakal et al., 2018; Urfels et al., 2020). Policy-oriented studies tend to focus narrowly on adoption rates, technical efficiency, and aggregate productivity impacts, treating farmers as a homogeneous category and treating technology access primarily as a function of information and credit availability (Foster et al., 2021; Adhikari et al., 2025).

A more petite body of social science research has begun exploring equity and governance dimensions. Sugden et al. (2014) provide important documentation of how groundwater expansion in the Terai is occurring in a context of extreme land inequality and insecure tenancy, raising concerns about who benefits. Valadaud (2022) examines elite capture in WUAs, indicating how better-positioned farmers dominate institutional spaces. Research on groundwater's collective dimensions remains limited in Nepal. Much of the gender-water literature emphasises how climate change and water scarcity shape gendered labour burdens and constrain women's authority in water use and adaptation strategies (Sultana, 2018; Goodrich et al., 2021). Studies linking out-migration and irrigation governance in Nepal are still emerging. Sugden et al. (2021) provide initial evidence of complex interactions between cyclical labour out-migration, remittance flows, and agrarian transformation, including implications for agricultural intensification and labour allocation. Further work by Meinzen-Dick and Pradhan (2021) shows how male out-migration can interact with irrigation governance structures, women's participation, and institutional responses under changing demographic and labour conditions.

However, significant gaps remain. First, existing research rarely adopts explicitly intersectional approaches that examine how multiple axes of inequality, land tenure, caste, gender, class, and migration interact and combine to shape access. Most studies examine single dimensions in isolation. Second, insufficient attention has been paid to the micro-politics of development interventions and to the specific mechanisms by which elite capture operates beyond mere documentation. Third, the role of technology itself, how specific technological designs, configurations, and meanings emerge and stabilise, remains under-theorised in Nepal's irrigation literature. Fourth, the long-term implications of differential irrigation access for agrarian change, class differentiation, and social mobility have not been systematically investigated. My research explicitly addresses these gaps through an intersectional, mixed-methods approach grounded in interdisciplinary theoretical synthesis.

2.4 Political Ecology and Hydro-Social Approaches: Water, Power, and the Co-production of Nature and Society

2.4.1 Foundational Concepts in Political Ecology

Political ecology emerged in the 1980s and 1990s as an explicitly political and critical approach to understand environmental issues, challenging both apolitical technical environmentalism and romantic cultural ecology (Blaikie & Brookfield, 2015). The field's foundational premise is that environmental conditions and resource access patterns cannot be explained through ecological or technical factors alone, but must be understood as produced through political-economic processes operating across multiple scales, from the local to the global (Robbins, 2012; Roberts, 2020). Early Political ecology combined insights from cultural ecology's attention to human-environment interactions with dependency theory and world-systems analysis, arguing that environmental degradation in the Global South reflected unequal power relations, colonial legacies, and capitalist integration rather than population pressure or peasant ignorance (Benjaminsen & Svarstad, 2021).

Several core concepts and analytical commitments define political ecology as it has evolved. First is the insistence that environmental knowledge is never neutral but is shaped by power, interests, and social position; as Goldman et al. (2011) refer as knowing nature through science and society. Whose knowledge counts, which environmental narratives become dominant, and what solutions are deemed legitimate reflect underlying power relations (Forsyth, 2004). Second, political ecologists emphasise multi-scalar analysis, tracing connections between local resource conflicts and broader political-economic structures, including markets, states, development institutions, and global capitalism

(Perreault et al., 2015; Neumann, 2009). Environmental outcomes in specific places are understood as produced through processes linking local actors to external forces. Third, political ecology has increasingly emphasised environmental justice, examining who benefits and who bears the costs of the specific environmental changes and resource governance arrangements, and highlighting struggles by marginalised groups for environmental rights and recognition (Roberts, 2020).

A particularly influential strand within political ecology explicitly focused on water, developing the hydro-social approach (Budds et al., 2014). This perspective fundamentally challenges the conventional conceptualisation of water as a pre-existing natural resource that societies manage, govern, or distribute. Instead, hydro-social scholars argue that water and society are co-produced; water is made social through the technologies, infrastructures, institutions, and power relations that mobilise it, while these socio-technical arrangements are themselves shaped by water's materiality, distribution, and variability (Bakker, 2002; Swyngedouw, 2009). Water is thus understood as a hybrid entity that is simultaneously natural and social, material and cultural, flowing through and produced by socio-technical networks (Hoffmann & Villamayor-Tomas, 2023).

This hydro-social perspective has generated important insights into irrigation systems. Boelens et al. (2014) discuss that irrigation infrastructure is not a neutral technical artefact but embodies and reproduces particular social orders, property regimes, and power relations. The design of canal systems, the placement of wells, the choice of pump technologies, these apparent technical decisions privilege certain users over others, enable forms of control and exclusion, and shape possibilities for accumulation and marginalisation (Molle et al., 2010). Budds et al. (2014) show how groundwater aquifers become socio-natural entities actively produced through extraction patterns, legal frameworks defining water rights, and state regulatory practices or their absence. An aquifer's meaning, accessibility, and sustainability are thus social achievements rather than natural givens.

2.4.1.1 Feminist Political Ecology: Gender, Intersectionality, and Situated Knowledge

Feminist political ecology (FPE) represents a crucial intervention that has fundamentally reshaped political ecology by insisting that all environmental relations are gendered and that gender cannot be understood in isolation from other axes of power and identity (Elmhirst, 2011; Rocheleau et al., 2013; Farhall & Rickards, 2021). Early FPE work documented how environmental changes and resource access processes affect men and women differently, due to gendered divisions of labour, property rights, and social roles (Schroeder, 1999). Women are shown to bear disproportionate burdens of

environmental degradation, walking longer distances for water and fuel, working harder to cultivate degraded soils while being excluded from decision-making spaces where environmental policies are determined (Jackson, 1993; Fonjong & Zama, 2023).

However, FPE has evolved beyond these initial 'women and environment' approaches toward more sophisticated, theoretically grounded analyses (Elmhirst, 2011; Nightingale, 2011). Contemporary FPE draws on feminist theory to examine how gender, as a system of power relations rather than binary categories of men and women, shapes environmental knowledge, resource control, and political struggles (Leach, 2007; Rocheleau et al., 2013). This involves analysing masculinities and femininities, examining how gender intersects with other identity categories and power relations, and interrogating how environmental interventions and conservation programmes can reinforce or challenge gender hierarchies (Nightingale, 2006; Elmhirst, 2011; Caretta & Rothrock, 2021).

Particularly crucial for my research is FPE's adoption and development of intersectionality as an analytical framework. Originating in Black feminist legal scholarship and critical race theory (Crenshaw, 1991; Collins, 2009), intersectionality insists that systems of oppression and axes of social difference, race, class, gender, sexuality, caste, and ethnicity, are not separate independent variables but are interlocking, mutually constitutive, and fundamentally inseparable (Cho et al., 2013). Feminist political ecologists have demonstrated that intersectionality is essential for understanding environmental inequality and access to resources. Nightingale (2011), working in Nepal, shows how the lived experiences and political subjectivities of rural women are shaped simultaneously by gender, caste, class, and location in ways that cannot be captured by examining any single axis alone. Sultana (2011) demonstrates how, in Bangladesh, intersectional positions shape differential vulnerability to environmental hazards and access to adaptation resources. Intersectional approaches have also been used to examine indigenous women's struggles over land, territory and political authority in Latin America. For example, Picq (2018) shows how indigenous women in Ecuador challenge overlapping systems of patriarchy, colonial, authority, and state power through their struggles for territorial rights, legal recognition and indigenous justice.

FPE scholars working on water have produced particularly relevant insights. Zwarteveen and Boelens (2014) analyse how water technologies and irrigation institutions are deeply gendered, often burdening women with intensified labour while excluding them from ownership of technology, access to training, and institutional authority. Ahlers and Zwarteveen (2009) critique the gender

mainstreaming approaches that are dominant in water policy, arguing they often produce superficial inclusion without challenging underlying patriarchal power structures. Cleaver and Hamada (2010) demonstrate how attention to women's practical participation in water management groups misses deeper issues of recognition, authority, and legitimacy, which structure whose knowledge and preferences matter. The body of work by these scholars establish that understanding water access requires analysing not just formal rules and technical systems, but the gendered (and intersectionally structured) social relations through which water is accessed, controlled, and contested. It is worth noting that Soto (2000) argues formalising property rights empower the poor, Boelens and Vos (2014) counter that formalisation often dispossesses marginalised groups by privileging those already advantaged in formal systems. This study finding that documentation requirements systematically exclude landless and tenant farmers from irrigation subsidies support Boelens and Vos critique.

2.4.2 Access and Property: Conceptual Tools from Political Ecology

Political ecology has generated sophisticated conceptual frameworks for analysing resource access, which move beyond narrow legal conceptions of property rights. The most influential is Ribot and Peluso's (2003) ‘theory of access’, which they define as the ability to benefit from things, including resources, persons, institutions, and symbols. This deliberately broad definition shifts attention from legally defined rights (which may exist on paper but remain unexercised) to the existing abilities to derive benefits, which may operate through mechanisms other than formal property rights. Ribot and Peluso identify multiple strands in the bundle of powers that enable access: rights-based access (legal property rights); structural and relational mechanisms (through social identity, social relations, and networks); and mechanisms of access control and maintenance (through technology, capital, markets, labour, knowledge, authority, and social relations).

This access framework has been productively applied to irrigation and water studies. Zwarteveen and Boelens (2014) use it to analyse how water access operates through multiple, overlapping, and sometimes contradictory mechanisms, such as formal water rights, infrastructure placement, technical knowledge, pump ownership, social networks, and gender norms, which together produce highly differentiated abilities to benefit from water resources. The framework enables analysis of how marginalised actors may nominally possess rights but lack effective access due to structural barriers and, conversely, how powerful actors may access and control resources without formal rights through their social position and connections. Karamchedu (2024) presents an analysis of groundwater access in India, indicating how large farmers' control over groundwater operates not just through pump

ownership but also through their capacity to shape local knowledge of aquifer conditions, influence bank credit allocation, and deploy caste status to exclude others from drilling in certain areas.

Building on Ribot and Peluso (2003), Sikor and Lund (2010) discuss the politics of possession, examining how claims to property are established, legitimised, contested, and transformed through political processes. They argue that property is not a static legal institution but an ongoing political achievement, constantly being made and remade through practices of claiming, regulating, excluding, and legitimating. This perspective is particularly valuable for understanding contexts like rural Nepal, where multiple, overlapping systems of land tenure and resource rights coexist, where there are statutory laws, customary norms, development programme rules, local power relations, and where the effective meaning of property is negotiated in practice rather than determined by formal law alone (Upreti et al., 2009; Nightingale et al., 2019).

These conceptual tools from political ecology provide crucial analytical resources for my research. The access framework enables me to examine not just who formally owns irrigation pumps, but the multiple mechanisms, including land tenure, caste status, gender norms, network position, bureaucratic literacy, and political connections, through which farmers' actual abilities to benefit from irrigation technology are structured. The concept of co-production sensitizes analysis to how groundwater, irrigation technology, and social relations mutually shape one another rather than existing as separate domains. Intersectionality provides the analytical strategy for examining how multiple axes of difference combine to shape access. However, political ecology alone is insufficient. It often lacks the depth of class analysis needed to understand agrarian differentiation processes and insufficiently theorises technology itself. This requires turning to scholarship on agrarian change and science and technology studies.

2.5 Agrarian Change and Class Differentiation: Technology as Driver of Social Transformation

2.5.1 The Agrarian Question and Classical Debates

Scholarship on agrarian change has deep roots in late nineteenth- and early twentieth-century debates about the agrarian question, fundamentally, the question of what happens to peasantries and rural societies under capitalism (Bernstein, 2010; Byres, 1996). Classical Marxist theorists, particularly Kautsky (1899/1988) and Lenin (1899/1967), argued against both romanticised agrarian populism and assumptions of peasant stagnation, demonstrating that rural societies under capitalism undergo

continuous, dynamic, and often violent processes of transformation. Their central analytical insight was that peasantries are not homogeneous social categories but are internally differentiated into emerging rural classes with fundamentally different and increasingly antagonistic relationships to the means of production, particularly land.

Lenin's (1899/1967) study of rural Russia provided the paradigmatic analysis of agrarian differentiation, the process through which some peasant households accumulate land, capital, and productive assets, gradually transforming into commercial farmers or rural capitalists who employ wage labour and produce for markets, while other households lose land, are unable to reproduce themselves through farming alone, and are proletarianised into agricultural or industrial wage workers. This process is driven by multiple reinforcing mechanisms: unequal access to land and capital; differential exposure to market risks and price fluctuations; varied success in adopting new technologies and production methods; and the accumulation of small advantages or disadvantages across generations. The outcome is a polarised agrarian structure characterised not by homogeneous peasantry but by distinct classes: rich peasants/capitalist farmers; middle class peasants struggling to maintain viability; poor peasants supplementing inadequate farm income with wage labour; and landless agricultural labourers (Patnaik, 1987; Bernstein, 2010).

While classical agrarian question debates focused on European and Russian contexts, scholars have extensively applied and adapted these frameworks to understand agrarian transformations in the Global South, particularly in the postcolonial era (Byres, 1996; Bryceson et al., 2005). The Green Revolution in South Asia has been the central focus of this scholarship. While mainstream development narratives celebrated the Green Revolution as a technical success, bringing higher-yielding seed varieties, chemical fertilisers, and irrigation to millions of farmers, critical agrarian political economy scholars documented how these technological changes accelerated differentiation rather than benefiting farmers equally (Patnaik, 1987; Harriss-White, 2003). New technologies required significant capital investment, access to credit, an assured water supply, and the capacity to bear the risks of market volatility – advantages that better-positioned farmers possessed but that marginal and poor farmers lacked (Walker & Ryan, 1990; Brass, 2005). Although Green Revolution technologies were designed to be scale-neutral and were widely adopted across farm sizes, and while they increased labour intensity and demand, the distribution of gains was shaped by unequal access to complementary resources and institutions, contributing over time to agrarian differentiation, rural indebtedness, and landlessness (Shiva, 1993; Patel, 2013).

2.5.2 Contemporary Agrarian Change: Differentiation, Accumulation, and Dispossession

Contemporary agrarian change scholarship builds on classical foundations while engaging new empirical realities of globalisation, neoliberal restructuring, and environmental change (Akram, Lodhi & Kay, 2010; Bernstein, 2010). Bernstein's (2010) influential synthesis articulates several key concepts for analysing contemporary rural transformations. The simple reproduction squeeze refers to the tightening constraints on small-scale producers' ability to reproduce themselves and their livelihoods through farming alone, driven by rising input costs, declining and volatile commodity prices, loss of access to common property resources, and climate variability. This squeeze forces rural households into increasingly desperate strategies, including distress sales of land and assets, taking on high-interest debt, entering precarious wage labour, and out-migration in search of livelihood alternatives.

Bernstein emphasises that contemporary agrarian change produces multiple, divergent class trajectories rather than a single linear path. Some rural households successfully accumulate, consolidating landholdings, mechanising production, accessing high-value commodity chains, diversifying into non-farm enterprises, and transitioning into small-scale capitalist farmers or rural entrepreneurs. Others maintain precarious positions as petty commodity producers, caught between partial proletarianisation (needing to work for wages to subsidise farming) and struggles to retain land and farming identity (Li, 2014; Bernstein, 2017). Still others are dispossessed, losing access to land through indebtedness, eviction, or market pressures, and becoming fully proletarianised into wage labour in agriculture, industry, or services, or joining the vast surplus populations for whom capitalism generates no stable employment (Li, 2014).

Technology remains central to these processes. White (2012) analyses how agricultural mechanisation in Southeast Asia drives both labour displacement and new patterns of accumulation. Patel (2013) examines how biotechnology and corporate control over seeds reshape power relations in agriculture. Oya (2012) shows how irrigation infrastructure investment in Africa creates differentiated opportunities for accumulation and marginalisation, depending on farmers' pre-existing positions. A consistent finding across this literature is that technological change introduced into contexts already marked by inequality tends to reinforce and deepen, rather than reduce, that inequality (Byres, 1996; Brass, 2005). Technologies become instruments through which well-positioned actors consolidate advantages and accumulate, while poorly positioned actors face intensified pressures and potential dispossession.

2.5.3 Migration, Agrarian Change, and Livelihood Diversification

An important strand of contemporary agrarian change scholarship examines the complex relationships between rural out-migration and agricultural transformation, particularly relevant to my Nepal case, where migration is pervasive. Classical perspectives tended to view migration as a symptom of agrarian crisis and dispossession; people left because they could not sustain livelihoods in agriculture (Asfaw et al., 2010; De Haas, 2010). However, more recent scholarship emphasises migration's diverse causes, meanings, and consequences that vary significantly across differentiated rural populations (Bhandari & Ghimire, 2016; Rigg, 2016).

For some households, migration represents a successful diversification strategy enabled by prior accumulation, with remittances funding further agricultural investment, land purchases, and business ventures that strengthen rural positions (De Haas, 2010; Jackson et al., 2025). For others, migration reflects desperation under the reproduction squeeze, with remittances barely covering debt payments and subsistence needs, providing survival rather than accumulation (Gartaula et al., 2014; Maharjan et al., 2020). Migration's effects on agriculture are similarly differentiated. Remittances can fund agricultural intensification, including investments in irrigation, mechanisation, and commercialisation, thereby maintaining or strengthening farm viability (Tuladhar, 2014). Alternatively, migration can cause agricultural de-intensification due to labour shortages, with fields left fallow or shifted to less labour-intensive crops (Maharjan et al., 2020; Sunam et al., 2021).

Gender dimensions are critical. Feminisation of agriculture, as men leave and women assume farming responsibilities, is widely documented but carries contradictory implications (Gartaula et al., 2014; Meinzen-Dick et al., 2022). Some research suggests that migration can empower women by increasing their authority in agricultural decision-making, expanding their mobility, and recognising their economic contributions. Other studies find that women's labour intensifies without commensurate increases in authority or control over resources, as male household heads maintain decision-making power remotely and patriarchal norms constrain women's autonomy (Nightingale, 2019; Jannat et al., 2025). These divergent findings likely reflect the differentiated positions of women across class, caste, and life-cycle stages. Migration's gendered effects are not uniform but intersectionally structured.

The agrarian change literature provides my research with essential tools for understanding irrigation technology not as an external input but as embedded within and constitutive of differentiation processes. It sensitises analysis to how seemingly small differences in technology access can

accumulate over time into divergent class trajectories. However, this literature's treatment of technology itself is often thin, treating technologies as relatively uniform innovations whose social effects depend on context, but insufficiently examining how they acquire meaning, how alternative technological configurations emerge or are foreclosed, and how technologies stabilise in forms reflecting particular interests. This requires engagement with science and technology studies (STS) elaborated in the following section.

2.6 Science and Technology Studies: The Social Construction and Political Life of Technologies

2.6.1 Challenging Technological Determinism: SCOT and Interpretive Flexibility

Science and technology studies (STS) emerged as an interdisciplinary field in the 1970s and 1980s, fundamentally challenging dominant assumptions about the nature of science and technology, and their relationship to society (Bijker et al., 2012). Against widespread technological determinism, the assumption that technologies have inherent properties and inevitable social effects that unfold independent of social context, STS scholars argue that technologies are socially constructed (Winner, 1980). This does not mean technologies are arbitrary or imaginary, but rather that their design, meaning, use, and effects are shaped through social processes involving choices, negotiations, and power relations among differently positioned actors.

The social construction of technology (SCOT) framework, developed by Pinch and Bijker (1984), and later elaborated by Bijker (1995), provides a systematic approach for analysing how technologies emerge and stabilise. SCOT introduces several core concepts central to my analysis. First is relevant social groups, the various actors (users, designers, producers, regulators, etc.) who share similar meanings and understandings of a particular technological artefact (Pinch & Bijker, 1984). Importantly, these groups may interpret the same technology very differently based on their interests, experiences, and social positions. Second is interpretive flexibility, the recognition that technological artefacts are open to multiple, often radically different interpretations by various relevant social groups (Kline & Pinch, 1996). A tubewell is not a singular object with one fixed meaning; it means different things to a large landowner, a tenant farmer, a woman managing fields during male out-migration, a groundwater hydrologist, and a development agency official. These different interpretations are not misunderstandings but reflect genuine differences in how technology relates to each group's material interests, social position, and practical concerns.

Third is closure, the social and political process through which interpretive flexibility gradually narrows, and one configuration, meaning, or use of a technology becomes stabilised and accepted as the normal or natural form (Bijker, 1995). Crucially, closure is not achieved through discovering an objectively superior technical solution, but through social processes in which one group's interpretation prevails over others. Closure may occur rhetorically (convincing others that a problem is solved), through redefinition of the problem (reframing what the technology is supposed to accomplish), or through dominance (one group has sufficient power to impose its interpretation) (Pinch & Bijker, 1984). Once closure is achieved, it becomes increasingly difficult to challenge or reverse, as supporting infrastructure – technical, institutional, financial, and ideological – becomes organised around the stabilised form.

SCOT has been productively applied to diverse technologies, including bicycles, fluorescent lighting, missile systems, and agricultural machinery, demonstrating how those that appear inevitable in retrospect emerge through contingent processes involving social choices and power relations (Bijker, 1995). Kline and Pinch (1996) show how American farmers in the early twentieth century interpreted automobiles not as transportation devices but as flexible power sources for agricultural work, using cars to pump water, saw wood, and thresh grain; an interpretation eventually foreclosed as automobiles stabilised around transportation functions. This example illustrates how users can interpret technologies in ways designers never intended, and how some interpretations become marginalised as closure occurs around dominant meanings.

While SCOT provides valuable analytical tools, it has faced important critiques. Winner (1980) argues in his influential essay "Do Artifacts Have Politics?" that some technologies embody inherently political qualities that constrain how they can be used and what social arrangements they support. Winner distinguishes between technologies that are political in specific contexts (e.g., tomato harvesters designed for large-scale operations that disadvantage small-scale farmers) and those with inherently political characteristics (e.g., nuclear power plants that require centralised, authoritarian management for safety). Winner’s concern is that SCOT's emphasis on interpretive flexibility and social construction may obscure how technologies, once stabilised and marginalised, can constrain social possibilities and become difficult to reinterpret or reconfigure.

This critique is particularly relevant for understanding irrigation technologies in contexts of deep structural inequality. While SCOT illuminates how tubewells and pumps are interpreted differently

by various social groups, Winner's perspective reminds us that once irrigation infrastructures marginalise in specific configurations, individually owned electric pumps require land title for meter connections, and privately drilled deep tubewells are beyond poor farmers' financial reach, they create material realities that structure subsequent possibilities in ways not infinitely flexible (Pfaffenberger, 1992). The political challenge is not just interpretive but material: how to transform stabilised socio-technical configurations that systematically advantage some groups while marginalising others.

Feenberg (2012) attempts to synthesise constructivist and critical perspectives through his critical theory of technology. He argues that technologies are indeed socially constructed and interpretively flexible, but within contexts profoundly shaped by capitalism and power relations that systematically bias technological development toward certain configurations, serving dominant interests. Feenberg distinguishes between primary instrumentalisation (the technical rationality involved in designing artefacts for specific functions) and secondary instrumentalisation (the social embedding of technologies within contexts, uses, and meanings). Democratic technological politics, he argues, requires expanding participation in secondary instrumentalisation, challenging closure and reopening interpretive flexibility to allow marginalised groups' interests and interpretations to reshape technologies.

2.6.2 Technology and Development in the Global South

STS scholars examining technology in Global South contexts have produced insights particularly relevant to my research. Cozzens and Kaplinsky (2009) critique how development policy and practice often treat technology transfer as a straightforward technical process, assuming technologies designed in the Global North can be unproblematically adopted elsewhere. They demonstrate how this ignores crucial differences in social context, institutional capacity, power relations, and local knowledge systems that shape whether and how technologies function in new settings. Technologies carry social scripts and assumptions from their contexts of origin regarding available infrastructure, property relations, labour costs, gender roles, and regulatory frameworks that may not translate across contexts (Akrich, 1992).

Edgerton (2007) challenges innovation-centric technology studies that focus disproportionately on invention and early adoption, arguing for greater attention to technology in use over long periods and in diverse contexts. The concept of creole technologies describes how technological artefacts are adapted, modified, and hybridised as they circulate across contexts, often subverting designers'

intentions and dominant narratives. This perspective usefully challenges both technological determinism and deficit models that frame Global South contexts as simply lagging in adopting Northern technologies.

Postcolonial STS scholars emphasise how technological development and diffusion remain entangled with colonial legacies and ongoing global power relations (Anderson, 2002; Harding, 2008). Abraham (2014) shows how nuclear technology in India was simultaneously a site of national pride and technological sovereignty, and a continuation of colonial relations of dependence and hierarchy. Mavhunga (2014) demonstrates how mobility technologies in southern Africa were shaped by and served in projects of colonial extraction and control. This scholarship insists that understanding technology in the Global South requires examining not just local social construction processes but how these are embedded within global systems of inequality, dependency, and knowledge hierarchy.

Particularly relevant to irrigation technology, Stone (2007) analyses the contested introduction of Bt[9] cotton in India, showing how this technology was simultaneously celebrated as a biotechnological breakthrough by proponents and condemned as corporate biopiracy by critics. Different social groups, multinational corporations, Indian seed companies, large farmers, small farmers, environmental activists, and state regulators interpreted Bt cotton through radically different frames, reflecting their positions and interests. The technology's effects were similarly divergent: some farmers benefited substantially while others experienced crop failures, mounting debts, and devastating losses. Stone's analysis reveals how interpretive flexibility persists even after formal closure, with ongoing struggles over how to understand and regulate the technology.

2.6.3 Infrastructure Studies: Power, Breakdown, and Invisibility

Recent STS scholarship on infrastructure provides additional conceptual resources for analysing irrigation systems. Star (1999) articulates key characteristics of infrastructure: it is embedded in other structures and social arrangements; it is transparent to use (becoming visible primarily upon breakdown); it is learned as part of membership in communities of practice; it links with conventions of practice; and it embodies standards that shape possibilities for connection and use. Infrastructure is

[9] Bt cotton refers to a genetically modified cotton variety that contains a gene from the soil bacterium Bacillus thuringiensis (Bt), enabling the plant to produce a protein that is toxic to major insect pests such as the cotton bollworm. The technology is intended to reduce reliance on chemical insecticides and improve crop yields.

thus never merely technical but fundamentally social, shaping who can connect to what networks and on what terms.

Edwards (2002) introduces the concept of infrastructural inversion, in which background infrastructure becomes foregrounded during breakdowns, revealing dependencies and social arrangements ordinarily invisible. When pumps fail, electricity cuts out, or tubewells run dry, the social relations of water access regarding who have backup systems, who have resources to repair quickly, who can draw on social networks for assistance, who fall into crisis, become starkly visible. Anand (2017) demonstrates how urban water infrastructure in Mumbai embodies and reproduces social hierarchies, with infrastructure quality, reliability, and maintenance mapping onto caste and class geographies. Informal settlements receive intermittent, low-pressure water requiring constant labour to access, while elite neighbourhoods enjoy an uninterrupted supply. Infrastructure thus becomes a medium through which inequality is materially enacted and experienced in everyday life.

Larkin (2013) emphasises infrastructure's political and aesthetic dimensions, arguing that infrastructures are not just technical systems but are political technologies that organise social life, shape the circulation of people and resources, and serve as symbols of modernity, progress, or failure. The visible presence of irrigation pumps, electric meters, and tubewell platforms in rural landscapes does not simply facilitate agricultural production; it marks distinctions between modern/traditional, developed/backward, included/excluded, shaping how farmers understand their own positions and futures. This symbolic dimension helps explain why access to technology matters beyond purely functional considerations: it carries meanings related to belonging, progress, and social worth.

Infrastructure studies scholarship sensitises my analysis to how irrigation technologies function as infrastructures that embed social relations, connect farmers differentially to water sources and energy grids, become visible through breakdown and crisis, and carry both symbolic and functional significance. The material infrastructure of tubewells, pumps, pipes, electric lines, and meters is not neutral hardware but embodies specific social arrangements and power relations that shape patterns of inclusion and exclusion.

2.7 Synthesising Perspectives: Identifying Gaps and Theoretical Needs

Having reviewed four interconnected bodies of literature, I can now identify specific gaps, limitations, and opportunities for theoretical synthesis that my research addresses. First, while irrigation development literature documents inequality in technology access, it typically lacks theoretical

frameworks for explaining *how* and *why* social positions translate into differential access. Descriptions of unequal outcomes are abundant; rigorous analysis of causal mechanisms is scarce. Moreover, this literature tends to examine single axes of inequality (land size, caste, or gender) in isolation rather than at their intersections, missing how multiple dimensions combine to produce specific configurations of advantage and disadvantage.

Second, political ecology provides powerful concepts for analysing power and resource access, but has insufficiently engaged with class analysis and agrarian political economy. Much political ecology water scholarship focuses on governance institutions, knowledge politics, and identity without adequate attention to class relations, accumulation dynamics, and the material political economy of agrarian capitalism. As Bakker (2010) and others argue, political ecology needs stronger engagement with Marxist analysis to avoid losing sight of capitalism as a structuring force. Conversely, agrarian change scholarship often treats technology as a relatively undifferentiated 'input' whose adoption depends on capital access and market integration, without sufficiently interrogating how specific technological configurations emerge, what meanings they carry for different social groups, and how technologies themselves embody and reproduce power relations.

Third, while science and technology studies have developed sophisticated frameworks for analysing how technologies are socially constructed and politically consequential, STS work on Global South agrarian contexts remains relatively limited. Much SCOT analysis focuses on industrial technologies in Global North contexts. Applications of agricultural technologies in settings marked by extreme inequality, precarious livelihoods, and postcolonial development interventions are less developed. Moreover, STS scholarship sometimes insufficiently theorises the deep structural inequalities, particularly class relations, which shape whose interpretations of technology matter and whose interests' technological closure ultimately serves.

Fourth, intersectionality, now widely invoked in academic discourse, remains underutilised as a rigorous analytical framework for understanding technological access. Many studies claim intersectional approaches while examining single identity categories or treating multiple dimensions as additive rather than mutually constitutive. Demonstrating empirically and theoretically *how* intersectional positions shape material outcomes requires explicit analytical strategies that existing literature on irrigation in South Asia rarely employs.

Fifth, the specific mechanisms through which elite capture operates in development interventions remain inadequately theorised. While elite capture is widely documented as an empirical regularity, fine-grained analysis of *how* it is accomplished through specific practices, discourses, and strategic manoeuvres, through which well-positioned actors appropriate resources intended for marginalised groups, is less common. Platteau (2004) and Dasgupta and Beard (2007) provide important analyses of elite capture mechanisms, but applications to irrigation technology interventions in South Asian contexts are limited.

Finally, while migration's relationships with agricultural change and technology adoption are increasingly recognised as important, existing scholarship has not adequately theorised how it interacts with other dimensions of social position to produce differentiated outcomes. Does migration primarily serve as an independent shock that reshapes positions, or does it operate through and amplify pre-existing inequalities? How do remittances interact with land tenure, caste status, and gender relations to enable or constrain irrigation investment?

These gaps collectively point toward the need for a synthetic theoretical framework that: (1) integrates insights from political ecology, agrarian change, and STS while addressing their respective limitations; (2) provides conceptual tools for analysing how multiple axes of inequality intersect and interact to shape technology access; (3) connects community processes of institutional navigation and technological interpretation to structures of agrarian political economy; (4) examines specific mechanisms through which power operates to produce differential access; and (5) theorises technology not as external input but as embedded within and constitutive of social relations. The bundled architecture of access framework, elaborated in the following section, is designed to meet these theoretical needs.

2.8 Bundled Architecture of Access: An Integrative Conceptual Framework

In this dissertation, I develop the concept of bundled architecture of access to understand how irrigation technologies are taken up, controlled, and sustained in agrarian systems marked by layered social, material, and institutional inequalities. This framework emerges from my engagement with three theoretical traditions: the social construction of technology (SCOT); the political ecology of resources; and agrarian political economy. Each of these literatures offers valuable but partial insights into how technology and power intersect. SCOT draws attention to the interpretive flexibility of artefacts and the role of social groups in stabilising technological meaning (Pinch & Bijker, 1984;

Bijker, 1995). Political ecology situates resource management within structures of power and discourse, revealing how environmental governance reflects and reproduces social hierarchies (Robbins, 2012; Blaikie & Brookfield, 2015). Agrarian political economy, meanwhile, illuminates how production relations, class structures, and property regimes can accumulate and who is dispossessed (Bernstein, 2010; White, 2018).

Therefore, these traditions reveal that irrigation technologies cannot be understood as neutral artefacts that simply diffuse across space and time. Instead, they are social and political forms embedded in configurations of power, property, and recognition (Winner, 1980; Boelens & Vos, 2014). The concept of bundled architecture of access framework brings these insights together by focusing on how farmers' ability to benefit from irrigation is not a discrete event but a cumulative process that unfolds through the alignment of multiple layers of access. It allows me to examine how social hierarchies, institutional rules, and physical infrastructures interlock to determine who can adopt and sustain technology, and whose aspirations are foreclosed even when infrastructure physically surrounds them.

The bundled architecture of access framework provides an analytical lens that links micro-level practices to macro-structural forces without them collapsing into each other. It recognises the significance of human agency, how farmers navigate, negotiate, and occasionally subvert barriers, while showing how such agency is conditioned by larger structures of land, capital, caste, and gender. My purpose in articulating this framework is not to present a universal model but to develop a grounded analytical tool for explaining how access and inequality are co-produced through technological systems.

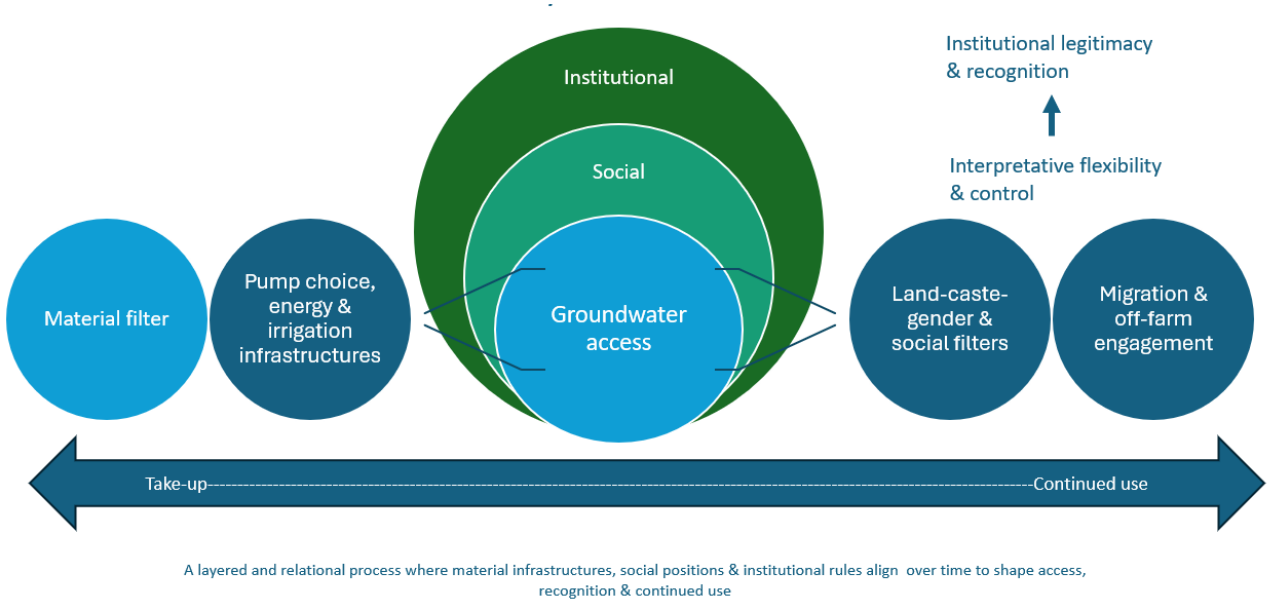

Figure 1 Bundled Architecture of Access: A Layered Framework

2.8.1 Reframing Access: From Event to Architecture

Existing studies of irrigation technology adoption often conceptualise access as a discrete decision or threshold (Glover et al., 2016). Within behavioural and economic frameworks, individuals are positioned as rational actors who adopt technologies when benefits exceed costs, subject to information, credit, or risk constraints (Rogers, 2003). These perspectives have generated valuable insights, but they tend to abstract technologies from their social and political contexts. Technologies appear to be stable tools awaiting user choice, while inequality is treated as an external condition rather than part of the technological system itself.

In this study, I reconceptualise access as an architectural phenomenon. Access is not a single barrier to be crossed, but a series of interdependent thresholds to be navigated sequentially. Each threshold represents a distinct but connected dimension of access, secure tenure, capital, a well or pump, energy connection, institutional recognition, and social legitimacy, each of which is both necessary and conditional. Passage through one layer enables entry into the next, but exclusion at any point blocks progress through the entire structure. Access is therefore cumulative and path-dependent, where advantage and exclusion are built up over time through the ordering of these filters.

The architectural metaphor captures this sequential and cumulative logic. It allows me to see how early exclusions compound and how small differences in resources or status become magnified as farmers move through successive gates. For example, secure land tenure opens access to tubewell

installation, which in turn enables eligibility for energy connections, which, in turn, determines whether electric pumping is technically and economically feasible. Those excluded at any earlier stage cannot easily compensate by effort or innovation because the architecture itself is structured to reproduce advantage. By moving from a binary to an architectural conception of access, I reframe technology adoption as a relational process: not only about who has what resource, but also about how material infrastructures, institutional rules, and social positions interact to produce durable configurations of inclusion and exclusion.

This reconceptualisation also shifts the analytical unit from the individual to the collective pathway. Instead of asking whether a household adopts technology, I ask how its position across material, social, and institutional layers enables or obstructs trajectories of access. This focus on sequence and configuration provides the foundation for the framework's four theoretical premises.

2.8.2 Foundational Premises

The bundled architecture of access framework rests on four interrelated theoretical premises. These premises translate abstract debates from SCOT, political ecology, and agrarian political economy into a coherent structure for analysing how access to irrigation technology is built, constrained, and sustained.

The first premise is that access is multidimensional, cumulative, and sequentially dependent. Following Ribot and Peluso (2003), I define access as 'the ability to derive benefits from things', a formulation that extends beyond property rights to encompass the broader bundle of powers – technological, social, and institutional – through which benefits flow. My contribution lies in theorising how these powers are ordered and nested. Certain forms of access occur logically and materially prior to others. Secure land tenure: makes it possible to install a well; a well makes it meaningful to invest in a pump; a pump enables participation in programmes or markets, which, in turn, may determine who benefits from electricity subsidies or groundwater use. Exclusion at one layer forecloses the layers that follow. Inclusion at early stages does not guarantee progression, but it opens possibilities that would otherwise be inaccessible.

This cumulative logic has two implications. First, exclusion is self-reinforcing. When farmers are denied access to foundational layers such as tenure or institutional recognition, they are effectively locked out of subsequent opportunities. Second, interventions targeting downstream layers, such as subsidising pumps, cannot produce equitable outcomes if upstream filters remain closed.

Understanding access as sequential, therefore shifts analytical attention from isolated adoption decisions to the broader pathways and temporal dependencies that structure them.

The second premise is that social structures are intersectional and co-constitutive. I draw on intersectionality theory (Crenshaw, 1991; Hill Collins, 2009) and feminist political ecology (Nightingale, 2011; Sultana, 2011; Elmhirst, 2011) to understand how class, caste, gender, and migration interact to shape differentiated experiences of access. These dimensions do not operate independently or additively. Instead, they combine to produce distinct positionalities, configurations of advantage and constraint that cannot be reduced to single variables. For instance, a Dalit woman tenant experiences exclusion through the simultaneous workings of caste hierarchy, gendered property norms, and insecure tenure. Her position in each domain reinforces her marginality in the others. Intersectionality thus provides an analytical lens for understanding how power operates through combination rather than through isolated effects, and why interventions addressing only one axis of inequality (e.g. gender quotas without addressing land or caste) often have limited transformative potential.

The third premise is that technologies are socially constructed yet materially consequential. From SCOT, I adopt the insight that technologies are interpretively flexible; their meanings and functions emerge through social negotiation (Pinch & Bijker, 1984; Bijker, 1995). A groundwater pump can represent empowerment, modernity, dependence, or control depending on who uses it and under what circumstances. However, I also build on Winner's (1980) argument that technologies can be inherently political, and Boelens and Vos' (2014) claim that water-control technologies embody power relations. Once stabilised and marginalised, once wells are dug, meters installed, and networks extended, technologies acquire a form of durability that constrains future action. They channel flows, define control zones, and create dependencies that are difficult to reverse. Technologies are therefore both socially shaped and materially shaping; they reflect the power relations that brought them into being and reproduce those relations by structuring future possibilities.

The fourth premise is that structures enable and constrain but do not determine outcomes. Drawing on critical realism (Bhaskar, 2008) and structuration theory (Giddens, 1984; Archer, 2012), I conceptualise the material, social, and institutional filters as real structures that exert causal influence, but of which effects are mediated by human agency. Structures make specific actions easier and others harder; they shape probabilities rather than certainties. Farmers exercise agency within these structural

constraints, forming networks, improvising technical solutions, or leveraging informal ties to navigate bureaucratic systems. Similarly, elites must act strategically to maintain dominance, often through control of information or institutional capture. This dual emphasis on structure and agency enables an analysis that can explain patterned inequality without erasing individual and collective action.

2.8.3 The Three Filters of Access

Building on these premises, the bundled architecture of access framework conceptualises farmers' engagement with irrigation technologies as mediated through three filters: material, social, and institutional. Each filter operates as a structuring condition that shapes both the potential to access technology and the ability to sustain its use over time. Although analytically separable, these filters are empirically intertwined; each one influences and reinforces the others.

The material filter encompasses the physical and technical infrastructures that define the spatial and energetic parameters of irrigation. It includes the depth of aquifers, the siting of wells and meters, the quality of electrical infrastructure, and the legacy of past investments. These elements are not merely technical; they are sedimented outcomes of political and historical processes of investment, neglect, and competition (Ferguson, 1990). The placement of a well on one farmer's plot, for instance, confers physical control over the source and hence bargaining power over others. Distance from infrastructure increases costs and dependence. Energy type, costs associated, voltage stability, transformer capacity, and load schedules determine whether electric pumping is viable or whether farmers must rely on costlier alternatives. Early technological choices generate lock-ins that limit future adaptation, as subsidies, spare parts, and technical standards converge around dominant configurations.

The social filter refers to the hierarchies and relations of caste, gender, class, kinship, and brokerage that shape who can claim legitimacy and who exercises authority in collective arrangements. These relations determine whose claims are recognised in public institutions and who gains access through networks of trust and reciprocity. Brokerage and gatekeeping emerge when individuals control the interface between communities and bureaucracies, deciding who is included or excluded from programmes. Network density and boundary shape determine whether cooperation is inclusive or confined to privileged groups. Social sanctioning, through ridicule, exclusion, or intimidation, reinforces hierarchy and deters challenge, ensuring that power relations are reproduced even in the absence of overt coercion.

The institutional filter encompasses the formal rules, procedures, and documentary requirements that govern programme eligibility and resource distribution. Land certificates, contribution ratios, verification visits, and agency coordination shape who becomes eligible to the state (Scott, 2020). Bureaucratic processes that appear neutral often reproduce inequality by aligning with the capacities of those who are already privileged. Drawing on Bijker's (1995) notion of closure, I identify three forms of institutional stabilisation that sustain exclusion. *Rhetorical closure* reframes inequality as a technical necessity, justifying land-title requirements as measures of efficiency or accountability. *Procedural closure* embeds exclusion in everyday routines, tight deadlines, complex forms, and deposit requirements that few marginal farmers can meet. *Technical closure* arises when a specific technology model, such as individually metered electric pumps, becomes standardised, rendering alternatives illegible or unsupported.

The three filters, material, social, and institutional, rarely function in isolation. In practice, they interact in ways that shape how access is built, blocked, and sustained over time. These interactions operate through three mechanisms: sequential dependency, through which access depends on moving through thresholds in a particular order; amplification and attenuation, whereby advantages and disadvantages across domains reinforce or weaken one another; and lock-in and closure, through which certain configurations of access become stabilised and difficult to dislodge. Together, these mechanisms explain why some actors progress smoothly through successive stages of access, while others encounter barriers that compound rather than recede.

The first mechanism of interaction is sequential dependency, which describes how progression through each layer of architecture depends on successfully navigating the previous layer: secure tenure often precedes eligibility for formal programmes; access to a reliable well precedes adoption of electric pumps; and programme recognition follows once eligibility is documented. When the order of thresholds is rigid, early exclusions foreclose later opportunities entirely. This cumulative pattern means that inequality is reproduced not through a single act of denial but through a sequence of design choices that shape who can move forward. By emphasising sequence, I shift the analytical lens from snapshots of adoption to trajectories of access and stagnation.

The second mechanism is amplification and attenuation, which refers to how advantages and disadvantages across filters interact non-linearly. A farmer with land and institutional recognition may multiply these advantages through social capital and network authority (Mottaleb et al., 2019). At the

same time, a landless woman may find her disadvantages mutually reinforce one another across the same domains. The combination of large landholding and upper-caste identity amplifies access to bureaucratic support. At the same time, the intersection of gender, caste, and tenancy attenuates potential gains, even when one dimension, such as technical skill or local trust, appears favourable. In this way, privilege and marginality do not simply add up; they interact to produce distinctive positionalities that structure access possibilities.

The third mechanism is lock-in and closure, which captures how particular configurations of access become durable and resistant to change. Once a system is established around a specific technological model, such as individual electric pumping, economic and institutional incentives begin to align around that configuration. Subsidies, training, repair markets, and even local aspirations adapt to it, creating strong feedback loops that render alternatives impractical. Similarly, administrative routines that once served expedience can harden into procedural norms that resist reform. Over time, these dynamics produce path dependency: advantages and exclusion become self-reinforcing, sustained not only by power but also by the inertia of material systems and bureaucratic practice.

Collectively, these three mechanisms – sequential dependency, amplification, and closure – explain how inequality persists even in settings of active technological diffusion. They allow me to trace how opportunity and constraint are not random but structured into the architecture of access itself. Interventions that target only one filter rarely succeed because the architecture as a whole operates through interlocking dependencies. For example, expanding irrigation subsidies without reforming tenure documentation may increase overall pump ownership while leaving tenants and women without benefits. Likewise, extending grid lines without addressing social gatekeeping may improve technical potential but not actual access. By analysing these interactions, I can move beyond the question of whether technology spreads to ask how its spread reconfigures the landscape of inclusion and exclusion.

2.8.4 Positionality as the Analytical Lens

At the centre of this conceptual framework lies the idea of positionality, which serves as a bridge between the structural and individual levels of analysis. Positionality refers to a farmer's specific and evolving location within the bundled architecture, at the intersection of their material conditions, social identities, and institutional visibility. It captures both the constraints that arise from structural position and the agency exercised through practice and negotiation.

I treat positionality as multidimensional, intersectional, relational, dynamic, and consequential. It is multidimensional because it encompasses material resources, social relationships, and institutional standing simultaneously. It is intersectional because these dimensions do not operate independently but interact to produce unique combinations of privilege or vulnerability. It is relational, because positions have meaning only in relation to others; what it means to be a 'large-scale landholder' or a 'tenant' depends on the local distribution of resources and norms. Positionality is dynamic because people's locations in the architecture can shift over time as they accumulate or lose resources, as policies change, or as household structures transform. However, such mobility is often partial, constrained by the stickiness of past investments and entrenched hierarchies. Finally, positionality is consequential, shaping what actions individuals can take, what risks they perceive, and how institutions respond to them.

This relational view of positionality allows me to integrate structure and agency without reducing one to the other. Farmers' actions, whether adopting, adapting, or contesting irrigation technologies, are meaningful only when situated within the positions from which they act. Similarly, structural inequalities become visible only through the differentiated ways people inhabit them. Positionality thus serves as the conceptual hinge connecting macro-level patterns of exclusion to micro-level practices of navigation and resistance.

Conceptually, the bundled architecture of access framework offers three main analytical contributions. First, it shifts the understanding of access from possession to alignment. Access is not defined by owning a pump or a meter but by the alignment of infrastructures, relationships, and institutions that make its use possible. This redefinition clarifies why households with similar resources can have vastly different outcomes depending on how these elements interact.

Second, it shifts attention from actors to positions. Rather than treating farmers as isolated decision-makers, the framework situates them within relational fields of power and recognition. This approach foregrounds how decisions and opportunities are structured by one's position in relation to others – landowners, tenants, brokers, bureaucrats – and the rules that bind them.

Third, it reframes equity in terms of sequences rather than opportunities. Equality cannot be assessed by the number of technologies distributed, but by whether the sequence of thresholds allows equitable progression through architecture. Policies that equalise opportunities later in the process cannot undo inequalities embedded in earlier filters unless the upstream conditions are also restructured.

Methodologically, this framework supports a mixed-method research design. Institutional analysis reveals how rules are formalised and stabilised, technography captures the everyday workings of devices and infrastructures, network analysis identifies patterns of brokerage and exclusion, and ethnographic observation uncovers meanings, negotiations, and embodied practices (Jansen & Vellema, 2011). These methods together enable tracing how material, social, and institutional filters interact, how positionalities are formed, and how access trajectories unfold over time.

This multi-method approach also has ethical implications. Because recognition and eligibility are part of the very architecture being studied, research interactions can influence participants' visibility. Requesting documents or recording narratives can confirm or contest a farmer's standing within the institutional system. Reflexivity, therefore, is integral to the research process. I have approached these interactions with care, aware that knowledge production is itself embedded in the same architectures of access that structure irrigation governance.

The concept of bundled architecture of access makes a broader theoretical contribution by bridging debates across technology studies, political ecology, and agrarian change. Within SCOT, it extends the notion of interpretive flexibility to include not only the social negotiation of meaning but also the sequencing of access mechanisms, showing how technological stabilisation interacts with institutional design. Within political ecology, it grounds abstract discussions of power and environment in the concrete spatial and procedural arrangements that determine resource distribution. Within agrarian political economy, it links relations of production to the technical and institutional systems that sustain them, offering a fine-grained view of how class and property relations are reproduced through infrastructure.

Although this framework emerges from the empirical context of groundwater irrigation in Nepal, its conceptual logic is not bound by geography. The idea of bundled architecture of access applies to other settings where access depends on layered systems, such as energy options, transitions, and land titling, where institutional recognition and social legitimacy determine who can use technology and who remains excluded despite its physical presence.

By conceptualising access as layered, cumulative, and relational, I move beyond simple binaries of adopters and non-adopters toward a dynamic understanding of how people navigate complex socio-technical landscapes. The bundled architecture of access framework recognises that structures constrain without fully determining outcomes, and that farmers, whether elite or marginalised, act

strategically within these constraints. In the empirical chapters that follow, I use this framework to examine how irrigation technologies marginalise power, how access pathways differ across positions, and how cumulative advantages and exclusions are built and sustained. In this way, the framework not only provides an analytical vocabulary for understanding irrigation but also offers a broader perspective on the politics of technology, inequality, and social change.

3 Chapter Three: Research Methodology

3.1 Introduction: Researching Intersectionality, Positionality, and Technological Access

This chapter presents the methodological architecture for examining how farmers are differentially positioned to access and benefit from groundwater irrigation technology, within an agrarian system structured by the intersection of land tenure, caste, gender, class, and migration, in Nepal's Terai region. The central analytical challenge animating this research is in understanding not merely *that* access to groundwater irrigation technology is unequal – this is well established in existing scholarship (Shah, 2009; Birkenholtz, 2017; Shrestha & Clement, 2019; Sugden et. al, 2021) – but precisely *how* and *through what mechanisms* a farmer's unique, intersectionally defined social position enables or forecloses their capacity to engage with, adopt, control, and ultimately derive benefits from the technology.

The concept of positionality sits at the analytical core of this research. Drawing on insights from feminist theory, critical race studies, and postcolonial scholarship, positionality refers to the specific, situated location of individuals within multiple, overlapping, and mutually constitutive social structures and systems of power (Rose, 1997; Alcoff, 1988; Haraway, 1988). Positionality is not reducible to any single axis of identity or social stratification. It is not simply about being a woman, or a Dalit, or a tenant farmer, or affected by migration. Instead, it is concerned with how these different dimensions of social life intersect and interact in specific contexts to shape an individual's lived experience, opportunities, constraints, knowledge, and agency (Crenshaw, 1991; Hill Collins, 2009). This understanding demands methodological approaches capable of capturing both structural patterns of inequality and the lived experiences, institutional dynamics, and meaning-making processes through which these patterns are produced, negotiated, and sometimes contested.

The research employs a mixed-methods design (Sweetman et al., 2010) that integrates quantitative analysis of access patterns, ethnographic immersion in farmer life-world, and institutional analysis of development interventions. This design responds directly to three sub-questions guiding the inquiry. The first sub-question asks: *What are the relationships between a farmer's position through the axes of land tenure status, caste identity, gender, and household migration status, and their access to and ownership of irrigation technologies?* Through rigorous quantitative analysis, this question identifies

which dimensions of social position are most predictive of technology access, how different axes interact to create compounded advantage or disadvantage, and whether certain intersectional positions produce effects that are more than simply additive (McCall, 2005).

The second sub-question shifts from the statistical to the ethnographic, asking: *How do farmers from marginalised positions experience and negotiate groundwater access, and livelihood challenges, within unequal agrarian structures?* Through this question, the research moves beyond abstract patterns to understand the human dimension of inequality, the everyday practices, tactical negotiations, and moments of resistance through which marginalised actors navigate constrained landscapes (Certeau & Certeau, 2013). It addresses the interpretive flexibility of technology, exploring how different social groups ascribe radically different meanings to the same irrigation infrastructure based on their positionality (Bijker, 1995; Pinch & Bijker, 1984).

The third sub-question focuses analytical attention on formal institutions and development interventions, asking: Through what structural, institutional, and social mechanisms do irrigation support programmes produce differential outcomes, and how do better-positioned actors consolidate advantage within formally inclusive programme spaces? This question treats institutions not as neutral technical structures but as political arenas where power is exercised, contested, and reconfigured (Cleaver, 2002; Mehta et al., 2001). It examines the micro-practices of institutional capture through which better-positioned actors bend ostensibly inclusive programmes to serve their interests (Platteau, 2004).

The chapter proceeds as follows. Following this introduction, Section 3.2 articulates the philosophical foundations, critical realist ontology, and feminist intersectional epistemology that inform all methodological choices. Section 3.3 presents the overall research design, explaining how mixed-methods enable inquiry into the multiple dimensions of positionality. Section 3.3.2 provides details on site selection, including Saptari district, where Shambhunath Municipality is located, and the specific Wards where research was conducted. Section 3.4 comprehensively describes data collection methods, including the evolution from structured to informal approaches as field relationships deepened. Section 3.5 outlines analytical strategies for quantitative, qualitative, and visual data. Section 3.6 addresses ethical considerations and, finally, the chapter concludes in Section 3.7 with a discussion of methodological limitations and how they shape knowledge claims.

Throughout the chapter, attention is paid to the messy realities of fieldwork, the initial plans that required adaptation, the methodological pivots necessitated by field circumstances, the opportunistic

data collection that enriched planned approaches, and the iterative learning that shaped evolving methods. As Mosse (2004) has established through a critical ethnography of development practice, honest methodological accounting requires acknowledging the gap between research-as-planned and research-as-practiced, recognising that valuable insights often emerge through improvisation and serendipity rather than pre-designed protocol alone.

3.2 Ontological and Epistemological Foundations: Critical Realism Meets Feminist Intersectionality

Methodological choices rest on foundational assumptions about the nature of social reality and how knowledge about that reality can be produced. This research is informed by critical realist ontology (Bhaskar, 2008) integrated with feminist intersectional epistemology (Crenshaw, 1991; Haraway, 1988; Hill Collins, 2009), a combination that enables analysis of both structural constraints and situated knowledges, material conditions and social meanings, systematic patterns, and diverse experiences.

3.2.1 Critical Realist Ontology: Structures, Mechanisms, and Stratified Reality

Critical realism distinguishes between three domains of reality: the empirical (what we observe and experience); the actual (events that occur whether they are observed or not); and the real (underlying structures and generative mechanisms that produce events but cannot be directly observed) (Bhaskar, 2008). This stratified ontology provides crucial grounding for research on groundwater access and inequality. At the empirical level, we observe differential patterns of tubewell ownership, variations in irrigation intensity across social groups, and visible instances of exclusion from water user associations or subsidy programmes. At the actual level, numerous events and processes occur, such as credit negotiations, bureaucratic decisions, household deliberations, and social negotiations over water sharing, which generate empirical patterns that researchers may not directly witness. At the fundamental level, deep structures, property regimes, caste hierarchies, patriarchal relations, capitalist markets, and state condition the possibilities for actual events and empirical patterns, though these structures are not directly observable but must be theoretically conceptualised and empirically inferred (Danermark et al., 2002).

This ontology justifies the research's multi-method approach. Quantitative analysis of survey data reveals empirical patterns and systematic associations between caste, landholding, gender, migration status, and technology ownership. However, surveys alone cannot explain *why* these patterns exist or

illuminate the mechanisms that generate them. Ethnographic methods, participant observation, informal conversations, and witnessing everyday interactions can access the actual level and reveal the processes, negotiations, and events through which structures generate observable outcomes. Theoretical analysis, drawing on political ecology, agrarian political economy, and science and technology studies, helps identify and theorise the fundamental structures and mechanisms, testing whether observed patterns align with theoretical expectations for how power, property, and technology interact (Sayer, 2008).

Critically for this research, critical realism rejects both structural determinisms, in which structures mechanically produce outcomes with no role for agency, and voluntarist interpretivism, in which meanings and choices operate independently of material constraints (Archer, 2012). Instead, it conceptualises social reality through emergence, in which higher-level phenomena arise from but are not reducible to lower-level components, and stratification, in which reality operates simultaneously at multiple levels (Bhaskar, 2008). Groundwater access emerges from interactions between land tenure structures, caste systems, household gender relations, migration dynamics, institutional arrangements, technological systems, and everyday practices. None of these alone determine outcomes, but together they produce observable patterns of access and exclusion. Understanding access requires investigating these multiple levels and their interactions, which is precisely what the bundled architecture of access framework, elaborated in Chapter Two, attempts to theorise, and what the mixed-methods design attempts to empirically examine.

3.2.2 Feminist Intersectional Epistemology: Situated Knowledges and Compounding Inequalities

While critical realism provides ontological grounding, the research is equally informed by feminist intersectional epistemology that centres the concept of positionality and insists on partiality and situatedness of all knowledge (Haraway, 1988; Rose, 1997; Harding, 2008). Feminist epistemology challenges the possibility of objective, view-from-nowhere knowledge, arguing instead that all knowledge is produced from particular social positions and reflects specific standpoints (Alcoff, 1988). This does not imply relativism, where all knowledge claims are equally valid, but instead emphasises that knowledge is always partial, shaped by who produces it, from where, and under what social relations.

Intersectionality, as conceptualised by Crenshaw (1991) and developed by McCall (2005), Collins (2009), and others, provides the core epistemological framework for understanding how multiple systems of power and identity categories intersect to produce complex patterns of privilege and oppression. Intersectionality insists that social categories like gender, caste, class, and ethnicity are not additive, where being Dalit plus being female equals double disadvantage, but rather are mutually constitutive (Crenshaw, 1991; Ghosh & Banerjee, 2023; Suntharalingam, 2023). A Dalit woman's experience is not simply the sum of 'Dalit experience' plus 'female experience'. However, it is qualitatively distinct, shaped by caste-specific forms of gendered subordination and gender-specific forms of caste discrimination. As Collins (2009) argues, intersecting systems of oppression create a 'matrix of domination' in which power relations are organised and experienced along multiple, simultaneous axes.

For this research on groundwater access, intersectional epistemology has profound methodological implications. First, it requires analytical approaches that can capture interaction effects among different dimensions of social position, how gender's effect on technology access varies by caste position, or how land tenure shapes opportunities differently for male versus female household heads (McCall, 2005). Quantitative analysis must test for statistical interactions, not merely additive effects. Qualitative analysis must attend to how intersecting positions create qualitatively distinct experiences and constraints.

Second, intersectionality demands recognition of intra-category heterogeneity, substantial variation within social categories that simple categorisation obscures (Hill Collins, 2009). 'Dalit farmers' are not homogeneous; they include landed and landless, male and female, migrant and non-migrant, each experiencing distinct opportunities and constraints. 'Women farmers' include high-caste and low-caste, land-owning and tenant households, and out-migrant and non-migrant households, with radically different access to resources and power. Research methods must be capable of revealing this internal diversity rather than imposing homogenising category assumptions (McCall, 2005).

Third, feminist epistemology emphasises situated knowledge and standpoint theory, with the recognition that marginalised social positions can generate insights into power relations precisely because marginalised people navigate multiple knowledge systems, including their own experiential knowledge, and dominant knowledge frameworks (Harding, 2004). This suggests that research should not merely extract data from marginalised farmers but should position their perspectives and

interpretations as legitimate knowledge with analytical value. Methodologically, this informed the research use of participatory visual methods and the prioritisation of farmers' interpretations and meanings, over researcher-defined categories (Haraway, 1988).Finally, feminist methodology emphasises reflexivity, critical examination of how the researcher's positionality shapes knowledge production (Rose, 1997; Sultana, 2011).

3.2.3 Synthesising Critical Realism and Feminist Intersectionality

Some scholars view critical realism's commitment to objective reality, and feminist standpoint epistemology's emphasis on situated knowledge, as incompatible (Carter & New, 2004). However, following Bhaskar's (2008) later work on critical realist feminism, this research treats them as complementary. Critical realism acknowledges that while reality exists independently of our knowledge of it, all knowledge is socially mediated, theory-laden, and fallible. Feminist epistemology recognises that while knowledge is positioned and partial, this does not preclude making defensible claims about reality or adjudicating between better and worse explanations (Harding, 2004).

Practically, this synthesis means the research analyses both structural patterns, using quantitative methods to reveal systematic inequalities in access, and meaningful action, using qualitative methods to understand how people navigate, interpret, and resist structures (Sayer, 2008). It examines material constraints, water availability, technology costs, land tenure insecurity, and social constructions, what irrigation symbolises, whose knowledge is valued, as well as how development is discursively framed. It attends to both structures of Critical Realism and Feminist Intersectionality, in how property regimes, caste hierarchies, and institutional rules limit options and agency, and how people make choices, pursue projects, deploy tactics, and sometimes transform structures (Archer, 2012).

This philosophical foundation directly informed all subsequent methodological choices: the mixed-methods design that combines structural analysis with interpretive understanding; the analytical focus on intersectionality, requiring examination of interaction effects; the participatory elements that recognise marginalised farmers as knowledge producers; and the reflexive attention to researcher positionality. The remainder of this chapter details how these philosophical commitments were translated into research practice.

3.3 Research Design: A Critical Sequential Mixed-Methods Approach

The research employs a sequential mixed-methods design (Creswell & Plano Clark, 2018) that begins with quantitative mapping of access patterns, followed by qualitative investigation to explain observed patterns and explore dimensions not captured quantitatively, and is complemented by visual ethnographic methods that disrupt conventional research power relations. This design enables both breadth, systematic documentation of patterns across representative samples, and depth, a nuanced understanding of processes, lived experiences, and contested meanings.

Mixed-methods research has gained increasing legitimacy across the social sciences, particularly in development studies, where complex, multidimensional phenomena require diverse analytical strategies (Creswell, 2015). However, this research specifically adopts critical mixed-methods (Mertens, 2024), an approach that foregrounds issues of power, inequality, and social justice, and explicitly positions research to contribute to social transformation rather than merely describe existing conditions.

Several considerations justify this mixed-methods approach for investigating differential positionality and technology access. First, the three sub-questions require fundamentally different methodological approaches. The first sub-question, outlined in the Section 3.1, demands quantitative analysis capable of testing associations and interaction effects across representative samples. The second sub-question, outlined in the Section 3.1, requires ethnographic immersion, access to lived experiences, and the recognition of tactical negotiations invisible to surveys. The third sub-question, presented in the Section 3.1, necessitates institutional ethnography and key informant analysis examining governance processes and elite practices. No single method could adequately address this range of questions (Greene et al., 1989).

Second, different methods access different dimensions of groundwater access. Quantitative surveys document technology ownership patterns, household characteristics, and social positions across large samples, enabling statistical analysis of systematic associations. However, surveys struggle to capture institutional dynamics, everyday negotiations, power relations, and subjective meanings, which are dimensions better accessed through ethnographic observation, informal conversations, and participatory visual methods. Using multiple methods provides a more comprehensive understanding than any single approach, with each method's strengths compensating for others' limitations.

Third, the design's particular analytical power lies in sequential explanation (Creswell & Plano Clark, 2018). Quantitative analysis identifies patterns requiring explanation, for example: Why do Dalit tenant farmers have dramatically lower tubewell ownership rates than high-caste landowners, even controlling for landholding size? Why do female-headed households show variable irrigation outcomes despite similar land access? Do remittance-receiving households exhibit divergent technology adoption patterns, and if so, why? A qualitative investigation then explores the generative mechanisms, social processes, and contextual factors that produce these statistical patterns, examining credit access barriers, caste discrimination experiences, household labour dynamics, migration decision-making, and institutional exclusion processes that surveys measure imperfectly or not at all (Tashakkori et al., 2021).

Fourth, multiple methods examining the same phenomena enable triangulation, comparing findings to assess convergence, mutual confirmation, or divergence that reveals complexity (Moran-Ellis et al., 2006). When surveys show systematic exclusion of particular social groups from subsidy programmes, interviews reveal selection mechanisms, observations document their operation in practice, and institutional documents confirm eligibility criteria, triangulated evidence strengthens the conclusions. Conversely, when methods produce contradictory findings, this signals important complexity requiring nuanced interpretation rather than simple conclusions (Moran-Ellis et al., 2006).

Finally, mixed-methods foreground power relations in the research process itself (Mertens, 2024). Conventional surveys and interviews position the researcher as a knowledge extractor and participants as data sources. Visual ethnographic methods, particularly when combined with participatory approaches, can partially disrupt these dynamics by enabling participants to frame their own representations, document their priorities, and participate in knowledge interpretation (Pink, 2013; Wang & Burris, 1997). While power asymmetries between researcher and researched can never be fully eliminated, methodological choices can work to redistribute epistemic authority (Sultana, 2011).

3.3.1 Research Questions and Methods Mapping

The central research question asks:

How are farmers differentially positioned to access and benefit from groundwater irrigation technology within an agrarian system structured by the intersection of land tenure, caste, gender, class, and migration?

To address this question, the thesis is organised around three interlinked sub-questions. Each sub-question targets a distinct layer of access architecture: structural distribution; lived practice; and institutional mediation. Together, they require different forms of evidence and different analytical lenses. Rather than treating methods as interchangeable, the research design aligns each sub-question with a specific set of data and analytical strategies, as presented in Table 1 below:

Table 1 Mapping Sub-questions to Methods, Analysis, and Contribution

Sub-Questions	**Methods**	**Analytical approach**	**Contribution**
Sub-Question 1: What are the relationships between a farmer's position through the axes of land tenure status, caste identity, gender, and household migration status, and their access to and ownership of irrigation technologies?	Household survey (n = 401) on technology access, land tenure, and social position. Statistical analysis in Jamovi.	Descriptive statistics to map access patterns. Bivariate tests to examine associations between each axis and each technology. Multivariate logistic regression, including interaction terms, to test non-additive and compounding effects (Crenshaw, 1991; McCall, 2005).	Establishes the scale and structure of inequality in irrigation access. Identifies which dimensions of position matter most. Tests whether intersecting positions generate multiplicative rather than additive effects. Provides the quantitative baseline for the qualitative chapters.
Sub-Question 2: How do farmers from marginalised positions experience and negotiate groundwater access, and livelihood challenges, within unequal agrarian structures?	Ethnographic immersion, participant observation, informal conversational interviews, and winter-season video ethnography.	Thematic analysis of field notes and interviews. Narrative analysis of life histories. Interpretive analysis of everyday practices and technology meanings (Mosse, 2008; Emerson et al., 2011).	Shows how water access is lived and negotiated. Reveals micro-practices through which farmers secure water. Captures agency alongside constraint. Demonstrates how the same technology carries different meanings for differently positioned actors.
Sub-Question 3: Through what structural, institutional, and social mechanisms do irrigation support programmes produce differential outcomes, and how do better-positioned actors consolidate advantage within formally inclusive programme spaces?	Interviews with institutional actors (n = 31 across national, district, and local levels), policy and programme documents, and observation of implementation processes.	Analysis of targeting and farmers' selection. Discourse analysis of policy texts and official narratives.	Exposes how institutions reproduce inequality. Identifies concrete mechanisms of elite capture. Shows how 'inclusive' programmes consolidate differential access when filtered through existing hierarchies.

3.3.2 Research Phases, Timeline, and Methodological Evolution

Field research was conducted between April 2023 and January 2024 through a sequence of interlinked activities that evolved in response to field conditions and emerging analytical needs. Rather than following a rigid, prescriptive design, the methodological approach shifted over time from structured, institutionally oriented engagements to more immersive, ethnographic, and relationship-based practices. This progression reflects both deliberate adaptation and the kinds of learning that only prolonged field presence makes possible. Far from weakening the research, this evolution deepened its analytical reach and ethical grounding.

The research began in Kathmandu with institutional mapping among national and international actors working on agriculture, water resources, and rural development. Interviews were conducted with representatives from government agencies, including: the Ministry of Agriculture and Livestock Development; the Department of Water Resources and Irrigation; and the Ministry of Energy, Water Resources and Irrigation. Interviews with international development organisations included: United Nations agencies and bilateral donors; research institutes, including the International Water Management Institute, with whom I had prior project collaboration; and with national NGOs engaged in irrigation and groundwater governance. These interviews served several purposes: to understand the policy frameworks and programme designs shaping groundwater development; to identify key institutional actors and map inter-organisational relationships; to access programme documents, evaluations, and policy analyses not publicly available; and to situate the study within contemporary debates on irrigation governance. Interviews at this stage were semi-structured, guided by prepared protocols while allowing flexibility to follow emergent themes (Bryman, 2016). Given the professional context and the informational orientation of these encounters, a formal interview format was appropriate.

Following this institutional mapping, intensive fieldwork shifted to Saptari District in Madhesh Province. Site selection was informed by a literature review, scoping conversations with researchers and practitioners, and practical feasibility considerations. During proposal development in 2022, I contacted the Municipal Deputy Chief of Shambhunath to confirm the municipality's suitability. In April and May 2023, I conducted in-person meetings with Ward chairpersons across several Wards to assess ethical appropriateness, access conditions, and research feasibility. Ward 2 and Ward 4 were selected as primary research sites because they offered irrigation infrastructures, tenure arrangements, and social compositions relevant to the groundwater context. Prior working relationships developed

through IWMI projects played a significant role in facilitating entry. In particular, the Chairperson of Ward 2 had been a collaborator in earlier work, providing institutional continuity and strengthening the research's legitimacy in the eyes of local officials and residents.

From June to August 2023, fieldwork focused on community entry and household survey preparation. This involved: meetings with Ward officials, farmer group leaders, and influential community members; informal community walks and preliminary household mapping; identification of potential key informants; pre-testing the survey instrument with approximately 30 households; and recruiting and training research assistants and enumerators. These activities were essential for building trust, securing informed participation, and developing the context. A household survey was implemented from September to November 2023 (see Section 3.5.1) for sampling and field procedures. I simultaneously engaged in an intensive ethnographic engagement mode (see Section 3.5.2). Overlapping with this ethnographic immersion, the winter irrigation season from November 2023 to January 2024 provided optimal conditions for visual ethnography (see Section 3.5.4). Winter is the peak irrigation period for wheat, vegetables, lentils, and other rabi crops, when dependence on groundwater becomes most evident. With informed consent, I filmed farmers as they irrigated fields, operated pumps, managed water distribution, and negotiated access.

3.4 Site Selection and Field Context: Ward 2 and Ward 4 of Shambhunath Municipality at Saptari District

Case study location selection profoundly shapes what can be known and how findings can be generalised (Yin, 2018). This section explains the rationale for selecting Saptari district within Nepal's Terai region, and specifically Ward 2 and Ward 4 of Shambhunath Municipality within Saptari district, as research sites.

3.4.1 The Nepal Terai: Regional Context and Significance

The Terai is Nepal's southern lowland belt, a narrow strip of fertile alluvial plains stretching along the Indian border. Despite comprising only 23% of Nepal's land area, the Terai is disproportionately significant: it contains approximately 50% of the national population; produces over 60% of food grains; accounts for the majority of agricultural commercialisation and export production; and is the centre of industrial and infrastructure development (Regmi, 1999; Sugden, 2021; National Statistics Office, 2024). The Terai is characterised by relatively flat topography, fertile soils, high agricultural

potential, better infrastructure and market access than Nepal's hills and mountains, and closer economic and social integration with northern India, given the open border.

Water resources in the Terai differ fundamentally from those in Nepal's hills. While hill agriculture relies primarily on rainfall and small-scale diversions from perennial mountain streams, the Terai benefits from extensive river systems fed by Himalayan snowmelt and, critically for this research, shallow aquifers that enable widespread groundwater access through tubewells (Pant, 2011; Chakraborty et al., 2023). Historically, the state prioritised large canal irrigation systems in the western Terai districts, while the eastern regions, including Saptari, developed under more mixed irrigation regimes, combining public tubewells, private shallow tubewells, scattered canal systems, and substantial rainfed cultivation (Sugden et al., 2014). Since the 1990s, groundwater development through private shallow tubewells has accelerated dramatically, driven by remittance investment, government and donor subsidies, and agricultural intensification pressures, making the eastern Terai the site of Nepal's ongoing ‘groundwater revolution' (Shah, 2009; Sugden et al., 2014).

The Terai is also characterised by profound social inequalities, making it an ideal context for research on positionality and differential access (Sugden, 2016). Land distribution is highly unequal, with coexisting substantial landless populations and extensive holdings by absentee landlords (Sugden, 2021).

Caste hierarchies remain powerful, with complex interactions between hill-origin high castes (Bahun-Chhetri), *Madhesi* plains-origin upper castes (Yadav, Thakur), indigenous groups (particularly Tharu), and Dalit communities (including Chamar, Musahar, Dom, and other caste groups) (Gellner, 2007). Gender inequalities pervade property ownership, agricultural decision-making, public participation, and mobility, with women systematically excluded from land titles, ownership of irrigation technology, and formal agricultural institutions (Zwarteveen & Meinzen-Dick, 2001; Nightingale, 2011; Bhukhaju Shrestha & Siwakoti, 2025). Class differentiation is pronounced, with capitalist farmers employing wage labour, middle peasants engaged in petty commodity production, and substantial populations of marginal farmers, tenant farmers, sharecroppers, and landless agricultural labourers coexisting among relations of dependence and exploitation (Sugden, 2016). Labour migration is pervasive, with some households sending members for high-wage international migration to Gulf countries and Malaysia, while others engage in low-wage seasonal migration to India, creating differentiated access to remittance capital for agricultural investment (Sugden et al., 2021).

These intersecting inequalities – land tenure, caste, gender, class, and migration – make the Terai an analytically rich site for investigating how social positionality shapes technology access. The research questions animating this study could not be adequately addressed in more socially homogeneous or less stratified contexts. The Terai's combination of widespread groundwater irrigation, agricultural dynamism, and profound social stratification provides an ideal setting for examining how multiple axes of difference intersect to produce differential technological access (McCall, 2005).

3.4.2 Saptari[10] District Selection: Rationale and Characteristics

Within the Terai, Saptari district in Madhesh Pradesh (Province 2) was selected based on multiple criteria, balancing analytical appropriateness with research feasibility. First, groundwater irrigation predominance characterises Saptari's agricultural landscape. Unlike western Terai districts, where large canal systems dominate irrigation infrastructure, Saptari relies heavily on groundwater through an estimated 18,000 private shallow tubewells, public deep tubewells, and scattered canal access (Agriculture Knowledge Centre Rajbiraj, 2021). This groundwater predominance makes Saptari ideal for studying groundwater-specific access dynamics, institutional arrangements, and social relations that differ fundamentally from those in surface irrigation contexts, where collective management structures and upstream-downstream dynamics create distinct exclusion mechanisms.

Second, Saptari exhibits extraordinary social heterogeneity encompassing *Madhesi* upper castes (Yadav, Thakur, Rajput), hill-origin Bahun-Chhetri who migrated during and after the Rana period, Tharu and other indigenous groups, multiple Dalit caste groups (Chamar, Musahar, Dom, Dusadh, Ram, Sada), and Muslim minorities. This heterogeneity enables examining how multiple axes of social position intersect, directly addressing the intersectionality framework central to the research (Crenshaw, 1991). The district's caste composition, according to 2021 census data, includes approximately 31% OBC (Other Backward Classes) groups, 26% upper caste (hill and *Madhesi* combined), 19% Dalit, 15% Tharu/indigenous, and 9% other categories, though these proportions vary substantially across Wards and villages (National Statistics Office, 2024). This diversity contrasts with some Terai districts where single caste or ethnic groups comprise overwhelming majorities, limiting analytical purchase on intersectional dynamics.

[10] District is a pre-federal Nepal administrative unit which is bigger in landmass and comprised of multiple Village Development Committees, and the municipality is a smaller landmass post-federal Nepal; it is part of the local government and a powerful unit post-2015. I refer to Saptari along with the Shambhunath Municipality because, in a lot of data terms, Saptari is still referred to.

Third, migration intensity and differentiation in Saptari enable examining how migration interacts with other dimensions of positionality. An estimated 25%-30% of households have at least one member in foreign employment, primarily in Gulf countries (Qatar, Saudi Arabia, United Arab Emirates), Malaysia, and India (Sugden, 2016; Maharjan et al., 2020). Critically, migration is differentiated along class and caste lines. Wealthier households with some initial capital access, go to higher-wage international destinations requiring substantial upfront costs (typically NPR 100,000-200,000 or approx. USD 750-1,500 for recruitment fees, travel, and documentation), generating significant remittance flows that can finance irrigation technology investment. Poorer households, particularly Dalits and some Tharu families, engage primarily in low-wage seasonal labour migration to India, which requires minimal costs but yields insufficient returns for capital accumulation (Sugden et al., 2021; Sunam et al., 2021). This differentiated migration landscape enables investigation of how migration status and type interact with caste, gender, and land tenure to shape irrigation investment capacity.

Fourth, Saptari represents a middle position in Terai agrarian dynamism and commercialisation, neither as highly commercialised and capitalist as peri-urban districts near major cities, nor as stagnant as the most remote border districts. The district exhibits growing agricultural commercialisation with vegetable cultivation for regional markets, tobacco production under contract farming arrangements, and intensified cereal production, alongside persistent subsistence-oriented production among marginal farmers (Sugden et al., 2014). This mixed agrarian landscape enables the examination of technology access dynamics across varying commercialisation levels and accumulation strategies, from subsistence farmers for whom irrigation enables food security to commercial farmers for whom irrigation underwrites market-oriented production.

Fifth, pragmatically, my prior involvement with International Water Management Institute (IWMI) projects in Shambhunath Municipality in Saptari district provided crucial advantages. (*I worked at IWMI for over five years and engaged in the irrigation research project in Saptari for around four years.*) Existing relationships with local officials, farmer leaders, and community members facilitated research entry, enhanced legitimacy by allowing community members to verify my prior work and enabled me to build on contextual knowledge rather than starting from scratch (Mosse, 2004). While all research requires building new relationships and cannot rely solely on prior connections, these existing networks provided important foundations, accelerating the trust-building process essential for ethnographic research. This prior engagement occurred several years before the current research,

providing sufficient temporal distance such that the current study did not become entangled in IWMI project politics or expectations while maintaining residual relational capital.

Finally, research feasibility considerations influenced selection. Saptari's location, accessible from Kathmandu via direct highway connection (approx. 8-9 hours by bus and 40 minutes by flight), yet sufficiently distant to constitute a genuinely rural context, balances accessibility with remoteness. Security conditions were adequate during the research period. Linguistic diversity, primarily Maithili with substantial Nepali use, plus Tharu languages in some areas, required multilingual capacity but was manageable through research assistant recruitment and my existing Nepali and Maithili fluency. District and municipal officials expressed openness to research collaboration, issuing necessary permissions and providing administrative support where needed.

3.4.3 Ward 2 and Ward 4 of Shambhunath Municipality Selection: Specific Research Sites

Significantly, the Ward 2 Chairperson was the same elected representative with whom I had collaborated during a previous IWMI project engagement several years prior. This institutional continuity proved invaluable. This Ward Chair remembered the prior collaboration positively, vouched for my credibility with community members during initial introductions, facilitated connections to farmer leaders and key informants, and provided ongoing informal support throughout fieldwork. This reflects how prior research relationships, when conducted ethically and reciprocally, can facilitate subsequent research access (Mosse, 2004). However, researchers must be cautious that such relationships do not create obligations or expectations that compromise research independence. In this case, sufficient time had elapsed, and the current research had different objectives than the prior IWMI work, maintaining clear boundaries while benefiting from residual trust. Despite this clarity, I had to repeatedly re-emphasise that the research was conducted as part of an academic study and that no water infrastructure construction was included.

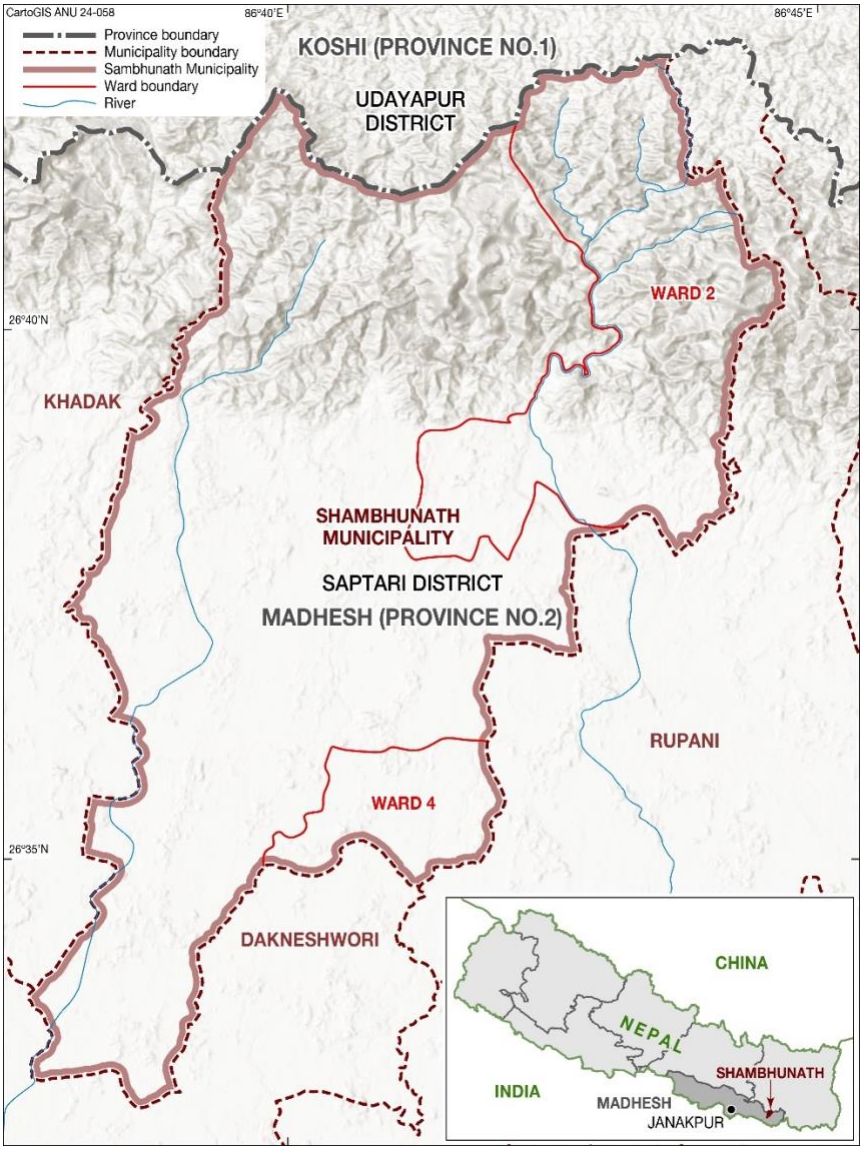

Figure 2 Study Sites: Ward 2 and Ward 4 at Sambhunath Municipality, Saptari District, Madhesh Province, Nepal

3.4.3.1 Ward 2 Characteristics

Ward 2 encompasses approximately 620 households spread across semi-contiguous settlement clusters. The Ward is located approximately 3-4 kilometres from the Saptari Municipality administrative centre, with relatively good road access via a paved road connecting to the district headquarters. Social composition is highly diverse, with no single caste or ethnic group comprising a majority. According to household mapping conducted during the community entry phase in May-June 2023, approximate composition includes: *Madhesi* upper castes (Yadav, Thakur), approximately 30%; Tharu and other indigenous groups, approximately 25%; Dalit communities (primarily Chamar and Musahar), approximately 22%; hill-origin Bahun-Chhetri, approximately 15%; and OBC groups,

approximately 8%. This diversity enables examining interactions between multiple social positions rather than binary comparisons.

Land distribution in Ward 2 is moderately unequal. Based on Ward-level agricultural records and household survey data, approximately 20% of households control an estimated 55% of cultivable land, though this concentration is less extreme than in some other Terai areas, where historical zamindari (landlord) systems created more concentrated landholding patterns (Sugden, 2016). Landlessness affects approximately 15% of households, while marginal holdings of less than 0.5 hectares characterise another 30%. Medium holdings of 2-5 hectares comprise about 20% of households, and large holdings exceeding 5 hectares represent approximately 8% of households.[11]

Irrigation infrastructure in Ward 2 is mixed, comprising an estimated 95-110 private shallow tubewells (exact numbers are difficult to establish as informal wells installed without official registration are common), approximately 15-20 deep tubewells (some public, some privately owned), scattered hand pumps used for both domestic purposes and small-scale irrigation, and limited canal access reaching the Ward's northern sections from a small canal system serving several Wards. This infrastructural diversity enables examining how access dynamics differ across technology types. Market access is relatively good, given proximity to the municipal centre and paved road access, enabling commercial vegetable cultivation for district and regional markets. Migration rates are moderate to high, with substantial variation. Some upper-caste and Tharu households have members in Gulf countries generating significant remittance income (often NPR 30,000-50,000 monthly or USD 225-375), while many Dalits and some Tharu households engage in seasonal Indian migration, generating minimal returns (often NRs 8,000-12,000 monthly or USD 60-90).

3.4.3.2 Ward 4 Characteristics

Ward 4, where I established primary residence during the ethnographic phase, encompasses approximately 580 households in a more geographically concentrated settlement pattern than Ward 2. The Ward is located approximately 7-8 kilometres from the municipal centre, connected via a partially paved road that becomes muddy and sometimes impassable during heavy monsoon rains, indicating

[11] Land size is reported in both hectares (ha) and the local unit *kattha*, as used by the Agriculture Knowledge Centre (AKC) in Nepal's agricultural reporting. In the Terai, 1 ha ≈ 30 *kattha*. According to the AKC categories, households are classified as: landless/tenant; marginal (< 0.5 ha); small (0.5–2 ha); or medium/large (> 2 ha). The ranges used here are: < 0.1 ha (≈ 3 *kattha*); 0.1–0.2 ha (≈ 3–6 *kattha*); 0.2–0.5 ha (≈ 6–15 *kattha*); 0.5–1 ha (≈ 15–30 *kattha*); 1–2 ha (≈ 30–60 *kattha*); 3–4 ha (≈ 90–120 *kattha*); 5–10 ha (≈ 150–300 *kattha*); and > 10 ha.

somewhat poorer infrastructure than Ward 2. This infrastructural difference enables examining how market access and connectivity interact with social position to shape technology adoption, as transportation costs for inputs and outputs affect irrigation investment returns (Birkenholtz, 2017).

The social composition differs notably from that of Ward 2. The Tharu population is substantially higher, approximately 40% of households, reflecting historical Tharu predominance in this area prior to subsequent migrations. The Dalit population comprises approximately 15%, the *Madhesi* upper castes are approximately 28%, and the hill-origin Bahun-Chhetri are approximately 17%. This different composition, particularly the Tharu majority, enables the examination of indigenous dynamics around land and water that differ from those in areas where Tharu populations are minorities facing discrimination from dominant castes (Sugden, 2016).

Irrigation in Ward 4 relies almost entirely on groundwater, with an estimated 80-95 private shallow tubewells, approximately 10 deep tubewells, and virtually no canal access. This groundwater dependence makes Ward 4 particularly well-suited for examining groundwater-specific access dynamics, free from the confounding factor of alternative surface water sources. Market access is moderate, better than truly remote villages, but requires motorcycle or tractor transport to reach major markets, constraining perishable vegetable production, relative to Ward 2, and favouring less perishable crops like wheat and lentils.

Importantly, Ward 4 has benefited from several NGO and government irrigation development interventions over the past decade, including a subsidy programme for tubewell installation implemented 2015-2017, an agricultural cooperative promoting vegetable production established in 2018, and periodic agricultural extension initiatives. This intervention history enables examining how development programmes mediate positionality, directly addressing the third sub-question about institutional mediation. I was able to access programme documents, interview programme staff and beneficiaries, and observe ongoing programme activities during fieldwork.

Migration rates in Ward 4 are very high, particularly among Tharu households, many of whom have members working in Malaysia or India. According to household survey data, approximately 38% of households in Ward 4 had at least one member in foreign employment during the research period, compared to approximately 28% in Ward 2. This higher prevalence of migration enables more intensive examination of migration-irrigation linkages, including how remittances finance technology

investment and how male out-migration affects women's agricultural roles and irrigation access (Gartaula et al., 2014).

These two Wards provide complementary research contexts that enable a controlled comparison. Ward 2's greater social diversity, better market access, and more advantaged average conditions enable examining how inequalities operate even in relatively favourable contexts, testing whether proximity to markets and infrastructure ameliorates social exclusions or whether positionality effects persist regardless of locational advantages. Ward 4's Tharu-majority composition, poorer infrastructure, greater reliance on migration, and a history of development interventions enable in-depth examination of indigenous land dynamics, migration-irrigation linkages, and programme implementation processes. Together, they provide systematic variation across key dimensions, social composition, infrastructure, market access, and intervention history, while remaining within a single district context, enabling controlled comparison while maintaining contextual depth and coherence (Yin, 2018).

3.4.4 Seasonal and Agricultural Context

Research timing was structured around Nepal's agricultural calendar, which profoundly shapes irrigation demand, labour availability, and farmers' time and attention. Nepal's Terai agriculture operates primarily on two cropping seasons. The monsoon or *kharif* season (June-October) centres on paddy rice cultivation, which relies primarily on rainfall supplemented by limited irrigation during dry spells or delayed monsoon onset. This is a labour-intensive period that involves rice transplanting, weeding, and eventually harvesting, leaving farmers with limited time for research participation. Irrigation demand is relatively low during the monsoon season when rainfall provides most crop water requirements, making irrigation technology access dynamics less visible and less consequential for agricultural outcomes (Pant, 2011).

The winter or *rabi* season (November-March) and the pre-monsoon period (April-May) involve the cultivation of wheat, lentils, vegetables, oilseeds, and other crops that rely heavily on irrigation, as rainfall is minimal during these months. This is the period when groundwater irrigation technology becomes most critical and most intensively used, making social relations around water access, tubewell operation, labour arrangements, and inter-farmer negotiations highly visible. In winter, irrigation determines whether farmers can cultivate second crops at all, and irrigation intensity directly affects yields and production values (Sugden et al., 2014). Additionally, agricultural labour demands

are somewhat lower during mid-winter (January-February), after wheat planting but before harvest, creating more time for farmers to participate in research activities.

The research timeline was strategically structured around these seasonal rhythms. Household survey administration occurred between September and December 2023, when farmers could reflect on recent monsoon experiences and anticipate winter irrigation needs. This timing enabled capturing both monsoon and winter perspectives. The intensive ethnographic immersion phase spanned June 2023 through January 2024, encompassing the entire winter irrigation season (December-March), the spring pre-monsoon season (April-May), and the early monsoon season (June-July). This extended timeframe enabled the observation of seasonal variations in irrigation practices, water availability, social relations, and institutional activities. Visual ethnographic documentation was concentrated from November 2023 through January 2024, the peak winter irrigation period when irrigation activities were most intensive and consequential. This seasonal structuring ensured data collection aligned with irrigation cycles rather than imposing arbitrary research timelines disconnected from agricultural realities (Hammersley, 2015).

3.5 Data Collection Methods: Surveys, Ethnography, Institutional Analysis, and Visual Documentation

This section presents the four primary data collection approaches I employed: household surveys; ethnographic immersion; institutional interviews; and visual documentation – followed by a detailed explanation of how I analysed these diverse data sources. Each method contributed distinct forms of evidence that, when integrated, provide a comprehensive understanding of how social position shapes access to irrigation technology.

3.5.1 Household Survey: Quantifying Access Patterns Across Social Positions

The household survey provided the quantitative backbone of this research, systematically documenting technology ownership patterns, household characteristics, and livelihood strategies across 401 households in Ward 2 and Ward 4 of Sambhunath Municipality. I designed this survey to understand key concepts from my theoretical framework, particularly the intersecting dimensions of social position identified through intersectionality theory – land tenure, caste, gender, and migration status – and their relationship to irrigation technology access (McCall, 2005; Hill Collins, 2009).

I developed the survey instrument through iterative pre-testing with approximately 15 households in July-August 2023, which revealed necessary adjustments to language, question ordering, and response categories, to better match local realities. The final instrument comprised 94 questions organised across eight thematic sections: household composition and social characteristics; land tenure and agricultural assets; irrigation technology access and infrastructure; agricultural production and commercialisation; household economics and livelihood strategies; water governance and institutional participation; gender relations and intra-household dynamics; and perceptions, priorities, and technology meanings. This comprehensive scope enabled examining not just technology ownership as an isolated outcome but the broader socio-economic and institutional contexts shaping access.

I employed stratified systematic sampling to ensure representation across geographical blocks, landholding categories, and gender, as represented in Table 2. Each Ward was subdivided into three blocks based on population density, confirmed through consultations with Ward leaders, since official documentation was unavailable. In Ward 2, samples were collected from Kanakpatti Pachwarie & Uttarwari (68 households, 17.0%), Kanakpatti Purbaria (80 households, 20.0%), and Khairbana-Valuwai (53 households, 13.2%). In Ward 4, sampling covered Sirajjadi (87 households, 21.7%), Sakhua (80 households, 20.0%), and Naraiya (33 households, 8.2%). Within the blocks, every second household was systematically selected, ensuring equitable representation while maintaining sampling efficiency.

The sample distribution reflected the agrarian structure of my research sites: 303 households (75.6%) held less than 1 hectare of land (including rented land), while 98 households (24.4%) held 1 hectare or more. This predominance of smallholders made the sample particularly well-suited for investigating access barriers faced by resource-constrained farmers. Gender representation achieved was 152 female respondents (37.9%) and 249 male respondents (62.1%); falling short of my 50% female target but substantially exceeding the typical rates in Nepal, where women's voices are often absent. Respondents within households were selected purposively, taking into account availability at the time of the survey; in some nuclear households and those affected by male out-migration, women were therefore interviewed.

A team of six trained enumerators (three female, three male; all native Maithili speakers fluent in Nepali) conducted surveys over 12 weeks from mid-September through November 2023. I trained these enumerators intensively over four days, covering survey content, interviewing techniques,

ethical protocols, cultural sensitivity to caste and gender hierarchies, and use of the Kobo Toolbox digital data-collection platform on tablets. Enumerators worked in gender-balanced pairs, with female enumerators interviewing female respondents, where possible, to enhance comfort discussing sensitive household dynamics. Each survey averaged 70-80 minutes, conducted at times convenient for farmers rather than imposing rigid schedules.

Multiple quality control measures were implemented, including: daily debriefing sessions reviewing completed surveys; random spot checks of approximately 10% of surveys during household revisits; and real-time data quality monitoring through Kobo Toolbox's built-in validation rules, to prevent impossible values or contradictions. Following data collection, I conducted systematic cleaning in Excel and analysis in Jamovi, converting local land measurement units to standardised hectares, constructing derived variables, including total effective landholding and wealth indices, and documenting all decisions in detailed codebooks.

Table 2 Sample Distribution Across the Study Wards 2 and 4

Characteristic	**Category**	**Count**	**Percentage (%)**
District	Saptari	401	100.0%
Municipality	Sambhunath Municipality	401	100.0%
Ward	Ward 2	201	50.1%
	Ward 4	200	49.9%
Block (Ward 2)	Kanakpatti Pachwarie & Uttarwari	68	17.0%
	Kanakpatti Purbaria	80	20.0%
	Khairbana-Valuwai	53	13.2%
Block (Ward 4)	Sirajjadi	87	21.7%
	Sakhua	80	20.0%
	Naraiya	33	8.2%
Landholding	Less than 1 hectare (<30 *kattha*)	303	75.6%
	1 hectare or more (≥30 *kattha*)	98	24.4%
Respondent Gender	Male	249	62.1%
	Female	152	37.9%

The quantitative component of this study addresses the first sub-question outlined in the section 3.3.1 about the intersection of social positions shaping access to groundwater irrigation technologies. Survey data were analysed in multiple stages to identify patterns of inequality and to examine how social and material conditions jointly structure technological access.

I began with descriptive analysis to document sample characteristics and baseline patterns of irrigation access. Frequency distributions, percentages, and cross-tabulations were used to map household characteristics and technology use across the study area. These descriptive statistics revealed pronounced inequalities. For example, access to tubewells and electric pumps varied sharply across caste groups and landholding categories, signalling that irrigation technologies were unevenly distributed and socially patterned. These initial patterns warranted deeper inferential analysis.

Bivariate analysis was then conducted to examine whether simple group-level differences in irrigation access were statistically detectable. An important caveat governs interpretation of these tests: because the social attributes being compared, caste, land, land ownership, gender of household head, and migration status are correlated with each other in the sample, bivariate comparisons are descriptive summaries and cannot disentangle the independent contribution of any single attribute. A finding that Dalit households have lower electric pump access than non-Dalit households in bivariate analysis will partly capture land ownership effects rather than caste alone. The multivariate logistic regression models in Section 4.4 carry the primary analytical weight for interpreting independent and combined effects. Independent-sample t-tests were used for binary technology outcomes treated as proportions. These tests assessed whether access rates differed across gender, caste, land ownership, and migration status beyond what would be expected by chance. For instance, t-tests compared mean access rates between Dalit and non-Dalit households, landless and land-owning households, and female- and male-headed households. The purpose of these tests was descriptive rather than causal. They established which dimensions of social position were associated with differential access and provided an empirical basis for specifying multivariate models.

The core analytical strategy is multivariate regression, which is used to test intersectionality's central claim that social positions do not simply add up but interact to shape outcomes (Crenshaw, 1991; McCall, 2005). Binomial logistic regression models are estimated with irrigation technology access as the dependent variable. Rather than focusing solely on ownership, the analysis operationalises access to technology. In the study area, irrigation is also frequently achieved through rental, borrowing, or shared arrangements. Treating ownership as the sole indicator would therefore misclassify many irrigating households as non-users. For each technology, a household is coded as having access if it either owns the technology or reports secure and regular use through rental or sharing, during the study period. This operationalisation aligns measurement with everyday practice and with the conceptual distinction between property and access (Ribot & Peluso, 2003).

Separate models are estimated for tubewell access, diesel pump access, electric pump access, and agricultural electricity meter access. All dependent variables are binary, coded 1 if the household has access and 0 otherwise. Logistic regression allows estimation of the conditional association between each explanatory variable and the likelihood of access while holding other factors constant. This approach allows, for example, to distinguish whether observed caste differences reflect underlying land tenure patterns or whether caste operates as an independent axis of exclusion.

The selection of explanatory variables is grounded in a substantial body of literature on groundwater irrigation in South Asia. The models include age, caste, migration status, land access, education, and gender. Land access is a foundational determinant of irrigation technology uptake. Numerous studies show that farmers with larger landholdings are more likely to invest in fixed and capital-intensive infrastructure, while those cultivating marginal or fragmented plots are often relegated to water markets or face constrained access (Pariyar et al., 2018). Beyond land, caste hierarchies continue to mediate control over groundwater resources. Dominant caste groups not only own a disproportionate share of irrigation infrastructure but also exercise informal authority over local water governance, often excluding Dalit and lower-caste farmers from effective access (Narain et al., 2019; Dixit & Dutta, 2024).

Migration and remittances play an ambivalent role. While some migrant households use remittance income to invest in pumps or wells, others disengage from farming or lack the local presence required for everyday irrigation management. Education, particularly at secondary and higher levels, has been associated with greater adoption of improved agricultural technologies through enhanced access to information and decision-making capacity (Kumar & Doan, 2025). Age may further shape willingness to invest in or experiment with new technologies, with younger farmers often more open to innovation and older farmers more risk-averse (Kumar & Doan, 2025). Gender is a cross-cutting axis of inequality. Although women contribute substantially to agricultural production, structural constraints such as insecure tenure, limited access to credit, and exclusion from irrigation user groups continue to marginalise them within irrigation governance, and in ownership and control of water technologies (Quinn, 2009; ODI, 2016; Kandel et al., 2025). These variables are therefore theoretically and empirically justified as key factors shaping differentiated access to groundwater irrigation.

To represent the layered role of land, a two-stage modelling strategy is employed. Model A uses the full sample and includes binary indicators for land ownership and land renting. This specification

captures land as a threshold condition for entry into irrigation regimes. Model B restricts the sample to land-owning households and replaces the binary ownership indicator with landholding size categories, derived from locally meaningful agrarian thresholds. This allows land to be analysed as a gradient among those who have already crossed the ownership threshold. Together, these models distinguish land as a gateway from land as stratified-within ownership.

Formally, for each technology outcome Y_i, the probability of access is modelled using a binomial logistic specification:

$$logit\big(P(Y_i = 1)\big) = \alpha + \beta X_i$$

where X_i includes household social position (gender and caste), migration status, and land tenure measures. In the full-sample models, land is represented by binary indicators for ownership and rental. In the landowner-only models, these are replaced by landholding categories. Results are reported as odds ratios to facilitate interpretation.

These quantitative analyses produce the empirical patterns presented in Chapter Four. They identify which dimensions of social position most strongly predict irrigation access, show where apparent inequalities persist after controlling for correlated factors, and reveal how (dis)advantages compound across land, caste, gender, and infrastructure. In doing so, they provide a robust statistical foundation for the qualitative chapters that follow, which examine how these structural patterns are lived, negotiated, and reproduced in everyday irrigation practice.

3.5.2 Ethnographic Immersion

Alongside other data collection methods, I undertook intensive ethnographic immersion, living primarily in Ward 4 while maintaining regular engagement with Ward 2. This phase addressed Sub-Question 2 outlined in the section 3.3.1 on how marginalised farmers experience, interpret, navigate, and contest structural constraints, a topic requiring depth that surveys alone cannot provide.

I rented a room in a local household in Ward 4, which enabled me to participate daily in community rhythms rather than commuting from the district headquarters. This residential arrangement supported ongoing interactions in everyday spaces such as tea shops, fields, markets, and homes, and allowed observation across seasons as irrigation demands and household dynamics shifted (Emerson et al., 2011). Prolonged presence helped build relationships and trust, while recognising that power asymmetries between researcher and participants remained.

Daily practice followed ethnographic principles of immersion and opportunistic observation. Mornings often involved accompanying farmers during irrigation and other farm work. Days included visits to diverse households, time in public gathering spaces, attendance at cooperative and WUAs meetings, and follow-up on emerging leads. Evenings were devoted to writing detailed field notes that reconstructed observations and conversations, and recorded analytical reflections.

Participant observation and documentation formed the core of this work (Hammersley, 2015) (Atkinson, 2007). I participated in agricultural activities where appropriate, including irrigating, harvesting, and market trips. This participation reduced social distance, fostered reciprocity, and offered insight into the embodied dimensions of irrigation labour, including pump handling, breakdowns, and the practical skills required to manage water. It also created space for informal conversations during shared work, which formal interviews rarely produce.

At the same time, I maintained an analytical focus on patterns and power relations. I focused on irrigation practices, water distribution arrangements, and technology maintenance, as well as social relations shaped by caste, gender, and class. I also observed institutional processes through meetings and Ward interactions, paying attention to who attended, who spoke, how decisions were made, and how beneficiary selection unfolded in practice.

I maintained a daily field journal, usually written each evening, documenting observations with contextual detail and reflexive notes about positionality (Emerson et al., 2011). Over the field period, this journal exceeded 40,000 words and became a central source for analysis.

During immersion, I shifted my primary qualitative approach from formal semi-structured interviews to informal conversational interviews. Early attempts at formal interviews often reinforced power asymmetries and limited disclosure, especially on sensitive issues such as caste discrimination, intra-household conflict, and institutional capture (Sultana, 2009). I therefore relied mainly on purposeful conversations that emerged from everyday interactions in fields, tea shops, household compounds, and markets, while still probing for detail and following research themes (Swain & King, 2022).

This conversational approach improved access to sensitive topics. Caste discrimination and exclusion often surfaced indirectly through shared work and sustained interaction, rather than in response to direct questioning. Gendered dynamics similarly emerged more clearly in conversations with women, especially when men were absent, allowing discussion of decision-making, labour burdens, and aspirations for greater control.

In total, I engaged in informal conversational interviews with approximately 120 farmers across both Wards. Many involved repeated exchanges over time, and around 35 to 40 farmers became key informants with whom I had ongoing conversations, providing a longitudinal view of changing circumstances. I sought diversity across social positions, including landowners and tenants, large and marginal farmers, landless labourers, Dalit communities, and women managing farms of households affected by migration (Hill Collins, 2009).

Documentation practices reflected the informality of these encounters. I did not record most conversations, as this would have disrupted natural interaction (Emerson et al., 2011). Instead, I wrote detailed reconstruction notes soon after conversations. For especially information-rich narratives, I requested permission to audio-record. Approximately 65 farmers consented to recorded conversations, which I transcribed in Maithili or Nepali and translated key sections into English.

Ethnographic materials were analysed through thematic analysis. I coded field notes, transcripts, and documents iteratively, moving from open coding to more focused coding and theme development. I wrote analytical memos to connect patterns to the thesis framework and to integrate qualitative insights with quantitative findings. Narrative analysis complemented thematic coding by tracing how farmers described trajectories of access and exclusion over time. Throughout, I used constant comparison across incidents, social positions, and data sources, including attention to deviant cases that challenged emerging interpretations (Emerson et al., 2011).

3.5.3 Institutional Actor Interviews

I conducted interviews with institutional actors at national, district, and local levels to examine how governance processes shape irrigation access and how formal institutions mediate positionality. These interviews focused on how power operates through organisations, how policies are designed and implemented, and how elite actors leverage institutional positions, examining the Sub-question 3 outlined in the section 3.3.1 (Cleaver, 2007; Mosse, 2004).

At the national level in Kathmandu (April-May 2023), I interviewed 12 representatives from government agencies, international development organisations, and NGOs, including: the Ministry of Agriculture and Livestock Development; the Department of Water Resources and Irrigation; the Ministry of Energy, Water Resources and Irrigation; the Water and Energy Commission Secretariat; FAO Nepal; IWMI Nepal; and civil society organisations working on irrigation and water rights. These semi-structured interviews (60-110 minutes, audio-recorded with consent) examined irrigation

policies, groundwater governance frameworks, programme design and targeting, inter-agency coordination, and equity challenges.

At district and local levels in Saptari (June-December 2023), I interviewed 19 actors, including district officials, municipal leaders, Ward chairpersons, NGO and project staff, private-sector suppliers, and leaders of farmer organisations. These conversations, increasingly informal over time, focused on programme implementation, beneficiary selection, resource constraints, community relations, and observed practices of elite capture. The Ward 2 Chairperson and several NGO staff became key informants, providing candid insider accounts of political pressures, subsidy manipulation, and conflicts across governance levels.

Institutional interviews were analysed alongside farmer data through thematic coding, comparison of official accounts with lived experience, and attention to how different actors framed problems and solutions. This was complemented by document analysis of policies, guidelines, implementation reports, beneficiary lists, correspondence, and local records. Using critical discourse analysis, I examined framings, silences, and whose interests were centred or obscured. For example, policy texts that framed irrigation as a technical problem while remaining silent on caste discrimination revealed how depoliticised narratives mask structural inequality. Comparing eligibility criteria with actual beneficiary lists revealed systematic gaps: marginalised farmers were excluded, while elites secured benefits through manipulation.

3.5.4 Visual Ethnography: Capturing Embodied and Spatial Dimensions

I employed video documentation during November 2023 through January 2024, the peak winter irrigation season, to capture embodied, spatial, and material dimensions that verbal methods alone could not access (Pink, 2013). Visual methods are increasingly recognised for their unique analytical affordances, particularly in understanding practices, spatial arrangements, material interactions, and embodied knowledge that is difficult to articulate verbally.

Video ethnography served multiple analytical purposes. First, it captured embodied and practice-based dimensions of technology use, the physical labour of pump operation, bodily techniques for managing water flow, spatial movements during irrigation, and material interactions between people and technical systems; which practitioners often cannot articulate because practices become so routinised. Second, the video provided visual evidence that complemented and sometimes complicated verbal accounts, enabling comparisons between what people claimed they did and their

actual practices, revealing contradictions between normative claims and reality. For instance, farmers described water sharing as cooperative and fair, but the video revealed subtle discrimination: Dalit farmers received water only after upper-caste farmers finished. Third, video elicitation, watching footage with participants and discussing what was shown, generated rich conversations where farmers narrated and interpreted practices, explained rationales, provided insider analytical perspectives, and sometimes expressed surprise seeing their own practices from an external viewpoint (Henry & Fetters, 2012). These became collaborative analytical moments, generating insights that neither the participants nor I would have reached on our own. Fourth, video captures spatial and material dimensions that are difficult to convey textually, including field layouts and water systems, the distances farmers travel for water, the material conditions of pumps and infrastructure, environmental contexts, and operational scales.

I filmed, using a handheld digital camera, approximately five farmer households across diverse social positions who consented to be documented during irrigation activities. Participant selection purposefully sought diversity: farmers with different technology access arrangements (tubewell owners, water purchasers, shared well users, entirely dependent farmers); caste diversity (high-caste Tharu, Dalit from multiple communities); gender diversity (male farmers, women managing irrigation in migration contexts, women performing labour in male-present households); and land tenure diversity (landowners, tenants, sharecroppers). Filming sessions ranged from 30 minutes to over three hours, depending on the activities being documented. I generated approximately 18 hours of footage across diverse contexts, technologies, crops, land types, scales, and social arrangements.

The visual analysis involved multiple processes, following Pink's (2013) principles. First, systematic viewing of all footage, with detailed notes documenting observable phenomena: technical practices and material interactions; social interactions and power dynamics; spatial arrangements and movements; embodied dimensions of labour and technique; environmental contexts; and contradictions relative to verbal accounts. Second, rich segments underwent detailed micro-analysis involving repeated viewing, sometimes frame-by-frame, capturing subtle interaction dynamics, technical details, spatial-temporal patterns, and non-verbal communication that casual viewing might miss. These proved especially valuable for gaining insider knowledge of technical practices and social dynamics that I could not fully interpret from visual evidence alone. Fourth, I used selected clips in community presentations and validation workshops towards the end of the fieldwork, where groups

watched and discussed the footage, generating collective conversations about irrigation inequalities and potential improvements.

3.5.5 Integrated Mixed-Methods Synthesis

The analytical power of the research derives not from individual methods but from their integration, producing a richer understanding than any single approach (Creswell & Plano Clark, 2018). Integration occurred at multiple points. During data collection, preliminary quantitative results identified patterns that required qualitative explanation, directing ethnographic investigation toward specific topics. Qualitative observations suggested hypotheses testable quantitatively. During analysis, I constantly compared quantitative and qualitative findings. Statistical patterns of systematic exclusion were explained by qualitative data revealing specific mechanisms: credit barriers, information exclusion, discriminatory supplier treatment, and institutional subsidy capture. Qualitative findings about exceptional cases, for example, Dalit farmers succeeding despite systemic barriers, prompted quantitative analysis examining distinguishing factors, revealing roles of Gulf remittances or unusual patron-client relationships.

In the presentation through empirical chapters (Four to Seven), I integrate findings rather than present methods separately. Each chapter combines quantitative evidence documenting patterns with qualitative evidence explaining mechanisms and meanings, and visual evidence illustrating embodied and spatial dimensions. This integrated presentation reflects how understanding emerges from synthesis rather than isolated methods (Moran-Ellis et al., 2006). Triangulation, comparing findings across methods, confirmed interpretations when methods converged as well as revealed complexity when they produced complementary findings (Okunwaye, 2024). Surveys showing Dalit ownership rates being below high-caste rates, interviews revealing mechanisms of discrimination, observations documenting discriminatory interactions, and documents showing Dalit exclusion from subsidies, provided triangulated evidence strongly supporting claims of caste-based exclusion. Conversely, surveys showing variable outcomes among female-headed households required a qualitative investigation, revealing that this category encompasses highly heterogeneous situations depending on caste, landholding, migration status, and kinship networks, underscoring the importance of intersectionality rather than single-axis categorisation (Hill Collins, 2009).

3.6 **Ethical Considerations**

This research was conducted in accordance with the ethical standards and procedures of the Australian National University (ANU). Ethical approval for the study was obtained through the ANU Human Research Ethics Committee (HREC) prior to the commencement of fieldwork. The ethics application was submitted in January 2023, and formal approval was granted in March 2023, before any data collection activities began. The approved ethics protocol detailed the research objectives, methodological approach, and strategies for engaging, informing, and protecting participating communities throughout the research process.

The ethics application explicitly outlined procedures for community engagement, informed consent, and risk minimisation, recognising the sensitivity of conducting research with marginal, tenant, Dalit, and women farmers. Prior to data collection, the researcher engaged with local communities to explain the study's purpose, the nature of participation, and how the information would be used. Consent to participate was obtained from all participants before surveys, interviews, photo documentation, and video recording were conducted. Consent was obtained in a manner appropriate to local contexts, using clear verbal explanations in the local language, and participants were informed of their right to decline participation or withdraw at any stage without consequence.

Given the social, economic, and political sensitivities associated with land tenure, caste relations, migration, and gender, particular care was taken to ensure that participation did not expose individuals or households to harm, discomfort, or social risk. No personal identifiers were recorded in the dataset, and all household-level data were anonymised at the point of data entry. Names of individuals, households, and specific locations were removed or replaced with codes to protect participant confidentiality. Where visual material was collected, consent was sought separately, and participants were informed about how video and photographic data would be used for academic and dissemination purposes.

ANU’s institutional requirements for ethical research practice were applied to data management and storage. All quantitative and qualitative data are securely stored on a password-protected ANU-issued computer, and access to the data is restricted to the researcher and her supervisory team. The researcher is required to, and has complied with, the ANU's annual ethics review and reporting requirements, including updates on data handling, storage, and analysis processes as the research progressed from data collection to analysis.

In addition to formal institutional ethics approval, the research adhered to principles of relational and community-based ethics. This included ongoing engagement with participants and communities beyond one-time data extraction, sensitivity to local power relations, and reflexivity regarding the researcher's positionality. Ethical practice in this study thus extended beyond procedural compliance to include respectful, transparent, and accountable engagement with communities throughout the research process.

3.7 Conclusion

This chapter has outlined the methodological foundation of the study, including its research design, site selection, data collection, and analytical strategies. The approach combines survey analysis with intensive ethnography and visual methods, allowing the research to capture both the scale of inequality and the processes and meanings through which it is produced. The shift toward informal, conversational methods proved essential for studying sensitive issues of power and discrimination, where formal interviews limited disclosure. Visual ethnography further extended what could be observed and analysed by making embodied and spatial dimensions of irrigation visible. Together, these choices operationalise intersectionality by examining multiple, overlapping dimensions of social position through both statistical modelling and purposive qualitative sampling, while maintaining reflexive attention to positionality and power.

The empirical chapters build on this foundation. Chapter Four examines quantitative patterns of differential access across intersecting social positions. Chapter Five analyses the mechanisms through which these inequalities are produced and sustained. Chapter Six explores how marginalised farmers experience, navigate, and sometimes resist structural constraints. Chapter Seven synthesises the findings, develops theoretical contributions, and considers policy implications. Across these chapters, surveys document patterned inequality, ethnography explains how it works in practice, visual data reveal embodied dimensions, and their integration produces insights that no single method could generate.

4 Chapter Four: Irrigation as Bundled Access: Land, Infrastructure, and the Uneven Politics of Groundwater

4.1 Introduction

I spent ten months with farmers, women and men, migrants and returnees, landowners and tenants, some working in fixed arrangements, others navigating shifting constellations of ownership and rent, across multiple parcels. These farmers worked their fields with a variety of electric pumps, diesel motors, rented tubewells, or none of these at all. As my fieldwork drew to a close, one question lingered with unexpected clarity, a question that had formed over hundreds of conversations, and which crystallised as I packed my bags to return to Australia:

> *'What does it mean to need water to grow, to sense it just below your land, yet still be unable to reach it?'*

One tenant farmer's words stayed with me:

> *'I can see water just beneath my feet, but I cannot always reach it. I need land, electricity, and money for the motor. Even with all that, I still need to know someone in the office if I want help. For a small farmer like me, every drop of (ground)water comes with its own fight*.' *(Field interview, Saptari, December 2023)*

This reflection captures a core theme of this chapter: access to groundwater is never simply about the presence of infrastructure or natural resources. It is shaped by farmers' positions within unequal structures of land tenure, social networks, caste hierarchies, bureaucratic systems, and gendered labour relations. Irrigation, in this context, must be understood as both a material and social process, technically mediated, but socially constructed.

This chapter begins with this grounded insight to question the assumption that irrigation access is primarily a matter of infrastructure and technology. While engineering and policy frameworks focus on groundwater depletion, pump efficiency, or irrigation coverage (particularly in the context of climate change), farmers' everyday encounters with groundwater are embedded in layered social, technological, and institutional systems. What is at stake is not just the presence or absence of a tubewell or pump, but the accumulation of multiple prerequisites for water access: secure land tenure; capital for machines; connections to bureaucratic offices; and the ability to navigate caste and gender norms.

I refer to these intersecting constraints as *bundled architecture of access*, the layered conditions through which irrigation infrastructure is made usable or inaccessible. Technologies such as electric pumps, meters, and tubewells are not neutral tools; they are political devices embedded in structures of land control, subsidy eligibility, and bureaucratic recognition. Drawing on insights from political ecology and STS (Bijker, 1995; Mollinga, 1998), I argue that irrigation access is co-produced through both material and social orders.

Using a mixed-methods approach, household survey data (N=401), regression analysis, interviews, and video case studies, this chapter shows that landholding size strongly predicts access to formal irrigation infrastructure. However, it also reveals the strategies employed by those excluded: borrowing pumps; relying on remittance income; switching between diesel and electric technologies; or navigating informal networks.

Groundwater access, then, is not just about infrastructure – it is about who can assemble the necessary conditions for access: land; a tubewell; a pump; electricity; and a meter. It is also about who is seen and supported within the context, and who is not. This chapter explores these layered dynamics by combining statistics with stories, and offers a grounded account of how groundwater access is produced at the intersection of infrastructure, identity, and inequality. It asks not just how water flows, but whom it flows for, and at what cost.

4.2 Context of the Study Area

This study draws on empirical research conducted in Wards 2 and 4 of Shambhunath Municipality, located in Saptari District, Nepal. A total of 401 farming households, 201 from Ward 2 and 200 from Ward 4, were selected through a stratified random sampling approach, designed to capture the differentiated agricultural arrangements and social positions that shape resource access, particularly in relation to land, tubewells, pumps, and electric meter connections.

The demographic profile of the study households reflects the layered and complex social terrain through which irrigation technologies must circulate. Gender, caste, and class intersect in structuring both access to and control over irrigation infrastructure. A striking 86.28% of the surveyed households are male headed, a figure that points to deeply entrenched patriarchal norms embedded in the social make-up of the study area, with far-reaching implications for the gendered dynamics of technology adoption.

Patterns of educational attainment further illuminate the structural inequalities within the study population. Over one-third of household heads (37.66%) are illiterate, while only 4.99% have attained education beyond the secondary level. Such educational stratification is not merely a backdrop but an active factor shaping households' capacities to navigate information about irrigation technologies, subsidies, and market opportunities.

The ethno-social composition of the sample reveals historically embedded structures of caste and ethnicity that continue to shape contemporary agricultural practices. Chaudhari households constitute 42.39% of the sample, followed by Terai Dalit households at 25.44%. Muslim households make up 10.97%, with the remaining 21.20% comprising a range of other caste and ethnic groups. In this analysis, Dalit and non-Dalit caste groups (other caste groups) have been categorised separately, as the subsequent sections will draw on this distinction to examine how marginalised caste groups differ from others in their access to land and water resources. These categories, far from being inert social labels, have concrete material consequences for land access, credit relations, and the uptake of irrigation technologies.

Migration emerges as a critical livelihood strategy, adopted by 46.63% of households. Among them, internal migration within Nepal accounts for 46.01% of cases, while a slightly larger proportion (53.99%) involves migration to foreign countries. Migration patterns are not uniform across the two Wards: internal migration is more prevalent in Ward 4 (60.15%) than in Ward 2 (31.54%), whereas international migration is more common in Ward 2 (68.46%) than in Ward 4 (39.85%). These patterns suggest differentiated access to mobility pathways, with implications for labour availability, remittance economies, and investment in agricultural infrastructures.

Groundwater dependence is widespread among study households, with approximately 72% relying on it as their primary irrigation source, largely because no functional surface-water irrigation system operates in the study area. Of these groundwater-dependent households, approximately two thirds have direct access to a tubewell on their own or rented land. The remaining third depend on water purchased or borrowed from neighbours, a pattern that signals significant gaps in access to fixed groundwater infrastructure. The survey item captures self-reported groundwater dependence and does not distinguish between direct tubewell extraction and access mediated through informal water markets. Similarly, tubewell ownership (51%) and pump ownership appear in the analysis as distinct conditions of technology access, since the two technologies are frequently decoupled in the study

villages: a household may own a tubewell but rent pump access by the hour, or own a pump but access water through a shared tubewell.

Ownership patterns of irrigation technologies further reflect stratified access. Electric pumps are owned by 57.86% of households, yet only 20.20% have secured access to a subsidised electric meter, despite 44.89% being aware of such support provisions. This gap between awareness and access signals important barriers – bureaucratic, financial, and social – that mediate the uptake of infrastructural entitlements (discussed in Chapter Six).

Land ownership remains widespread (81.05%), yet the small size of landholdings often necessitates renting additional agricultural land: 44.89% of households rent additional land to sustain their farming activities. Here, ownership does not necessarily translate into agricultural security or autonomy. While 81.05% of households report owning agricultural land, shown in Table 3, a figure that might initially suggest widespread land access, closer examination reveals significant stratification in landholding sizes. Nearly half (46.15%) of landholding households possess less than 0.5 hectare, with an additional 21.54% owning between 0.5 and 1.0 hectare. Cumulatively, 67.96% of land-owning households cultivate plots of less than 1 hectare, firmly establishing the dominance of small-scale agriculture in the study area.

This prevalence of marginal landholdings has profound implications for technological adoption pathways. As Ribot and Peluso (2003) observe in their theory of access, the ability to benefit from resources depends not only on rights (to land, already marginal) but on the bundles of powers available to different actors. Here, limited landholding size represents a significant structural constraint on farmers' capacity to invest in permanent irrigation infrastructure, an example of what Bernstein (2010) terms the reproduction squeeze facing smallholder agriculture in contexts of increasing resource pressure.

This analytical focus on barriers to technology access rests on a prior assumption worth making explicit the research treats technology uptake as broadly desirable for the households that currently cannot access it, and non-access as structural constraint rather than a choice. For most households in this sample, the qualitative evidence in Chapter Five confirms this assumption holds, marginal and tenant farmers actively want reliable irrigation access and have made real efforts to obtain it. For some households with diversified remittance income and lower agricultural dependence, however, lower technology investment may reflect a deliberate portfolio decision, a rational calculation that returns

to irrigation investment are insufficient given available alternatives (Edgerton, 2007; Glover et al., 2019). The structural analysis that follows treats this range of aspiration as part of the lived complexity the data captures, while holding the barriers facing those who do not access as its primary analytical focus.

Comparisons between the two study Wards reveal further layers of differentiation. Diesel and petrol pump ownership remains marginal overall, but is notably higher in Ward 4 (7.48%) than in Ward 2 (1.0%). In contrast, electric meter registration is significantly more common in Ward 2 (62.96%) than in Ward 4 (37.04%), suggesting possible variations in access to electrification infrastructure and subsidy mechanisms between the Wards. In the chapters that follow, I present analyses primarily based on aggregated data from the overall study area, while attending to key intra-Ward differences that illuminate broader patterns of irrigation technology adoption among marginal and tenant farmers.

In the sections to come, I discuss that technological access is not merely a function of market availability or individual choice but is fundamentally embedded within socio-spatial configurations of land ownership, tenure security, and property fragmentation. The findings contribute to the scholarly understanding of how technological adoption in agrarian settings is mediated through complex political-economic structures, rather than through neutral diffusion processes (Bijker et al., 2012; Mollinga, 2014). The survey data reveal a pattern of land distribution that is characteristic of agrarian systems, and qualitative data show experiences of increasing fragmentation and intensification pressures.

Table 3 Demographic Characteristics of Ward 2 and Ward 4 of Shambhunath Municipality, Saptari, Nepal

Indicators	**Ward 2 (N)**	**Ward 2 (%)**	**Ward 4 (N)**	**Ward 4 (%)**	**Total (N)**	**Total (%)**
Total Households (N)	201	50.12%	200	49.88%	401	100
Household head						
Male	168	83.58%	178	89.00%	346	86.28%
Female	33	16.42%	22	11.00%	55	13.72%
Education						
Illiterate	71	35.32%	80	40.00%	151	37.66%
Primary	99	49.25%	61	30.50%	160	39.90%
SLC (School Leaving Certificate)[12]	23	11.44%	47	23.50%	70	17.46%

[12] The School Leaving Certificate (SLC) in Nepal is the national examination taken at the end of Grade 10 and marks the completion of secondary schooling.

Indicators	Ward 2 (N)	Ward 2 (%)	Ward 4 (N)	Ward 4 (%)	Total (N)	Total (%)
Higher education	8	3.98%	12	6.00%	20	4.99%
Other caste groups						
Chaudhary	80	39.80%	90	45.00%	170	42.39%
Muslim	44	21.89%		0.00%	44	10.97%
Hill Vaisya	22	10.95%		0.00%	22	5.49%
Sah	9	4.48%	27	13.50%	36	8.98%
Hill Chhetri	3	1.49%	2	1.00%	5	1.25%
Yadav	2	1.00%	2	1.00%	4	1.00%
Baniya	1	0.50%	2	1.00%	3	0.75%
Terai Chhetri	1	0.50%		0.00%	1	0.25%
Bhagat	0		6	3.00%	6	1.50%
Thakur	0		2	1.00%	2	0.50%
Tharu	0		2	1.00%	2	0.50%
Dalit caste groups						
Hill Dalit	4	1.99%	0		4	1.00%
Terai Dalit	35	17.41%	67	33.50%	102	25.44%
Migration households	99	49.25%	88	44.00%	187	46.63%
Migrated individuals	130	49.43%	133	50.57%	263	65.59%
In-migration	41	31.54%	80	60.15%	121	46.01%
Out-country migration	89	68.46%	53	39.85%	142	53.99%
Irrigation source						
Groundwater	143	71.14%	147	73.50%	290	72.32%
Canal water	0		1	0.50%	1	0.25%
River water	9	4.48%	35	17.50%	44	10.97%
Pond water	13	6.47%	8	4.00%	21	5.24%
Irrigation technology						
Tubewell owners	102	50.75%	102	51.00%	204	50.87%
Diesel/petrol pump owners	2	1.00%	28	14.00%	30	7.48%
Electric pump owners	121	60.20%	111	55.50%	232	57.86%
Solar pump owners	0		0		0	0.00%
Electric subsidy awareness	98	48.76%	82	41.00%	180	44.89%
Electric meter registration	51	52.04%	30	36.59%	81	20.20%
Land owned	161	80.10%	164	82.00%	325	81.05%
Land rented in	101	50.25%	79	39.50%	180	44.89%
Land rented out	10	4.98%	42	21.00%	52	12.97%

4.2.1 Seasonal Cropping Patterns in Study Sites

The seasonal crop data from Wards 2 and 4 of Shambhunath Municipality reveal interesting patterns in crop distribution across seasons. In the monsoon season, the predominant crop is paddy (rice), cultivated by the vast majority of households (farmers' engagement depicted in Figure 3, Figure 4, Figure 5 and Figure 6). It accounts for 94.9% of all crops grown during this season, highlighting its critical role in the local agricultural landscape. Paddy cultivation is almost universal during the monsoon, underscoring its significance as a staple crop during this time. Aside from paddy, the cultivation of green leafy vegetables (1.5%), millet (0.5%), and other vegetables (3.8%) is limited but still noteworthy, representing a small yet diverse portion of the crop profile. These crops are cultivated by fewer households, indicating their secondary importance during the monsoon season compared to paddy. In contrast, the winter season presents a more diversified cropping pattern (as seen in Figure 7).

The main crop in winter is wheat, cultivated by 63.0% of households, making it the most widely grown winter crop. This is followed by potatoes (36.5%) and mustard (33.2%), with other vegetables grown by 21.0% of households. Despite the diversity, paddy is rarely cultivated in winter, with only 12.9% of households growing it. This marks a shift from the monsoon season, where paddy was nearly universal. Winter cropping is more varied, and crops such as mustard and wheat reflect farmers' adaptability to the cooler, drier conditions of the season.

The summer season shows a decrease in both the number and percentage of households engaged in crop cultivation, compared to the monsoon and winter seasons. In summer, green leafy vegetables, maize, and other vegetables are the main crops, with 51.6% of the total crops being other vegetables. Green leafy vegetables and maize account for 22.6% of the summer crops. Paddy cultivation is much less common in summer, with only 12.9% of households growing it. The lower number of households engaged in summer cropping suggests that it is more selective, possibly due to higher temperatures, water scarcity, or other factors that limit crop growth during this period.

In addition to seasonal crops, mango is an important annual crop cultivated by a smaller but significant number of households. With 92 households (6.6% of the total) reporting mango cultivation, it represents a niche fruit but is important to those engaged in its production. Given that mangoes are a perennial crop, they provide additional income and food security for farmers, supplementing their seasonal crop yields.

Overall, the seasonal crop patterns indicate that paddy is the dominant crop during the monsoon. At the same time, the winter season features a more varied cropping pattern, with a strong presence of potato, wheat and mustard. The summer season, in contrast, sees a significant decrease in cropping intensity, with fewer households engaged in crop production. The shift from a predominance of paddy to a more diverse crop mix in winter, and a reduction in summer cropping, highlights the influence of seasonal farming practices in the region. Additionally, mango cultivation, as a perennial crop, offers farmers an opportunity to diversify their agricultural portfolio and generate year-round income.

Table 4 Seasonal Crop Table in Ward 2 and Ward 4 of Shambhunath Municipality – Monsoon Among Households (hhs[13])

Crop Type	Main Crop (hhs)	Second Main Crop (hhs)	Third Main Crop (hhs)	Counts (hhs)	% of Total	Cumulative %
Paddy	374	13	–	387	94.9%	94.9%
Green leafy vegetables	1	4	1	6	1.5%	96.4%
Millet	1	–	1	2	0.5%	96.9%
Other vegetables	3	10	2	15	3.8%	100.0%

Table 5 Seasonal Crop Table in Ward 2 and Ward 4 of Shambhunath Municipality – Winter Among Households (hhs)

Crop Type	Main Crop (hhs)	Second Main Crop (hhs)	Third Main Crop (hhs)	Counts (hhs)	% of Total	Cumulative %
Wheat	230	9	6	245	63.0%	63.0%
Mustard	44	64	18	126	33.2%	96.2%
Other vegetables	26	23	31	80	21.0%	79.1%
Potato	28	66	46	140	36.5%	100.0%

Figure 3 Aerial View of Saptari District During the Monsoon Season, 2023

Figure 4 Farmers Ploughing Fields and Transplanting Paddy during Land Preparation

[13] Tables here and in the following sections describe overall patterns across the study area, unless otherwise stated, rather than Ward-level comparisons.

Figure 5 A Farmer Weeding Her Paddy Field Amidst the Rain

Figure 6 A Family Working Together to Weed Their Paddy Field

Table 6 Seasonal Crop Table in Ward 2 and Ward 4 of Shambhunath Municipality – Summer Among Households

Crop Type	**Main Crop (hhs)**	**Second Main Crop (hhs)**	**Third Main Crop (hhs)**	**Counts (hhs)**	**% of Total**	**Cumulative %**
Green leafy vegetables	3	3	1	7	22.6%	22.6%
Maize	6	1	–	7	22.6%	45.2%
Other vegetables	12	3	1	16	51.6%	96.8%
Paddy	4	–	–	4	12.9%	100.0%

Table 7 Perennial Crop - Mango in Ward 2 and Ward 4 of Shambhunath Municipality

Crop Type	**Counts**	**% of Total**
Mango	92	6.6%

Some farmers reported that they have begun cultivating mangoes in response to increasingly uncertain rainfall patterns and rising irrigation costs. For these farmers, mango represents a relatively low-risk crop that offers the potential for stable agricultural income with minimal labour, irrigation, and input requirements (e.g. Figure 8). Farmers explained that while young mango trees require irrigation during the first year to establish, they typically do not irrigate the trees in subsequent years.

However, I also found that this shift toward mango cultivation is not uniformly accessible to all farmers. Several marginal and tenant farmers, particularly those renting land or working on tiny plots, reported being unable to make such transitions due to limited or insecure land access. Importantly, farmers had not entirely replaced seasonal or annual crops with mango; instead, they had integrated mango trees into part of their land as a strategy to diversify income and hedge against agricultural risks compared to labour- and input-intensive crops like paddy or vegetables.

Figure 7 Ward 4 Farms in The Winter Season, A Stark Contrast to the Luscious Green Fields of The Monsoon Season

Figure 8 A Paddy Field Interplanted with Young Mango Trees, as Some Farmers Adapt to Uncertain Rainfall and Irrigation Challenges by Diversifying Income with Mango Cultivatio

4.3 Irrigation Technologies as Socio-Technical Assemblages

The irrigation landscape in the study area comprises diverse technologies with differential accessibility profiles. Rather than viewing these technologies as neutral tools, they are better understood as what Bijker (1995) calls socio-technical ensembles, material artefacts embedded within specific social arrangements that govern their distribution, use, and benefits. Tubewells, electric pumps, diesel pumps, and electric meters (which, I argue, bundle with land to form a technological complex, from tubewells to pumps to subsidised meters in the case of electric pumps) constitute a technological complex in which accessibility is stratified according to existing land relations and social hierarchies.

Tubewells, permanent structures requiring significant capital investment, physically inscribe land rights into the landscape. By contrast, electric and diesel pumps represent more mobile forms of technology (*although they can be permanently set up, farmers in the study area typically do not).* Both electric and diesel pumps are typically installed temporarily and removed after use to mitigate theft risk in a context where equipment security remains problematic. Electric meters occupy an intermediate position: usually as fixed installations but occasionally relocated between plots depending on cultivation patterns and seasonal water requirements. This varied materiality of irrigation technologies creates what Jessop et al. (2008) call socio-spatial selectivity: differential accessibility based on users' positioning within property regimes.

Table 8 presents such a comprehensive typology of access modalities that I observed in the study area for various irrigation technologies, demonstrating the complex arrangements through which farmers negotiate technological access beyond simple ownership. This typology illustrates the diverse means through which actors gain, control, and maintain access to resources despite formal property constraints (Ribot & Peluso, 2003).

The typology reveals how farmers develop adaptive strategies to navigate technological access despite property constraints. In addition to direct ownership, farmers engage in borrowing, renting, and combinatorial arrangements that constitute bricolage, a creative adaptation of access mechanisms to overcome structural limitations (*not in institutional rules but the way farmers access water and land privately at the household level, in this chapter*) (Cleaver & Hamada, 2010; Mirhanoğlu et al., 2023). These arrangements illustrate how technological access operates through social networks and negotiated arrangements rather than solely through market transactions or formal property rights.

Table 8 Modes of Access to Irrigation Technologies

Category	**Infrastructure/Resource Access Type**	**Access Details**
Land	Owned	The farmer owns the land outright.
	Leased	Land is rented for agricultural purposes through sharecropping (*batiya*) or fixed (*thekka*) rental arrangements.
	Mankhab[14]	Access to land is granted temporarily through loaned capital (e.g., neighbour's land).
	Combination	Farmer operates on a mix of owned, leased, and/or loan interest land (*Mankhab*) due to operational needs.
Tubewell	Owned Land	A tubewell built or operated on privately owned land.
	Leased Land	A tubewell is set up on rented/leased farmland by landowners or tenant farmers.
	Borrowed	Tubewell shared temporarily with permission (e.g., from a neighbour's land).
	Combination	Farmers access tubewells in a combination of modalities across different land parcels, with and without tubewells.
Electric Pump	Owned	The farmer owns the electric pump.
	Rented	The farmer rents the electric pump for use.
	Borrowed	An electric pump has been temporarily borrowed from others.
	Combination	Farmers use a combination of pumps depending on their access to other farmers.
Diesel Pump	Owned	The farmer owns the diesel pump and operates it independently.

[14]Mankhab refers to a local land-leasing arrangement in which the cultivator lends money to the landowner and is permitted to cultivate the land until the loan is repaid, with land use serving as interest on the loan.

Category	Infrastructure/Resource Access Type	Access Details
	Rented (with Labour)	Diesel pump and operator's service are rented; charges include labour, pump use, delivery pipes, and diesel fuel costs.
	Combination	Farmers use a combination of electric and diesel pumps based on situational needs, especially when one type of pump is unavailable or unsuitable.
Electric Meter	Owned & Registered	The farmer has an official electric meter registered in their name (shown in **Error! Reference source not found.**).
	Rented	Meter connection is rented from the provider, along with any additional fees.
	Borrowed	A farmer temporarily accesses electricity via someone else's connection.
Delivery Pipes	Owned	The farmer owns the irrigation pipes in full.
	Rented	Pipes are rented in combination with a diesel pump via the diesel renter; charges are typically per hour for diesel irrigation services.
	Borrowed	Pipes are temporarily borrowed, requiring no immediate cost.
	Owned + Borrowed	Farmers may use a combination of owned and borrowed pipes to complete large irrigation setups.

Figure 9 A Pump House Near a Farm, Constructed with Support from the ACIAR IWMI Research Project

Figure 10 Farmers, After Setting an Electric Pump for Irrigation, with an Electric Meter Mounted on a Wooden Pole

4.4 Economic Dimensions of Technological Selection

The cost structure of these technologies creates a field of technological positioning in which economic capital significantly determines which technologies are accessible to different categories of farmers (Bourdieu, 2002). Table 9 presents the economic parameters of various irrigation technologies, highlighting the material constraints that shape technological choice and accessibility.

Electric pumps emerge as the dominant technology in the study area, with their relative affordability (NPR 8,000-15,000[15]). Moreover, ease of use makes them the preferred choice over alternatives, as detailed in the upcoming section. There is price variation across technologies by procurement location, showing how geographic positioning further influences technological access in different markets: farmers choose larger markets near southern Indian borders. In comparison, farmers restricted to smaller local markets face less favourable prices.

The subsidised electricity rate of NPR 2.50 per unit for agricultural purposes theoretically enhances the accessibility of electric pump systems. However, this subsidy mechanism operates through institutional pathways that privilege land-owning farmers while systematically disadvantaging landless and tenant farmers, a pattern in which state resources are channelled through pre-existing structures of social power (Boelens, 2014). The requirement for land documentation in order to access subsidised electricity connections exemplifies access control; that is, the ability of certain actors to mediate others' access to resources through institutional gatekeeping (*described at length in Chapter Six*).

Diesel pumps present an alternative technological pathway with distinct advantages and constraints. Their independence from electrical infrastructure makes them viable in areas lacking grid connectivity. However, their substantial operational costs (NPR 159 per Liter for fuel) create ongoing financial burdens that disproportionately impact resource-constrained farmers. This trade-off shapes technological decision-making among the poor, with the complex weighing of immediate accessibility against the cost-intensive use of diesel pumps.

The case of solar pumps demonstrates how cutting-edge sustainable technologies can remain inaccessible despite apparent policy support (Bassi, 2018). Solar-powered irrigation has been embedded in Nepal's alternative energy plans and, as of 2024, the country has installed about 2,000 subsidised solar irrigation pumps (Chand et al., 2024; Kafle et al., 2024). Despite subsidies covering up to 60% of costs (Shrestha & Uprety, 2021), the substantial initial investment (*approximately NPR 400,000 contingent upon the size of the solar pump; the reference to this cost is taken from a solar panel installed through government support at Ward 4, which is not functional at present*) places these systems beyond the reach of virtually all farmers in the study area. The five defunct systems observed (*three in Ward 2, two in Ward 4, through support from government and non-government agencies not*

[15] 1 USD = NPR 136.46 in 2025.

reflected in the survey) stand as material testament to the gap between policy and practice in development interventions where well-intentioned irrigation and sustainability initiatives fail to account for the realities of their intended farmers (Li, 2007; Nightingale, 2017).

As one farmer articulated:

> *'Even with the subsidy, we could not afford the solar pumps; they are just too expensive to install, and no one is using them now.' (Field interview, Saptari, August 2023)*

This statement encapsulates the disjuncture between technological potential and socio-economic reality that characterises many rural development interventions (*discussed in detail in Chapter Six*).

The accessibility of irrigation technologies is further structured by institutional arrangements that mediate between farmers and state resources (Bhattarai et al., 2025). The subsidy system for electric pumps is administered through a network of local offices (*the Ward offices, Groundwater Resource Development Board Office [GWRDB] in Lahan; Agriculture Knowledge Centre [AKC] in Rajbiraj; and the Prime Minister Agriculture Modernization Project [PMAMP] office in Kadma, as discussed in Chapter Six*).

For landless and tenant farmers, these institutional encounters frequently result in exclusion due to documentation requirements that presuppose land relations (*again discussed in detail in Chapter Six*). The requirement for land ownership certificates or formal rental agreements systematically disadvantages those operating under informal tenure arrangements, a pattern that illustrates how state bureaucracies, despite formal neutrality, frequently reproduce existing social hierarchies through apparently technical administrative requirements (Ferguson, 1990; Li, 2007; Sugden et al., 2021).

Documentation exclusion is one of several mechanisms shaping who can and cannot access irrigation technology. Understanding differential technology access requires documenting the empirical pathways through which households actually obtain or fail to obtain access. The field data reveal six distinct routes: outright purchase using households savings or remittance income, concentrated among medium and larger landowners; informal credit at high interest rates from local money-lenders, available to some smallholders with social connections; formal government subsidies, restricted to those with formal documentation, bureaucratic literacy, and political connections at the municipality or district level; second-hand acquisition and inherited equipment, particularly relevant for diesel pumps which circulate through networks of kind and neighbours; group-based ownership through

NGO or project facilitation, documented in Chapters Six and Seven; and water purchase from better-equipped neighbours, the dominant modality for tenant and landless households, with prices shaped by social power and seasonal scarcity rather than competitive market dynamics (Brown et al., 2021; Thapa et al., 2023).

The installation of electric meters, crucial for accessing subsidised electricity rates, requires both financial investment (approx. NPR 5,000) and navigating bureaucratic procedures predicated on formal land documentation. This dual barrier exemplifies institutional exclusion, discussed by Kabeer (2000) – the systematic marginalisation of certain groups through apparently neutral institutional practices that presuppose resources or capabilities unequally distributed in society.

Table 9 Local Rental Characteristics and Payment Arrangements by Irrigation Technologies

Technology Type	**Cost (NPR)**	**Operation Unit**	**Unit Price (NPR)**	**Local Rental Payment (Farmer-reported)**	**Subsidy**
Tubewell	NPR 15,000 and up, depending on depth	Upfront cost	18,000 for 55 feet	No cost	Yes
Electric Pump	8,000 to 15,000	Per unit	15 non-subsidised	Yes	Yes
Electric Meter	5,000	Per unit	2.50	20 to 22 per unit	Yes
Diesel Pump	Around 15,000	Per Liter	159	250-300	Yes
Solar Pump	Around 400,000 depending on cost	Upfront cost	No operational cost	NA	Yes

Note: All values are based on farmers' accounts of locally prevailing payment and rental arrangements for irrigation technologies, including the ways costs are charged and recovered in practice (for example, per unit of electricity, per litre of diesel, or per irrigation event), rather than standardised operating costs per unit of water.

4.5 Technological Access Across the Tenure Divide: Empirical Evidence

The distribution of irrigation technologies across varied land tenure arrangements reveals profound disparities in access. Drawing on both quantitative survey data and farmers' narratives, I discuss how access to irrigation technology is systematically patterned by land relations, creating a structural geometry of access that privileges certain actors while constraining others (Ribot & Peluso, 2003). These patterns reflect how technologies are embedded within fields of power, creating social spaces where resource access is negotiated through multiple, intersecting forms of capital (Bourdieu, 2002).

Table 10 provides compelling evidence of how landholding size fundamentally structures technological access among land-owning households. For farmers with the smallest holdings (less than 0.2 hectares), technology adoption remains strikingly modest, with only 23.7%-28.9% owning

tubewells or electric pumps, respectively. This pattern illustrates the concept of material thresholds in technological adoption: minimum resource requirements that exclude those with insufficient capital, as observed in India and Nepal (Misquitta & Birkenholtz, 2021; Kafle et al., 2022). The minimal access to electric meters at this scale (only 18.4%) demonstrates how institutional barriers compound economic constraints for marginal landholders, reflecting what Ferguson (1990) identifies as the anti-politics of development, seemingly neutral bureaucratic requirements that systematically exclude marginalised groups.

As landholding size increases beyond 0.2 hectares, a dramatic threshold effect emerges. Ownership rates for both tubewells and electric pumps rise sharply to 60% for households with 0.2-0.5 hectares, while electric meter access increases proportionally. This escalation exemplifies political ecologists bringing to light the accumulation by technological advantage (Robbins, 2012), the process by which those with greater resource endowments can more readily capitalise on technological innovations, further widening resource disparities. The near-universal adoption (90% to 100%) of irrigation technology among the largest landholders (above 2 hectares) hints at the peak of the technology divide, the reinforcement of socio-economic stratification through ostensibly neutral technological systems.

Table 10 Irrigation Technology Ownership and Electric Meter Access by Landholding Size

Owned Landholding Size[16] (*kattha*[17])	**Frequency of households (hh)) in the category**	**Own Tubewell (n, %)**	**Own Diesel Pump (n, %)**	**Own Electric Pump (n, %)**	**Electric Meter Access (n, %)**
< 0.1 ha (≈3 *kattha*)	15	4 (26.7%)	0 (0.0%)	4 (26.7%)	1 (6.7%)
0.1–0.2 ha (≈ 3–6 *kattha*)	38	9 (23.7%)	2 (5.3%)	11 (28.9%)	7 (18.4%)
0.2–0.5 ha (≈ 6–15 *kattha*)	97	58 (59.8%)	8 (8.2%)	64 (66.0%)	17 (17.5%)
0.5–1 ha (≈ 15–30 *kattha*)	92	60 (65.2%)	7 (7.6%)	63 (68.5%)	23 (25.0%)
1–2 ha (≈ 30–60 *kattha*)	70	59 (84.3%)	10 (14.3%)	61 (87.1%)	18 (25.7%)

[16] I have used the land size range based on Nepal's AKC's land categorization. Only land size categories recorded in the survey are presented.

[17] 1 *Nepali kattha = 0.0338 hectare (ha);* Nepali kattha is different from Indian katha, where *1 katha = 0.012* hectare. Bigha is the larger unit: 1 Bigha equals 20 *kattha (about 0.677 hectares).* The categories of land size used here follow the categorization of the AKC in Rajbiraj (a government body) for land size data collection and reporting in Madhesh province. The symbol ≈ refers to 'around'.

Owned Landholding Size[16] (*kattha*[17])	**Frequency of households (hh)) in the category**	**Own Tubewell (n, %)**	**Own Diesel Pump (n, %)**	**Own Electric Pump (n, %)**	**Electric Meter Access (n, %)**
2–4 ha (≈ 60–120 *kattha*)	11	10 (90.9%)	1 (9.1%)	10 (90.9%)	4 (36.4%)
5–10 ha (≈ 150–300 *kattha*)	1	1 (100.0%)	0 (0.0%)	1 (100.0%)	0 (0.0%)
>10 ha (>300 *kattha*)	1	1 (100.0%)	1 (100.0%)	1 (100.0%)	0 (0.0%)
Total	325	202 (62.2%)	29 (8.9%)	215 (66.2%)	70 (21.5%)

Beyond mere size, the spatial configuration of landholdings creates additional barriers to technological adoption. Many households in the study area operate multiple non-contiguous plots of land, creating fragmented farmland that complicates tubewell construction. Unlike contiguous holdings, fragmented plots multiply the capital and logistical requirements for irrigation infrastructure, a burden particularly acute for resource-constrained smallholders.

The experience of a female farmer from Ward 2 explains this challenge with remarkable clarity:

> *'It gets expensive to irrigate all plots... the tubewell is constructed on the land parcel near my house. We farm paddy during the monsoon season on the plot that is far, and during other seasons, we leave it fallow. It gets expensive. How can we invest in all the land?' (Field interview, Saptari, December 2023)*

Her narrative exemplifies the adjustments farmers make in response to resource-constraining circumstances. By concentrating irrigation investments on plots near her residence, she strategically allocates scarce labour and capital to those parcels where the expected returns are greatest, and management costs are the lowest. This represents a pragmatic adaptation to spatial and material constraints rather than a failure of access (van der Ploeg, 2008).

4.6 Tenancy and Technological Marginalisation

In the preceding sections, I have explored farmers' access to irrigation technologies, particularly within the context of land ownership. However, a further layer of complexity arises when examining the accessibility of these technologies on rented land. The disparities in technological access between tenants and landholding farmers illustrate how land tenure shapes access to groundwater. As shown

in Table 10, only 13.0% of rented agricultural plots in the sample were equipped with tubewells, compared with 62.2% of landowning households that reported access to tubewell irrigation on at least part of their owned land. While this is not a direct plot-level comparison, the contrast highlights a pronounced disparity in the ability to secure long-term irrigation infrastructure. This pattern reflects both the investment disincentive associated with tenure insecurity (Besley, 1995) and the limited authority of tenants to undertake permanent land improvements. In practice, tenants' capacity to install tubewells is constrained not only by uncertainty over continued land access, but also by landlords' control over major land-use decisions, even where such investments might otherwise be economically viable.

Table 11 Distribution of Tubewell Adoption by Land Rental Status

Tubewell on rented land	**Counts**	**% of Total**
No	349	87.0%
Yes	52	13.0%

In Table 12, I further disaggregate technology access among tenant farmers by plot size, revealing a pattern of technology concentration in medium-sized rentals (0.2 to 1.0 hectare). Even at these more viable scales, technological adoption remains significantly lower than on equivalently sized owned plots; 27.2% of tenants have tubewells compared to 62.2% of owners, with similar disparities for electric pumps (32.8% vs. 66.2%) and electric meters (11.7% vs. 21.5%). These systematic differences demonstrate socio-technical regimes (Mollinga, 1998), and stable configurations of technology, policy, markets, and farmer practices that privilege certain actors while marginalising others.

Table 12 Frequency of Access/Use by Land-rented Size

Land-rented Size Category	**Tubewell on Rented Land**	**Electric Pump Used**	**Diesel Pump Used**	**Electric Meter Access**
	Count (%)	Count (%)	Count (%)	Count (%)
< 0.1 ha (≈3 *kattha*)	2 (1.1%)	2 (1.1%)	0 (0.0%)	0 (0.0%)
0.1–0.2 ha (≈3–6 *kattha*)	8 (4.4%)	12 (6.7%)	1 (0.6%)	2 (1.1%)
0.2–0.5 ha (≈6–15 *kattha*)	24 (13.3%)	29 (16.1%)	15 (8.3%)	9 (5.0%)
0.5–1.0 ha (≈15–30 *kattha*)	13 (7.2%)	14 (7.8%)	8 (4.4%)	10 (5.6%)
1.0–2.0 ha (≈30–60 *kattha*)	2 (1.1%)	2 (1.1%)	0 (0.0%)	0 (0.0%)
Total	49 (27.2%)	59 (32.8%)	24 (13.3%)	21 (11.7%)

The differences in how tenants access irrigation technology provide deeper insight into the dynamics of their access. Instead of directly owning or installing irrigation infrastructure, tenant farmers

frequently establish networked arrangements of borrowing and renting, strategies that are shaped by the precarious nature of their land tenure. This flexible, relational, and uncertain form of access reveals the daily negotiations tenant farmers engage in, sometimes advantageous, at other times less so, highlighting the contextual reconfiguration of technologies to accommodate specific social circumstances. These adaptive strategies reflect the agency of tenant farmers within the structural constraints of their tenure status, but not for all tenant farmers. However, these strategies also point towards a significant disparity in technological capabilities, with tenant farmers facing limitations compared to their land-owning counterparts.

4.6.1 Rental Arrangements and Infrastructural Disincentives

Moreover, farmers' ability to access and adopt groundwater irrigation technologies is profoundly shaped by land tenure arrangements in the study area. Nearly 45% of households surveyed (180 out of 401) reported renting agricultural land, indicating a substantial proportion of cultivators operating without secure land ownership. The predominance of small rental plots (approx. 65% cultivate less than 0.5 hectares) creates limited ability for tenants to acquire capital and resources, due to treacherous tenure regimes that pose structural limitations on productive investment and constrain technological adoption.

Table 13 presents the overwhelmingly informal nature of tenancy, with only 0.5% of renters reporting any written agreement. This aligns with North's (1990) identification of informal contracting arrangements in which uncertainty about future rights, thereby weakening incentives for long term investment (Karn et al., 2021). Such arrangements create a fundamental tension between the long-term investments required for fixed infrastructure and the short-term nature of land use under insecure tenure. This temporal disconnect, driven by uncertain land rights, significantly impedes the adoption of irrigation technologies, as farmers are hesitant to invest in infrastructure without guaranteed, long-term access to the land.

The historical context of tenancy arrangements further illustrates how policy legacies shape contemporary technological possibilities. The reluctance to formalise leases stems from landowners' enduring wariness of Nepal's Land Reform Act of 1964, which, in theory, allowed tenants to claim partial ownership rights. Despite the law's limited practical impact (only about 1% of land was formally redistributed), it produced path dependence, the persistent influence of past institutional arrangements on current practices (Pierson, 2000). As one landowner in Ward 4 explained:

'If I give them a contract, tomorrow they will ask for half the land. Better to do it verbally.' (Field interview, Saptari, August 2023)

This statement reflects a strategic avoidance of formalising tenure security, as landowners perceive such practices as a threat to their formal claims over the land. Consequently, the prevailing informality, evidenced by the fact that 98.89% of rental arrangements lack written documentation, contributes to precarious, uncertain tenure structures. These informal arrangements perpetuate unequal risk distribution and continue to reinforce a feudal-like context in land relationships.

The three primary rental arrangements observed in the study area – sharecropping (*batiya*), fixed rental (*thekka*), and loan-based leasing (*mankhab*) – create distinct incentive structures for irrigation technological investment. In *batiya* arrangements, the normative expectation of shared costs rarely materialises in practice, as one tenant's experience shows:

'They [landowners] take half the crop but won't spend a single rupee on water or seeds. When we plant vegetables, they come to the farm and take a bagful without asking for it or paying.' (Field interview, Saptari, June 2023)

The deliberate informality and exploitation by landowners highlight opportunistic behaviours, especially when such practices deviate from the norm. This imbalance leads to what Marxian scholars describe as surplus extraction without reinvestment (Bernstein, 2010), a pattern that both hinders sustainable resource management and perpetuates agrarian inequality.

I observed that land with established irrigation infrastructure commands significantly higher rental rates in the study area, reflecting the capitalisation of infrastructure value into land prices. Water-accessible land is in high demand, and this pricing differential makes well-irrigated land increasingly inaccessible to marginal farmers, as verified by the experience of a Dalit woman in Ward 4:

'I used to rent land just five minutes away from my house, where I could use electric water. But now a big fish farm owner gave more money, and the landlord gave him everything. He has leased the land for 10 years in higher land rent. I can't compete.' (Field interview, Saptari, December 2023)

Her subsequent adaptation, or rather the only viable option available, is to walk over an hour to a non-irrigated plot where she cultivates paddy during the monsoon season, when water is relatively accessible. However, in the summer and winter seasons, she can only grow low-water-intensive crops, a limitation that contributes to her marginalisation. She added:

'I grow what I can without water, mostly allas tallas (flax seeds). It's not much, but I have no choice.' (Field interview, Saptari, December 2023)

This reflected how technological exclusion, through limited access to poor-quality land, directly limits livelihood options, leading to capability deprivation (Sen, 1999) and restricting the freedoms necessary to engage in agricultural activities.

Table 13 Land Rental Distribution, Tenure Type, and Landowner Contribution in Leased Land

Category	**Response Detail**	**Count**	**% of Total (n = 401)**
Households Renting-in Agricultural Land	Yes	180	44.9%
Size of Rented-in Land (Among Renters, n=180)	< 0.1 ha (≈ 3 *kattha*)	5	2.8%
	0.1–0.2 ha (≈ 3–6 *kattha*)	33	18.3%
	0.2–0.5 ha (≈ 6–15 *kattha*)	84	46.7%
	0.5–1.0 ha (≈ 15–30 *kattha*)	52	28.9%
	1.0–2.0 ha (≈ 30–60 *kattha*)	6	3.3%
Formal Tenancy Agreement (Among Renters)	Yes	2	0.5%
Landlord Contributions (Among Renters)	Irrigation Infrastructure	9	2.2%
	Fertilisers	10	2.5%
	Labour	3	0.7%
	Tractor	9	2.2%
	Other Inputs	0	0.0%

Building on the discussion of irrigation practices on rented land, it is important to consider how these technological and tenure dynamics manifest across agricultural seasons. The cultivation of land in the study area follows a clear seasonal pattern that, in turn, reflects both ecological rhythms and infrastructural constraints. During the monsoon season, when rainfall is abundant and irrigation needs are minimal, 90.4% of households report cultivating all available land. This period represents the highest level of land use intensity.

However, in the winter season, cultivation becomes increasingly contingent on technological access, particularly to groundwater sources. Only 46.8% of households cultivate all their land during this time, while 53.2% leave some land fallow. This shift signals the growing importance of irrigation technologies, which are unevenly accessible depending on land tenure, equipment ownership, and financial capacity. By summer, these constraints intensify further: only 25.8% of households cultivate all their land, while nearly 75.0% leave land fallow. This seasonal decline reflects not only diminishing water availability but also reduced labour (often due to migration), higher farming costs, and insecure returns on investment.

It would be insufficient to explain this seasonal contraction in cultivation purely through a technological lens. Instead, the decision to leave land uncultivated is shaped by a layered set of challenges, limited and uneven access to irrigation, insecure or temporary tenure arrangements, and the broader economic burdens of smallholder farming.

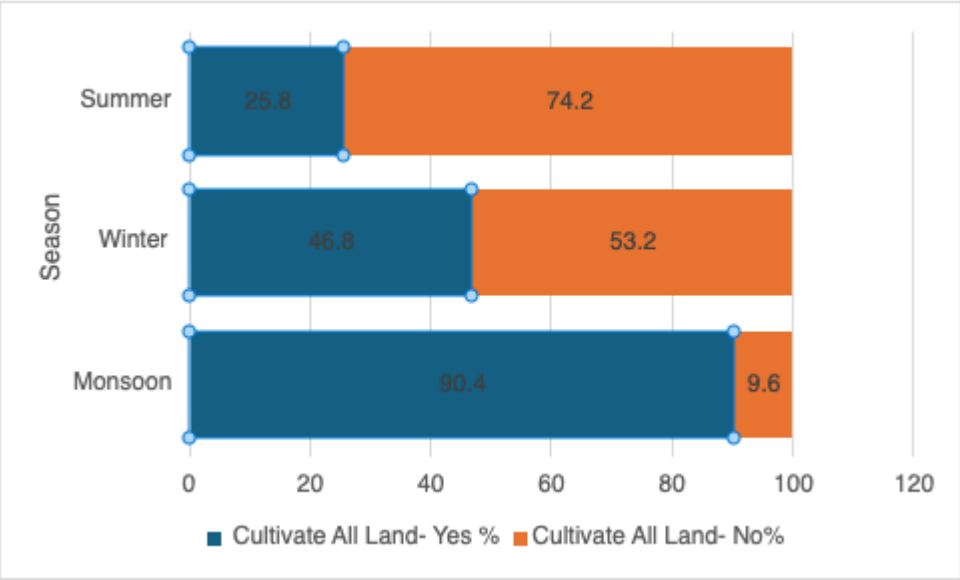

Figure 11 Seasonal Cultivation Patterns, Households Reporting Full vs. Partial Land Use (%)

These concerns are further compounded by widespread perceptions of climate change among the farming population. As Table 14 shows, two-thirds of respondents (66.3%) reported that rainfall has decreased over the past ten years, while only a quarter perceived an increase. A striking 94.1% of households noted that these changes have affected their irrigation needs, and 76.6% reported a shift in the timing and duration of rainfall events. This confirms that groundwater dependence is unfolding within a broader context of environmental uncertainty, where reliance on rainfall can no longer be assumed to offer reliable irrigation, even during the monsoon season. The declining rainfall predictability only heightens farmers' reliance on groundwater technologies and may, at the same time, exacerbate existing inequalities in access to them.

Table 14 Farmers' Perception of Changes in Rainfall Pattern Over the Last 10 Years and Impact on Irrigation

Category	**Response Type**	**% of Total**
Change in Rainfall Pattern	Increased	25.4
	No change	8.2
	Decreased	66.3
Impact on Irrigation Needs	Yes	94.1

Category	Response Type	% of Total
	Not sure	4.1
	No	1.8
Shift in Rainfall Timing/Duration	Yes	76.6
	Not sure	5.5
	No	18.0

4.6.2 Drawing Land Relations as Technological Gatekeepers

The empirical evidence presented in this section demonstrates that access to groundwater irrigation technologies in Shambhunath Municipality is fundamentally structured by land tenure arrangements, rather than by market availability or farmers' preferences alone. These findings challenge technocentric narratives by revealing how technologies operate not as neutral tools but as systems in which benefits flow through channels carved by existing resource inequalities.

The advantages conferred by secure landownership, including certainty of future access, eligibility for subsidies, and greater command over infrastructural investment, translate into technological privileges that reproduce existing agrarian hierarchies. Conversely, the vulnerabilities associated with tenancy, including informality, insecurity, and minimal landlord support, manifest as both diminished incentives and reduced practical capacity for technological adoption.

These findings indicate that, in the study area, groundwater governance and irrigation equity are shaped not only by financial and technical barriers but also by the underlying land tenure relationships that fundamentally structure farmers' access to technology. As groundwater becomes increasingly crucial for agricultural adaptation to climate variability, ensuring equitable access to irrigation technologies is no longer just a technical challenge but a core issue of agrarian justice (Nandigama et al., 2025).

4.7 Caste-Based Land Relations: Foundations of Agricultural Inequality

To further contextualise the dynamics of land and irrigation access, it is essential to examine the role of caste in shaping these relationships within the study area. The distribution of land resources across caste groups reveals deeply entrenched patterns of social stratification, which also significantly influence technological access. These caste-based land relations reflect enduring inequality, persistent disparities that are reproduced across generations through institutional mechanisms and social boundaries (Nightingale, 2011). As Mosse (2004) notes, such inequalities are not solely economic but

institutionalised systems of social closure that structure access to productive resources along generational lines.

Table 15 illustrates the distribution of land ownership across different caste groups, revealing significant disparities in land access and ownership within the sample. Among the surveyed households, the Chaudhary caste emerges as the dominant land-owning group, with 95% of its members owning land, predominantly in small (<0.5 ha) to medium-sized (1-2 ha) holdings. The Chaudhary group, comprising 170 households out of the total 401 households in the survey, exemplifies the concept of "accumulated history" as proposed by Bourdieu (2002), in which the legacies of historical privilege are embedded in contemporary resource distributions. The relatively larger landholdings owned by this group provide a foundation for agrarian dominance, conferring not only control over productive resources but also broader social and technological advantages (Lahiri-Dutt, 2014; Pattnaik & Lahiri-Dutt, 2022). This concentration of land ownership in the Chaudhary caste stresses the crucial role of land as a material asset that enhances access to agricultural technologies and opportunities for innovation.

In stark contrast, the Baniya, Bhagat, and Hill Chhetri caste group members possess only marginal landholdings, primarily below 0.1 hectare. Baniya households (3 in total), Bhagat households (6), and Hill Chhetri households (5) represent a small proportion of the respondents, yet their limited landholdings are indicative of the significant constraints they face. These constraints align with Sen's (2010) notion of entitlement failure, in which structural limitations on access to resources curtail individuals' or groups' capacity to enhance their well-being. These small landholdings, often inadequate for viable farming, face access barriers and systemic obstacles that hinder full participation in the everyday realities of food production and agricultural systems, and limit their potential to access technologies.

The Muslim, Sah, and remaining caste groups, with landholdings typically ranging from 0.2 to 0.5 hectares, occupy a more moderate position in terms of land ownership. With 44 Muslim households and 36 Sah households among the respondents, these groups represent a significant portion of the sample. Although they are better positioned than those with marginal or no land, their landholdings still reflect a vulnerable agricultural status. Their positioning necessitates supplementary income strategies, such as land rental, to produce food and engage in farming activities.

The Terai Dalit group represents an interesting case, as it combines limited land ownership with significant reliance on land rental markets. Among the 102 Terai Dalit households surveyed, 54 (52.9%) rent land, primarily plots ranging from 0.5 to 1 hectare. Despite their ability to lease land, their reliance on land rental arrangements remains precarious, as their land claims are less secure than direct ownership. Finally, the Thakur and Tharu castes, with nearly complete landlessness, embody the most extreme form of structural marginalisation. With only two households from each caste group in the survey, these households represent the furthest margins of agrarian society. Their near-total exclusion from land ownership places them at the periphery of agrarian relations.

To conclude, the distribution of land ownership across caste groups highlights ongoing social inequalities that affect access to resources and agricultural opportunities. These disparities not only restrict land access but also influence the adoption of irrigation technologies, as explored in the following section.

Table 15 Caste-wise Distribution of Land Ownership and Landholding in Shambhunath Municipality

Caste Group	**Total Households**	**Households with Land (%)**	**Households with No Land (%)**	**Brief Land Size Distribution (summary)**
Other caste groups				
Baniya	3	3 (100%)	0 (0%)	Own small plots (0.2–0.5 ha)
Bhagat	6	6 (100%)	0 (0%)	Some with medium land (1–2 ha)
Chaudhary	170	161 (94.7%)	9 (5.3%)	Broad range: small (<0.5 ha) to medium (1–2 ha)
Hill Chhetri	5	5 (100%)	0 (0%)	Small landholdings (mostly 0.2–1.0 ha)
Hill Vaisya	22	18 (81.8%)	4 (18.2%)	Small plots (<0.5 ha)
Muslim	44	37 (84.1%)	7 (15.9%)	Mostly small to medium (some up to 1–2 ha)
Sah	36	36 (100%)	0 (0%)	Small to medium-sized plots (up to 1–2 ha)
Terai Chhetri	1	1 (100%)	0 (0%)	Medium plot (0.5–1.0 ha)
Thakur	2	2 (100%)	0 (0%)	Very small holdings (mostly 0.2–0.5 ha)
Tharu	2	2 (100%)	0 (0%)	Very small holdings (0.5–1.0 ha)
Yadav	4	3 (75%)	1 (25%)	Small holdings (mostly <0.5 ha)
Dalit caste groups				
Terai Dalit	102	48 (47.1%)	54 (52.9%)	Mostly landless; small plots (<0.5 ha) among those with land
Hill Dalit	4	3 (75%)	1 (25%)	Very small plots (mostly 0.2–0.5 ha)

Table 16 Caste-wise Ownership and Access to Irrigation Technologies

Caste	Total Respondents	Own Tubewell	Own Diesel Pump	Own Electric Pump	Electric Meter Access [18]
Other caste groups					
Baniya	3 (0.7%)	33.30%	33.30%	66.70%	33.30%
Bhagat	6 (1.5%)	66.70%	16.70%	83.30%	33.30%
Chaudhary	170 (42.4%)	65.90%	9.40%	71.80%	17.10%
Hill Chhetri	5 (1.2%)	60.00%	20.00%	80.00%	0.00%
Hill Vaisya	22 (5.5%)	18.20%	0.00%	22.70%	18.20%
Muslim	44 (11.0%)	59.10%	0.00%	63.60%	25.00%
Sah	36 (9.0%)	72.20%	16.70%	83.30%	30.60%
Terai Chhetri	1 (0.2%)	100.00%	0.00%	100.00%	0.00%
Thakur	2 (0.5%)	0.00%	0.00%	0.00%	0.00%
Tharu	2 (0.5%)	100.00%	0.00%	100.00%	100.00%
Yadav	4 (1.0%)	25.00%	25.00%	75.00%	25.00%
Dalit Caste Groups					
Terai Dalit	102 (25.4%)	22.50%	3.90%	28.40%	9.80%
Hill Dalit	4 (1.0%)	25.00%	0.00%	25.00%	25.00%

Table 16 presents a caste-based context for access to irrigation technology. Dominant castes, including Chaudhary (65.9% ownership) and Sah (72.2%), have substantially higher access rates than Terai Dalits (22.4%) and Hill Dalits (25.0%). I argue that this pattern illustrates discriminatory access mechanisms through which marginalised groups experience systematic exclusion from critical infrastructure, mediated by interlocking formal and informal barriers, including elite capture, as I discuss in the following empirical chapters. The stark ownership gap reveals hierarchical access to technology that closely aligns with caste identity.

Chaudhary (71.8%) and Sah (83.3%) households show significantly higher ownership rates, while Dalit households remain underrepresented. Further, only 9.8% of Terai Dalit households and 25.0% of Hill Dalit households have electric meter access, illustrating institutional barriers associated with land requirements that disproportionately affect marginalised communities. A Terai Dalit respondent articulated this challenge:

[18] Electric meter access is most commonly reported among households with land ownership documents, reflecting the requirement of formal land documents to obtain agricultural electricity connections.

'Without land, even getting a meter is a big deal. We want connection but how can we bring proof of land?' (Field interview, Saptari, July 2023)

I find that only 3.9% of Terai Dalit households own diesel pumps, compared to 9.4% of Chaudhary households and 16.7% of Sah households, likely reflecting the prohibitive cost of this technology. Nearly half (47%) of Terai Dalits and a quarter (25%) of Hill Dalits report owning no agricultural land. I contend that this fundamental resource inequality establishes land ownership as a precondition for technological participation and effective agricultural citizenship. Based on my findings, these disparities in resource allocation shape farmers' agricultural livelihoods, creating compounding disadvantages for marginalised caste groups.

To fully understand the implications of caste-based disparities in land and technology access, it is necessary to turn to the everyday experiences that reveal how exclusion is embedded in the fabric of social life. The qualitative narratives of Dalit respondents reveal how technological exclusion is embedded within broader patterns of social discrimination. These accounts illustrate boundary maintenance, practices that reinforce social distinctions and preserve group-based privilege. As one Dalit farmer recounted:

'You know what happened at the temple last year? I went there one evening, and they stopped me at the entrance. "People of small caste aren't allowed here", they said directly. They mean us Dalits.' (Field interview, November 2023)

This testimony exemplifies practised untouchability, the continued enforcement of ritual exclusion despite formal legal prohibitions, as caste-based discrimination is illegal but continues (Jodhka, 2017). The persistence of such discrimination demonstrates deeply internalised rules governing social interaction that structure both sacred and secular spaces.

Another farmer's description of experience related to caste-related restrictions adds another layer of discrimination:

'Just two years ago, when I first moved here... you wouldn't believe it. Being a Dalit meant we couldn't touch something, like their (privileged caste) trees in public spaces. We were banned. They treated us as if our touch would pollute everything.' (Field interview, Saptari, November 2023)

This account surfaces ritualised and internalised avoidance, practices that physically enact notions of purity and pollution through spatial segregation. The extension of such exclusion to environmental

resources (‘not even the trees’) demonstrates ecological marginalisation, the restriction of access to natural resources based on social identity (Agarwal, 2001).

The connection between social exclusion and irrigation access becomes obvious, yet hidden, in accounts of water-sharing practices:

> *'I go to them and say, “I'll pay you for the water, just let me use your tubewell.” But they always have the same excuse, “Oh, we haven't finished watering our own fields yet.” But I can see their fields are already watered. They just don't want to help us[19].' (Field interview, Saptari, December 2023)*

This narrative reflects what scholars of everyday discrimination describe as techno-social exclusion: the reinforcement of social boundaries through seemingly neutral, technical decisions about resource sharing. The refusal to share irrigation infrastructure, even when compensation is offered, reveals how entrenched hierarchies are maintained and negotiated in everyday interactions.

4.7.1 Intersectionality of Exclusion: Caste, Land, and Technology

Testimonies of farmers in the preceding section reveal how caste identity intersects with land ownership to produce distinctive patterns of technological access. These intersecting exclusions exemplify mutually constitutive relations (Yuval-Davis, 2006), the ways multiple forms of disadvantage interact to produce unique configurations of vulnerability. The data reveal three primary patterns of intersectional disadvantage.

First, land ownership serves as a mediating factor in access to technology. For landless Dalits, the absence of land creates compounded exclusion, cascading barriers that simultaneously preclude access to multiple resources. Second, land limitations are compounded by their lack of access to permanent tubewell infrastructure, which serves as the foundation for accessing the pumps and discounted irrigation tariffs. Third, social norms regarding resource sharing systematically disadvantage lower caste groups. The reluctance of dominant caste members to share irrigation infrastructure with Dalits, despite financial compensation, makes access uneasy and links with identity-based access failure blockage. These experiences show exclusionary closure (Parkin, 1979), practices that restrict access to resources based on group membership; here, caste, a form of downward exercise of power.

[19] Instances of caste-based discrimination were not shared openly at the beginning of my fieldwork. Many participants initially claimed that such discrimination no longer existed and was a thing of the past. However, after spending several months in the community, a younger female participant from Ward 4 eventually shared her personal experience.

At the same time, I observed that a small number of marginalised caste farmers are actively engaging in irrigation practices and making concerted efforts to enhance their access to water and land by investing in local irrigation enterprises. Although these cases represent a minority, they are important to highlight because they reveal the diverse strategies marginalised groups employ to navigate structural constraints. In Ward 4, one individual has launched a diesel pump rental business to strengthen his agricultural livelihood. To illustrate this dynamic, I present a video case study in Chapter Five featuring a farmer from a marginalised caste background. This case explains that although not all marginalised caste farmers can adopt irrigation technologies, some are creating opportunities to make irrigation work for them through entrepreneurial initiatives.

The video further emphasises the critical role of family labour in sustaining irrigation activities. It shows that men do not perform irrigation work exclusively; instead, women and children also contribute substantially to farm labour and water management, roles that often remain invisible in conventional narratives of agricultural practice. This observation serves as a segue into the next section, which focuses on gender dynamics in irrigation. Specifically, the video documents how women not only participate in agricultural labour but also directly operate and manage irrigation technologies. The question is how to translate such engagement into transformative change that benefits women. Such evidence challenges prevailing gendered assumptions about irrigation work and highlights the need for a more inclusive understanding of who participates in, and benefits from, the adoption of irrigation technologies.

4.8 Gender, Land Ownership, and Irrigation Infrastructure

Following the analysis of caste-based disparities, this section examines gender as another critical axis of differentiation structuring access to land and irrigation infrastructure. Drawing on household-level quantitative data and qualitative insights, I examine how patterns of resource control and technological access in agrarian systems shape gender relations. The findings reveal persistent structural inequalities that shape gendered disadvantages, even though 80.1% of women in Nepal are engaged in agricultural work, largely in low-return subsistence activities, compared to 59.4% of men (Sharma Basnet et al., 2021).

> *'When my father-in-law was alive, I used to help him irrigate our rented land. Now that he has passed away and my husband works abroad, I manage everything on my own. I do all the irrigation work alone now.' (Field interview, Saptari, December 2023)*

This is a narrative from a woman farmer in a migrant household that exemplifies a broader transformation occurring in the study area, in which female farmers increasingly assume primary responsibility for irrigation management in both migrant and non-migrant households. However, as the following analysis demonstrates, these roles typically unfold within constraints shaped by gendered patterns of resource control that limit women's decision-making authority and technological capabilities.

Table 17 reveals significant disparities in land ownership between male- and female-headed households. Among the 401 surveyed households, only 13.7% (n=55) were female-headed, a demographic imbalance that itself reflects broader patriarchal social structures. This means female headship is not, of itself, associated with substantially lower land ownership rates; the more analytically significant vulnerabilities of female-headed households arise from average landholding sizes, social barriers to water user group participation, and limited access to formal documentation processes rather than from lower land ownership rates within the group. This difference is modest. The figure that female-headed households represent only 10.5% of all surveyed households that are both female-headed and land-owning should be interpreted carefully; it is driven primarily by the small overall share of female-headed households in the sample (13.7%) rather than a distinctively lower rate of landownership within this group. The more analytically significant constraints on female-headed households arise from smaller average landholding sizes, social barriers to participating in water user groups, and limited access to formal documentation processes, all of which compound to restrict technology access even where nominal land ownership exists. According to the 2021 National Census Report, only 21.7% of households in Madhesh Province are headed by women, well below the national average of 31.6%, and just 11.8% of families report that women own property (National Statistics Office, 2024).

A larger proportion of female-headed households[20] (52.7%) reported renting land more than male-headed households (43.6%), suggesting that land leasing plays a more critical role in enabling female farmers to access cultivable land. This pattern indicates that women utilise rental arrangements to compensate for weaker ownership rights, a strategic adaptation to structural constraints. However, in absolute terms, female-headed households still comprise a smaller portion of total renters (7.2%

[20] A female-headed household is defined here as one in which a woman is the senior member or main decision-maker. In the survey, women were identified as household heads either because they actively made key decisions or because adult men were absent or had migrated. This distinction is important, as female-headed households do not always indicate greater agency and may instead reflect vulnerability, shaped by male out-migration. See glossary for definition.

versus 37.7% for male-headed households), reinforcing gender inequalities in overall land access that fundamentally constrain women's capacity to adopt irrigation technologies. Furthermore, it is important to note that female-headed households tend to rent land in smaller plots than male-headed households.

An important stipulation of this quantitative analysis in this chapter is that it operationalises gender through household headship, comparing female-headed households and male-headed households. This captures the structural position of households where women hold formal decision-making responsibility but does not yet capture the experiences of the majority of rural women, who live in male-headed households where they manage irrigation work daily without corresponding decision-making authority, formal entitlement, or access to extension services in their own names (Sultana, 2009; Meinzen-Dick et al., 2022). Chapter Five addresses this directly through qualitative case studies of women managing irrigation in male-out migrant households, providing evidence of practical burdens and strategic adaptations that household-level statistics cannot capture.

Table 17 Land Ownership and Rented-in Access by Gender of Head of Household

Land Access Type	**Gender of Head of Household**	**No. of HHs**	**% within Gender Group**	**% of Total HHs (n=401)**
Own Agricultural Land	Female HH (n=55)	42	76.4%	10.5%
	Male HH (n=346)	283	81.8%	70.6%
No Agricultural Land	Female HH	13	23.6%	3.2%
	Male HH	63	18.2%	15.7%
Rented-in Land Access	Female HH	29	52.7%	7.2%
	Male HH	151	43.6%	37.7%
No Rented-in Land	Female HH	26	47.3%	6.5%
	Male HH	195	56.4%	48.6%

A closer examination of intra-household land ownership reveals further nuances in gendered access to land. It must be noted that land entitlement does not necessarily guarantee decision-making power or control over land-related matters (World Bank, 2019); however, it can serve as a basis for some degree of economic security (Meinzen-Dick et al., 2025). Among the 42 female-headed households with land ownership, 52.4% reported that the land was registered in a male family member's name, suggesting that, even in households led by women, male relatives often retain legal control over the land. Only 33.3% reported land ownership in a female family member's name, and just 14.3% had land registered jointly. The share of joint land ownership reflects the influence of the 2011 Joint Land

Ownership (JLO) policy, which allows spouses to register land in both names for a minimal fee of NPR 100 and offers a 25%-50% tax exemption depending on location (Ghimire et al., 2024). These patterns raise important questions about the meaning of male and female household-headship, whether such headship translates into tangible access to resources like land, and whether the nature of headship differs by gender.

In contrast, among male-headed households with land, 53.4% reported land in a male member's name, while 21.2% had land in a female member's name, and 25.4% reported joint ownership. This pattern indicates that, while men dominate land titles across both household types, male-headed households are more likely to use joint titling practices (25.4% vs 14.3% in female-headed households). These findings align with feminist political ecology perspectives that emphasise the problematic of joint land ownership and discuss how formal property rights often reproduce patriarchal norms, even when household arrangements shift (Agarwal, 2001; Deere & León, 2003).

The persistence of male ownership even in female-headed households hints at a patriarchal bargain, strategic compromises women make to secure access to resources within constraining social structures. At the same time, a study in Nepal's Sunsari district shows significant increases in women's monthly savings, improved access to credit, and participation in farmer cooperatives among women with joint land ownership (Ghimire et al., 2024). These intra-household dynamics critically shape women's ability to access irrigation technologies, as legal land ownership often underpins eligibility for infrastructural support, subsidies, and loans.

Table 18 Gendered Patterns of Land Ownership within Households

Land Ownership in the Household	Female HH (N=42)	Female HH (%)	Male HH (N=283)	Male HH (%)
Male member of the family	22	52.4%	151	53.4%
Female member of the family	14	33.3%	60	21.2%
Both male and female	6	14.3%	72	25.4%
Total	42	100.0%	283	100.0%

A further analysis of landholding sizes in Table 19 reveals further gender-based stratification affecting irrigation capabilities. Among land-owning female-headed households, 59.6% owned less than 0.5 hectares, with 42.9% owning between 0.2 and 0.5 hectares. In contrast, male-headed households displayed a wider distribution across larger land categories, with 4.9% owning less than 0.1 hectares, 11.0% owning 0.1 to 0.2 hectares, 27.9% owning 0.2 to 0.5 hectares, and 28.6% owning 0.5 to1 hectares.

Particularly revealing is the near absence of large landholders among female-headed households. While 23.7% of male-headed households owned between 1 and 2 hectares, only 7.1% of female-headed households did so. Furthermore, none of the female-headed households reported owning more than 2 hectares, while approximately 4.0% of male landowners fell into the 3 to10+ hectare category.

This stratification has critical implications for the adoption of irrigation technology. Smaller landholdings limit economies of scale in irrigation investments, restrict eligibility for state-supported programmes that require minimum landholdings, and disincentivise the adoption of higher-cost technologies such as electric or solar irrigation systems. Female-headed households, predominantly smallholders, thus face structural constraints due to both their gendered positioning and land size limitations.

Table 19 Agricultural Land Size Distribution by Gender of Head of Household

Land Size Category[21]	**Female HH (n=42)**	**% of Female HH**	**Male HH (n=283)**	**% of Male HH**	**Total HH (n=325)**	**% of Total HH**
< 0.1 ha (≈3 *kattha*)	1	2.4%	14	4.9%	15	4.6%
0.1–0.2 ha (≈3–6 *kattha*)	7	16.7%	31	11.0%	38	11.7%
0.2–0.5 ha (≈ 6–15 *kattha*)	18	42.9%	79	27.9%	97	29.8%
0.5–1.0 ha (≈15–30 *kattha*)	11	26.2%	81	28.6%	92	28.3%
1–2 ha (≈30–60 *kattha*)	3	7.1%	67	23.7%	70	21.5%
3–4 ha (≈90–120 *kattha*)	2	4.8%	9	3.2%	11	3.4%
5–10 ha (≈150-300 *kattha*)	0	0.0%	1	0.4%	1	0.3%
> 10 ha (≈120-300 *kattha*)	0	0.0%	1	0.4%	1	0.3%
Total	42	100.0%	283	100.0%	325	100.0%

[21] Households owning land of recorded size are presented.

4.8.1 Gender Disparities in Irrigation Technology Access

Table 20 disaggregates irrigation technology access by gender of household head. Of the 55 female-headed households in the sample, 22 owned a tubewell on their own land, representing 40.0% of female-headed households. The comparable figure for male-headed households was 182 of 346 (52.6%). Although female-headed households were less likely to own tubewells, this difference appears to reflect their concentration among households with smaller landholdings, where investment in fixed irrigation infrastructure was generally less common across all household types, rather than female headship acting as an independent barrier to ownership. Female-headed households were, however, more likely to report access to tubewells on rented land (23.6% compared with 11.3% for male-headed households), suggesting a greater reliance on rented land and shared irrigation arrangements where ownership of fixed infrastructure is constrained.

Differences are more pronounced for some technologies than others. Diesel pump ownership was uncommon among female-headed households, with only one household (1.8%) owning a diesel pump compared with 8.4% of male-headed households. Female-headed households were also less likely to rent diesel pumps (7.3% versus 11.3%). In contrast, ownership of electric pumps was broadly comparable between the two groups, with 52.7% of female-headed households and 58.7% of male-headed households reporting ownership. Similarly, access to subsidised agricultural electricity meters was almost identical, with 18.2% of female-headed households having access compared with 17.9% of male-headed households. These findings suggest that gender disparities are not uniform across irrigation technologies. While female-headed households remain disadvantaged in relation to some forms of irrigation infrastructure, particularly diesel pumps and tubewell ownership, they appear to achieve comparable access to electric pumps and subsidised electricity once the necessary enabling conditions, such as land access and infrastructure, are in place.

These descriptive patterns should be interpreted cautiously because they do not account for other factors that shape irrigation technology access, including landholding size, tenancy arrangements, caste, migration, and electricity availability. The multivariate analysis presented later in this chapter therefore provides a more robust assessment of the independent contribution of gender after controlling for these overlapping influences. Drawing on Naila Kabeer's (2000) framework of resources, agency, and achievements, women's access to irrigation technologies can be understood as reflecting constraints across all three dimensions: resource ownership (particularly land), decision-making agency, and technological achievements. At the same time, the findings indicate that these

gendered inequalities are mediated through broader structural conditions rather than female headship alone. This interpretation is consistent with scholarship on gender and technology, which argues that technological systems both reflect and reproduce existing social inequalities while also being shaped by wider institutional and socio-economic contexts (Zwarteveen, 2008).

Table 20 Comparison of Irrigation Technology Access by Gender of Head of Household

Irrigation Technology	**Female HH (n=55)**	**% of Female HH**	**Male HH (n=346)**	**% of Male HH**	**Total HH (n=401)**	**% of Total HH**
Own Tubewell on Own Land	22	40%	182	45.4%	204	50.9%
Tubewell on Rented Land	13	23.6%	39	9.7%	52	12.9%
Own Diesel Pump	1	1.8%	29	52.6%	30	7.5%
Rent-in Diesel Pump	4	7.3%	39	11.3%	43	10.7%
Own Electric Pump	29	52.7%	203	58.7%	232	57.9%
Rent-in Electric Pump	19	34.5%	73	21.1%	92	22.9%
Access to the Electric Meter	10	18.2%	62	17.9%	72	18%

I also examined how irrigation-related responsibilities are shared within households. Table 21, Table 22 and Table 23 on irrigation repair responsibilities, farmer group membership, and agricultural office visits, respectively, highlight how gender shapes participation in agricultural networks and access to support systems.

In terms of irrigation repairs, male members dominate these tasks, with no female-headed households reporting women performing repairs independently. Only 7.3% of female-headed households reported that male members handled repairs, and another 7.3% indicated that both male and female members participated in repairs. This reflects gendered divisions of technical labour, in which irrigation repair is considered a male responsibility even in female-headed households, a pattern consistent with the literature on the masculinity of agricultural technology (Sultana, 2009).

Regarding participation in farmer groups, both female-headed (92.7%) and male-headed (93.0%) households show similarly low levels of engagement with formal agricultural networks. This widespread exclusion from formal farmer organisations, which typically facilitate knowledge exchange, resource pooling, and advocacy, likely affects all households but may particularly disadvantage female farmers, who already face constraints in accessing information and support through other channels.

Similarly, the frequency of agricultural office visits reveals a marked gender gap. A striking 92.7% of female-headed households reported never visiting agricultural offices, compared to 73.8% of male-headed households. Among those who visit these offices, female-headed households visit even less frequently, with only one female visiting annually, compared to 5.5% among male-headed households. This pattern aligns with literature on gender and agricultural extension services, which highlights how institutional structures often implicitly favour male farmers through timing, location, communication methods, and staff composition (O'Brien et al., 2016; Anshida Beevi et al., 2018; Witinok-Huber et al., 2021).

Table 21 Frequency of Irrigation Repair by Gender of Head of Household

Irrigation Repairs	**Female HH (n=55)**	**% of Female HH**	**Male HH (n=346)**	**% of Male HH**	**Total HH (n=401)**	**% of Total HH**
Female repairs irrigation	0	0.0%	3	0.9%	3	0.7%
Male repairs irrigation	4	7.3%	28	7.7%	32	8.0%
Male and Female repair irrigation	4	7.3%	28	7.7%	32	8.0%

Table 22 Farmer Group Membership by Gender of Head of Household

Farmer Group Membership	**Female HH (n=55)**	**% of Female HH**	**Male HH (n=346)**	**% of Male HH**	**Total HH (n=401)**	**% of Total HH**
No	51	92.7%	322	93.0%	373	93.0%
Yes	4	7.3%	24	7.0%	28	7.0%

Table 23 Frequency of Agricultural Office Visits by Gender of Head of Household

Frequency of Ag. Office Visit	**Female HH (n=55)**	**% of Female HH**	**Male HH (n=346)**	**% of Male HH**	**Total HH (n=401)**	**% of Total HH**
Every six months	1	0.2%	12	3.0%	13	3.2%
Every three months	1	0.2%	11	2.7%	12	3.0%
Monthly	0	0.0%	5	1.2%	5	1.2%
Never	52	13.0%	296	73.8%	348	86.7%
Yearly	1	0.2%	22	5.5%	23	5.7%

This analysis demonstrates how gender operates as a fundamental organising principle shaping agricultural resource access at multiple scales, from intra-household land control to technology ownership to institutional engagement. Female-headed households face systematic disadvantages in land ownership, land size, access to irrigation technology, and engagement with agricultural support networks. Even in households they head, women often lack formal ownership of land, which remains

under male family members' control, illustrating the persistence of patriarchal norms within changing household arrangements.

These findings contribute to feminist political ecology perspectives by demonstrating the embeddedness of gender disparities in agrarian structures, where women's increased labour participation has not translated to equitable resource control or technical capabilities. Drawing on Ribot and Peluso's (2003) theory of access again, we can understand that these patterns reflect women's limited bundle of powers in deriving benefits from agricultural resources, despite their growing responsibilities in agricultural production.

However, it is important to recognise that women are not merely passive actors within these constrained structures. Through the video testimony in the coming chapter, I present evidence that women continue to perform critical but often overlooked roles in water management and irrigation practices, even amidst significant limitations in land entitlements and restricted participation in technology-related decision-making spaces. In particular, women in households where male members have migrated, a phenomenon explored in the next section, often become de facto decision-makers in agricultural management. Such patterns of women becoming head of household, often in the absence or migration of male family members, may help explain why female-headed households tend to have lower levels of land entitlement and reduced access to tubewells associated with that land. They draw on familial and neighbourly networks to mobilise labour and organise irrigation activities. To illustrate these dynamics, I present a video featuring a woman farmer from a migrant household irrigating her winter wheat crop. Although using an electric pump offers some relief compared to the heavier diesel pumps, irrigation remains a labour-intensive task. The video captures how she resourcefully navigates labour constraints by drawing support from her immediate social networks. Although she was ultimately unable to irrigate her crops that day, the video reveals the adaptive strategies women farmers employ in restrictive agrarian environments.

4.9 Migration and its Influence on Irrigation Technology Adoption

Transitioning from the gender and irrigation links in the previous section, the feminisation of agriculture represents a significant socio-spatial transformation in Nepal's agrarian landscape, deeply intertwined with patterns of male out-migration (Kulkarni et al., 2021). This phenomenon exemplifies what Chant (2007) discusses, the feminisation of responsibility, in which women assume greater agricultural labour burdens without corresponding gains in control over resources. We see such a

phenomenon discussed in Nepal by KC and Race (2020), Leder (2022), and others. Scholars argue that even before migration, women contributed significantly to agricultural work, which was just invisible (Kawarazuka et al., 2022). I agree with these scholars' arguments, but I also witnessed changes in the new and additional agricultural and irrigation roles that women took on within migrant families (World Bank, 2015; Karn et al., 2021; Najjar, 2021; Suhardiman et al., 2023). Their responsibilities, including irrigation, had increased. During fieldwork, this transformation was marginalised through numerous encounters with women independently managing irrigation pumps, tasks historically dominated by men. (Although I do not mean to say that women did not perform irrigation roles; they were and are important irrigation actors who managed water in farms, even though they may not have operated pumps.) When asked about household division of labour, women frequently responded with variations of:

> *'My husband is abroad; I have to take care of everything here.' (Field interview, Saptari, December 2023)*

These narratives reveal the reconfiguration of gender relations precipitated by migration, creating de facto female-headed households in which women assume management responsibilities while men retain ownership and decision-making authority from afar. This section adds the layer of migration as it intersects with land ownership patterns, gendered access to irrigation technologies, and institutional participation to shape technological adoption decisions.

Approximately 46.7% of surveyed households reported having out-migration experience, as shown in Table 24, indicating that migration constitutes a significant livelihood strategy among agricultural households. The data reveal an intriguing dynamic: despite typically operating smaller landholdings and having more limited access to irrigation infrastructure, migrant households demonstrate notable adaptive capacities through livelihood diversification. This diversification potentially reduces their dependence on local water resources and agricultural production. Such behaviour is consistent with broader patterns of risk-spreading strategies, whereby households allocate labour across multiple sectors to mitigate vulnerabilities associated with environmental and economic uncertainties (Hess & Sovacool, 2020). The persistence of smallholders amidst ongoing social and economic transformations, despite longstanding expectations of their decline, is true in Nepal too, as is referred to as the puzzle of East and Southeast Asia examined by Rigg (2012). This reflects what McCarthy (2020) has described as "sideways mobility", a paradoxical form of progress in which households

diversify livelihoods and move out of poverty in statistical terms, yet continue to face enduring vulnerabilities such as food insecurity and infrastructural marginality.

Table 24 Distribution of Migration Status

Migration Status	Number of Households	Percentage
No Migration	214	53.3%
With Migration	187	46.7%
Total	401	100.0%

4.9.1 Gendered Dimensions of Migration and Technology Access

The intersection of gender and migration produces particularly nuanced outcomes in technological adoption contexts. As shown in

Table *25*, female-headed households, which constitute 13.7% of the sample, exhibit significantly higher migration rates and experience than male-headed households. This association requires careful interpretation. In the Terai context, a household is frequently classified as female headed precisely because the male head has migrated for labour: female headship and male outmigration are casually connected, with migration producing headship in the survey classification as often as headship predicts migration. The reported higher migration rates among female-headed households therefore reflect, in part, the definitional relationship between these variables rather than an independent association. The substantive analytical point is that the feminisation of farm management associated with male out-migration in the terai creates specific constraints women managing farms in the absence of the male household head report greater resistance to participation in water user group meetings, greater difficulty negotiating pump rental arrangements, and lower perceived legitimacy in accessing government subsidy offices, all of which reduce their effective access to the irrigation technology bundle (Gartaula et al., 2010; Maharjan et al., 2010).

Under these conditions, women often assume responsibility for day-to-day farming and household decisions, while major strategic choices may continue to be shaped by absent male members through ongoing influence and communication. Drawing on Kabeer's (2000) conceptualisation of agency, this configuration reflects the coexistence of power to and power over, highlighting that female-headed households formed through male out-migration experience differentiated and uneven distributions of decision-making authority rather than a uniform shift in control.

Table 25 Gender of Head of Household by Migration Status

Gender of head household head	No migration	With migration	Total	No migration (%)	With migration (%)
Female-headed households	17	38	55	30.9	69.1
Male-headed households	197	149	346	56.9	43.1

Note: Percentages are calculated within female-headed and male-headed households, respectively. It is important to note that the higher incidence of migration among female-headed households reflects the fact that many households are reported as female-headed as a consequence of male out-migration, rather than female headship causing migration.

4.9.2 Technology Adoption Patterns Across Migration Status

The analysis of irrigation technology access across migration status (Table 26) indicates broadly similar levels of access among households with and without migration. When assessed within each group, differences in access to electric pumps, tubewells, and diesel pumps are small and do not indicate a systematic disadvantage associated with migration status.

While migration status alone does not appear to substantially differentiate access to irrigation technologies, migration reshapes intra-household labour dynamics, often increasing women's responsibility for irrigation management and agricultural decision-making, as illustrated in the qualitative case studies. Although Table 26 does not show substantial differences in irrigation technology access by migration status, migration may nevertheless interact with technological adoption in more indirect ways by shaping household labour availability, investment priorities, and engagement with agriculture (De Haas, 2010). While remittances can provide financial capital for agricultural investments, the absence of labour within migrant households may constrain the ownership and active operation of irrigation infrastructure. In some cases, households may also reduce their agricultural activities, as migration provides alternative income-generating opportunities.

Migration-related dynamics are also reflected in farmer institutional participation. Overall participation in formal farmer organisations is low (7.0%) and shows similarly limited engagement among households with and without migration (Table 27). This uniformly low level of participation points to broader structural constraints on institutional engagement, which in turn limit access to irrigation technologies, training, and institutional support. For migrant households, particularly female-headed households, weak institutional ties may interact with existing gendered and tenure-based constraints, reinforcing challenges in agricultural resource management.

Together, these findings contribute to theoretical debates regarding the complex relationship between migration and technological adoption in agrarian settings. Rather than supporting a straightforward remittance–investment pathway that assumes migration facilitates technological access, the data

reveal a more nuanced relationship mediated by gender dynamics, land ownership, and institutional embeddedness.

Drawing on the sustainable livelihood framework, migration and irrigation technology adoption can be conceptualised as complementary yet sometimes competing livelihood strategies, shaped by household asset realities and broader structural constraints (Carney, 1998). For households with limited landholdings and weak institutional affiliations, migration may represent a more accessible and viable pathway to livelihood security than agricultural intensification through irrigation technology adoption. Conversely, households with greater land resources and stronger institutional engagement may be able to leverage both migration and technological access as mutually reinforcing strategies to enhance their livelihood security.

In the subsequent regression analysis, I further examine these interconnections by assessing how migration status, land ownership, gender, and institutional participation collectively influence the likelihood of irrigation technology adoption, while accounting for the complex interdependencies and potential endogeneity among these variables.

Table 26 Access to Irrigation Technologies in Households on the Basis of Migration

Technology type	**No migration (n = 214)**	**With migration (n = 187)**	**% of households with no migration**	**% of households with migration**
Electric pumps	160	147	74.8	78.6
Tubewell	127	108	59.3	57.8
Diesel pumps	38	31	17.8	16.6

Note: Percentages are calculated within households with and without migration, respectively.

Table 27 Farmer Group Membership Based on Households on the Basis of Migration

Membership Status	**No migration**	**With migration**	**Total**
Non-member	200 (49.9%)	173 (43.1%)	373 (93.0%)
Member	14 (3.5%)	14 (3.5%)	28 (7.0%)

4.10 Bivariate Differences in Irrigation Technology Access

This section examines bivariate differences in household access to groundwater irrigation technologies across three key social and economic dimensions: gender of head of household, caste, and land ownership. Independent-samples t-tests are used to assess whether simple group-level differences in access are detectable prior to multivariate analysis. The purpose of these tests is

descriptive rather than causal. They provide an initial assessment of inequality patterns and motivate the multivariate logistic regression models presented in this section. An important limitation of bivariate comparisons in this context is that the social attributes being compared are correlated with each other in ways that bivariate analysis cannot disentangle. For example, Dalit caste status and land ownership are associated, a comparison of Dalit versus non-Dalit tubewell ownership will therefore partially capture the effect of land ownership difference rather than caste alone. The multivariate logistic regression models presented from the following section onward provide appropriate analytical basis for interpreting the independent and combined contribution of caste, tenure, gender, and land size to technology access outcomes. The bivariate comparisons here serve as a transparent first-pass description of the data.

All irrigation access variables are binary indicators capturing ownership or access to specific technologies. Accordingly, reported group means represent the proportion of households with access to each technology. Throughout this section, results are interpreted cautiously, recognising that bivariate comparisons do not account for the joint influence of land tenure, migration, electricity infrastructure, and other structural factors that shape groundwater access in the study area.

Four outcome variables are examined: tubewell access; diesel pump access; electric pump access; and access to an agricultural electricity meter. The key grouping variables are defined as follows: gender of head of household (female-headed vs male-headed households); caste (Dalit vs non-Dalit households); and land ownership (landless vs land-owning households). Group differences are tested using independent samples t-tests.

4.10.1 Gender Differences in Irrigation Technology Access

Table 28 presents results from independent samples t-tests comparing female-headed and male-headed households regarding access to key groundwater irrigation technologies. Because all outcome variables are binary, reported means represent the proportion of households with access to each technology.

The results indicate that gender-based differences in irrigation access vary across technologies and are generally modest in magnitude. There are no statistically significant differences between female-headed and male-headed households in access to tubewells or agricultural electricity meters. Approximately 56% of female-headed households and 59% of male-headed households report access

to tubewells, while fewer than 20% of households in either group have access to an agricultural electricity meter. These differences are small and statistically insignificant.

A significant difference emerges, however, for diesel pump access. Male-headed households are substantially more likely to have access to diesel pumps than female-headed households (18.8% vs 7.3%; $p = 0.036$). This pattern suggests that gendered divisions of labour and control over physically demanding or fuel-dependent technologies may shape pathways into diesel-based irrigation. Diesel pumps require lifting, transport, fuelling, and mechanical handling, practices that are socially coded as masculine and often mediated through male labour and networks.

Electric pump access exhibits the reverse pattern: female-headed households report higher access rates than male-headed households (85.5% vs 75.1%), although this difference is only marginally significant ($p = 0.094$). While this does not meet the conventional 5% threshold, it is suggestive and aligns with qualitative accounts in which women describe electric pumps as easier to operate, less physically demanding, and more compatible with labour constraints created by male out-migration. The pattern suggests that gender may shape technological pathways rather than serve as a simple axis of exclusion. Because female headship is correlated with tenure, infrastructure location, and household composition, these descriptive differences are interpreted cautiously and revisited in the multivariate models.

Table 28 Gender Differences in Groundwater Irrigation Technology Access

Irrigation technology	**Female-headed households (N = 55)**	**Male-headed households (N = 346)**	**Mean difference (F − M)**	**p-value**
Tubewell access	0.564	0.590	−0.026	0.717
Diesel pump access	0.073	0.188	−0.115	0.036
Electric pump access	0.855	0.751	0.104	0.094
Electricity meter access	0.182	0.179	0.003	0.963

Note: Values represent proportions of households with access to each technology. Group differences are tested using independent-samples t-tests. Female-headed households are coded as 0 and male-headed households as 1. Mean differences are calculated as the difference between female-headed and male-headed households.

4.10.2 Caste Differences in Irrigation Technology Access

Table 29 presents results from independent-samples t-tests comparing Dalit and non-Dalit households' access to key groundwater irrigation technologies. In contrast to gender-based comparisons, the caste-based analysis reveals statistically robust differences across most technologies.

Non-Dalit households report substantially higher tubewell access than Dalit households (66.1% vs 37.7%; $p < 0.001$). Electric pump access shows an even sharper caste gradient, with 84.4% of non-Dalit households reporting access compared to 54.7% of Dalit households ($p < 0.001$). Access to agricultural electricity meters is also significantly higher among non-Dalit households (20.7% vs 10.4%; $p = 0.018$), although overall coverage remains limited across both groups.

Diesel pump access exhibits the opposite pattern. Dalit households report higher diesel pump access than non-Dalit households (27.4% vs 13.6%; $p = 0.001$). This does not necessarily indicate an advantage. It may reflect greater reliance on diesel where electrified alternatives are less available, less affordable, or less institutionally accessible.

Overall, these bivariate results indicate that caste-based inequalities in access to groundwater irrigation are substantial and consistent across fixed and electrified infrastructure, while diesel access appears more prevalent among Dalit households. As with gender, these comparisons do not account for other factors such as land tenure, migration, or electricity coverage. The following section, therefore, examines whether caste-based disparities persist when these factors are considered simultaneously in multivariate models.

Table 29 Caste Differences in Groundwater Irrigation Technology Access

Irrigation technology	**Dalit households (N = 106)**	**Non-Dalit households (N = 295)**	**Mean difference (D − ND)**	**p-value**
Tubewell access	0.377	0.661	−0.284	< 0.001
Diesel pump access	0.274	0.136	0.138	0.001
Electric pump access	0.547	0.844	−0.297	< 0.001
Electricity meter access	0.104	0.207	−0.103	0.018

Note: Values represent proportions of households with access to each technology. Group differences are tested using independent-samples t-tests. Dalit households are coded as 0 and non-Dalit households as 1. Mean differences are calculated as the difference between Dalit and non-Dalit households.

4.10.3 Land Ownership and Access to Irrigation Technologies

Table 30 presents results from independent-samples t-tests comparing landless and land-owning households in terms of access to key groundwater irrigation technologies. In contrast to the more muted gender patterns, land ownership produces significant and highly consistent differences across most technologies.

Land-owning households are far more likely to have access to tubewells than landless households. Only around one-quarter of landless households report tubewell access, compared to nearly two-thirds of land-owning households. This difference is highly statistically significant and reflects the fixed and land-embedded nature of tubewell infrastructure. Tubewells require secure placement on a plot and long-term investment, conditions that are largely unavailable to households without land.

A similarly strong pattern is evident for electric pumps. More than four-fifths of land-owning households report access to electric pumps, compared to just over half of landless households. Access to agricultural electricity meters shows the sharpest divide: fewer than 3% of landless households report having a meter, compared to over 20% of land-owning households. These differences are statistically robust and highlight the role of ownership as an institutional gateway into electrified irrigation systems, which require documentation and recognised tenure.

Diesel pumps exhibit a contrasting pattern. Differences between landless and land-owning households are small and statistically insignificant. Both groups report similar levels of access to diesel pumps. This suggests that diesel irrigation functions as a technology that remains available even where secure land tenure and formal infrastructure are absent. Unlike tubewells and electric systems, diesel pumps do not require permanent anchoring or bureaucratic eligibility and therefore circulate across tenure boundaries.

Table 30 Land Ownership Differences in Groundwater Irrigation Technology Access

Irrigation technology	**Landless households (N = 76)**	**Land-owning households (N = 325)**	**Mean difference (L − O)**	**p-value**
Tubewell access	0.276	0.658	−0.382	< 0.001
Diesel pump access	0.145	0.178	−0.033	0.484
Electric pump access	0.540	0.818	−0.278	< 0.001
Electricity meter access	0.026	0.215	−0.189	< 0.001

Note: Values represent proportions of households with access to each technology. Group differences are tested using independent-samples t-tests. Landless households are coded as 0 and land-owning households as 1. Mean differences are calculated as landless minus land-owning households

4.10.4 Migration and Access to Irrigation Technologies

Table 31 presents results from independent-samples t-tests comparing households with at least one migrated member and households without migrant members, in terms of access to key groundwater

irrigation technologies. In contrast to caste and land ownership, migration status does not produce clear or consistent differences in irrigation access at the bivariate level.

There are no statistically significant differences between migrant and non-migrant households in access to tubewells, diesel pumps, or electric pumps. Access rates are remarkably similar across the two groups. Around 59% of non-migrant households and 58% of migrant households report having access to a tubewell. Diesel pump access is also nearly identical, at approximately 18% among non-migrant households and 17% among migrant households. Electric pump access is slightly higher among migrant households, but the difference is small and not statistically significant.

Access to agricultural electricity meters shows a modest divergence. Migrant households report higher access than non-migrant households, with approximately 21% of migrant households and 15% of non-migrant households having a meter. This difference approaches statistical significance but does not meet the conventional 5% threshold.

Table 31 Migration Differences in Groundwater Irrigation Technology Access

Irrigation technology	**Non-migrant households (N = 214)**	**Migrant households (N = 187)**	**Mean difference (NM − M)**	**p-value**
Tubewell access	0.593	0.578	0.015	0.748
Diesel pump access	0.178	0.166	0.012	0.756
Electric pump access	0.748	0.786	−0.038	0.366
Electricity meter access	0.150	0.214	−0.064	0.094

Note: Values represent proportions of households with access to each technology. Group differences are tested using independent-samples t-tests. Non-migrant households are coded as 0 and migrant households as 1. Mean differences are calculated as the non-migrant household mean minus the migrant household mean.

4.11 Multivariate Analysis of Irrigation Technology Access

The bivariate analysis in Section 4.10 reveals pronounced and uneven patterns in access to groundwater irrigation technologies across gender of household head, caste, and land ownership. While these comparisons provide important descriptive insights, they do not account for the simultaneous influence of multiple household, social, and infrastructural characteristics that jointly shape irrigation access. This section, therefore, employs multivariate logistic regression models to estimate conditional associations among land tenure, land scale, caste, gender, migration, and access to different irrigation technologies.

Irrigation technologies in the study area differ markedly in their material characteristics and institutional requirements. Tubewells are fixed, land-embedded infrastructures that require substantial upfront investment and secure tenure. Electric pumps depend on both physical assets and grid connectivity. Diesel pumps are mobile but fuel-intensive and costly to operate. Electric meters represent a form of institutional infrastructure tied directly to state recognition and bureaucratic eligibility. Because these technologies operate through distinct socio-technical pathways, they are analysed as separate dependent variables rather than as a single aggregated measure of irrigation access.

Across all models, the dependent variables are binary indicators coded as 1 if the household owns or has access to the specified technology, and 0 otherwise. Odds ratios are reported to facilitate the interpretation of effect sizes.

4.11.1 Hypotheses (H) and Modelling Strategy

The multivariate analysis is guided by three core hypotheses derived from the bivariate results and the broader literature on groundwater irrigation in South Asia.

H1: Land access is a primary determinant of access to irrigation technology.

Households that own land and those with larger landholdings are expected to have higher odds of accessing fixed, capital-intensive irrigation technologies, particularly tubewells and electric pumps.

H2: Social identity continues to shape access beyond land ownership.

Caste-based disparities observed in the bivariate analysis are expected to persist after controlling for land access, reflecting the role of social position in mediating the placement of infrastructure, institutional recognition, and eligibility for state support.

H3: Different irrigation technologies are structured by distinct but overlapping access mechanisms.

Mobile technologies such as diesel pumps are expected to be more prevalent among households without access to electrified infrastructure, while access to electric pumps and electric meters is expected to be strongly conditioned by infrastructural connectivity and institutional requirements. The selection of explanatory variables in this study is grounded in a substantial body of literature on groundwater irrigation in South Asia. The models include gender of household head, caste, migration

status, and land ownership and rental, all of which have been shown to shape access to irrigation technologies through material, social, and institutional pathways.

Land access is a foundational determinant of irrigation technology uptake. Numerous studies demonstrate that farmers with larger landholdings are more likely to invest in fixed and capital-intensive irrigation infrastructure, while those cultivating marginal or fragmented plots are often reliant on water markets or experience constrained access to groundwater technologies (Kumar & Doan, 2025). Beyond land, caste hierarchies continue to mediate control over groundwater resources. Dominant caste groups not only own a disproportionate share of irrigation infrastructure but also exercise informal authority over local water governance, frequently excluding Dalit and lower-caste farmers from effective access (Narain, 2019).

Migration and remittances play an ambivalent role in irrigation access. While remittance income may enable some households to invest in pumps or wells, out-migration can also reduce on-farm labour availability and weaken everyday management capacity, thereby constraining effective use of irrigation technologies (Kandel et al., 2025). Education, particularly at secondary and higher levels, has been associated with greater adoption of improved agricultural technologies, including groundwater irrigation, through enhanced access to information and decision-making capacity (Kandel et al., 2025). Age may further shape willingness to invest in or experiment with new technologies, with younger farmers often being more open to innovation and older farmers being more risk-averse (Kumar & Doan, 2025).

Gender is a cross-cutting axis of inequality in irrigation access. Although women contribute substantially to agricultural production, structural constraints such as insecure tenure, limited access to credit, and exclusion from irrigation user groups continue to marginalise them within irrigation governance and in ownership of irrigation technology (Agarwal, 2010; Sugden et al., 2021). Together, these variables are theoretically and empirically justified as key factors shaping differentiated access to groundwater irrigation technologies. Their inclusion in the regression models enables a systematic assessment of how social position, material assets, and institutional conditions interact to structure access to irrigation technology.

To test these hypotheses, separate binomial logistic regression models are estimated for each irrigation technology. For tubewells, electric pumps, diesel pumps, and electric meter access, a two-stage modelling strategy is used. Model A uses the full sample and includes binary indicators for land

ownership and land renting to test whether land access, per se, differentiates technology access. Model B restricts the sample to land-owning households and replaces the binary land-ownership variable with landholding categories derived from the survey's agrarian classification system. This specification isolates the role of land scale among landowners without treating landless households as the baseline for all land comparisons. Model A, therefore, captures land as a threshold condition for entry, while Model B tests whether land functions as a gradient within ownership. Across technologies, models also include gender of household head, caste, migration status, and access to complementary infrastructures where relevant, enabling a consistent empirical framing while recognising that technology-specific access mechanisms differ.

4.11.2 Tubewell Access: Fixed Infrastructure and Socio-Spatial Power

Tubewells constitute the most fixed and land-embedded form of groundwater infrastructure in the study area. Unlike mobile pumps, tubewells require the capacity to anchor capital-intensive infrastructure on a specific plot and to sustain that investment over time. They therefore provide the clearest empirical test of Hypotheses H1 and H2 presented in the Section 4.11.1.

Two regression models are estimated. Model A uses the full sample (N = 401) and tests whether land access, per se, differentiates tubewell access. Model B restricts the sample to land-owning households (N = 325) and replaces the binary land indicator with landholding categories, allowing the analysis to isolate the role of land scale among those who already possess land. This structure directly addresses concerns about comparing multiple land categories with landless households and allows a distinction between land as a threshold condition and land as a gradient.

Table 32 reports the binomial logistic regression results for tubewell access. The dependent variable equals 1 if the household owns a tubewell or has secure, regular use rights through rental or shared arrangements, and 0 otherwise.

Table 32 Determinants of Tubewell Access: Binomial Logistic Regression

Predictor	**Model A: Full Sample (N = 401)**				**Model B: Landowners Only (N = 325)**			
	B	**SE**	**OR**	**p-value**	**B**	**SE**	**OR**	**p-value**
Intercept	−2.913	0.674	0.05	< .001	−3.568	0.940	0.03	< .001
Gender of household head (female = 1)	0.249	0.360	1.28	0.488	0.198	0.417	1.22	0.635
Caste (non-Dalit = 1)	−0.037	0.364	0.96	0.920	−0.259	0.449	0.77	0.563

Predictor	Model A: Full Sample (N = 401)				Model B: Landowners Only (N = 325)			
	B	**SE**	**OR**	**p-value**	**B**	**SE**	**OR**	**p-value**
Any household member migrated	−0.373	0.271	0.69	0.169	−0.394	0.306	0.67	0.198
Land ownership (yes = 1)	0.719	0.423	2.05	0.089	–	–	–	–
Land rented (yes = 1)	−0.745	0.304	0.47	0.014	–	–	–	–
Access to diesel pumps (yes = 1)	0.564	0.414	1.76	0.173	0.309	0.437	1.36	0.480
Access to electric pumps (yes = 1)	**3.482**	**0.446**	**32.52**	**< .001**	**3.233**	**0.500**	**25.36**	**< .001**
Electric meter access (yes = 1)	**0.953**	**0.398**	**2.59**	**0.017**	**0.837**	**0.412**	**2.31**	**0.042**
Landholding category (Model B only; ref: Category 1)								
Category 2 vs 1 (3–6 vs ≤ 3 *kattha*)	–	–	–	–	0.615	0.800	1.85	0.442
Category 3 vs 1 (6–15 vs ≤ 3 *kattha*)	–	–	–	–	**1.529**	**0.724**	**4.61**	**0.035**
Category 4 vs 1 (15–30 vs ≤ 3 *kattha*)	–	–	–	–	**1.694**	**0.734**	**5.44**	**0.021**
Category 5 vs 1 (30–60 vs ≤ 3 *kattha*)	–	–	–	–	**2.451**	**0.787**	**11.60**	**0.002**
Category 6 vs 1 (60–90 vs ≤ 3 *kattha*)	–	–	–	–	**3.431**	**1.411**	**30.92**	**0.015**
Category 9 vs 1 (150–300 vs ≤ 3 *kattha*)	–	–	–	–	16.356	1455.398	1.27e+7	0.991
Category10 vs 1 (> 300 vs ≤ 3 *kattha*)	–	–	–	–	16.047	1455.398	9.32e+6	0.991

Model fit:

Model A: McFadden R^2 = 0.328

Model B: McFadden R^2 = 0.308

Note: The dependent variable equals 1 if the household owns a tubewell or has secure, regular use rights through rental or shared arrangements, and 0 otherwise. Coefficients are reported as log-odds (B) with standard errors (SE); odds ratios (OR) are exp(B). Model A (full sample) uses land ownership and land rented as binary indicators. Reference categories for binary predictors are the absence category (0); for example, no tubewell access, no diesel pump access, no electric pump access, and no electric meter access. Model B (landowners only) restricts the sample to households that own land and replaces the binary land variable with landholding categories. The reference category is Category 1 (marginal holders). Landholding categories (Model B) are presented in detail in tables hereon for detail: Category 1 = ≤ 3 kattha (marginal, < 0.1 ha); Category 2 = 3–6 kattha (small, ~0.1–0.2 ha); Category 3 = 6–15 kattha (lower-medium, ~0.2–0.5 ha); Category 4 = 15–30 kattha (medium, ~0.5–1 ha); Category 5 = 30–60 kattha (upper-medium, ~1–2 ha); Category 6 = 60–90 kattha (large, ~2–3 ha); Category 9 = 150–300 kattha (very large, ~5–10 ha); Category 10 = > 300

kattha (estates, > 10 ha). Reference categories across both models are caste = Dalit, gender of household head = male-headed, migration = no migrant member, and land ownership and rental = no. Bolded coefficients indicate statistical significance at p < .05.

Categories reflect locally meaningful agrarian thresholds derived from the survey instrument used by Agriculture Knowledge Centre – a government agency based in Province 2 – and were retained to preserve substantive differences in farm scale. Very large categories have sparse observations and therefore yield unstable estimates; they are reported for completeness. All variance inflation factors are below accepted thresholds, indicating no multicollinearity concerns.

Model A indicates that land operates as a gateway to fixed irrigation, lending partial support to H1. Land-owning households have higher odds of accessing a tubewell ($p = 0.089$), while households cultivating only rented land exhibit substantially lower odds ($p = 0.014$). This asymmetry shows that tubewell access is not simply a function of cultivated area but of tenure security. Fixed groundwater infrastructure is anchored in property rather than in temporary use. Tubewells, therefore, require land as ownership, not merely land as a productive surface.

Model A also shows that complementary infrastructures are decisive. Access to electric pumps is strongly associated with tubewell access ($OR = 32.5$, $p < 0.001$), and access to an electric meter more than doubles the odds ($OR = 2.6$, $p = 0.017$). These results demonstrate that tubewells are embedded within a wider infrastructural assemblage. Technologies accumulate relationally. Entry into one system conditions entry into another, producing zones of compounding advantage and exclusion.

Caste, gender of household head, and migration do not emerge as statistically significant direct predictors in Model A. Caste, in particular, shows no independent effect once land, tenure status, and infrastructure are controlled ($p = 0.920$). This does not imply social neutrality. Rather, it indicates that social power operates upstream, shaping who becomes a landowner, at what scale, and with what institutional visibility. Identity-based exclusions are translated into landlessness, marginal holdings, and infrastructural absence before they appear in regression outputs. Power becomes embedded in property regimes and institutional routines.

Model B demonstrates that land continues to operate as a powerful stratifier among landowners, confirming that land functions not only as a threshold but as a gradient. Relative to households in the smallest landholding group (≤ 3 *kattha*), those cultivating 6–15 *kattha* have over four times the odds of tubewell access ($p = 0.035$). Households in the next category (15–30 *kattha*) have more than five times the odds ($p = 0.021$). For larger landholders, the effect intensifies sharply: households cultivating 30–60 *kattha* have over 11 times the odds ($p = 0.002$), and those in the 60–90 *kattha* range show odds exceeding 30 ($p = 0.015$). These effects are non-linear and at threshold. Marginal

increments in land do not produce proportional gains. Tubewell access becomes viable only once land reaches a scale that can absorb risk, justify sunk costs, and stabilise infrastructure. It is also important to note that the coefficients for the very large landholding categories are large but not statistically significant, which likely reflects sparse observations and heterogeneous land use among the largest landholders, rather than an absence of substantive effect.

Here, the results support H1 by showing that land operates both as a threshold and as a gradient for fixed irrigation, while H2 is supported in a relational sense: social identity shapes access upstream by structuring who becomes a landowner and at what scale.

This pattern reflects the conceptualisation of a bundled architecture of access in this thesis. Land operates as the first material layer in a wider assemblage of property, capital, labour, and institutional recognition. Only households embedded within durable tenure regimes can stabilise tubewells on their fields. Yet, land alone is not sufficient. Its effects are realised through infrastructural alignment and everyday capacity to mobilise labour and recognition.

Migration exhibits a negative association in both models, though it does not reach conventional significance thresholds. Substantively, the direction is meaningful. Tubewells demand embodied presence, coordination, and ongoing management. Out-migration appears to weaken the capacity to construct and maintain labour-intensive fixed infrastructure; at the same time, households with successful migrants may also be less oriented towards agricultural intensification, reducing incentives to invest in fixed irrigation even where remittances are available.

Gender of household headship does not emerge as a direct predictor in either model. As with caste, this absence should not be read as neutrality. Gender of household headship may still matter indirectly through its association with land documentation, household labour arrangements, and institutional visibility, but these pathways cannot be inferred as ‘women’s exclusion’ from household headship data alone. In these models, any gendered effects are more plausibly captured through proximate variables such as land tenure, documentation-dependent infrastructures (for example, electric meters), and the ability to mobilise labour and repair networks.

Viewed through the bundled architecture of access framework, tubewell access is not a discrete adoption decision. It emerges from the cumulative alignment of material assets, tenure security, labour capacity, and infrastructural recognition. Tubewells materialise socio-spatial power. They fix water access on the property, reproduce agrarian hierarchies, and stabilise advantage across seasons and

generations. Fixed irrigation does not diffuse across farms. It follows entrenched structures of land, identity, and recognition.

In the next section, this analytical lens is extended to electric pumps to examine how these structural dynamics persist or are reconfigured in a more mobile, infrastructurally mediated context.

4.11.3 Electric Pump Access: Social Identities, Infrastructural Connections, and Technological Transitions

This section assesses Hypotheses H2 and H3 for a transitional irrigation technology. It asks whether caste and gender are associated with electric pump access, net of land access (H2), and whether electric pumps are patterned more strongly by infrastructural alignment than by land variables alone (H3). Two models are estimated in Table 33. Model A uses the full sample (N = 401) and includes binary indicators for land ownership and land renting. Model B restricts the analysis to land-owning households (N = 325) and replaces the binary land indicator with landholding categories to examine whether land scale differentiates access among landowners.

Table 33 Determinants of Electric Pump Access: Binomial Logistic Regression Results

Predictor	**Model A: Full Sample (N = 401)**				**Model B: Landowners Only (N = 325)**			
	B	**SE**	**OR**	**p-value**	**B**	**SE**	**OR**	**p-value**
Intercept	−0.540	0.681	0.58	0.428	0.364	1.043	1.44	0.727
Gender of household head (female = 1)	−0.878	0.496	0.42	0.077	**−1.412**	0.670	**0.24**	**0.035**
Caste (non-Dalit = 1)	**1.028**	0.401	**2.80**	**0.010**	**1.186**	0.531	**3.27**	**0.025**
Any household member migrated	0.186	0.334	1.21	0.577	0.083	0.406	1.09	0.837
Land ownership (yes = 1)	0.243	0.478	1.28	0.612	–	–	–	–
Land rented (yes = 1)	0.599	0.408	1.82	0.142	–	–	–	–
Access to tubewell (yes = 1)	**3.566**	0.458	**35.39**	**< 0.001**	**3.294**	0.502	**26.94**	**< 0.001**
Access to diesel pumps (yes = 1)	**−1.112**	0.439	**0.33**	**0.011**	−0.329	0.532	0.72	0.537
Electric meter access (yes = 1)	17.612	1082.879	4.45e+7	0.987	18.118	1079.244	7.39e+7	0.987
Landholding category (Model B only; ref: Category 1)								

Predictor	Model A: Full Sample (N = 401)				Model B: Landowners Only (N = 325)			
	B	**SE**	**OR**	**p-value**	**B**	**SE**	**OR**	**p-value**
Category 2 vs 1 (3–6 vs ≤ 3 *kattha*)	–	–	–	–	−1.123	0.812	0.33	0.167
Category 3 vs 1 (6–15 vs ≤ 3 *kattha*)	–	–	–	–	0.304	0.719	1.36	0.673
Category 4 vs 1 (15–30 vs ≤ 3 *kattha*)	–	–	–	–	−0.203	0.725	0.82	0.780
Category 5 vs 1 (30–60 vs ≤ 3 *kattha*)	–	–	–	–	0.258	0.847	1.30	0.760
Category 6 vs 1 (60–90 vs ≤ 3 *kattha*)	–	–	–	–	−0.847	1.541	0.43	0.583
Category 9 vs 1 (150–300 *kattha*)	–	–	–	–	16.052	10754.013	9.36e+6	0.999
Category 10 vs 1 (> 300 *kattha*)	–	–	–	–	16.381	10754.013	1.30e+7	0.999

Model fit:

Model A: McFadden R^2 = 0.432

Model B: McFadden R^2 = 0.450

Note: The dependent variable equals 1 if the household owns an electric pump or has secure, regular use rights, and 0 otherwise. Coefficients are reported as log-odds (B) with standard errors (SE); odds ratios (OR) are exp(B). Significant effects are bolded.

Model A (full sample) includes binary indicators for land ownership and land renting, as well as access to complementary infrastructures (tubewell, diesel pump, and electric meter). Reference categories for binary predictors are the absence category (0); for example, no tubewell access, no diesel pump access, no electric pump access, and no electric meter access.

Model B (landowners only) restricts the sample to households that own land and replaces the binary land variable with landholding categories. The reference category is Category 1 (≤ 3 kattha, marginal holdings). Land categories follow locally meaningful agrarian thresholds derived from the survey instrument: Category 1 (≤ 3 kattha, marginal, reference), Category 2 (3–6 kattha), Category 3 (6–15 kattha), Category 4 (15–30 kattha), and Category 5 (30–60 kattha). Categories 6, 9, and 10 represent progressively larger holdings but contain very few observations and therefore yield unstable estimates; they are reported for completeness. Reference categories across both models are caste = Dalit, gender of household head = male-headed, migration = no migrant member, and land ownership and rental = no. Bolded coefficients indicate statistical significance at $p < .05$.

Electric pumps sit between mobility and fixation. They can be transported across plots, but their use depends on fixed infrastructure such as tubewells and electricity connections, and, in some cases, on formal recognition through the electricity system. In this sense, electric pumps are best read as socio-technical objects embedded in unequal landscapes of land, infrastructure, and institutional visibility (Neumann, 2009; Boelens et al., 2016; Almazán & Prádanos, 2024).

In the full sample (Model A), land ownership is not statistically associated with electric pump access ($p = .612$), and land renting is also not significant ($p = .142$). The strongest associations in Model A

are infrastructural. Households with tubewell access have far higher odds of having an electric pump (OR = 35.39, $p < 0.001$). Diesel pump access is negatively associated with electric pump access (OR = 0.33, $p = 0.011$), consistent with substitution between energy regimes rather than cumulative stacking.

Caste remains important in both models. In Model A, non-Dalit households have higher odds of electric pump access than Dalit households (OR = 2.80, $p = 0.010$). This association persists among landowners in Model B (OR = 3.27, $p = 0.025$), indicating that caste differences are not explained solely by the ownership threshold. This pattern fits an intersectional materiality reading in which social position shapes practical access to bureaucracies, information, and infrastructural opportunities, even among households that already own land (Nightingale, 2011). The case material on meter registration, subsidy procedures, and cooperative membership provides concrete examples of how these advantages are assembled and converted into irrigation access.

Gender shows a different pattern once the models are aligned to the results. In Model A, the association between female-headed households and electric pump access does not reach conventional significance ($p = 0.077$). In Model B, female-headed households have lower odds of electric pump access (OR = 0.24, $p = 0.035$). This marginally significant negative association is notable because bivariate comparisons show higher reported electric pump access among female-headed households; the reversal in Model B suggests that the bivariate pattern is likely confounded by correlated factors (for example, migration-related household composition, infrastructural location, or the conditional landowner-only sample), rather than indicating a simple headship effect. This does not contradict women's day-to-day engagement with pumps. It suggests that, among landowners, household headship remains linked to control over assets, investment decisions, and the ability to mobilise labour and repair networks. The qualitative accounts help interpret how women manage these constraints through practical action, which can be read as effective agency rather than a shift in underlying gendered authority (Molyneux, 1985; Kabeer, 2000). Women described the shift from diesel to electric pumping in terms of daily effort and timing:

> *'The diesel one is heavier and takes more effort to start. We used to wait for someone to help us. Now, we can just turn it on ourselves.' (Field interview, Saptari, December 2023)*

> *'We still need to fix the pipe and check the line. But it is easier than the diesel one. That one would make us tired before we even started watering.' (Field interview, Saptari, December 2023)*

'I cycled to Laukha and bought an electric pump. I used my money from selling vegetables. Now I do not have to worry about irrigation. I can water whenever I need. It gives me peace of mind.' (Field interview, Saptari, December 2023)

These accounts speak to why electric pumps are attractive under gendered labour constraints, but they do not imply empowerment in a structural sense. As Sultana (2011) argues, access and empowerment should not be conflated. Women may operate pumps and coordinate irrigation while still facing limits on recognised ownership, repair support, and decision authority over placement and water distribution. In these terms, the qualitative evidence supports the argument about effective agency, while the regression indicates that asset control among landowners remains gendered.

Land scale does not differentiate electric pump access among landowners in Model B. None of the landholding categories differ significantly from marginal owners (≤ 3 *kattha*) at conventional levels. This runs counter to the expectation that farm size would stratify access to electric pumps. Instead, the pattern suggests that electric pumping is structured less by land scale and more by infrastructural alignment, particularly tubewell access.

Electric meter access has a very large, estimated coefficient but is not statistically significant ($p = 0.987$) and likely reflects sparse cells or separation. For this reason, it is more defensible to interpret meter access primarily through dedicated electric meter models rather than treating it as a stable predictor within the electric pump model. Substantively, the broader pattern across models still points to a bundled architecture: electric pump access clusters around prior groundwater infrastructure, and around social and institutional positioning that shapes who can move into electrified regimes.

Overall, the results clearly support H3. Electric pumps are most strongly patterned by infrastructural connectivity, especially tubewell access, and by substitution away from diesel. H2 is also supported in relation to caste, which remains significant even among landowners. Gender effects are sensitive to specification and are most evident among landowners, where female-headed households have lower odds of access, a pattern best interpreted alongside the qualitative evidence on day-to-day labour, constraints, and coping strategies.

4.11.4 Diesel Pumps and Agricultural Marginality

This section examines Hypotheses H2 and H3 for a transitional irrigation technology. It asks whether social identity continues to shape access beyond land ownership (H2) and whether diesel pumps are structured primarily through exclusion from electrified infrastructure and through substitution

dynamics (H3). As with tubewells and electric pumps, a two-stage modelling strategy is used. Model A estimates associations in the full sample (N = 401). Model B restricts the analysis to land-owning households to examine whether land scale differentiates diesel access among those who already possess land.

Diesel pumps occupy a particular position in the local irrigation landscape. They are mobile and privately procured. They do not require grid connection, meters, or bureaucratic approval. At the same time, they are costly to operate and physically demanding to use. They therefore offer a window into how farmers irrigate when formal and cheaper infrastructure does not reach them.

Table 34 Determinants of Diesel Pump Access: Binomial Logistic Regression Results

Predictor	**Model A: Full Sample (N = 401)**				**Model B: Landowners Only (N = 325)**			
	B	**SE**	**OR**	**p-value**	**B**	**SE**	**OR**	**p-value**
Intercept	−1.861	0.737	0.16	0.012	−2.778	1.270	0.06	0.029
Gender of household head (female = 1)	0.941	0.557	2.56	0.091	1.100	0.643	3.00	0.087
Caste (non-Dalit = 1)	**−1.234**	**0.351**	**0.29**	**< 0.001**	**−1.440**	**0.381**	**0.24**	**< 0.001**
Any household member migrated	−0.040	0.285	0.96	0.887	−0.128	0.311	0.88	0.680
Land ownership (yes = 1)	**0.942**	**0.476**	**2.57**	**0.048**	–	–	–	–
Land rented (yes = 1)	−0.234	0.343	0.79	0.495	–	–	–	–
Access to tubewell (yes = 1)	0.610	0.396	1.84	0.123	0.341	0.428	1.41	0.427
Access to electric pumps (yes = 1)	**−0.955**	**0.419**	**0.39**	**0.023**	−0.390	0.492	0.68	0.428
Electric meter access (yes = 1)	−0.263	0.404	0.77	0.516	−0.340	0.410	0.71	0.406
Landholding category (Model B; ref: Category 1 – ≤ 3 *kattha*)								
Category 2 vs 1 (3–6 *kattha*)	–	–	–	–	1.901	1.138	6.69	0.095
Category 3 vs 1 (6–15 *kattha*)	–	–	–	–	1.553	1.113	4.73	0.163
Category 4 vs 1 (15–30 *kattha*)	–	–	–	–	1.341	1.116	3.82	0.230
Category 5 vs 1 (30–60 *kattha*)	–	–	–	–	1.890	1.136	6.62	0.096
Category 6 vs 1 (60–90 *kattha*)	–	–	–	–	2.002	1.357	7.40	0.140

Predictor	Model A: Full Sample (N = 401)				Model B: Landowners Only (N = 325)			
	B	**SE**	**OR**	**p-value**	**B**	**SE**	**OR**	**p-value**
Category 9 vs 1 (150–300 *kattha*)	–	–	–	–	−12.270	1455.398	~0	0.993
Category 10 vs 1 (> 300 *kattha*)	–	–	–	–	18.862	1455.398	1.56e+8	0.990

Model fit:

Model A: McFadden R^2 = 0.077

Model B: McFadden R^2 = 0.097

Note: The dependent variable equals 1 if the household owns a diesel pump or has secure, regular access, and 0 otherwise. Coefficients are reported as: log-odds (B) with standard errors (SE); odds ratios (OR) are exp(B). Significant effects (p < .05) are bolded. Model A (full sample) includes binary indicators for land ownership and land renting. Reference categories for binary predictors are the absence category (0); for example, no tubewell access, no diesel pump access, no electric pump access, and no electric meter access. Model B (landowners only) restricts the sample to households that own land and replaces the binary land variable with landholding categories. The reference category is Category 1 (≤ 3 kattha, marginal holdings). Land categories follow locally meaningful agrarian thresholds: Category 1 (≤ 3 kattha), Category 2 (3–6 kattha), Category 3 (6–15 kattha), Category 4 (15–30 kattha), Category 5 (30–60 kattha), Category 6 (60–90 kattha), Category 9 (150–300 kattha), and Category 10 (> 300 kattha). Very large categories contain few observations and yield unstable estimates; they are reported for completeness. Reference categories across both models are caste = Dalit, gender of household head = male-headed, migration = no migrant member, and land ownership and rental = no. Bolded coefficients indicate statistical significance at p < .05.

Model A indicates a pronounced caste gradient in access to diesel pumps. Dalit households have substantially lower odds of owning on diesel pumps than non-Dalit households (OR =0.29; $p < 0.001$), consistent with Table 34. This caste gradient in diesel pump ownership cannot be attributed to formal eligibility barriers alone, since diesel pumps are commercially available without land documentation requirements. It reflects instead capital constraints, exclusion from second-hand and rental machinery markets, and caste structured social networks that mediate access to information about pump availability and pricing. This finding deepens the bundled architecture of access argument: differential access operates through informal social markets as well as formal institutional channels. Dalit farmers are not simply excluded from electric infrastructure; they also face barriers to the costlier, less efficient alternative.

This aligns closely with qualitative evidence. In one interview, a Dalit woman explained that the landowner from whom she leased land had rented electrified plots to a fishery entrepreneur, forcing her onto a more distant parcel without electricity.

> *'The land with wire went to someone else, we had to go where there is no line.' (Field interview, Saptari, November 2023)*

This is infrastructural exclusion in practice. It works through spatial sorting rather than overt refusal. Yet 'access' in the regression sense does not mean affordability or autonomy. Farmers repeatedly spoke about the burden of diesel irrigation:

> *'The land we have is not enough to afford a pump. The better-off families can get electric or diesel pumps, but for us, it's only hand pumps or nothing.' (Field interview, Saptari, December 2023)*

Another added:

> '*Yes, diesel pumps are available for rent, but the cost… sister, the cost is too much. Sometimes we have no choice. Our paddy needs water, so we rent one. But then we are left wondering how to pay for it.' (Field interview, Saptari, November 2023)*

What appears statistically as access often signals deeper exclusion from state provisioning and infrastructural transition. Land remains a material gate within this architecture. In Model A, land ownership increases the odds of diesel pump access ($p = 0.048$), indicating a threshold effect. Diesel systems become viable only once households cultivate enough land to justify fuel, maintenance, and rental costs. Model B shows that this threshold persists among landowners, but with weaker statistical precision. Relative to marginal holders (≤ 3 *kattha*), households cultivating 3–6 *kattha* and 30–60 *kattha* exhibit substantially higher odds of diesel access (OR ≈ 6–7), although these effects fall just short of conventional significance. This pattern suggests that diesel pumps occupy a middle tier: largely unattainable for the smallest farmers, increasingly viable for those cultivating beyond marginal scales, and gradually displaced among the largest and best-connected households.

This produces a segmented landscape. Smallholders remain dependent on manual or informal water sources. Medium landholder farmers rely on diesel as a costly bridge. Larger and better-connected farmers transition to electric systems. Within the bundled architecture of access, diesel functions as a technology of take-up rather than continuation. It enables irrigation where infrastructure does not reach, but it rarely moves farmers toward recognised, subsidised, or low-cost systems.

The substitution dynamic between diesel and electric pumps reinforces this reading. In Model A, households with electric pumps are significantly less likely to use diesel ($p = 0.023$). Once a household invests in one system and its routines, with its energy source and maintenance practices, switching becomes unlikely. Diesel and electric pumps, therefore, form divergent pathways rather than complementary layers.

Gender does not reach conventional significance ($p = 0.091$), yet the direction of effect suggests that male-headed households are more likely to access diesel pumps. This resonates with Sultana's (2009) account of embodied technological practice. Diesel pumps require lifting heavy machinery, handling fuel, and carrying out mechanical repairs, all of which are shaped by masculine norms of labour competence. At the same time, qualitative accounts show that women often arrange rentals, negotiate access, and manage irrigation in migration-affected households (Quisumbing & Pandolfelli, 2010; Suhardiman et al., 2023). These forms of participation remain invisible in household-level ownership data.

Overall, the regression results and qualitative accounts show that diesel pump access arises from the intersection of material scarcity, caste positioning, and institutional omission. Diesel pumps persist where electrification does not reach, where documentation is absent, and where farmers remain outside bureaucratic recognition. They enable irrigation, yet confine users to high-cost, high-labour, and low-legitimacy systems.

Rather than reflecting individual choice, diesel adoption is better understood as a relational outcome shaped by land thresholds, caste hierarchies, and infrastructural absence (Ribot & Peluso, 2003; Birkenholtz, 2017). Within the bundled architecture of access, diesel pumps occupy a lower but resilient tier: a technology of coping that enables irrigation under exclusion, yet rarely enables transition into recognised and affordable regimes of use. Therefore, these findings support H2 by showing that caste continues to shape irrigation access beyond land ownership, and they support H3 by locating diesel pumps within a pathway of exclusion. Diesel irrigation emerges not as a step toward modernisation, but as a durable response to being left outside electrified regimes.

4.11.5 Electric Meter Access and the Politics of Rural Electrification: Materiality, Land, and Infrastructural Citizenship

This section examines Hypotheses H1 and H3 for an institutional irrigation infrastructure. It asks whether land access is associated with electric meter ownership (H1) and whether access is structured through sequential infrastructural alignment rather than solely through household characteristics (H3). Two models are estimated. Model A uses the full sample to assess whether land ownership differentiates access. Model B restricts the sample to land-owning households to examine whether land scale matters once the ownership threshold is crossed.

Table 35 Determinants of Electric Meter Access: Binomial Logistic Regression Results

Predictor	**Model A: Full Sample (N = 401)**				**Model B: Landowners Only (N = 325)**			
	B	**SE**	**OR**	**p-value**	**B**	**SE**	**OR**	**p-value**
Intercept	−19.799	638.958	2.52e-9	0.975	−19.391	823.361	3.79e-9	0.981
Gender of household head (female = 1)	0.043	0.409	1.04	0.917	0.135	0.435	1.15	0.755
Caste (non-Dalit = 1)	−0.406	0.429	0.67	0.344	−0.672	0.439	0.51	0.126
Any household member migrated	0.374	0.282	1.45	0.186	0.337	0.292	1.40	0.249
Land ownership (yes = 1)	**1.734**	0.808	**5.66**	**0.032**	–	–	–	–
Land rented (yes = 1)	−0.271	0.327	0.76	0.407	–	–	–	–
Access to tubewell (yes = 1)	**0.930**	0.397	**2.54**	**0.019**	**0.853**	0.420	**2.35**	**0.042**
Access to diesel pump (yes = 1)	−0.266	0.404	0.77	0.510	−0.256	0.417	0.77	0.540
Access to electric pump (yes = 1)	16.521	638.957	1.50e+7	0.979	17.213	823.361	2.99e+7	0.983
Landholding category (ref: Category 1 – ≤ 3 *kattha*)								
Category 2 vs 1 (3–6 *kattha*)	–	–	–	–	1.262	1.188	3.53	0.288
Category 3 vs 1 (6–15 *kattha*)	–	–	–	–	0.436	1.137	1.55	0.702
Category 4 vs 1 (15–30 *kattha*)	–	–	–	–	0.987	1.134	2.68	0.384
Category 5 vs 1 (30–60 *kattha*)	–	–	–	–	0.819	1.152	2.27	0.478
Category 6 vs 1 (60–90 *kattha*)	–	–	–	–	1.328	1.304	3.77	0.309
Category 9 vs 1 (150–300 *kattha*)	–	–	–	–	−17.042	6522.639	3.97e-8	0.998
Category 10 vs 1 (> 300 *kattha*)	–	–	–	–	−16.786	6522.639	5.13e-8	0.998

Model fit:

Model A: McFadden R^2 = 0.171

Model B: McFadden R^2 = 0.138

Note: The dependent variable equals 1 if the household has an electric meter and 0 otherwise. Coefficients are reported as log-odds (B) with standard errors (SE); odds ratios (OR) are exp(B). Significant effects are bolded ($p < .05$).

Model A (full sample) includes binary indicators for land ownership and land renting. Reference categories for binary predictors are the absence category (0); for example, no tubewell access, no diesel pump access, no electric pump access, and no electric meter access.

Model B (landowners only) restricts the sample to households that own land and replaces the binary land variable with landholding categories. The reference category is Category 1 (≤ 3 kattha, marginal holdings). Land categories follow locally meaningful agrarian thresholds: Category 1 (≤ 3 kattha), Category 2 (3–6 kattha), Category 3 (6–15 kattha), Category 4 (15–30 kattha), Category 5 (30–60 kattha). Categories 6, 9, and 10 represent progressively larger holdings but contain very few observations, producing unstable estimates; they are retained for completeness. Reference categories across both models are caste = Dalit, gender of household head = male-headed, migration = no migrant member, and land ownership and rental = no. Bolded coefficients indicate statistical significance at p < .05.

Electric meters represent formal enrolment within the state electricity system. Access requires proximity to grid infrastructure, payment of connection fees, and documentary proof of land ownership. Meters, therefore, provide a test of whether irrigation access is patterned primarily by material endowments or by institutional recognition.

In Model A, land ownership is significantly associated with access to an electric meter. Land-owning households have markedly higher odds of possessing a meter than landless households (OR = 5.66, p = 0.032). This pattern supports H1 and indicates that meter access is sharply differentiated at the point of ownership. In Model B, which is conditional on land ownership, none of the landholding categories differ significantly from marginal owners (≤ 3 *kattha*). Once the ownership threshold is crossed, additional land scale does not produce systematic variation in meter access. The results thus indicate a threshold effect rather than a gradient.

This aligns with the institutional design of rural electrification. The Nepal Electricity Authority requires formal land documentation for meter registration, rendering tenants and those cultivating under informal arrangements ineligible. As one farmer in Ward 2 explained:

> *'Without land, who will give us a meter? Even if we could pay the deposit, we need land documents. That is why only those with their own fields, or at least some secure lease, can apply.' (Field interview, Saptari, July 2023)*

Within the bundled architecture of access, land thus operates as the primary institutional gate. Ownership converts directly into eligibility.

The models also identify a consistent association between tubewell access and electric meter ownership. In the full sample, households with tubewells have higher odds of possessing a meter (OR = 2.54, p = 0.019). This relationship persists among landowners (OR = 2.35, p = 0.042). This pattern is consistent with H3 and points to a sequential process of infrastructural alignment, in which prior investment in groundwater infrastructure is associated with subsequent electrification.

A farmer from Ward 4 described this progression:

'First, we dug a tubewell with others. Then we used diesel. But diesel became expensive. An electricity pole was constructed near our farms some years ago. So, when my brother returned from the Gulf, we tried for an electric meter to reduce costs.' (Field interview, Saptari, August 2023)

Although migration does not reach statistical significance (p = 0.186 in Model A), such accounts show how remittance income often enables infrastructural upgrading, linking social mobility with material accumulation.

Diesel pump access is not significantly associated with meter ownership in either model (p = .510 in Model A; p = 0.540 in Model B). Diesel and electric systems appear as parallel rather than sequential pathways. Diesel sustains irrigation where formal electrification is absent or institutionally inaccessible, rather than serving as a direct stepping stone into the electric regime.

Gender of household head, caste, age, and education do not emerge as statistically significant predictors. This should not be read as social neutrality. Instead, it indicates that exclusions are mediated through proximate variables such as land tenure and documentation. When ownership is unequally distributed and bureaucratically encoded, its effects absorb and obscure the workings of social identity within the regression.

This is illustrated in a video case study in Chapter Five of a Dalit tenant farmer whose attempt to secure a subsidised meter was blocked by his tenure status. Despite having the capital and procedural knowledge, his informal lease rendered him ineligible. His experience shows how exclusion operates through administrative criteria rather than overt refusal.

In regression terms, electric meter access is patterned by layered conditions. Materially, it is associated with prior infrastructure such as tubewells. Institutionally, it is conditioned by ownership-based eligibility. Within the bundled architecture of access, meter ownership marks the point at which material capacity and bureaucratic recognition align, while landlessness marks the point at which infrastructural aspiration is deferred.

4.12 Discussion: Irrigation as Bundled Access, Not Individual Adoption

This chapter has shown that groundwater irrigation in Shambhunath Municipality is not a matter of simple technological choice or infrastructure availability. Instead, access unfolds through what this thesis conceptualises as a bundled architecture of access: a cumulative alignment of material, social, and institutional (discussed in detail in chapters Six and Seven) layers that together determine who can adopt, operate, and sustain irrigation technologies. These layers include: material infrastructures such as tubewells, pumps, and electric meters; social positioning shaped by caste, gender of head of

household, class, and tenure; and institutional recognition that confers or withholds legitimacy. Access is therefore neither binary nor linear. It is a layered achievement that requires navigating sequential thresholds of inclusion and exclusion (Ribot & Peluso, 2003; Mosse, 2004; Boelens, 2016; Bijker, 1995).

The multivariate analyses presented in this chapter provide empirical grounding for this argument. Tubewell access is the strongest predictor of both electric-pump use and electric-meter ownership. Land ownership serves as a gateway to fixed irrigation, while land scale determines which landowners can stabilise capital-intensive infrastructure. Electric pumps and meters emerge not as standalone devices but as downstream layers that become available only once prior material and institutional conditions are met. Diesel pumps persist in the spaces left behind by electrification, sustaining irrigation where formal infrastructures and bureaucratic recognition do not reach. Irrigation access consequently accumulates rather than diffuses. Each layer builds on the last, producing infrastructural momentum for some households and compounding exclusion for others.

This perspective departs from technocentric accounts that treat adoption as a rational decision shaped by income, awareness, or efficiency. Instead, it situates irrigation technologies within the intertwined politics of land, infrastructure, and recognition. The regressions show that access is not merely about having resources but about being positioned within a socio-technical field that privileges some trajectories and forecloses others. Caste remains significant even after controlling for land, and tubewell access consistently dominates all downstream outcomes, indicating that inequality is produced through structural alignment rather than individual choice.

4.12.1 Access as a Cumulative and Layered Process

The first central insight of this chapter is that irrigation access is cumulative and layered. Participation in one system is a condition for entry into the next. Tubewells enable electric pumping. Electric pumping becomes viable only with meter access. Meter access depends on ownership and documentation. The models demonstrate this sequential logic. In the tubewell regressions, electric pump access multiplies the odds of tubewell access, and electric meter access further increases them. In the electric pump models, tubewell access is the single strongest predictor. In the electric meter models, tubewell ownership again plays a decisive role. Infrastructure begets infrastructure.

This layered structure reproduces inequality through accumulation. Households that manage to establish the first layer, often through land ownership or social capital, gain durable advantages.

Subsequent layers become cheaper, easier, and institutionally supported. By contrast, households excluded from the first layer face mounting barriers as each successive technology presumes what they lack. This is the essence of bundled exclusion, multiplied by each infrastructural gap.

The land categories used in this chapter make these dynamics visible. For tubewells, marginal landholders with less than 3 *kattha* remain largely excluded. Access rises sharply only once land reaches 6–15 *kattha,* and accelerates thereafter. These threshold effects show that land does not operate as a smooth gradient of advantage. Instead, it functions as a gate that must be crossed before fixed infrastructure becomes viable. The property rule is evident here. Land tenure structures not only determine who controls water but also which infrastructures can exist in the first place.

For electric meters, the pattern is even starker. Land ownership is significant in Model A, whereas land scale is not in Model B. Meter access hinges on whether one owns land, not how much. This reflects the institutional design of electrification, in which document ownership directly translates into eligibility. Once the ownership threshold is crossed, additional land does not systematically increase access. Here, land operates not as an economic resource but as an administrative credential.

Therefore, these findings show that irrigation inequality is not primarily a problem of diffusion or awareness. It is a structural property of the technological field. Access requires alignment across multiple layers. When any layer is missing, the entire bundle becomes unstable.

4.12.2 Technology Pathways and Positionality

A second insight concerns the differentiated technological pathways through which farmers engage in irrigation. The regressions reveal a clear junction between diesel and electric systems. Diesel pumps concentrate among households excluded from electrification, particularly Dalit and land-poor households represented in Models A and B, confirming that diesel operates as a technology of last resort rather than a pathway of advancement. Electric pumps are clustered with tubewells and meters (Mitchell et al., 2021). The negative association between diesel and electric pumps confirms the logic of substitution rather than complementarity. Once a household invests in one system and its routines, energy source, and maintenance practices, switching becomes unlikely (Mottaleb, 2018).

These pathways are not merely technical; they are positional. Electric systems flourish in the upper layers of the bundle, among households that have cleared bureaucratic hurdles and secured institutional recognition. Diesel persists in the lower layers, enabling irrigation under exclusion.

Bijker's (1995) notion of interpretive flexibility becomes visible here. The same pump signifies stability and entitlement for one group, and debt and exhaustion for another. Technologies are read and used through the lens of social position.

Electrification reduces running costs and the need for physical labour. It allows women and older farmers to irrigate independently. Yet, these benefits remain conditional upon grid access and documentation. What appears as technological progress is therefore the outcome of political sorting, of who counts as an energy citizen (Von Schnitzler, 2013). Diesel irrigation, by contrast, signals endurance under constraint. It keeps crops alive while binding farmers to high costs and precarious arrangements.

4.12.3 Agency Under Constraint

A third insight concerns agency under constraint. The chapter reveals patterns that complicate straightforward readings of exclusion. Dalit households show substantially lower odds of owning diesel pumps, and the analysis suggests this reflects not only capital constraints but exclusion from informal social markets through which second hand equipment circulates. Yet female-headed households report higher electric pump access rates, in the bivariate comparisons, although the difference is only marginally significant. In the multivariate models, however, female headship is associated with lower odds of electric pump access among landowners, suggesting that women's day-to-day operation of pumps does not necessarily translate into control over assets, repair networks, or investment decisions (cases discussed in Chapter Five).

Dalit farmers' reliance on diesel reflects infrastructural exclusion. Many lease land in areas without electric lines or formal eligibility. They adopt costlier, more labour-intensive technologies that are less popular among dominant groups. This is a tactical reversal in Li's (2007) sense. It secures practical access while reinforcing dependence. Similarly, women's higher use of electric pumps reflects labour shortages created by male migration. Drawing on Kabeer (2000), this is effective rather than transformative agency. It enables coping without reworking the underlying distribution of authority.

These findings extend science and technology studies by providing quantitative evidence for interpretive flexibility in practice. Different groups form distinct relationships with the same artefact because they occupy different positions within the access architecture. These findings also nuance political ecology by showing that agency operates within, not outside, structural constraints. Farmers

work the bundle; they borrow, rent, share, and improvise. Yet, these strategies rarely accumulate into lasting inclusion.

4.12.4 Relational Bricolage and Informal Access

A fourth insight concerns the centrality of informal and relational access. Formal ownership of technology remains rare, especially on rented land. Yet, irrigation persists through dense webs of borrowing, renting, and sharing. These arrangements illustrate Ribot and Peluso's (2003) distinction between access and property. Farmers mobilise kinship, caste, and neighbourhood ties to secure temporary water (examples are presented in Chapter Five). Cleaver's (2007) notion of relational bricolage captures this practice. Irrigation becomes a social achievement rather than a purely technical one.

For tenant farmers, these networks are indispensable. Women often coordinate these exchanges, leveraging reciprocity where bureaucratic recognition is absent. These practices represent relational repair within the bundle. They compensate for missing institutional layers, yet they remain fragile. They collapse when relations sour or when state programmes privilege documented ownership, displacing long-standing arrangements.

This has direct policy implications. Interventions that focus only on distributing equipment or extending credit risk undermining the very social infrastructures that sustain irrigation. Carefully recognising cooperative forms of ownership, supporting a longer-term engagement, factoring in the role local-level power plays in seeking benefits (among community members), and legitimising and enabling an environment for shared meters or pumps could transform bricolage into stability (Huyer, 2016; Mirhanoğlu et al., 2023).

4.12.5 Institutional Recognition and Infrastructural Citizenship

The final layer of the bundle is institutional recognition. The electric meter crystallizes this layer. It is an artefact of infrastructural citizenship (Von Schnitzler, 2013). It delivers energy and confers legitimacy. The regressions show that land ownership sharply differentiates access to meters. Tubewell ownership further increases it. Qualitative cases show how document requirements translate social hierarchies into administrative outcomes. Dalit tenants with savings and knowledge remain ineligible because their leases are informal and maybe landless. Women must apply through male relatives even when they manage farms.

These exclusions operate through procedural neutrality. As Ferguson (1990) and Li (2007) argue, bureaucratic rules depoliticise inequality by encoding it as eligibility. Knowledge alone cannot overcome this gatekeeping. Only a fraction of those aware of subsidies obtain them. Technological access, therefore, becomes inseparable from recognition, and creating an enabling environment to support farmers with such a lack can help them to access subsidised groundwater.

4.13 Conclusion

This chapter has shown that irrigation access is produced through layers of a bundled architecture of access that aligns land, infrastructure, and legitimacy. Regression models reveal the structural contours of this architecture. They show where thresholds lie, how gradients form, and where substitution occurs. Yet, they cannot capture how these layers are lived, negotiated, and felt.

Chapter Five turns into this lived terrain. Through video and photo case studies of landless and marginal women farmers, it traces how irrigation unfolds in practice. These women navigate the lower tiers of the bundle. They borrow pumps, stretch hoses across boundaries, carry fuel, negotiate with neighbours, and time irrigation around others' schedules. Their stories show what it means to irrigate without ownership, to depend on relations rather than rights, and to work within infrastructures that were never designed for them.

If this chapter maps the architecture, the next inhabits it. It moves from statistical patterns to embodied labour; from thresholds and odds ratios to fatigue, improvisation, and care. Together, they show that groundwater irrigation in rural Nepal is not only a technical system. It is a lived politics of access.

5 Chapter Five: Living with Irrigation: Gendered Labour, Tenurial Insecurity, and Everyday Water Access

5.1 Introduction

Building upon the preceding chapter's analysis of how land tenure, caste, class, and gender relations condition access to groundwater via tubewells and pumps, Chapter Five undertakes an in-depth exploration of the lived realities shaped by these intersecting structures. It moves beyond statistical associations to ethnographic inquiry, through video and photo case studies, in order to understand how marginalised farmers adopt and engage with irrigation technologies in everyday life.

In the agriculturally intensive yet ecologically vulnerable Terai region of Nepal, access to groundwater has become increasingly indispensable for sustaining rural livelihoods. This shift is driven by changing rainfall patterns and the broader transformations accompanying agrarian change. While the literature on irrigation technologies has largely focused on their economic efficiency, market integration, and formal institutional frameworks (Shah, 2009), relatively limited attention has been paid to the social and political dimensions of technology adoption, particularly how historically marginalised farmers navigate access under informal and unequal conditions. This chapter addresses this gap by foregrounding the everyday experiences of tenant, landless, Dalit, and women farmers, examining how they adopt, adapt, and repurpose irrigation technologies within a context of structural constraint and limited institutional support.

The analysis extends the prior chapter's findings by examining how groundwater access is mediated through entrenched social hierarchies and property regimes. By engaging in detailed case-based research, this chapter seeks to illuminate how these structural relations manifest in practice. The five case studies presented herein were deliberately selected to capture the complexity of marginal farmers' engagement with irrigation technologies. While all selected cases feature households that have managed to access groundwater infrastructure, this selection is intentional: the aim is to learn from the practices, negotiations, and everyday strategies through which access is secured and maintained. These cases offer insight, not only into success, but also into struggle, breakdown, and improvisation.

The theoretical orientation of this chapter draws from science and technology studies (STS), particularly frameworks that view technology as socially constructed and embedded within power-laden social relations (Bijker et al., 1987). The social construction of technology (SCOT) framework

(Pinch & Bijker, 1984) provides a useful lens for analysing how different social groups interpret, engage with, and shape technologies in ways that reflect their situated interests and constraints. This perspective is extended to the rural South Asian context, where caste-based hierarchies, gender norms, precarious land tenure, and class relations constitute highly uneven terrains of technological access and use (Udas & Zwarteveen, 2010; Sharma, 2021).

The five case studies – drawn from Wards 2 and 4 of Shambhunath Municipality – capture both the barriers encountered, and the innovative strategies employed, by farmers navigating multiple forms of marginality. These include: a Dalit household operating a diesel pump rental enterprise; a tenant farmer preparing for electrification amidst the constraints of the *mohiyani* tenure system; a woman managing irrigation in a household affected by male migration; a woman intermittently supported by her natal family to operate an electric pump; and a single woman who has incrementally secured both land and irrigation infrastructure. Together, these cases illuminate how persistent structural inequalities coexist with, and are sometimes contested by, acts of agency, adaptation, and community-based cooperation. Vignettes are considered an underutilised yet necessary method for understanding gender norms as well as the social and informational barriers that contribute to the low adoption of agricultural technologies, while also revealing how men and women adopt these technologies differently (Surendran-Padmaja et al., 2023); hence, I have used four video studies and one photo case study as vignette-based approaches to explore how groundwater is accessed and how irrigation technologies are adopted.

This chapter argues that irrigation technology adoption among marginalised farmers is not a linear process of diffusion nor a mere function of affordability. Rather, it constitutes a relational and negotiated practice involving interactions with landowners, kin networks, neighbours, state actors, and the material technologies themselves. Outcomes are shaped by both the constraining effects of entrenched inequalities and the enabling possibilities afforded by social networks, diverse livelihood strategies, and individual initiatives. Attending to this dialectic between structure and agency offers deeper insight into the differentiated trajectories of technology adoption among resource-poor farmers.

The broader contribution of this chapter lies in its reconceptualisation of technology adoption as a socially embedded process. By situating irrigation technology use within broader systems of exclusion and informal negotiation, it challenges dominant policy discourses that prioritise technical and economic interventions while neglecting the socio-institutional contexts that shape access. The

analysis calls for more context-sensitive policy designs that explicitly account for caste, gender, and class-based exclusions in irrigation provisioning.

Methodologically, this chapter contributes to irrigation and development studies by demonstrating the utility of video ethnography and narrative documentation in capturing the social, material, and embodied dimensions of technology use. Four case studies are based on extended video recordings of irrigation practices, enabling direct observation of labour processes, technical improvisations, and gendered divisions of work; dimensions often absent from survey-based or interview-only methods. The fifth case draws on in-depth narrative interviews and visual documentation to highlight the temporal and affective dimensions of technological engagement.

Case selection was guided by theoretical sampling to capture heterogeneity across caste, gender, land tenure, and pump type, with all cases reflecting marginality along at least one of these axes. Each case documents not only the use of irrigation technology but also household composition, land access modalities, labour arrangements, social networks, and the historical trajectories of access to technology. Particular attention is paid to how farmers navigate the intersection of formal rules and informal practices in securing and maintaining irrigation infrastructure.

Rather than presenting isolated 'success stories' the cases are treated as sites through which the everyday dynamics of exclusion, negotiation, and adaptation can be understood. The analysis foregrounds the social labour and technical improvisation that characterise technology use among marginalised groups, offering a nuanced and textured account of irrigation practice under constraint.

In doing so, the chapter underscores the need to move beyond reductive accounts of technological adoption, and instead attend to its social and political underpinnings. By centring the voices and practices of those most affected by systemic exclusion, it contributes to a more grounded and inclusive understanding of how irrigation technologies are accessed, contested, and repurposed in rural Nepal.

5.2 Case Narratives

5.2.1 Case 1: Dalit Household Irrigation Enterprise and Gendered Technological Adaptation

This case focuses on a Dalit household in Sakhuwa, Shambhunath Municipality, that has built a livelihood around renting diesel pumps to neighbouring farmers. What makes this case particularly significant is not only the household's upward mobility through technological entrepreneurship but also the gendered configuration of labour and expertise that underpins their irrigation enterprise.

Despite systemic exclusions in accessing land, credit, and public infrastructure (Cameron, 2010), this family has managed to position itself as one of the diesel-based irrigation service providers in its locality.

Figure 12 Link to Video Case One; or Click on the Play Button to Watch

The household consists of a nuclear family (husband, wife, and two sons aged 4 and 10), with extended kin residing in adjacent dwellings. Their entry into irrigation entrepreneurship began approximately 18 years ago, when the male head of household migrated to Kathmandu to take up wage labour in the furniture manufacturing sector. The income he earned there provided the initial capital to purchase their first diesel pump, an important infrastructural asset that laid the foundation for their current business. Over time, they expanded their local enterprise to three pumps, including a second-hand purchase for NPR 14,000.

They now offer pump rental services at NPR 300 per hour (recently raised from NPR 250 due to diesel price hikes), including the pump, diesel, and necessary piping. For an additional NPR 500 per day,

farmers can hire labour for water channelling and distribution, though this is chosen by only a minority of renters. The business serves farmers who lack access to their own irrigation infrastructure, thereby filling a critical gap.

While the technical and economic aspects of this irrigation enterprise are often foregrounded in assessments of adoption, what is equally important, though frequently overlooked, is the gendered labour that sustains the system. The male household head is primarily responsible for the visible and technically coded work of transporting and operating the diesel pumps. However, it is the woman in the household who takes charge of field-level irrigation management on their own farm: deciding when and how to irrigate, maintaining temporary channels, and adapting irrigation techniques based on specific crop-water needs. For instance, she distinguishes between flood irrigation for wheat and a more labour-intensive, plate-based sprinkling method for lentils and flaxseed, as documented in the video. These forms of labour, while central to farm water management, may go unrecognised in formal policy narratives or development programming (Ahlers & Zwarteveen, 2009).

The division of labour in this household is not simply a case of gendered task differentiation; it also reflects broader social hierarchies in the way technological skill is defined and valued. Pump operation is often equated with technology use, while field-level irrigation management, performed largely by women, may be treated as secondary or supportive. This renders a significant portion of irrigation labour invisible, particularly in contexts where irrigation is narrowly defined as the manipulation of mechanical infrastructure (Meinzen-Dick & Zwarteveen, 1998). Yet, as the video documentation of this case shows, irrigation is a labour-intensive, embodied, and ongoing set of practices that require physical stamina and knowledge of farm water management.

The household's 10-year-old son also assists with irrigation work by accompanying his mother to the fields and monitoring water flow across plots. This illustrates the intergenerational labour contribution. At the same time, such everyday practices around farm and water lead to transmission of situated irrigation knowledge outside of formal training or extension programmes, further reinforcing the idea that technological learning and innovation do not occur only through institutionalised mechanisms but also through everyday practice in the family and the field (Leder et al., 2017).

Importantly, the household has also used income from the irrigation business to secure land. They now own three *kattha* for vegetable cultivation and sharecrop an additional one *bigha* for paddy and wheat. In a region where caste-based barriers to land ownership remain significant (Sharma, 2021),

this trajectory of land purchase through irrigation entrepreneurship is notable. It creates a virtuous cycle: access to irrigation technology enables land cultivation, which in turn supports agricultural income and further investment in infrastructure.

The case also reflects evolving gender dynamics within the broader farming community. The husband notes that more women are now renting pumps, a shift linked to men's out-migration for off-farm work. This changing client base does not necessarily indicate a straightforward empowerment narrative, as most pump services are still controlled and mediated by male providers. However, it does signal the growing presence of women as irrigation decision-makers, a trend that development actors should consider when designing irrigation support programmes.

Thus, this case illustrates how marginalised households can navigate structural constraints by strategically adapting technology, combining off-farm income, entrepreneurial initiative, and gendered labour to build irrigation-based livelihoods. It also challenges narrow definitions of irrigation work and technology use by demonstrating how women's roles in water management, though often unrecognised, are central to the sustainability and success of such enterprises. This case highlights irrigation labour, which includes not only pump operation but also intensive fieldwork in water application, distribution, and crop-level decision-making, carried out by men, women, and children.

5.2.2 Case 2: Tenant Farmer – Proactive Adaptation Under Tenure Constraints

The second case centres on a tenant farmer from the Sarala caste who demonstrates strategic adaptation to irrigation constraints within the confines of limited land tenure security. His story exemplifies how smallholders, despite historical exclusions from landownership and irrigation infrastructure, actively seek to transform their farming possibilities through calculated investments and the creative use of institutional knowledge.

The farmer currently cultivates 36 *kattha* of land, of which 18 *kattha* are held under the *mohiyani hak* (registered tenancy rights) system. This legal provision, although granting him the right to cultivate and claim a share of the land's produce, does not provide full land ownership or the legal authority to register for certain infrastructural entitlements. His family's connection to the land traces back to the historical *zamindari* system, during which their tenancy relationship was first established. The current landowner resides in India and returns annually to claim a share of the harvest, resulting in a semi-

stable yet constrained tenure arrangement that precludes complete long-term security or autonomy in infrastructure planning.

Figure 13 Link to Video Case Two; or Click on the Play Button to Watch

Despite these limitations, the farmer has made significant investments in groundwater irrigation. He has installed two tubewells at depths of 105 and 155 feet, an expensive undertaking given his tenure status. These installations, financed independently, represent a proactive response to increasing water stress and the demands of commercial agriculture. As documented in the field video, he has also begun preparations for a potential electric pump connection, a shift from his current reliance on labour-intensive manual pumps. His ability to make these investments is made possible by his complementary off-farm employment as a government school peon, a stable income stream that provides financial cushioning and planning flexibility. He summarises his farming philosophy as:

> *'Hold a government job, grow vegetables.'*

This encapsulates a hybrid livelihood model common among adaptive tenant farmers (see Sugden et al., 2021). The farmer's strategic investments are not only technical but also institutional. He has repeatedly engaged in bureaucratic efforts to access subsidies and secure formal electric meter connections. These include multiple visits to Ward offices and electricity authorities, lobbying through his local Ward Chairperson, and developing an understanding of government procedures. Yet, despite his persistent engagement, he remains excluded from formal electrification due to legal ambiguities surrounding his land tenure. The physical proximity of installed electric poles, visible just three poles away from his fields, stresses the irony of infrastructural exclusion under partial tenure. His case illustrates what scholars have referred to as infrastructural reach without infrastructural rights (Anand, 2017), in which visible state investment does not translate into inclusion in services.

The farmer's irrigation practices are shaped by both his financial capacity and the infrastructural constraints of his tenure status. Although he currently uses a labour-intensive manual handpump to irrigate his fields, capable of covering only 1.00-1.15 *kattha* per session, he is actively planning a shift to electric-powered irrigation. Video footage from the field captures the physical exertion involved in this manual method and the logistical limitations it imposes on farming. Having experimented previously with petrol and diesel pumps, he ultimately rejected these technologies due to high recurring fuel costs and limited economic returns. His interest in an electric pump is based on a clear cost-benefit rationale: he estimates that, with access to subsidised electricity tariffs, the infrastructure costs could be recovered within five to six months, highlighting a keen understanding of the technological costs he would incur (Rana et al., 2021).

What is particularly notable in this case is the farmer's sustained engagement with local institutions in pursuit of an electric irrigation subsidy. He has made repeated visits to Ward offices, land management, and the local electricity authority, coordinated through the Ward Chairperson, and gradually developed familiarity with bureaucratic procedures. Yet, despite his sustained efforts and growing institutional literacy, he remains excluded from formal access to the electric subsidy, largely because his legal land tenure status does not meet the eligibility criteria. The infrastructural injustice is made especially visible in his own account: electric poles have been installed up to three poles away from his field, but his application for a meter connection has been stalled indefinitely. This disjuncture between the visible presence of state infrastructure and the inability to access it reflects what scholars have termed infrastructural reach without infrastructural rights (Anand, 2017), a phenomenon where the state's developmental presence is materially observable but institutionally inaccessible.

In addition to his irrigation investments, the farmer has developed a diversified and entrepreneurial farming strategy. He directly cultivates 28 *kattha*, while leasing out an additional 10 *kattha* for fish farming at a rental rate of three *maan* per *kattha* per year. His cropping pattern includes staple grains as well as high-value crops such as vegetables and bananas, indicating a shift toward commercial-oriented agriculture. He anticipates that electrified irrigation and subsidy would increase his annual profits by NPR 25,000 to 30,000, further reinforcing the economic logic of his infrastructural aspirations.

Largely, this case highlights the layered complexities of technology adoption among tenant farmers. Tenure insecurity operates as a key institutional barrier, preventing access to subsidised irrigation infrastructure even for farmers who demonstrate financial capacity and bureaucratic persistence. Nevertheless, the farmer's ability to invest in tubewells and plan for electrification is enabled by livelihood diversification, particularly stable off-farm income. His repeated engagement with government offices stresses both the potential and limitations of institutional navigation under insecure tenure. Furthermore, his rejection of costly diesel and petrol technologies, and his interest in electric alternatives, reflect a conscious assessment of infrastructural trade-offs. Most importantly, this case challenges any simplistic portrayal of tenant farmers as passive actors. Instead, it demonstrates how they actively strategise within the constraints of their positionality, negotiating infrastructure, markets, and institutions in ways that are both creative and pragmatic.

5.2.3 Case 3: Migrant Household Woman – Navigating Labour Burden and Informal Water Markets

This case presents a 25-year-old woman from a marginalised *Madhesi* Dalit community in Sakhwa block, who has taken on sole responsibility for irrigation and farming on rented land. The shift in household labour arrangements, due to her husband's migration to Malaysia three years ago and the subsequent death of her father-in-law, has left her entirely in charge of all agricultural tasks. Her experience illustrates the intensification of women's labour burdens in migrant households and the challenges of navigating irrigation infrastructure without formal land rights or labour support.

The woman cultivates nine *kattha* of land through a *thekka* rental agreement, which requires fixed in-kind payments of approximately 40kg of paddy per 0.004 hectares to the landowner. Prior to her father-in-law's passing, the household farmed nearly one *bigha*, but the cultivated area was reduced following his death. This reduction highlights the direct relationship between the availability of

household labour and the scale of agricultural production in tenant farming systems. Such a phenomenon is called deactivation by van der Ploeg (2008), suggesting that levels of agricultural production are actively contained or even reduced.

Figure 14 Link to Video Case Three; or Click on the Play Button to Watch

Video documentation of the woman's irrigation work reveals the physically demanding nature of her tasks. Each irrigation session begins with her transporting a 20-kilogram electric pump and multiple delivery pipes from her house to the field, roughly 500 meters. This daily movement of equipment, necessitated by concerns over theft, adds significant labour even before irrigation begins. Upon arrival at the field, she installs the pump independently, connecting it to the tubewell and sealing the joints with improvised materials, mud, cloth, and rubber, to prevent air leakage. These temporary seals require constant attention, as they often dry out or loosen during irrigation, disrupting water flow.

The pump site is located 300 to 400 meters from various parts of the field, compelling her to make repeated trips back and forth during a single irrigation session. This back-and-forth movement is

necessary to monitor water distribution, identify leaks, and troubleshoot malfunctions. The video shows how such constant movement fragments her workflow and creates a physically taxing irrigation cycle. Pipe leakages are a recurrent issue, especially at connection points where older and newer pipe sections are joined. She is often seen spending more time fixing these technical problems than irrigating crops, underscoring how the inadequacy of materials and labour support undermines the smooth application of water to her crops.

Despite these challenges, she has found strategic ways to address infrastructure and cost-related constraints. As a landless tenant, she is ineligible for government-subsidised electricity connections, which are tied to formal landownership. However, she has arranged to use a subsidised electric meter registered under a neighbour's name. This informal arrangement allows her to purchase electricity at a rate higher than the state-subsidised price but still significantly lower than commercial rates or the cost of operating a diesel pump. Similarly, she draws water from a tubewell on the landowner's brother's fallow land, an arrangement that avoids competition for infrastructure and facilitates timely irrigation.

Her case reveals that access to irrigation technology, such as electric pumps, is not sufficient without supporting infrastructure and labour capacity. She possesses the technical skills required for pump operation, installation, and repair. However, the absence of labour support, as seen in Case 1 and in her own case, previously provided by her father-in-law, means that all tasks, from transporting heavy equipment to system maintenance and monitoring, fall solely on her shoulders. The cumulative physical and temporal burden limits the efficiency and sustainability of her irrigation practice.

What emerges from this case is a clear picture of how marginal and landless farmers rely on informal networks and personal negotiations to secure access to critical infrastructure. Her use of a neighbour's subsidised meter and a nearby tubewell reflects her ability to mobilise social relationships to compensate for formal exclusions. Yet, these arrangements remain insecure and contingent, reflecting the broader precarity of landless tenant farmers operating outside formal support systems.

Overall, the case illustrates how technological capacity and farmer agency are shaped and constrained by structural conditions, particularly those related to land tenure, labour availability, and access to infrastructure. As rural out-migration continues to reshape household labour arrangements in Nepal, individual resilience alone is unlikely to offset the burden of infrastructural inadequacy and policy exclusion. This case, therefore, emphasises the need to understand irrigation technology not only as a

material artefact but also as a system embedded in labour regimes, tenure structures, and informal institutions that govern everyday agricultural practice (Lawoti, 2010).

5.2.4 Case 4: Managing Electric Pump Irrigation Amid Labour Reorganisation and Technological Constraints

This case explores the experiences of a woman farmer managing irrigation on approximately two *bigha* (1.3 hectares) of land in a nuclear household, legally owned by her husband, who has migrated abroad for employment. Her household consists of herself and two school-aged children, reflecting a broader trend in which women increasingly assume managerial responsibilities in agriculture due to male out-migration.

Figure 15 Link to Video Case Four; or Click on the Play Button to Watch

The family's transition from diesel to electric pumps marks a shift not only in technology but also in labour dynamics and infrastructure use. The electric pump, while considered easier to operate than diesel alternatives, still requires significant physical effort during setup. The video documentation

shows the woman farmer and her father transporting and installing the electric pump and delivery pipes over approximately 400 meters between the tubewell and the field. Though electric pumps reduce operational costs and eliminate the need for diesel fuel, the infrastructural configuration, particularly the physical separation between power source, pump location, and fields, intensifies labour demands. This family is required to monitor electrical connections at the house (150 meters away), maintain the tubewell pump, and manage water distribution across the field.

The household currently uses an agricultural electricity meter, which has reduced irrigation costs. Her husband applied for a subsidised electric meter; the woman farmer herself is unfamiliar with the application procedures. Although she manages the daily physical and technical aspects of irrigation, the administrative domain remains gendered, with formal interactions with state or utility institutions still largely navigated by male household members.

In this context, the farmer mobilises family support to cope with labour-intensive irrigation tasks. Her father travels from a neighbouring municipality to assist with irrigation. Together, they are observed facing and improvising around several technical challenges, including air leakage at pipe joints, motor overheating, aged pipe deterioration, and fluctuating electricity supply. Their adaptive strategies include sealing leaks with mud, cloth, and rubber, trimming damaged sections of pipe, and consulting neighbours for troubleshooting. However, persistent technical issues eventually led to a pump malfunction, with smoke emission indicating possible motor failure, highlighting the limits of informal repair strategies in the absence of formal technical support.

This case exemplifies the dual dynamics of progress and constraint. On one hand, the adoption of electric pumps signals an expansion in women's engagement with irrigation technologies. On the other hand, the burden of labour and unresolved infrastructural challenges continue to structure women's engagement with agricultural technologies. The increased participation of women in irrigation, while indicative of growing skill and responsibility, does not necessarily translate into reduced workloads or equitable control over irrigation resources. Instead, it reflects the broader restructuring of agrarian labour in contexts of male migration, where women's roles expand to fill vacated responsibilities, often without necessarily corresponding redistribution of institutional or infrastructural support.

This case underlines the importance of addressing not only access to technology but also the embedded structural limitations, including fragmented infrastructure, inadequate repair services, and limited

institutional literacy among farmers, which shape how irrigation technologies are actually used and maintained in practice.

5.2.5 Case 5: Persistence Against Social Exclusion – A Single Woman Farmer's Technological Journey

Figure 16 The Case Farmer Sarala, Stands on Her Farm with Her Winter Mustard Crop

This case study examines the journey of Sarala, a single woman farmer, from the Sah[22] caste in Shambhunath Municipality, toward adopting irrigation technology (Raut, 2026). Her experience illuminates how gendered social relations, informal land ownership, and exclusion from formal institutions shape the everyday practice of farming and technological decision-making. Despite facing multiple layers of marginalisation, including legal, economic, and social exclusions, this farmer has independently acquired land, installed irrigation systems, and operated electric pumps, challenging dominant gender norms and exclusionary institutional practices.

[22] Direct names used in all cases are fictitious.

The respondent, a 60-year-old woman from a non-Dalit caste, has been managing a farm independently for the past 25 years, following her husband's abandonment. Without any inherited land or initial financial support, she engaged in intensive agricultural wage labour, vegetable cultivation, and cattle rearing to save money over the course of decades. Through this labour, she gradually purchased approximately 10.5 *kattha* of land across three separate transactions. Her first acquisition was 2.5 *kattha*, followed by 4.5 *kattha* nine years ago (at NPR 22,000 per *kattha*), and 3.5 *kattha* five years ago (at NPR 60,000 per *kattha*). Her capacity to acquire land, despite having no formal education or familial support, demonstrates significant financial discipline and strategic foresight (Raut, 2026).

Figure 17 Sarala Manages the Electric Connections for Her Irrigation Pump.

She also engaged in a prolonged legal battle to claim rights over her husband's property. Although a court initially recognised her entitlement to the land on grounds of child custody, the husband resisted implementation, resulting in a delay of over two decades. As of the time of this research, she has regained control over the land, although the formal documentation process remains incomplete. Her

case demonstrates how, for women, legal rights to land are often undermined by procedural barriers and male contestation, reinforcing the gendered precarity of land tenure.

In response to increasingly unreliable rainfall patterns, the farmer invested in two tubewells over the last decade (Raut, 2026). The first, installed nine years ago, was 55 feet deep and two inches in diameter, at a cost of NPR 7,000. The second tubewell, deeper and more costly, was installed for NPR 18,000, including NPR 10,000 for materials and NPR 8,000 for labour. These installations reflect her growing recognition of groundwater irrigation as essential to sustaining agricultural productivity amid climatic shifts. Despite lacking formal training, she learned to operate and maintain the system independently through observation and repeated trial.

Figure 18 Sarala Carries Her Irrigation Pump Home

To operate the system, she uses a 2.5 HP electric pump connected to an agricultural meter. The first meter was registered under her name at the cost of NPR 4,200. Later, she secured a second meter under her daughter's name, for NPR 2,000, to increase irrigation capacity. She learned about the availability of subsidised agricultural meters informally during farmer group meetings; meetings she was not formally invited to but attended uninvited to access information.

'I heard about the subsidised agricultural meters during farmer meetings. I wasn't invited to these meetings, but I went anyway because I needed to know what was happening. No one was going to tell me otherwise.' (Field interview, Saptari, December 2023)

Over time, she purchased three electric pumps. The first, a 1.5 HP Chinese model, cost NPR 6,000. The second, an Indian model with a five-year warranty, cost NPR 9,000. She actively compares market prices and service quality between local towns and cross-border markets in India. Notably, she transported one of the pumps from the Indian border town of Laukaha, hidden in sacks of vegetables to avoid import taxes.

'I wrapped the pump in sacks of vegetables when I crossed the border (to avoid import taxes). I was scared they would catch me.' (Field interview, Saptari, December 2023)

Figure 19 Sarala Shows HerElectric Pump Setup Which Includes Locally Sourced Wires and Connectors

Her independent operation of pumps and use of a bicycle for transport elicited criticism and ridicule from community members. The technologies she adopted, particularly electric pumps, are typically associated with male farmers and are considered beyond the technical capacity of women, especially single women without male family support.

'People said "She will have an accident, or she will get electrocuted." They thought women shouldn't operate pumps or ride bicycles. But I didn't listen. I had no choice; I had to support my family.' (Field interview, Saptari, December 2023)

This reflects the broader social perception that associates technology use and decision-making with masculinity. Her persistence despite these social constraints illustrates how necessity can drive women to contest restrictive gender norms in agrarian settings.

Despite her resourcefulness, the respondent remains excluded from formal agricultural support systems. She is often bypassed in subsidy allocations, such as the distribution of insecticide sprayers, and faces discrimination from Ward-level officials. She attributes this exclusion to her gender, caste status, and lack of formal political connections.

'*They look down on women and ignore us.' (Field interview, Saptari, December 2023)*

The exclusion has significant implications. Without access to subsidies or institutional credit, her investments in irrigation and farming technologies are entirely self-financed, increasing her economic vulnerability.

After the tragic loss of her two sons in a workplace accident, the woman received NPR 20 lakh in compensation. However, the community attempted to extract NPR 15 lakh from her, arguing that a single woman without sons should not retain such wealth. Her refusal to comply led to social retaliation, including the daily dumping of garbage near her land, a symbolic and material act of social ostracism carried out under the directive of the Ward chair.

'They dump garbage next to my property every day. It's their way of punishing me for not giving up my money, for being a woman who stands up for herself.' (Field interview, Saptari, December 2023)

Beyond managing her own farm, the respondent supplements her income through wage labour. She earns NPR 400 per day and often undertakes tasks that would typically require two workers. Occasionally, she negotiates contracts on a per-*kattha* basis. Her work ethic is well recognised, and she is frequently rehired by local landowners.

'I work hard so they will hire me again. Sometimes I do the work of two people to earn more.' (Field interview, Saptari, December 2023)

Figure 20 Sarala Works in Her Vegetable Fields. Her Diversified Cropping Strategies Provide Year-Round Sustenance and Income.

This case illustrates how the adoption of irrigation technology by women farmers is embedded in a broader terrain of gendered exclusion, informal tenure arrangements, and institutional neglect. The respondent's experience demonstrates how access to irrigation is not merely a technical or economic question, but a deeply social and political one. Her ability to independently acquire land, install tubewells, and operate electric pumps was made possible not by supportive policies but by self-determination, informal networks, and years of arduous labour.

Importantly, this case challenges gendered assumptions that frame women as passive or risk-averse in agricultural technology adoption. Despite structural constraints, the respondent exercised considerable strategic agency, navigating informal markets, cross-border trade, and technical systems while resisting patriarchal control over land and capital.

Her exclusion from institutional support systems, including subsidies, training programmes, and participation in farmer groups, underscores the need for more inclusive governance mechanisms that recognise women farmers not as beneficiaries but as active agents of agrarian transformation.

Integrating gender-sensitive irrigation policies with targeted support for single women farmers is essential to ensure equitable access to technology and sustainable agricultural livelihoods.

5.3 Discussion: Navigating Constraints, Creating Possibilities

5.3.1 Layered Architecture of Access: Land, Tenure, and Irrigation Technology Adoption

The empirical cases in this chapter make visible a patterned reality that is easily missed when irrigation is reduced to devices or to the binary of ''has technology/doesn't have technology'. In Shambhunath, access is bundled: tubewells, pumps, and meters cohere as a composite system in which feasibility and benefits turn on how farmers are positioned within land tenure, social relations, and bureaucratic recognition. Following Murdoch's (2006) view of technologies as assemblages, I analyse groundwater irrigation as a bundled architecture of access in which material, social, and institutional layers must align for adoption to become sustained, affordable, and legitimate. This approach resonates with feminist and critical agrarian scholarship, which insists that infrastructure is not only material but also social, and structured by power relations that determine who is recognised and who is rendered peripheral (Ribot & Peluso, 2003; Bebbington, 1999; Pratt, 2006).

The cases show that tenure is neither a simple owner/tenant binary nor a purely legal category. It is a spectrum of recognitions that may include formal certificates, customary claims, documentary fragments, or social endorsements, each carrying different capacities to unlock investment and protection. In Case 2, a *mohiyani* (registered tenant) status supports investment in semi-fixed infrastructure (a tubewell), yet the tenant remains ineligible for an electric meter, because its institutional gate requires full land documents. In other words, partial tenure recognition translates into partial infrastructural access: the material layer (tubewell) is possible; while the institutional layer (meter) remains closed. This friction embodies facets of legal pluralism in practice (Meinzen-Dick & Pradhan, 2002; Borras, 2023), wherein formal state law, customary tenure, and lived arrangements intersect to shape (and limit) the pathways through which irrigation becomes viable.

Throughout the chapter, livelihood diversification emerges as a recurrent risk buffer under tenure uncertainty. The tenant in Case 2, like others, underwrites irrigation investments through off-farm income, echoing wider agrarian processes in which remittances, petty trade, and seasonal labour bridge cashflow gaps in farming (Rigg et al., 2016). In Case 3, a Dalit woman farming under *thekka* (sharecropping) taps kinship and neighbourhood networks to negotiate informal access to meters and reduce water costs, explaining how social capital can partly substitute for missing documents and

weak claims (Cleaver, 2010; Ren et al., 2022). These practices are not marginal; they instantiate a central proposition of access theory: what matters is not only legal right but the ability to benefit, assembled through identity, knowledge, networks, and resources (Ribot & Peluso, 2003).

At the same time, ownership still matters profoundly. Cases 4 and 5 establish that inherited or purchased titles smooth the path to tubewell construction and substantially increase the probability of clearing the meter gate, reaffirming the persistent centrality of land in structuring irrigation access (Agarwal, 2001). Yet, Case 1 strategically disrupts this hierarchy: a Dalit entrepreneur, without land, strings together mobile diesel technologies into a water service enterprise, decoupling early access to water from property. Rather than denying the power of legibility as a principle of state administration (Scott, 2020), this case shows how entrepreneurs can circumvent legibility by operating through informal markets, circulating cash, and building reputation, a parallel route to asset formation that challenges the presumed sequence of title followed by tubewell and by meter.

These findings speak to patterns identified elsewhere. In Ghana and Burkina Faso, informal and customary tenure often provide sufficient confidence for farmers to invest in pumps, while gendered power asymmetries contour who can consolidate and scale such investments (Bryan & Garner, 2022; Musah et al., 2024; Alhola & Gwaindepi, 2024). My contribution is to make explicit how, under legal pluralism, perceived tenure security operates as a gradient. Where a farmer sits on these gradient conditions, both the feasibility of semi-fixed infrastructures (tubewells) and the likelihood of crossing bureaucratic thresholds (meter registration), is considered. In other words, what looks like a single decision to 'adopt a technology' is, in practice, a sequence of preconditions for which alignments are socially uneven.

To clarify how these alignments work in everyday life, I specify the bundle as three interrelated layers that are analytically distinct, yet practically intertwined.

5.3.1.1 Tubewells as Semi-Fixed Infrastructure

Tubewells require capital, coordination with drillers, and a credible cost-recovery horizon. They are, therefore, tied to land relations that can support medium-term investment. Owners (cases 4, 5) invest directly and amortise; tenants and sharecroppers (cases 2, 3) negotiate partial rights, shared use, or contingent access through dense social ties. This is polycentric governance (Ostrom, 2010) in practice: overlapping norms and authorities, family, Ward offices, cooperatives, and customary leaders govern

who drills, where, and on what terms. The fixed tubewells anchor irrigation in place, and that place is a property relation.

5.3.1.2 Pumps as Mobile, Flexible Technologies

Diesel and electric pumps add mobility and market intermediation to the irrigation repertoire. Case 1 shows that pump ownership can itself be a livelihood (selling water), while cases 3 and 5 reveal rental and sharing that allow day-to-day irrigation without formal property, so long as a tubewell exists to tap. But mobility does not entail equality: rental prices, fuel costs, and the spatial distribution of tubewells ensure that mobile access remains differential and contingent on social positioning, cash on hand, and seasonal risk.

5.3.1.3 Electric Meter Connections as Bureaucratically Entrenched Gateways

The electric meter condenses institutional recognition. It is where 'rules of recognition' bite hardest: documents, fees, and procedural navigation sort households into eligible and ineligible energy users. As Case 2 illustrates, meter eligibility can be decisive in locking households into diesel dependence or enabling a transition to lower-cost, grid-based irrigation. In meter denial, farmers face a narrower window for irrigation timing and an enduring exposure to price volatility in fuel markets, both of which feed back into cropping decisions and risk tolerance.

Across these layers, the cases reaffirm Ribot and Peluso's (2003) distinction between rights and the ability to benefit. Farmers in my study combine off-farm incomes, social capital, and entrepreneurial tactics to assemble access despite partial documentation and precarious tenure. The Dalit entrepreneur (Case 1) exemplifies Bebbington's (1999) asset pathway: transforming human capital (technical skills), financial capital (remittances), and social capital (trust and reciprocity) into physical capital (pumps) and, eventually, into natural capital (land). Yet, broader evidence warns against romanticising such trajectories. As Koirala and Bashyal (2025) show, remittances frequently stabilise consumption rather than catalyse asset accumulation, and durable hierarchies of caste and class limit the scalability of entrepreneurial success. Comparative work likewise indicates that rural migrants' households in Nepal and Indonesia have seldom acquired enough land to reinvest meaningfully in agriculture (Sunam et al., 2021). Technology opens a path; property and recognition determine how far most can walk it.

Policy built on the premise that formal title must precede subsidy predictably reproduces exclusions, especially for tenants, women, and Dalit farmers who work within informal or overlapping tenure

regimes. A more promising stance is territorial pluralism (Boelens & Vos, 2014): recognising coexisting governance regimes and designing hybrid arrangements that align programme rules with lived tenure practices (Suhardiman & Giordano, 2012). In this spirit, intermediary institutions, pump rental markets, neighbourhood irrigation committees, and user groups deserve support as bridges within transitional agrarian economies. As Soto (2000) argues, aligning policy with the ways assets already function in practice can generate inclusion without gutting accountability. My cases also caution that partial recognition can exclude in new ways: acknowledging some informal practices while refusing to loosen documentary requirements for meters simply moves the bottleneck without solving it.

A related point concerns the interpretation of non-participation in farmer groups and irrigation committees. Across the case studies, many marginalized farmers, particularly tenants, landless households, and Dalit community members, did not engage with formal collective irrigation structures. This should not be read as disinterest in collective water management. For households that repeatedly encountered exclusion in programme processes, non-participation is a rational response to predictable exclusion: a calculated withdrawal from spaces where the social costs of failed participation: the time invested, the humiliation of rejection, the visibility that comes with making a claim, outweigh the expected benefits (Platteau, 2002; Scott, 2020). Understanding this as a rational disengagement rather than apathy or incapacity is analytically important: it shifts the question from how to motivate marginalised farmers to participate, to how to redesign the institutional spaces from which they currently have good reason to stay away.

In short, tubewells and pumps are not self-scaling ‘technical fixes’. Their daily functioning turns on division of labour, cash availability, and trust networks, all historically sedimented and socially differentiated. What appears, on paper, to be a replicable technological package is, in practice, a field of relational constraints and opportunities. I therefore theorise irrigation as a relational infrastructure: farmers traverse it by stitching together tenancy agreements, rentals, and neighbourhood ties – the everyday politics that make water flow.

5.3.2 Embodied Technologies and Gendered Labour in the Everyday Politics of Irrigation

The case narratives vividly render a second core theme: irrigation is embodied and gendered work, reorganised by migration, shifting household composition, and the feminisation of agriculture (Deere & Doss, 2006; Doss et al., 2018). Rather than reiterating the common trope of ‘women as resilient

farmers', I analyse how gendered labour, knowledge, and authority are reconfigured by the very infrastructures designed to democratise access.

Women's agency is empirically present, not as a rhetorical flourish but as a daily technical practice. In cases 1, 3, 4, and 5, women schedule irrigation, monitor flows, fix minor faults, and negotiate access with neighbours and line mechanics. They also navigate institutional interfaces: in Case 5, a woman attends Ward meetings seeking information on subsidised electric meters, despite bureaucratic chill and social hostility; in Case 3, a Dalit woman negotiates the use of a neighbour's subsidised meter to reduce irrigation costs; in Case 1, the household disaggregates labour such that the husband operates the pump while the woman and her son direct water across beds by hand – precision work that determines erosion, infiltration, and crop stress. These practices unsettle the assumption that irrigation is exclusively 'men's domain' while also showing that women's technical engagements are often undervalued because they occur in less visible, less 'mechanical' tasks.

This pattern aligns with Leder's (2024) observation from Western Nepal: male out-migration raises women's visibility in water management. But visibility is not equivalent to empowerment. As Maharjan et al. (2020) argue, workloads can increase even as decision authority remains uneven. I therefore draw on feminist political ecology (Nightingale, 2011; Rocheleau et al., 2013) to approach irrigation as a material-semiotic assemblage: bodies, devices, and meanings that together produce gendered authority. Wajcman (2010) reminds us that 'technical expertise' has historically been masculinised; women's practical knowledge is discounted when expertise is equated with machine ownership or formal credentials (Caretta & Rothrock, 2021). My observations show women performing embodied expertise, improvising with plates to deflect flows, adding cloth to reduce intake clogging, re-seating gaskets with limited tools, work indispensable to irrigation but rarely recorded as "technical" (Haraway, 1998).

The cost of this expertise is time. "Time poverty" (Bardasi & Wodon, 2006) clarifies why women's access to extension, training, or programme offices remains truncated: irrigation is layered onto reproductive labour, caregiving, and market errands. Case 4 is illustrative: despite paternal support, the cumulative demands of household work and irrigation squeeze time for attending training or navigating subsidy paperwork (Anderson et al., 2021). In practical terms, irrigation comprises multiple tasks with different embodied demands – starting a pump, guiding water along ridges,

plugging leaks, cleaning screens, priming lines, negotiating timing – all of which can fall to women in male-absent households.

Against this background, the widely celebrated shift from diesel to electric pumps, while cheaper and less labour-intensive, requires careful assessment. Electrification does reduce physical effort at the point of start-up and curtails fuel logistics. Yet, in many migrant households, these gains are absorbed by newly added responsibilities: planning irrigation alone; caring for dependents; managing petty cash; and handling farm-to-market errands. In my field site, electrification did not always produce a net reduction in women's labour; rather, it restructured labour and sometimes intensified it (Udas & Zwarteveen, 2010). Benefits are real but conditional: they depend on meter access, control over timing and allocation, and budget authority. As shown across South Asia, the dual burden persists even as women perform more agricultural tasks (Agarwal, 2001).

Class and remittance flow further stratify these experiences. In some higher-remittance households documented elsewhere, hired labour can buffer women's workloads (Leder, 2024). By contrast, in lower-remittance or precariously resourced households, like cases 3 and 5, women shoulder irrigation and domestic work with minimal support. The same technology thus reduces drudgery for some and redistributes it or amplifies it for others. This intersection of class, gender, and resource access explains why headline claims ('electrification reduces women's work') are empirically unstable.

A second axis concerns recognition and vulnerability. Case 5 starkly shows that women can possess agency without recognition. Despite actively managing irrigation, she is sidelined in claims to land and entitlements, and faces intimidation, including garbage deliberately dumped near her land after she pursued formal claims following death of her sons. Kabeer's (2000) critique of 'neutral' administrative procedures is salient here: formal rules claim impartiality while reproducing inequalities. Feminist land rights scholarship likewise shows that formal ownership is neither necessary nor sufficient for control and security (Agarwal, 2001; Deere & León, 2003). In this sense, irrigation is not just labour; it is a site where social citizenship is negotiated and sometimes denied (Whittenbury & Davidson, 2009).

Design also matters. Barooah et al. (2023) find that agricultural tools often embed a male user archetype in torque demands, grip sizes, or priming procedures. In my cases, women frequently resolved design mismatches by redesigning practice: bracing elbows with sticks to turn stiff valves; using plates to steer flows; and adding cloth filters. These are not trivial hacks; they are situated design

under constraints (Agarwal, 2000; Meinzen-Dick et al., 2014). Knowledge circulates through informal channels as well. In Case 4, a woman's unfamiliarity with meter registration, formerly handled by her migrated husband, led her to engage in experiential and peer learning (Balasubramanya & Sadoff, 2018; Balasubramanya, 2019). Udas and Zwarteveen (2010) document similar exclusions in professional irrigation circles; while Cornwall and Rivas (2015) warn that 'gender mainstreaming' can be performative when institutions remain calibrated to male availability and authority. My reading of the cases is that women's technological engagement is often an achievement of necessity rather than an outcome of institutional support.

Finally, within households, operation, control, and benefit capture must be analytically distinguished. Theis et al.'s (2018) "bundle of rights" clarifies why a woman might operate or schedule irrigation without controlling expenditures or capturing proportional benefits (Meinzen-Dick et al., 2014). These internal asymmetries are sharpened at the intersection of caste and gender. The Dalit entrepreneur in Case 1 translates pumps into mobility yet encounters ceilings to accumulation, echoing partial but constrained mobilities elsewhere (Sunam, 2014; Sunam & McCarthy, 2016; Leder, 2024). The Dalit woman in Case 3 navigates *thekka* terms (surrendering half the harvest), informal meter borrowing, and solitary irrigation labour; and together, these produce a narrow margin for savings and asset growth. Courts and policy can deliver formal recognition yet leave everyday vulnerabilities intact (Deere & León, 2003).

To deepen the analysis of gendered labour within the bundled architecture, I turn explicitly to how women navigate irrigation work in relation to household, community, and institutional processes. The empirical material reveals that women's capacity to sustain irrigation depends not only on their own labour but also on the availability of support networks, from spouses, kin, and neighbours who help them traverse procedural and physical demands. In one case, the husband handled the institutional meter and subsidy application on behalf of the household. While the woman herself had limited knowledge of the formal process, she emphasised that this arrangement was practical given her already heavy workload and limited labour support at home. Her experience underlines how shared responsibility within the household can ease women's daily burdens and facilitate continuity of access (Bardasi & Wodon, 2006).

Rather than positioning institutions as inherently exclusionary, these findings highlight that bureaucratic and physical interfaces require mediation, often through cooperative or familial

collaboration (with caution and longer-term engagement, as explained in chapters Six and Seven). Where men have migrated, women's embodied expertise at the material layer (operating or coordinating pumps, troubleshooting) often expands. At the social level, they rely more on reciprocal labour, borrowing, and assistance from kin or neighbours to manage irrigation timing and costs. Women's capacity to stabilise irrigation, therefore, lies not only in individual perseverance but also in their ability to mobilise help and knowledge-sharing networks that make irrigation possible, despite limited time and labour resources (Agarwal, 2000; Deere & León, 2003).

The bundled architecture of access framework helps explain this coordination: women may not always be the formal applicants or document holders, yet their everyday work and technical knowledge underpin the operation of irrigation systems. Following Kabeer (2000), what appears to be administrative neutrality can in fact rely on assumed gender roles, in which men interface with formal offices while women sustain the material operations those offices enable. Recognition thus flows unevenly, but functionality, in making irrigation work, is deeply dependent on women's effort, adaptation, and often quiet coordination across layers.

A second dimension concerns risk and labour translation. Electrification reduces per-unit water costs once the meter is connected but obtaining that connection still requires upfront investment and coordination that can stretch household capacities. Women, often balancing irrigation with caregiving and market tasks, sometimes adjust their schedules; for instance, irrigating at night to manage shared access or timing constraints. These adjustments illustrate how technological transitions shift, rather than eliminate, labour demands (Udas & Zwarteveen, 2010). Women's workload thus remains intensive, but the nature of their effort changes from hauling fuel to managing timing and coordination. Where supportive husbands or kin share some administrative or technical tasks, the transition to electric irrigation can meaningfully relieve drudgery; where such help is absent, it tends to reorganise rather than reduce women's labour (Leder, 2024).

The cases also highlight that knowledge transmission is gendered but adaptive. While male kin handled registration, meter reading, or troubleshooting, women often learned through peer exchange, observation, or experiential practice, building what Haraway (1998) terms situated knowledge – practical, context-bound expertise embedded in embodied routines. Women in the field described learning by watching neighbours, experimenting with priming steps, or adjusting water flows through repeated trial-and-error. Such learning-by-doing, while informal, is robust and accumulative. Yet,

extension and training systems remain structured around formal sessions, typically during daytime hours or in distant venues, which exclude many women (Meinzen-Dick et al., 2014). These constraints do not indicate a lack of interest but reflect how women's irrigation work itself limits their availability for structured programmes.

When viewed through a relational lens, irrigation knowledge circulates horizontally across women's networks more than vertically through institutional channels. Women's ingenuity, using plates to guide water, cloth filters to prevent clogging, or makeshift valves, demonstrates technical competence born of necessity (Barooah et al., 2020). Far from peripheral, this hands-on innovation constitutes the operational heart of smallholder irrigation. Recognising it as such shifts the narrative from women as 'beneficiaries' to co-producers of functionality within Nepal's groundwater economy.

Thus, instead of depicting women's experiences as struggles against institutional barriers, the evidence points to collaborative negotiation within families and communities. Husbands who manage paperwork, brothers who liaise with electricians, and neighbours who share meters all act as crucial intermediaries. These micro-alliances make the layered access structure workable in everyday life. Where such collaboration is absent, such as in female-headed or low-labour households, the intensity of irrigation work becomes more visible. As Nightingale (2011) cautions, visibility of effort should not be mistaken for empowerment. 'More work' does not automatically mean 'more power'. Yet, when women's expertise is complemented by occasional male assistance or neighbourly reciprocity, the result can be a more balanced distribution of labour and smoother access to irrigation (Leder, 2024).

Therefore, women's agencies are not reducible to formal recognition but reside in the orchestration of multiple supports – technical, social, and familial – that allow irrigation systems to function. Electrification and institutional programmes succeed most when they align with these collaborative realities, acknowledging that women's participation and men's supportive involvement are both essential to the sustainability of groundwater use. The goal is not to critique institutions but to highlight that simplifying procedural steps, offering accessible service timing, and validating informal cooperation can substantially reduce women's daily irrigation burdens (Bardasi & Wodon, 2006; Udas & Zwarteveen, 2010).

Women's labour thus remains the backbone of local irrigation systems, their knowledge a vital yet often understated infrastructure of access. When institutional processes are complemented by intra-

household and community cooperation, they support water access, facilitate relatively easier access, and sustain irrigation amidst constraints of time, tenure, and labour. This perspective situates women's expertise, adaptive learning, and shared support to define the everyday politics of water.

5.4 Conclusion: Groundwater Access Through Everyday Lives

The four video studies and one photo case study presented in this chapter have provided an intimate lens into how women and men from diverse households – migrant, tenant, Dalit, and land-owning – navigate and sustain access to groundwater through their engagement with irrigation technologies. Each narrative revealed how material infrastructures, such as tubewells, pumps, and electric meters, become embedded in social relations, household strategies, and livelihood decisions. This visual ethnographic approach made visible the daily negotiations of labour, cost, and legitimacy that written data alone could not fully capture.

Across the cases, three themes recur. First, access to irrigation is structured through layered architectures of material, social, and institutional alignment, where each layer builds upon and constrains the next. Second, labour and collaboration are central to sustaining irrigation. Women's participation, often intensified by male out-migration, anchors the everyday operation of pumps and water distribution, while support from husbands, kin, or neighbours helps balance workloads and maintain continuity. Third, the experiences of Dalit and tenant farmers reveal how informal networks and adaptive strategies compensate for limited formal recognition, showing that water access depends not only on ownership but also on social and moral claims negotiated in practice.

Together, these case studies explain that irrigation technologies are lived infrastructures sustained through cooperation, embodied skill, and social resilience. They transform physical systems into social spaces where gender, class, and caste relations are continually remade.

The next chapter turns to the institutional scale, examining how irrigation support programmes in Shambhunath are accessed and sustained. Chapters Six and Seven examine these dynamics through cases of both rural elite farmers who shape irrigation provisions and marginal farmers who maintain access within these evolving systems.

6 Chapter Six: The Paradox of Progress – When Irrigation Technology Becomes an Instrument of Power

6.1 Introduction

'Yo k karyakram kasko ko lagi ho?'

'Who is this project for?' (Field interview, Saptari, July 2023)

This was a question I heard repeatedly in my study sites, posed by farmers, Ward officials, and elected representatives alike. It reflected a familiar expectation that any outsider engaging with the community, particularly one who looked different and frequently visited farms, offices, and homes, must be part of a programme offering some form of assistance. My presence, though driven by research, was often interpreted as the arrival of another development initiative. For some, my clarification that I was not there to implement a project led to disappointment. Others, however, believed that my work, hours spent in conversations, observations, and interviews, would inevitably lead to some form of 'project', if not immediately, then in the near future. This pattern is consistent with what Oliver de Sardan (2005) documents in communities exposed to repeated short duration development programmes: the regular arrival and departure of funded initiatives gradually produce communities that position themselves as recipients of external support rather than as agents of their own resource futures.

The depth of this expectation was evident throughout the fieldwork. Across the study villages, farmers' expectations of external support unfounded but grounded in a concrete institutional history. Over the years, various government and non-government agencies have facilitated access to groundwater in these communities, often through externally funded support. One project had introduced irrigation technologies, including electric pumps, pipes, and tubewells, through structured programmes. Other government agencies had provided subsidies or direct assistance, often secured through bureaucratic and political networks (detailed in Chapter Seven). My interactions revealed how deeply embedded these mechanisms were in shaping farmers' access to groundwater, not just through technology but also through relationships of influence and negotiation.

Almost always, the process of securing water-related support involved 'important people' consulting other 'important people' – bureaucrats, politicians, or individuals with affiliations to influential networks. Farmers who had closer ties to these intermediaries were better positioned to receive

assistance, whether for purchasing a pump, accessing pipes, or constructing tubewells. My presence in the village became another opportunity to voice concerns and ensure that their struggles with expensive, unreliable water access were heard. For many, this was a way to secure their place in future support, should it emerge. Others, recognising that immediate gains were unlikely, saw my research as a way to channel their concerns to those who 'control' development budgets and make policy decisions, hoping that their voices, documented and analysed, would eventually translate into action.

Another question that frequently followed was:

> *'Will the support be given to the farmer group or to individuals?' (Field interview, Saptari, July 2023)*

This recurring inquiry revealed much about the structure of groundwater access in my study sites. Having previously worked as a research officer at the International Water Management Institute (IWMI) on an irrigation project in the same region, I revisited farmer groups four years after the project's completion. I found that significant changes had taken place. Much of the support for groundwater irrigation had been distributed through farmer collectives, particularly in Ward 2, where an action research project had established group-based access to irrigation technology. These arrangements show that farmer group-based approaches can ease some of the constraints farmers face, but also reveal that they are shaped by existing social relations. This chapter, therefore, offers lessons on how these initiatives unfold in practice and why these conditions must be taken into account when designing farmer-group-based approaches.

6.2 Conceptualising and Implementing Collective Farming

In my study on groundwater access through external support in Saptari, I examined an intervention implemented through collective farming arrangements. This action research project began in 2015 in Kanakpatti village (Ward 2, Shambhunath Municipality), alongside similar initiatives in Koiladi Municipality (not included in this study), and selected sites in India. In this section, I explore the experiences of three farmer groups in Kanakpatti, focusing on how they navigated access to groundwater through irrigation infrastructure and agronomic support provided by external agencies, within a group-based farming framework, which I refer to as collective farming (as the project uses this term).

The project's origins can be traced to 2013, emerging from the IWMI's water research in the Eastern Gangetic Plains. During the development of research proposals on sustainable dry-season irrigation,

IWMI researchers identified severe livelihood insecurity among marginal and tenant farmers in Saptari. The socio-economic context of the Nepal study site reflected broader challenges in the Eastern Gangetic Plains, as documented in a project report:

> *'The region faces high poverty incidence, limited commercialisation, and significant inequalities in land ownership, complicated by entrenched gender and caste hierarchies.' (Field interview, Saptari, August 2023)*

These challenges were further exacerbated by food insecurity and widespread male out-migration, placing additional burdens on farmers, particularly women, who had to manage both agricultural and domestic responsibilities under severe resource constraints.

In response, the formation of farmer groups was envisioned as a strategy to address these challenges. The approach was grounded in a fundamental premise. The project's operational framework aimed to enable resource-constrained marginal farmers to address their agronomic and irrigation challenges. Collective arrangements were further envisioned to facilitate shared access to expensive agricultural equipment, such as pump sets and tubewells, while consolidating land plots and allowing the shared installation and use of irrigation infrastructure. This conceptual foundation led to the establishment of an integrated action research initiative titled "Improving Dry Season Irrigation for Marginal and Tenant Farmers on the Eastern Gangetic Plains". The project was implemented through a collaboration between IWMI, the University of Southern Queensland (USQ), and various government and non-governmental organisation (NGO) partners (Schmidt et al., 2019).

According to project personnel, a deliberate choice was made to adopt the term 'collectives' rather than 'cooperatives', to emphasise a broader scope of cooperation, particularly in shared irrigation infrastructure and land management, rather than focusing solely on market-oriented activities.

This approach resulted in the formation of three collectives at the project's inception within my study sites in Ward 2 (at Kanakpatti village), as part of a broader network of 20 collectives across project sites. These farmer groups varied in composition, with some comprising exclusively women and others maintaining mixed-gender participation (Schmidt et al., 2019).

6.2.1 Influences on Collective Farming Approaches

The conceptualisation of the collective farming intervention was informed by several successful experiences. One key inspiration was the fishery collectives established by an NGO named Sakhi, one

of the project partners in India, in Bihar's Madhubani district, in collaboration with women. These collectives showed positive economic returns over a decade of implementation, highlighting the potential benefits of cooperative production models.

Additionally, project documents indicate that the idea behind collectives was influenced by Agarwal's (2010) analysis of global collective farming experiences. Agarwal advocated for small-scale, voluntary, and participatory production units as a more effective approach to collective agriculture. This framework provided a theoretical foundation for the project's emphasis on small, farmer-led collectives rather than large-scale, state-controlled cooperatives.

Historical analysis also played a critical role in shaping the project's approach. Previous collective farming initiatives, particularly in socialist and postcolonial contexts, often struggled due to top-down implementation, excessively large operations, and heterogeneous membership structures that failed to account for class dynamics (Schmidt et al., 2019; Sugden et al., 2021).

The intervention design was further influenced by successful women's group initiatives in South India during the 2000s, particularly Self-Help Groups (SHGs) that managed common-pool resources (Sugden et al., 2021). These initiatives guided the viability of community-led resource management and provided an optimistic model for establishing similar foundations in Nepal and India.

Empirical evidence from comparative studies in Telangana and Kerala further reinforced the rationale for collective farming (Sugden et al., 2021). These studies indicated that women's collective farms achieved higher yields and returns than male-run, individually managed family farms. Key success factors identified in these cases included small group size, a focus on commercial crops, strong social networks, and institutional support structures, all of which were integrated into the project's design.

Despite these promising precedents, the project team anticipated several challenges. It remained aware of potential coordination challenges in implementing such models, as observed in previous SHG experiences. These included: potential conflicts arising from unequal labour contributions; complexities in output-sharing arrangements; decision-making inequalities influenced by gender, caste, and class hierarchies; and coordination difficulties in managing agricultural operations. Additionally, applying this model to privately owned, non-common-pool land was anticipated to pose further challenges in this new context.

Nonetheless, the intervention adopted a participatory approach, allowing farmers to shape collective arrangements tailored to their specific contexts and needs. As a project coordinator emphasised, this flexibility was critical in ensuring the sustainability and effectiveness of the collective farming model within the diverse socio-economic landscape of the project sites (Sugden et al., 2021).

6.2.2 Formation of Farmer Groups

The collective farming initiative was implemented across selected sites in Nepal and India, with this analysis focusing specifically on three farmer groups in Kanakpatti block of Ward 2, Shambhunath Municipality. The project combined government agencies, including Nepal's Department of Irrigation and Groundwater Resources Development Board, with NGO partners such as International Development Enterprise Nepal, supported by the local farmers' cooperative Krishak Samuha Sangh. This action research initiative, funded by the Australian Centre of International Agricultural Research (ACIAR), commenced in late 2014.

A comprehensive census was conducted at the project's initiation, revealing stark land ownership inequalities in Kanakpatti. A project coordinator explained:

> *'Our baseline survey showed that over half of village households were landless, with approximately 40% operating as tenant farmers under 50:50 sharecropping arrangements. This fundamental inequality shaped every aspect of our intervention design.' (Field interview, Saptari, June 2023)*

A project document shows that land ownership was severely concentrated, with only 3.8% of farmers cultivating plots larger than 2 hectares, yet controlling 27.0% of available agricultural land (Sugden et al., 2021). The remaining farmers operated as marginal or smallholders, with landholdings below 2 hectares, often supplementing these with additional leased land. A significant finding was that 60.0% of Saptari's agricultural land operated under tenancy arrangements.

The prevalence of absentee landlordism emerged as a critical factor, with an estimated 24% of land owned by urban-based landlords who, despite their physical absence, maintained substantial influence in their native villages. The tenancy arrangements predominantly followed a sharecropping model, with 85% of rented land in Kanakpatti operating under 50:50 crop-sharing agreements. The prevalent sharecropping system created significant disincentives for irrigation investment, which were shared during my field visit (in 2023/24, many years after the project).

A farmer explained during a focus group discussion:

> *'Why should we invest in tubewells when half the benefits go to the landlord? We cannot install permanent infrastructure on land we don't own.' (Field interview, Saptari, June 2023)*

This sentiment also aligns with the findings of previous research by Sugden and Gurung (2012) and Sugden et al. (2014), which highlight how tenure insecurity fundamentally constrains irrigation development.

The project document shows that the formation of farmers' collectives in Saptari was a strategic response to entrenched agrarian challenges, including land fragmentation, barriers to irrigation investment, and rising diesel and agricultural equipment costs (Schmidt et al., 2019). Climate change-induced vulnerabilities, coupled with widespread male labour migration to Gulf countries and Malaysia, further exacerbated these issues, leading to an increased agricultural workload for women despite their limited control over land and water resources. Given these socio-economic constraints, the project sought to determine whether collective farming could enhance irrigation access, optimise resource use, and strengthen the bargaining power of marginalised farmers, particularly women and tenant farmers.

The establishment of farmer collectives followed a structured participatory action research methodology that emphasised democratic engagement and farmer ownership of the process. The initial village selection process employed a systematic approach, as described by a project coordinator:

> *'We first created a shortlist of settlements that represented typical smallholder agriculture challenges in the region, leveraging our local partners' extensive knowledge. Focus group discussions on each settlement informed our final selection through a structured ranking tool.' (Field interview, Saptari, June 2023)*

The engagement process with farmers commenced in mid-2015 through community meetings facilitated by International Development Enterprises (iDE) Nepal and a pre-existing local farmer association. These initial discussions introduced the project concept, assessed farmers' perspectives on socio-economic and technical challenges, and explored potential cooperation models. According to the project staff, early consultations revealed nuanced farmer perspectives regarding cooperation levels. While farmers showed openness to medium-level cooperation for irrigation and marketing, they expressed reservations about pooling land and labour.

The project encouraged participation from marginal farmers, particularly those owning 0.5 hectares or less, as well as tenant farmers. Women's participation was actively encouraged, especially in

households with male out-migration. The project created two mixed-gender groups and one women-only group. It also identified farmers with leadership potential and broader social networks within each group, recognising that while homogeneous groups might reduce conflicts, they could limit the development of social capital.

Farmers' motivations for joining collectives were multifaceted. Access to 'free' irrigation technology, water management training, and support for dry-season vegetable production were significant incentives. However, some farmers recognised the inherent benefits of cooperation, as expressed by a group member recalling why she wanted to be part of the farmer collective:

> *'Although I was never a member of a farmer group before the project, I liked the idea of working together with others to save time. We would also get training and irrigation pumps.' (Field interview, Saptari, August 2023)*

Given the prevalence of tenant farmers and marginal landowners who formed these collectives, these farmers did not own land that could be pooled together in a single location. So, they had to lease land from a local landowner to create collective farming plots.

With support from project officers based in Saptari, farmers advocated fixed-rent contracts over sharecropping arrangements, based on research indicating greater benefits for tenants under fixed-rent systems (Sugden & Gurung, 2012). A project team member explained:

> *'Our involvement strengthened farmers' negotiating position with landowners to go with fixed-rent arrangements. Farmers did not prefer the sharecropping arrangement as, no matter an increase in yield, landlords claimed a share of the increased outputs, which was not attractive to these* farmers.' *(Field interview, Saptari, June 2023)*

Two distinct collective farming models emerged in Saptari during the project, shaped by farmers' cooperative preferences and their evolving group dynamics (Schmidt et al., 2019). These models demonstrated different approaches to managing groundwater access and agricultural operations.

Table 36 Type of Farming Collective Models Practised by Groups in Kanakpatti under the ACIAR Project

Collective model	**Target group**	**Levels of cooperation**	**Land arrangement**	**Labour arrangement**	**Collective sharing**	**Region where the model is piloted**
Model 1	Landless/tenants	Multipurpose comprehensive cooperation	Collective leasing of one contiguous area	Pooled labour within group	Land, labour, irrigation pump (electric and solar) and other inputs, all costs and produce	Kanakpatti group 1 and 2, Ward 2, Shambhunath Municipality
Model 2	Landless/tenants	Multipurpose medium cooperation	Collective leasing of one contiguous area, but maintaining individual sub-plots	Household labour on own land	Land preparation, irrigation, and input purchase	Kanakpatti group 1, 2 and 3 Ward 2, Shambhunath Municipality

Collective model 1 is a fully integrated cooperative model that combines collective land leasing (Schmidt et al., 2019). This first model emerged among tenant farmers who demonstrated a willingness to engage in comprehensive cooperation. A project facilitator explained the arrangement:

> *'Groups collectively leased land, shared all farming operations, and distributed costs and outputs equitably. Central to this model was the strategic placement of irrigation pumps on their collective plots, enabling shared access to groundwater resources.' (Field interview, Saptari, June 2023)*

Collective model 2 represents a moderate level of cooperation with partial integration of collective arrangements. This second model evolved in response to some farmers' reservations about complete labour pooling. Under this arrangement, farmers maintained individual autonomy over certain operations while cooperating on specific activities. A participating farmer described the approach:

> *'We collectively lease land and share critical resources like irrigation pumps but maintain individual responsibility for daily farming tasks on our designated subplots. This gave us flexibility while still benefiting from shared infrastructure.' (Field interview, Saptari, June 2023)*

The researchers noted the groups could transition between models based on their experiences and changing needs. For instance, Groups 1 and 2 implemented a hybrid approach, leasing two separate group plots: Collective model 1 for staple crops in one collective plot and Collective model 2 for

labour-intensive commercial vegetables in the second. A group member explained this strategic choice:

> *'Over two to three cropping seasons, we discovered that different crops demanded different levels of cooperation. Staple crops such as paddy and wheat worked well under full collectivisation, while vegetable cultivation required more individual attention and flexibility in labour arrangements.' (Field interview, Saptari, August 2023)*

Following the establishment of farmer groups, through the project support, members engaged in agricultural planning through regular group consultations, resulting in detailed seasonal cropping calendars. These calendars served as foundational guides for coordinating cultivation activities and resource allocation across different plots and seasons throughout the agricultural year.

The two Kanakpatti groups, 1 and 2, implemented distinct cultivation models, each addressing specific agricultural and organisational needs. Under Collective model 1, which emphasised full collective farming, members cultivated primary grain crops, including paddy, wheat, and oil seeds. This approach typically followed mono-cropping or dual-cropping patterns within each farming season, allowing for systematic crop rotation and shared labour arrangements. The selection of these staple crops aligned with traditional farming practices while ensuring food security for member households.

In contrast, Collective model 2 adopted a partially collective approach, in which members diversified their cultivation to include a range of vegetable crops. This model facilitated the production of high-value vegetables, such as eggplants, tomatoes, potatoes, and beans, meeting both market demand and household consumption needs. The partial collective nature of this model allowed members to maintain individual decision-making in crop selection, while benefiting from shared resources and collective marketing opportunities (Markelova et al., 2009).

Group 3 adopted a specialised focus on vegetable cultivation, selecting crops based on three primary criteria: members' agricultural expertise; household consumption requirements; and market potential. Their crop portfolio included potatoes, eggplants, radishes, onions, and cauliflower, reflecting a balance between commercial viability and domestic food security needs. This approach illustrated how collective farming could accommodate both market-oriented production and subsistence agriculture within a single organisational framework.

Members had varied experiences with their participation in farming collectives, ranging from the initial formation of the group to the practical aspects of labour, water sharing, and technology use.

A Kanakpatti Group 1 member described their decision-making process:

> *'Our meetings served different purposes. For the collective plot (under Model 1), where we farmed cereal crops all year round, we focused on coordinating labour input for irrigation, land preparation, and other activities, while in the individually managed group plot (under Model 2), we discussed who needed pumps to irrigate when.' (Field interview, Saptari, August 2023)*

The groups implemented a structured financial system through monthly contributions of NPR 100 per member to a collective fund. The group fund was intended to cover essential collective expenses, such as land preparation, equipment maintenance, and irrigation-related costs.

The group's irrigation infrastructure, including solar, diesel, and electric pumps, was provided through the project. Water management strategies varied by full collective plots (Model 1) and partial collective plots (Model 2).

A farmer from Kanakpatti Group 2 noted:

> *'Initially, the plan was we irrigate the whole plot together, taking turns with responsibility. The understanding was if someone could not make it on their day, another member covered for them, it was quite flexible that way (for model 1).' (Field interview, Saptari, August 2023)*
>
> *'In our individual plots (under model 2), we took turns using the irrigation pump. Since our plots weren't very large, we did not have to wait long between turns.'*
>
> *(Field interview, Saptari, August 2023)*

The collectives practised two distinct approaches to agricultural yield-sharing across the two collective models. Under Collective model 1, the arrangement followed a sharing system in which fixed rent payments were first deducted from the harvest, followed by an equitable distribution of the remaining yield among members.

As a Kanakpatti Group 2 member explained:

> *'After settling the landlord's fixed rent from our collective harvest (under model 1), we distributed the remaining produce equally among ourselves.' (Field interview, Saptari, August 2023)*

In contrast, Model 2 showed a hybrid approach. While maintaining shared arrangements for irrigation infrastructure and land leasing, this model preserved individual rights over crop harvest.

6.2.3 Overall Membership Patterns and Organisational Structure

The agricultural collectives established a consistent membership pattern of 7–8 members per group for creating spaces for collaborative farming practices. These comprised two groups, each incorporating both men and women, and another group that consisted exclusively of women farmers. The membership drew from Adivasi (indigenous) and Dalit communities, reflecting the local population's diversity.

All three groups adopted an individual-based membership model, rather than household-based representation, although household members actively participated in farming activities. This arrangement was intended to create a dynamic where members predominantly represented their households in group decisions.

Each collective (group) developed leadership structures through designated roles of chairperson, secretary, and treasurer to maintain clear channels for decision-making and financial oversight. The groups conducted monthly meetings to address formal matters, while their physical proximity, living within the same neighbourhood, allowed for daily informal interactions and problem-solving. According to the farmers, this arrangement supported continuous communication and timely responses to the groups' needs.

Some of the thought processes about collective farming groups regarding labour, irrigation infrastructure, ease of technology use, and relationships with landlords are given below. I will present a detailed group-wise experience on these matters in the subsequent section. One aspect to note is that different members in the farmer groups perceived some of these matters alike and others differently.

A Kanakpatti Group 1 member explained:

> *'We understood that collective farming was ultimately saving time, sometimes balancing work between group plots and our individual fields created labour scheduling challenges. In the paddy farming season, sometimes members needed to prioritise their private plots, especially during critical periods like transplanting or irrigation, which affected coordinating labour.' (Field interview, Saptari, August 2023)*

The irrigation infrastructure set up on the farm was viewed favourably by some farmers. Farmers shared that the constructed concrete pump houses served multiple functions, providing secure storage for equipment while hosting fixed electric pumps.

A project officer highlighted:

> *'The fixed electric pumps and compact solar systems markedly reduced the physical burden of irrigation. Simple activation through switchboards ensured water access compared to non-fixed diesel and electric pumps.' (Field interview, Saptari, August 2023)*

The establishment of fixed irrigation infrastructure significantly improved daily farming operations. As one farmer explained:

> *'The combination of on-site electric pumps and flexible delivery pipes made irrigation much easier. With collective plots, we no longer had to transport pumps from our homes to the fields, reducing both effort and time spent on irrigation.' (Field interview, Saptari, August 2023)*

Field observations documented the successful operation of irrigation infrastructure by both male and female farmers. A female farmer from Group 3 described the technological accessibility:

> *'The solar pumps were so much lighter and easier to handle. And with the electric pumps being fixed in the pumphouse, we didn't have to struggle with carrying heavy equipment anymore. Everyone in our group, both men and women, was managing irrigation.' (Field interview, Saptari, July 2023)*

This technological adaptation particularly benefited women farmers, who historically faced greater physical constraints in operating traditional irrigation equipment and lacked labour for home irrigation because family members had out-migrated.

Despite technological improvements, land tenure relationships remained complex and often precarious. The farmers noted how varying landlord attitudes within the same family could create operational uncertainty. A collective member explained:

> *'We had two landlords, both brothers - one was a doctor, and he was quite reasonable about rent. But his brother was much stricter and would sometimes threaten to raise our rent.' (Field interview, Saptari, July 2023)*

The farmers shared that, in some cases, divergent landlord approaches significantly affected their operational decisions and investment confidence. Even when technological barriers were overcome, tenure insecurity continued to influence collective farming outcomes. As one project officer noted:

> *'Yes, we installed a pump house and provided electric and solar pumps and pipes which made irrigation easier, but at the end of the day, it was still the relationship with landlords that really*

determined how well these groups could farm. No matter how good the equipment was, if farmers weren't secure about their land access, it affected everything else. The monetary equivalent rent was paid in crop yield, which is a common local practice.' *(Field interview, Saptari, July 2023)*

The farmer groups exhibited distinct organisational characteristics defined by their demographic composition and operational arrangements (Schmidt et al., 2019). These groups were categorised as follows:

Table 37: Membership Composition and Management Characteristics of Farmer Collectives in Kanakpatti (2015-2019)

Ward 2 farmer groups	**No of members**	**Male members**	**Female members**	**Caste/ethnic group**	**Farm/pond size (hectares)**	**Irrigation Infrastructures sharing (pump and tubewell)- post project**	**Labour and produce shared (project duration)**	**Labour and produce shared (post-project duration)**	**Collective model**
Kanakpatti group 1	8	0	8	Tribal	0.86 (total)				
Plot 1	8	0	8	Tribal	0.29	Partial	Yes	No	Model 1
Plot 2	8	0	8	Tribal	0.57	Partial	No	No	Model 2
Kanakpatti group 2	8	1	7	Tribal and Muslim	0.96				
Plot 1	8	1	7	Tribal and Muslim	0.22	Partial	Yes	No	Model 1
Plot 2	8	1	7	Tribal and Muslim	0.74	Partial	No	No	Model 2
Fishery Kanakpatti group (1&2)	16	Household membership		Tribal and Muslim	0.2007	No	Yes	No	Model 1
Kanakpatti group 3	7	2	5	Dalit	0.81	Yes	No	No	Model 2

(Schmidt et al., 2019)

The project invested in water management infrastructure, including tubewells complemented by electric and solar pumps (details for each group are given in the upcoming section).

Table 38 Irrigation Infrastructure Distribution and Technical Specifications Across Farmer Collectives in Kanakpatti (2015-2019)

Group Name	Number of Tubewells	Pump Types	Pump Capacity	Drip Irrigation System
Kanakpatti Group 1	2	1 Electric, 2 Solar	Electric: 4 HP, Solar: 0.5 HP	Yes
Kanakpatti Group 2	2	1 Electric, 1 Solar	Electric: 4 HP, Solar: 0.5 HP	Yes
Kanakpatti Group 3	2	1 Electric, 1 Solar	Electric: 4 HP, Solar: 0.5 HP	No
Fishery Group	1	1 Electric	Electric: 4 HP	Not Applicable

During the project period (2015–2019), a standardised rental rate was applied to land leased by farmer collectives. The three Kanakpatti groups each paid a uniform rate of 14 kg of paddy per *kattha*[23]. This rate was deliberately set below prevailing land rental rates, as the land allocated for collective farming had been barren prior to the project's initiation.

Table 39 Land Rent Rates in Farmer Collectives During the Project

Group name	Land rent during the project (2015-2019) (in NPR)
Kanakpatti Group 1	14 kg of paddy per *kattha*
Kanakpatti Group 2	14 kg of paddy per *kattha*
Kanakpatti Group 3	14 kg of paddy per *kattha*
Fishery Group	15,000 per year

Note: 1 USD=NPR 138.2; 1 kattha=0.0338 hectare (Nepali Kattha is different from Indian, spelled katha; 1 katha= 0.01264410374 hectare)

6.3 Collective to Contested: Analysing Group-Specific Patterns

6.3.1 Kanakpatti Group 1

Kanakpatti Group 1 comprised eight female members from the Chaudhary caste, representing the *Janajati* (indigenous) community. The group established a collective farming enterprise by leasing 0.86 hectares of agricultural land, strategically divided into two plots: 0.29 and 0.57 hectares.

The group implemented a dual management approach across its leased land. The larger plot (0.57 ha), while collectively leased under Collective model 2, was subdivided among members who independently cultivated vegetables according to their individual preferences throughout the monsoon, winter, and summer seasons. This arrangement maintained collective resource-sharing for irrigation infrastructure, including pumps, tubewells, and delivery pipes, while allowing autonomous decision-

[23] In this arrangement, land rent is fixed in kind as 14 kg of paddy per *kattha* per year. The rental obligation is defined by quantity rather than by monetary value, so fluctuations in paddy prices do not alter the agreed rental amount.

making in crop selection. Additionally, the group leveraged collective purchasing power for agricultural inputs.

The smaller plot (0.29 ha) was under a more integrated collective farming model 1. Here, members coordinated all agricultural activities collectively, including labour contributions, input sharing, irrigation task scheduling, and the equitable distribution of harvest yields. The cultivation pattern followed a seasonal rotation: paddy during the monsoon; wheat in winter; and lentils in summer. This systematic approach proved more manageable than vegetable cultivation due to its predetermined agricultural calendar and reduced coordination requirements. The group's irrigation infrastructure included three pump sets (one electric and two solar units), managed through a structured sharing system.

The group collected a monthly contribution of NPR 100 per member for a group fund, primarily designated for equipment maintenance and emergency expenses. Regular monthly meetings were held on the 5th of each month, which facilitated a comprehensive discussion of operational issues, irrigation scheduling, and labour allocation.

Kanakpatti Group 1 had an all-women executive committee, yet agricultural responsibilities were shared within their households. Family members, particularly husbands, played a supportive role in managing both individual and collective farming plots. While meetings and decision-making processes were agreed to be conducted independently by the group, family support was crucial for the farm's operational aspects.

The group itself had eight proactive women who were outspoken, hardworking, and entrepreneurial. After observing these practices for over a year, Group 1 was recognised by the project's local staff for its proactive farmers and farming practices. This recognition was further supported by the farmers' prior engagement in traditional crop production, including paddy and wheat, with some members also involved in vegetable cultivation.

A significant factor contributing to Kanakpatti Group 1's proactive approach to farming was their access to three irrigation pumps: one electric and two solar. The solar pumps, in particular, were highly appreciated for their ease of operation by the women, allowing them to use the equipment independently without waiting for male assistance, a common necessity for electric and diesel pumps at that time (around 2015). Unlike the heavier electric and diesel pumps, this 0.5-horsepower solar

pump, albeit dispensing limited water at a given time, was considered reliable and user-friendly by the project staff, making it especially suitable for the women in the group.

According to one of the members:

> *'The electric pump was more cumbersome to use than the solar pump, primarily due to its heavier weight and higher capacity of four horsepower.' (Field interview, Saptari, August 2023)*

Although starting the electric pump was straightforward, requiring only the flip of a switch on the switchboard, unreliable electricity posed significant challenges. Some women in the group shared that, because they had limited experience with pumps, they often struggled to understand why the pump would sometimes dispense water instantly and at other times dispense none at all, or only in limited quantities. This unpredictability sometimes led the pump to emit smoke, prompting the women to turn it off immediately. The electric pump's unreliability made the solar pump, which was more dependable and easier to use, a preferable option for some of the women in the group. Others found the electric pump easy to manage.

The solar tubewell and pump were installed at ground level, while the solar panel supplying energy to the pump was detachable, to prevent theft. The panel had to be attached before and detached after each use. The pump was housed in a small concrete structure built with project support, which also stored other irrigation and farm equipment, such as delivery pipes, panels, and fertilisers. Women would carry the solar panel to the farm and use the pump as needed.

To prevent overlap in irrigation times among the eight members, the group initially created a written irrigation schedule specifying designated irrigation hours. This scheduling applied to both the solar and electric pumps installed on the group's land through the project. The presence of two solar pumps and one electric pump adequately met the irrigation needs without competition among group members. As farming activities progressed, the members became more flexible with the irrigation schedule, accommodating household and other responsibilities that might prevent them from irrigating at designated times. This informal arrangement was feasible because the group members lived close to each other in the village block.

The farmers would start the pump, allowing it to deliver water to the crops through delivery pipes, and continue with other farm tasks, such as weeding, applying fertilisers, and managing the soil. If irrigation were the sole task, they would sometimes leave the solar pump running and periodically

check on the farm to ensure the pump on farm was working correctly. Although the women were proficient at operating the pump, household members also contributed to agricultural tasks on the farm, as irrigation and other farm work required labour.

This is where Tira's[24] (the husband of the female president of Kanakpatti Group 1) role was crucial; his expertise and support complemented the group's efforts, making irrigation infrastructure management easier. Tira took responsibility for managing the technical aspects of pump operation, addressing any issues that arose during use. The president shared his expertise made him the go-to person for troubleshooting and repairs, not only for his wife's needs but also for the other seven members of the group Whether it was fixing pump malfunctions, mending damaged pipes, or resolving electrical issues that caused low water output, Tira was the first to offer assistance.

Additionally, Tira supported non-pump-related farm activities. For instance, purchasing and transporting fertilisers from an agro-vet located one kilometer away was made easier by Tira's willingness to use his motorbike to carry fertiliser sacks. His consistent and reliable support endeared him to the group, making him a trusted figure for all matters related to group activities and an essential, occasional, yet constant resource.

During the project years until 2019, Tira, brought substantial benefits to the group through his expertise as a local irrigation pump repair mechanic. Throughout my involvement in the project and visits to the group, his family was noted for their progressive stance and willingness to host project meetings. Tira actively supported his wife's involvement in the group's activities. In the patriarchal society of Shambhunath Municipality, where it is challenging for women to participate in irrigation-related training and activities, his family supported his wife's participation in the project's three-to-four-day training sessions, despite the dominant patriarchal gender norms.

This supportive nature extended to the group as well, with the Kanakpatti Group 1 meetings held at the president’s house, which had a spacious courtyard easily accessible to all. Her husband Tira was also supportive of using the space for group activities. While the president received encouragement from family members to participate in training programmes, the level of support varied among families. For example, while the group’s president, who was actively supported by her husband, the treasurer (a woman member in the group), faced opposition from her mother-in-law, despite her

[24] All direct names of farmers used throughout this dissertation are fictitious.

husband's encouragement. This resistance stemmed from traditional gender expectations that discouraged women from participating in public group activities.

Furthermore, Tira frequently assisted all three groups, particularly in transporting irrigation equipment from the nearby market to the village. His connections in the local market enabled him to facilitate access to irrigation-related services and negotiate discounted rates for equipment repairs, a support mechanism especially beneficial for Dalit group members new to agricultural and irrigation practices.

The Dalit members expressed concerns about being overcharged at repair shops due to their unfamiliarity with pricing and negotiation. They recalled a specific instance in which a solar pump on their farm malfunctioned, requiring specialised repair services available only in Biratnagar. Given the lack of technical expertise in their local market, they sought assistance from Tira to transport and repair the pump. His role extended beyond logistical support; he also offered minor pump maintenance services to Kanakpatti Group 1 and occasionally to other groups, without financial compensation. His consistent involvement in technical support and repair work led to his recognition as a trusted and reliable figure among the groups.

While the initial project phase demonstrated successful collective management, particularly in labour sharing and produce distribution, these cooperative practices diminished following project completion. This transition reflects the complex dynamics of maintaining collective agricultural enterprises beyond external support frameworks, warranting further analysis of the factors influencing group cohesion and operational sustainability (Shunglu et al., 2022).

6.3.2 Kanakpatti Group 2

Kanakpatti Group 2 established a similar but slightly different organisational structure with eight members, comprising seven women and one man from the Chaudhary and Muslim communities. The group managed 0.96 hectares of leased land, implementing two distinct operational models. Under Model 1, they cultivated 0.22 hectares as a pure collective, sharing all agricultural tasks, irrigation infrastructure, and harvest yields. The remaining 0.74 hectares operated under Model 2, characterised by partial cooperation primarily in irrigation infrastructure sharing and occasional input coordination. The group's technological resources included two pump sets (one electric and one solar-powered) and two tubewells, representing significant shared capital investments.

The group established a monthly meeting schedule similar to Kanakpatti Group 1, and a monthly contribution system of NPR 100 per member was intended for pump maintenance and repairs. In addition, members could use the group pump for water access at a fee. This arrangement was suitable for the male member whose land was adjacent to the group-leased land. Similar to Kanakpatti Group 1, Group 2 also had an all-women executive committee and members received household support in agricultural labour.

Group 2 members also had prior experience with farming and irrigation, which aided them in their farm operations during the project. Although they had considerable farming experience, three out of the seven members were more familiar with grain production than vegetable cultivation. As the project commenced, some members of Group 2 began farming vegetables to sell their produce in the market and earn income. Those with less experience in vegetable farming leveraged the project's agronomic skills training to enhance their capabilities. Additionally, they learned from their peers who were already cultivating vegetables in the collectively leased plot, frequently seeking advice from each other and even from the farmers in Group 1.

For the women in Group 2, the solar pump was considered easier to use. However, they also used an electric pump, which irrigated the farm more quickly due to its higher horsepower (4 HP compared to the solar pump). As in Group 1, some women in Group 2 found it challenging to use the electric pump when voltage fluctuations disrupted its smooth, consistent operation.

Internal tensions emerged over vegetable farmer Radhe’s proposal to use the group's irrigation pump for his private land; he was a vegetable farmer even before the project began. As a member of the Muslim minority group in the village, known for generations of commercial vegetable farming, Radhe possessed extensive knowledge of farming and irrigation. Like Group 1, Group 2 had an irrigation schedule facilitated by the project. However, Radhe often asserted dominance over pump usage. He often reminded the women to be careful with the electric pump to avoid damaging it, since some lacked experience using it.

Group 2 also had a pump house equipped with one solar pump and one electric pump. Scheduling irrigation among the eight members was generally manageable, as the plots that each member tended were relatively small. The group had an established practice of recording electricity usage by monitoring electric meter readings before and after pump operation, ensuring fair cost distribution

among members. However, concerns arose over the male member's accountability, as other members doubted whether he accurately recorded and reported his electricity consumption.

The physical proximity of the collective plot to this male member's privately leased land led him to often use the group's pump for irrigation on his farm. While the established arrangement required members to contribute NPR 10 per unit of electricity consumed, he would occasionally refuse to pay water fees for irrigating his private plot using group infrastructure. This generated internal tensions, such as inconsistent adherence to payment obligations, particularly regarding private pump usage fees, and strained group relationships.

Further, Radhe sometimes prioritised his own water needs over other members', complicating irrigation for them. When the women protested and tried to negotiate the use of the pump for their plots, Radhe often responded bitterly, though he eventually allowed them to irrigate their fields. This created friction between Radhe and the women members, who felt he treated them condescendingly due to their gender. This male-dominant behaviour, common in the broader society, was particularly unwelcome because it disrupted their irrigation schedules and created tension within the group.

Pump maintenance was managed within the group, with the male member asserting his expertise in minor repairs. His self-proclaimed technical knowledge became a point of contention, as some members suspected he leveraged this role to justify his personal use of the pump. While Radhe handled minor pump repairs, the group had to take the pump to a repair shop at Traffic Chowk, a local marketplace one kilometer away, for significant repairs. They also relied on the treasurer's husband (Madhav), who had expertise in water infrastructure management. Additionally, Madhav served as the local land manager, locally known as a *kamtiya*, for the landlord from whom the group leased its land. This dual role positioned Madhav as a key intermediary, facilitating communication between the group and the landowner. Madhav's established connections enabled the group to participate in land-related negotiations, reinforcing his influence in its decision-making.

Group 2 also sought advice from Tira, who provided valuable insights into potential issues with the pump and advised on necessary repairs. Despite occasional conflicts, Group 2 continued its farming and irrigation activities.

During the project period, the group maintained collective labour-sharing arrangements and equitable distribution of agricultural produce. However, similar to the experience of Kanakpatti Group 1, these collective practices diminished after the project's conclusion. Members reasoned this transition,

suggesting that external support played a crucial role in maintaining collective farming practices and raising conflict, which raises important questions about the sustainability of such arrangements without ongoing institutional support.

This pattern of collective cohesion during project funding followed by fragmentation after project withdrawal is not incidental to these groups; it is structurally predictable. The project provided external facilitation through social mobilisers who organised meetings, mediated conflicts, and maintained relationships with landlords, alongside institutional support that enabled collective management. Research on farmer-managed irrigation systems in Nepal consistently shows that durable collective institutions emerge through long-term processes of trust-building, locally crafted rules, conflict resolution, and institutional adaptation rather than through short-term project interventions (Lam, 1998; Lam et al., 2010). Consequently, the programme's four-year implementation period was unlikely to provide sufficient time for collective arrangements to become self-sustaining after external support was withdrawn, illustrating what David Mosse (2004) describes as the tendency for successful project performance during implementation to mask the fragility of the institutions left behind.This experience is consistent with what development studies scholars have documented in communities exposed to repeated short-duration infrastructure programmes. The regular arrival and departure of funded initiatives gradually produce communities that position themselves as recipients of external support rather than as agents of their own resource futures (Oliver de Sardan, 2005). The solar pump experience described in this chapter fits this pattern: short-cycle delivery of infrastructure without sustained institutional accompaniment creates the expectation of further delivery rather than building the capacity for self-directed resource management. In societies with long histories of patron-client relationships, the challenge of building community agency over irrigation infrastructure is not primarily technical or financial but institutional, requiring the kind of sustained accompaniment that no short-cycle project can provide.

6.3.3 Fishery Group

After 2018, farmers in Kanakpatti group 1 and Kanakpatti group 2 expressed interest in leasing a nearby fishery pond owned by the same landowner from whom they were leasing agricultural land. This pond was situated between the two groups' collectively leased plots, approximately 300 meters apart. Originally, the pond was not considered an attractive livelihood option due to its suboptimal condition. The bunds around the pond had suffered from monsoon-induced soil erosion over the years, weakening them even though the pond remained operational. As a result, it had been leased to a local

villager for a nominal fee, and the fish farming conducted was not on a commercial scale. When this lease term ended, the groups saw an opportunity to pursue commercial fish farming.

The Fishery Group emerged from the strategic merger of Kanakpatti Group 1 and Group 2, aimed at diversifying farming practices while minimising labour demands. This newly consolidated group secured a lease for a 0.2007-hectare fishery pond from their existing landowner, providing them with an opportunity to explore aquaculture as an additional livelihood activity. The project supported the initiative due to the existing pond on the landowner's property and the nearby water source, which created favourable conditions for fish farming.

The decision to integrate fish farming as a supplementary enterprise was informed by a careful assessment of existing water resources. Farmers recognised that the proximity of irrigation wells and tubewells to the pond site, along with the pond's ability to retain monsoon water, provided an ideal setting for aquaculture. This interest was further fuelled by a project component proposing to use the pond for supplemental irrigation. Part of this plan involved repairing the pond and reinforcing the eroded bunds. As these activities unfolded, the project supported the group's interest in fish farming by offering necessary training.

A fishery expert from the livestock section of the agriculture office in Saptari district was invited to train farmers on suitable fish species for different pond layers, appropriate feed, fingerling sources, and pond maintenance to optimise fish production. Although some members had prior exposure to fishery practices, the group underwent comprehensive technical training facilitated by the project to strengthen their aquaculture management skills.

With this training, the group decided to form a new association and establish a code of conduct for pond maintenance. Unlike the crop-based collectives, which were primarily led by women, this new fishery group adopted a household membership model, allowing men to take prominent roles in decision-making and management. Tira was appointed president for his supportive role in the crop collective, earning significant support from other group members.

To ensure efficient management, the group implemented a structured operational framework, including a rotational feeding schedule. Each of the 16 members was assigned responsibility for feeding the fish on a rotating basis, ensuring that each individual contributed once every 16 days. This systematic labour-sharing approach maintained consistent care while equitably distributing workloads.

Additionally, the group transitioned from formal meetings to more informal and flexible interactions to facilitate better coordination and engagement.

The group's technological infrastructure included two electric pumps, one of which was repurposed from their existing crop irrigation system. The second pump was acquired through a subsidy from the Groundwater Resource Development Board, following the group's successful application for financial support. This funding enabled the construction of a tubewell and the installation of the pump in 2018, further strengthening the group's ability to sustain aquaculture activities.

The fishery enterprise is analytically significant beyond its practical dimensions. It represents what the bundled architecture of access framework would predict: a group of farmers who has secured the first layers of the bundle: collective land access through the lease, reliable water through the electric pump, and group organisational capacity, then leveraged these foundations to enter an entirely different productive domain that no external programme had planned for. The diversification was farmer-driven, informed by the groups' own assessment of their existing water infrastructure and market opportunity, and structured around a set of institutional arrangements (rotational feeding schedules, shared maintenance, new group membership rules) that they designed themselves. This is precisely the kind of adaptive, technology-enabled agricultural transformation that the groundwater revolution narrative promised, and it emerged here not from direct programme design is not to plan for specific diversification pathways, but to create the foundational access conditions: Secure tenure, reliable water, collective organisation, within which farmers can identify and pursue their own productive opportunities (Urfels et al., 2020).

6.3.4 Kanakpatti Group 3

Kanakpatti Group 3 consists of seven members, including two males and five females, all from the Dalit community. The group cultivated 0.81 hectares of land under Model 2 through a partial land lease. Unlike other farming collectives, Group 3 did not adopt a shared labour structure or engage in collective agricultural production beyond the project's duration. However, they jointly utilised two pump sets, one electric and one solar-powered, to irrigate their leased land. Prior to the project's intervention, most members had minimal experience with agriculture and irrigation technologies, which significantly shaped their initial approach to farming and water management.

The Dalit farming collective emerged from community consultations held during project meetings, which highlighted the community's urgent need for alternative livelihood options. Historically, Dalit

households in the region relied on income from informal labour, including construction work, village-based wage labour, and forest-based activities such as firewood collection. However, increasing the government's environmental restrictions on forest use disrupted these traditional income sources, necessitating a shift towards agricultural production. The Dalit community saw the project's offer of leased land with irrigation infrastructure as an opportunity to transition from wage labour to organised farming.

The provision of irrigation infrastructure was a critical factor that attracted farmers to this transition. Access to reliable water sources, particularly through electric and solar-powered pumps, prompted Group 3 to engage in farming despite their lack of prior experience. According to the project staff, the provision of irrigation pump technology significantly influenced the group's agricultural aspirations in two distinct ways. First, members anticipated that access to reliable irrigation would enable consistent crop cultivation, addressing their household food security concerns. Second, they viewed technology as a pathway to commercial agriculture through surplus production, particularly in vegetable cultivation, thereby generating additional income through market sales. The availability of irrigation infrastructure thus strengthened the group's confidence in transitioning to agriculture as an alternative livelihood strategy, complementing their previous dependence on forest-based and wage labour activities.

The group's engagement with irrigation technology was shaped by their limited agricultural background. Only two members possessed prior farming experience, acquired through agricultural wage labour that primarily involved manual tasks such as transplanting, weeding, and harvesting in paddy fields. This experience, while valuable for basic agricultural operations, did not include exposure to irrigation technology use and management.

The group initially assumed pump operation would be limited to simple power activation. However, irrigation management required a more complex technical understanding, including the ability to interpret pump operation from operational sounds, respond to electrical voltage variations, and maintain pump performance. This gap between anticipated and actual technical requirements highlighted the need for comprehensive training and ongoing support in technology adoption.

The group's technical capacity development occurred through multiple channels. While formal water management and pump operation training were provided through the project, the learning process extended beyond structured sessions. During the initial implementation phase, Group 3 accessed

technical support through both formal and informal networks. It regularly consulted local project staff and sought guidance from Tira.

The knowledge transfer process was further enhanced through inter-group learning, particularly from Kanakpatti Group 1 members who possessed greater irrigation management expertise. This pattern of technical skill acquisition aligned with broader observations in smallholder agriculture, where technology adoption frequently relies on peer-to-peer learning and community-based knowledge exchanges, supplementing formal training mechanisms.

Group 3's journey with irrigation technology revealed the complex process of translating technical knowledge into effective practice. In the initial months following project training, members approached water application with a straightforward but misguided philosophy: more water would yield better crops. This belief manifested in their daily practices, where they consistently over-irrigated their fields, resulting in waterlogged soil that ultimately compromised crop health.

> *'You know how we used to think? "Let's give lots of water, crops will grow faster!" But nature taught us differently. Our plants started looking sick instead of healthy. We learned the hard way that more isn't always better when it comes to irrigation.' (Field interview, Saptari, July 2023)*

Through daily observations of crop responses and conversations with experienced farmers from neighbouring groups, members began to recognise the subtle indicators of appropriate water application. They learned to observe soil moisture conditions, monitor plant responses, and adjust irrigation timing and duration accordingly.

The Dalit farmers' attempt to avail subsidised electric meters, however, revealed persistent institutional barriers rooted in land tenure requirements. Despite developing some technical competency in irrigation management, their status as landless farmers prevented them from accessing subsidised electric meters, a critical component for reducing irrigation costs. The Nepal Electricity Authority's policy requiring land ownership certificates, or formal rental agreements for subsidised connections, effectively excluded these farmers who cultivated land through informal tenancy arrangements.

The Dalit group addressed their exclusion from subsidised access to electricity through informal social networks. A strategic solution emerged when a member of Kanakpatti Group 1, Sarita, who possessed formal land lease documentation, agreed to register an electric meter under her name for the group's

use. This arrangement was considered at the time to be a way for marginalised farmers to navigate formal institutional barriers through social relationships and informal agreements.

The arrangement operated through a reciprocal benefit system. While the Kanakpatti Group 1 member, Sarita, provided legal documentation for meter registration, she gained access to the irrigation pump at a preferential rate of NPR 10 per unit consumed. This mutual benefit arrangement ensured the sustainability of the informal agreement. As one Dalit group member reflected:

> *'Without her help, we would have struggled to get an electricity connection. The formal system doesn't recognise farmers like us who don't own land.' (Field interview, Saptari, July 2023)*

This adaptive strategy showed that social capital is a crucial resource for marginalised farmers in accessing technological infrastructure. While such arrangements provided practical solutions, they also highlighted the continued dependence of landless farmers on informal networks to access essential agricultural resources. The success of this arrangement rested on trust relationships and mutual benefit, explaining how social networks can bridge gaps created by formal institutional exclusion.

As the group members gained experience in irrigation management, they diversified their farming practices. Initially, their primary focus was on high-value vegetable crops such as cauliflower, believing they would yield significant profits. However, due to their inexperience with vegetable farming, they encountered multiple challenges, including pest infestations, crop failures, and misjudgements in water requirements. After a year of farming, they shifted toward cultivating crops that were more resilient and less input-intensive, including zucchini, onions, chillies, eggplants, paddy, and wheat. The inclusion of staple grains was particularly necessary, as it provided food security while allowing the group to allocate a portion of their harvest for market sales.

As familiarity increased, the group adopted differentiated irrigation techniques tailored to crop requirements. They implemented furrow irrigation for onions and potatoes, in-row irrigation for chilies, and flood irrigation for staple grains. During the monsoon season, they supplemented natural rainfall with electric pump irrigation to sustain paddy cultivation.

Throughout the project's active phase, external support played a crucial role in ensuring the smooth operation of irrigation activities. A social mobiliser facilitated record-keeping, organised group meetings, and mediated conflicts related to water use and cost-sharing. The subsidised electricity tariff,

which lowered the per-unit cost from NPR 12–14 to NPR 2.5, further enhanced the economic feasibility of pump irrigation. However, the project's eventual withdrawal led to a decline in institutional support, creating uncertainties regarding the long-term sustainability of the group's irrigation access.

As the project neared completion in 2019, group members were expected to independently manage their water-related arrangements. This transition exposed underlying vulnerabilities in their group farming structure. While external interventions can catalyse initial technology adoption, long-term sustainability requires embedded institutional mechanisms that enable continued access to resources and maintenance of infrastructure. The gradual reduction in external support would lead to emerging tensions over water distribution, financial contributions for pump maintenance, and access to subsidised electricity.

6.3.5 Project Conclusion

The project concluded in 2019, marking a critical juncture for discussions on post-project sustainability and the transition of responsibilities to Nepal's newly established federal local governance system. During this phase, formal consultations were held with local government representatives, particularly from Ward 2, where the project had been active. Although Nepal had conducted local elections under the federal governance framework in 2017, institutional structures at the Ward level were still consolidating. At the time of the project's conclusion, Ward 2 faced significant transitional challenges, including the absence of formal office infrastructure and ongoing recruitment of municipal and Ward officials.

Amid such a reality, a Ward 2 representative, a local resident elected in 2017, actively supported the collective efforts of smallholder farmers. Recognising the community's challenges, particularly regarding water access, the representative aligned with the group's initiatives.

A key concern during this period was ensuring the sustainability of project interventions beyond its formal conclusion. While farmers continued agricultural activities using the irrigation pumps installed during the project, the absence of project officers who had provided essential technical and logistical support was considered a potential challenge.

The groups exhibited varying degrees of preparedness for independent agricultural management. Groups 1 and 2 demonstrated greater preparedness, having established a stronger foundation for post-

project farming. In contrast, Group 3, which had relied extensively on project support for irrigation training, seeds, and fertilisers, faced uncertainty about its ability to continue independently. Although the members had begun investing in their farms by the project's end, the concepts of self-investment and independent farming remained unfamiliar, raising concerns about long-term sustainability. However, the Ward-level government was identified as a potential institutional anchor for continuing support to farmer groups after project completion.

My post-project engagement with farmers revealed that, despite initial optimism that project interventions would yield sustained benefits, the post-project phase revealed gaps in achieving these expectations. Over time, the anticipated outcomes did not fully materialise, highlighting the complexities of sustaining development initiatives in contexts characterised by institutional transitions and limited local capacity.

6.3.6 Post-Project Transitions: From Collective to Current Practice

By 2023, four years had passed since the conclusion of the action research project that introduced collective irrigation technologies among farmer groups. While the project initially fostered cooperation in water management, sustained collaboration proved difficult. Through farm visits and interviews, it became evident that internal power dynamics, caste and gender relations, and economic interests significantly influenced the long-term viability of these collective initiatives.

This section shows how post-project changes shaped water access and resource control, highlighting both cooperation and exploitation among group members. It particularly focuses on how key individuals consolidated control over irrigation technologies, influencing both social relationships and economic benefits.

To break down the post-project experiences, I will start by examining the shared journey of groups 1 and 2, which was heavily influenced by their participation in the joint fishery group. Following this, I will shift my focus to Group 3, exploring the unique hurdles members faced and how they are living with them.

6.3.6.1 Diverging Paths: Power Struggles and Changing Group Dynamics

Although the project initially encouraged collective water management, the groups did not sustain their collaborative practices in the same manner after its completion. The limited project timeframe was insufficient to institutionalise long-term cooperation, especially within a socio-cultural context

where caste and gender dynamics historically shaped resource access. Additionally, internal group politics contributed to shifting operational approaches.

Key individuals – Tira, the husband of the president of Group 1; Radhe, a male member of Group 2; and Sarita, a female member of Group 1 – emerged as dominant figures across all three groups. While they facilitated access to irrigation infrastructure for some farmers, they also created obstacles for others.

The interests of different collectives became increasingly entangled, particularly between the crop groups and fishery group, as some members from the same households participated in both. While crop-based collective farms continued to operate, the introduction of the fishery group, perceived as a more lucrative endeavour, led to tensions. Economic incentives began to shift power away from collective decision-making, creating conflicts among group members.

6.3.6.2 Manipulation of Financial and Resource Control in Groups 1 and 2

The pre-existing agricultural cooperation between groups 1 and 2 underwent a significant transformation following their fishery venture. Despite their continued engagement in crop cultivation, the tensions arising from fishery management had ripple effects, fundamentally altering their established patterns of collaboration in agricultural activities.

Analysis of group dynamics revealed how profitable ventures could inadvertently trigger power consolidation within collective enterprises. The economic potential of the fishery emerged as a significant factor in reshaping group relationships. As the fishery collective gained financial potential, Tira, who was initially regarded as an advisor, began using his position for personal gain.

As one female group member reflected:

> *'Fish business was really good for us. We'd get income twice a year without putting in too much effort, especially since we had the pump to manage the water. I think that is exactly why T started playing his* games; *he saw how much money could come in and decided he wanted to keep it all to himself instead of sharing with the group.' (Field interview, Saptari, November 2023)*

The female farmer, Sarita, from Group 1, described how Tira gradually stopped maintaining financial transparency:

> '*He did not maintain any records. He started doing whatever he wanted.' (Field interview, Saptari, November 2023)*

Tira further misrepresented his financial contributions, falsely claiming that he had invested more in the fishery than he had, while appropriating the project's resources as his own. Women farmers found it difficult to challenge these claims due to entrenched gender norms.

Additionally, Tira maintained strategic alliances with two influential figures: Radhe, an assertive, agronomically skilled farmer from the Kanakpatti Group 2; and the land manager, husband of a Group 2 member. Together, they controlled pond-leasing decisions, restricting other members' access and silencing dissent.

When I asked other members about why Radhe and the land manager were selected to work with Tira, one farmer offered a candid explanation:

> *'Radhe would protest the decision if he weren't involved. He's known for being vocal, but he kept quiet because he was benefiting from working with Tira.' (Field interview, Saptari, July 2023)*

Similarly, the farmer added:

> *'You know how it works here - the land manager (Madhav) was basically the landowner's right-hand man. Tira was clever about* it; *he thought, "if I keep this manager on my side, the landowner will trust me." We tried to speak up against this, but nobody listened.' (Field interview, Saptari, November 2023)*

After the project concluded, Tira, Radhe, and the land manager took a further step by extending the pond lease for their exclusive use. Reflecting on this, another farmer noted:

> '*They offered a much higher lease amount compared to what Groups 1 and 2 paid during their collaboration. It felt unfair, but there was little we could do.' (Field interview, Saptari, November 2023)*

A female farmer further recounted how Tira manipulated the group's savings and credit system. When she took a loan of NPR 5,000 from the group fund, she was charged an excessive NPR 1,500 in interest, including additional interest on this amount. When questioned about these changes, she explained that Tira had unilaterally imposed new financial rules, taking control over the group's decision-making after the project ended.

With meetings being discontinued, members received only NPR 4,000 each when the fishery group dissolved. However, based on the frequency and scale of fish sales, many suspected that the actual earnings were much higher. Without access to financial records, members had no way to verify or contest the distributions.

One male farmer from Group 2, then involved in the fishery group, repeatedly demanded an accurate breakdown of investments and profits. However, Tira provided misleading calculations:

> *'The accounts are not transparent; everything is manipulated.' (Field interview, Saptari, November 2023)*

Frustrated by the lack of accountability, this farmer eventually left the group. Even though many members recognised that Tira was embezzling funds, they preferred to avoid conflict rather than challenge his authority.

During one of the interviews, I asked whether there were any existing records of financial transactions with Tira. He explained that, as the group began to experience internal conflicts, he had ceased maintaining the record book and eventually disposed of it. This decision, he noted, was a result of his diminished focus on group affairs during the period of discord.

6.3.6.3 Gendered Exclusion and Control Over Water Technologies

Beyond financial mismanagement, Tira and his allies also manipulated control over irrigation technologies. Women members contributed fish feed, primarily wheat feed, but suspected that their contributions were either misused or not used at all. A respondent explained:

> *'The president's husband never provided clear calculations. As a result, members stopped giving feed due to the lack of transparency.' (Field interview, Saptari, November 2023)*

Leasing decisions were made without consulting group members, further consolidating power in the hands of three influential men. When the fishery group disbanded, Tira prohibited other members from taking fish, instead using it for personal consumption and distributing it to his extended family. The group treasurer, a woman, was systematically excluded from financial transactions.

When asked how the three men in control managed to cooperate, a respondent explained:

> *'They came together because they were all manipulating the benefits without informing the group members. These three used to call "malah" (fishing contractors) and fish whenever they pleased.' (Field interview, Saptari, November 2023)*

Women were systematically marginalised in decision-making, reinforcing gendered patterns of exclusion. Even when a female member who understood the financial discrepancies attempted to raise concerns, the conversation eventually collapsed due to frustration and a lack of support. A male

member from the women's farming group also spoke out against these manipulations, but gendered power imbalances meant that one man challenging three others carried little influence.

The dissolution of collective fishery management was also influenced by personal experiences of exclusion and resource denial of some members. A critical incident involving Sarita, a former group member, illustrates how social relationships and resource access intersect with cultural practices and group dynamics.

The situation emerged during a culturally significant event, the traditional 14th-day funeral rite for Sarita's father-in-law. In local customs, this ceremony requires hosting a feast where fish hold both cultural and religious significance. S recounted her experience:

> *'I thought, since I am part of the fishery group, I could at least buy fish from our own pond for my father-in-law's shraddha [funeral rite]. When I approached T to purchase fish, he became angry and claimed the fish were too small to harvest. But I knew this was not true; he had sold fish just the week before without informing any of us in the group.' (Field interview, Saptari, November 2023)*

This incident marked a turning point in her participation in the collective. She elaborated on her decision to withdraw:

> *'Earlier, when Tira mismanaged funds, I remained quiet and tried to maintain group harmony. But when he denied me access during such a personally important cultural ritual, it became clear that my membership held no value. That's when I decided to leave the fishery group completely.' (Field interview, Saptari, November 2023)*

6.3.6.4 The Fate of Irrigation Technologies: Consolidation and Sabotage

As Tira and his allies monopolised financial and resource decisions, they also seized control of irrigation technologies. When asked about the fate of project-supported pumps, pipes, and solar-powered irrigation systems, a respondent revealed:

> '*All the pumps were taken by the president's family. They use them to irrigate their own land and do not allow other members to use these technologies.' (Field interview, Saptari, November 2023)*

The dynamics of power and control within the group became increasingly evident through the management of irrigation resources. One group member provided a detailed account of how the situation evolved:

'Tira gradually changed. He became power-hungry and wanted to control not just the fishery but also the irrigation pumps. When people started getting frustrated, he claimed he needed to keep the pumps and electrical wires safe, saying it was for security reasons.' (Field interview, Saptari, November 2023)

The member's tone grew more critical as they reflected on how their perception changed over time:

'At first, sir[25],we thought he was genuinely helping us. Such a nice man, we used to say! But now when I think about it, ah! He was just building our trust so he could take over the pumps later. These pumps, they are not like buying vegetables from the market - they cost lakhs! That's probably why he became so kanjoos [miserly] about them.' (Field interview, Saptari, November 2023)

The situation remained unchallenged, as the same member explained:

'You know, he was quite clever about it. He knew none of us would openly protest against him. So, he just kept the pumps to himself. What could we really do? He had positioned himself so carefully... like whenever there were minor problems with the pumps, he would fix them right away. This made it difficult for us to question his intentions at first. I mean, how do you challenge someone who appears to be helping the community? By the time we realised what was happening, it had become very difficult to confront him.' (Field interview, Saptari, November 2023)

Further, another critical incident occurred when the community's shared tubewell, installed for collective agricultural use, was found to have been deliberately sabotaged by the placement of stones in its shaft. This act of vandalism marked a significant shift in group dynamics.

Field interviews revealed the political context surrounding this incident. One group member described the situation with notable clarity:

'Everything was fine with the tubewell until these political issues started in our village. We could all guess who did this, but in our village, these things are hard to say openly, no?' (Field interview, Saptari, November 2023)

The timing of the sabotage coincided with a significant political development. Tira contested the Ward-level election in 2022. His attempt to secure the Ward representative position was unsuccessful. Hence, the group members believe this political defeat triggered the sabotage of the tubewell. A farmer who witnessed these changes explained:

[25]Some research participants addressed me as "sir". In this context, sir is a local term used for project staff or outsiders associated with offices or institutions. It is applied to both men and women and signals perceived authority rather than gender.

'The group's farmers believe Tira's response to political defeat manifested in systematic attempts to maintain control through access to irrigation resources.' (Field interview, Saptari, November 2023)

The case of Tira and his allies illustrates how irrigation technologies, initially introduced as collective resources, became tools for power consolidation. While technology adoption did occur, the process was neither equitable nor inclusive.

This case highlights a critical issue in irrigation technology adoption: the intersection of social power structures and resource governance. Although crop production required labour-intensive efforts and lost appeal once irrigation pumps became less accessible, technologies associated with land and water bodies gained value, reinforcing accumulation practices among those in positions of control.

Tira's initial support for gender-inclusive resource management shifted when economic stakes increased. By forging strategic alliances with other men who controlled access to land and finances, he marginalised women members, demonstrating that access to irrigation technology is not merely a technical issue but one embedded in broader socio-political hierarchies.

6.3.7 Kanakpatti Group 3 (Dalit Farmers): Post-Project Experience and Transitions

6.3.7.1 Continuing Farming Efforts

Following the conclusion of the irrigation project, my post-project interviews with Group 3, composed of Dalit farmers, revealed a landscape marked by both persistence and transformation, as well as emerging challenges. While the group has continued to engage in farming, their approach has evolved from initial experimentation to a more deliberate, strategic cultivation. Unlike the early years of the project, when agricultural activities were largely trial-based, farmers now employ structured decision-making in their production practices.

A site visit to their leased farmland provided tangible evidence of these improvements (based on my own field visits). Compared to their farm conditions between 2015 and 2019, the fields now exhibit well-structured furrows, suggesting a growing awareness of soil and water management. Farmers reported making weekly visits to the market, not only to sell their produce but also to assess price trends and identify vegetable varieties with higher profit margins. This shift reflects a transition from subsistence-oriented farming to a more market-responsive approach. Additionally, farmers have adopted multi-cropping, cultivating more than two crop types in the same plot. As they explained, this practice has enabled them to secure a supply of seasonal vegetables for household consumption while ensuring surplus production for sale.

However, their increased farming knowledge has concurrently intensified their dependency on irrigation, bringing new challenges to the fore. The non-functional state of the solar pump, which had previously been a critical resource that exempted them from electricity costs, has significantly disrupted their water access. Without this alternative energy source, the farmers must now rely more heavily on electric pumps, which puts a financial strain on them due to the additional electricity costs. As discussed in later sections, the politics surrounding access to electric pumps have further compounded this issue, leaving the group to face the complexities of sustaining irrigation beyond the project's conclusion.

6.3.7.2 Erosion of Group Support and Challenges in Collective Action

While the group's technical capacity in farming has improved, the social cohesion that the project had reinforced has weakened significantly. The departure of project facilitators and support structures has led to disorganisation in scheduled meetings and financial management. As one farmer noted:

> *'Earlier, when the project was running, the social mobiliser would come and help us organise meetings. They would remind everyone, keep notes, and make sure we discuss important things. Now there's no one to do this; everyone is busy with their own work, and it's hard to get people together. Who will take the initiative? Who will write down what we discussed? The motivation isn't there anymore because there's no one pushing us to meet regularly.' (Field interview, Saptari, November 2023)*

Despite this lack of structured engagement, the group continues to work together on matters that require everyone's attention. For example, when the pump broke down, members collectively contributed to its repair. This highlights that while external support structures are absent, they retain a functional, if sporadic, capacity for self-organisation when absolutely necessary.

However, savings as a group have ceased, with members now questioning the group's relevance in the absence of project oversight. They expressed this sentiment candidly:

> *'When sir used to come, we had to save, hold meetings, and keep all records. Now, sir doesn't come, who are we doing this for? Who's looking after us?' (Field interview, Saptari, August 2023)*

While they acknowledged that savings had previously helped maintain essential equipment, their current challenge is the lack of a neutral facilitator to coordinate and sustain these financial practices.

6.3.7.3 Wildlife Encroachment and its Impact on Farming

An additional challenge that has escalated since the project's conclusion is the increased threat posed by wild animals such as monkeys and pigs. The ongoing deforestation in the surrounding areas has depleted food sources for these animals, compelling them to invade farmlands in search of sustenance.

One female farmer recounted a particularly distressing incident:

> *'I had just planted potatoes, and overnight, the animals destroyed everything. I had to replant, but that was a major loss for us.' (Field interview, Saptari, August 2023)*

In response, farmers have resorted to night vigils, staying awake to guard their fields. This additional burden places considerable stress on farmers, particularly women, who already juggle multiple responsibilities.

6.3.7.4 Changing Social and Household Dynamics in Farming

My research also shed light on evolving gender and household roles within Group 3. While farming is largely a collective effort, individual circumstances have led to shifts in labour distribution. For example, one male group member left the group after the project ended and later migrated to India (Kashmir) for work. His wife, left alone at home, struggled to keep the farm going. As a result, the group members decided to take over the fallow plot, seeing potential in using the land for their farming. Their decision was influenced by multiple factors: proximity to their existing farmland, availability of irrigation infrastructure, and soil quality.

The intergenerational dynamics within some member families have improved, with senior family members, particularly fathers-in-law and mothers-in-law, assuming active and supportive roles in agricultural activities. This shift in familial labour allocation has reduced the workload burden on primary group members, enabling more equitable task distribution.

6.3.7.5 Shift to Individual Ownership of Irrigation Equipment

One of the most notable transformations within Group 3 is the shift from collective to individual ownership of irrigation delivery pipes. Initially, the group relied on the project-provided delivery pipes. However, when these pipes deteriorated, they chose to invest in their own pipes rather than replace them collectively. This decision was driven by previous conflicts regarding shared equipment maintenance.

One farmer explained:

'Earlier, when we shared pipes, it was always a headache. One person would drag them across rocks carelessly; another wouldn't store them properly. Nobody felt responsible. Then we decided to let each person buy their own pipes. Now if my pipe breaks, it's my responsibility. If I take care of it, it lasts longer. No more arguing about who damaged what.' (Field interview, Saptari, November 2023)

The transition to individual ownership of delivery pipes, while resolving immediate conflicts, represents a departure from the project's original vision of communal resource management. As one member observed:

'We still share the big things, the tubewell and pump, because we have to. But with smaller equipment like pipes, everyone prefers to manage their own. It is easier this way, even if it is not exactly what the project planned for us.' (Field interview, Saptari, November 2023)

This hybrid model of irrigation management has emerged organically: individual ownership of portable equipment coexists with shared access to fixed infrastructure. The arrangement reflects farmers' practical adaptations to local realities, balancing the benefits of collective access with the pragmatic advantages of individual control over certain components.

6.3.7.6 Expansion of Farming Land and Sharecropping Agreements

Among the eight Dalit members, two had prior farming experience before the project, while six began farming after its implementation. Despite the absence of formal project support, some farmers have expanded their farming activities. Two members have leased additional land from a private landowner, indicating their confidence that an additional farming plot will increase their food production.

One of these members has rented 25 *kattha* (0.85 ha) of land under a sharecropping arrangement, while another has leased 15 *kattha* (0.51 ha). When asked about this expansion, one farmer explained:

'We depended only on daily wages before; some days work would come, other days nothing. Now, with an additional farm, even if we earn less from labour, we have a little more rice and wheat in our house. We still work as labourers too, but there is some security.' (Field interview, Saptari, August 2023)

This shift away from wage work aligns with broader agrarian transformations, in which marginalised farmers seek greater autonomy in food production rather than relying on precarious labour markets.

However, challenges remain in expanding irrigation access to these newly leased plots. Currently, the farmers use extended delivery pipes to draw water from their existing group tubewell, as the new plots lack direct irrigation infrastructure. They pay for the irrigation. Additionally, the affordability of land leases has been a significant factor in their ability to expand land leasing. The land rent is fixed at a relatively low rate of NPR 400 per *kattha*, set during project-facilitated negotiations during its active phase. In contrast, farmers outside the project face higher land rental costs.

6.3.7.7 The Loss of External Mediation and its Implications

One of the most critical changes following the project's conclusion has been the loss of external mediators who previously played a crucial role in group cohesion and negotiations. During the project, social mobilisers intervened when the Dalit group faced unfavourable negotiations or disputes with other farming groups and landowners. In their absence, Group 3 has struggled to assert itself effectively. This is particularly evident in their interactions with Group 1 member Sarita, who initially assisted them with subsidised water billing but later turned this arrangement into a source of exploitation.

6.3.7.8 Control Over the Pump: The Emergence of Power and Exclusion

Sarita initially gained access to the pump through an agreement with the Dalit group, during which she assisted with the legal registration of the subsidised electric meter. However, post-project, she gradually asserted greater control over the pump, taking possession of the pump house key. Her justification for this action was that, since the electricity bill was in her name, she needed to ensure that the Dalit farmers paid the water tariffs they had incurred. According to her, this measure was necessary to prevent exploitation.

Despite this reasoning, the Dalit group found itself unable to challenge her authority. The inability to oppose her stemmed from the fact that she legally held the electric meter, even though the pump was originally intended for collective use. Furthermore, members' lower caste status contributed to their reluctance to confront her directly, as doing so could disrupt the existing social hierarchy, an upheaval they were not prepared to navigate.

6.3.7.9 Restricted Access and its Implications for the Dalit Group

With Sarita in control of the key, she and her husband were able to irrigate their own farm at their convenience. Since their land was adjacent to the Dalit group's rented plots and cultivated with high-water-demand crops such as vegetables, they frequently utilised the group's electric pump. This

resulted in an imbalance in access. The Dalit farmers now had to make repeated visits to Sarita's house to request the key whenever they needed to irrigate their fields. Although she occasionally granted them access, the inconvenience and irregularity of this arrangement eroded their sense of ownership over the pump.

For Dalit farmers, the loss of unrestricted access meant that their irrigation activities had to align with Sarita's willingness to grant them the key. This created logistical challenges, particularly because many of them depended on daily wage labour in addition to farming. The unpredictability of access made it difficult to synchronise irrigation schedules with their work routines, leading to frustrations and economic inefficiencies.

A member shared:

> *'We need permission to access something that was meant for us. Sometimes she allows us; sometimes she doesn't. If she is irrigating her fields, we must wait. But we have work too, we cannot afford delays…We installed the pump for our use, but now we have to beg for water while others profit from it.' (Field interview, Saptari, July 2023)*

6.3.7.10 Disparities in Tariff Payments and Economic Burden

Members of the Dalit group expressed concerns about the financial burden of irrigation costs. While Sarita insisted that she had taken control of the pump to ensure timely payments, Dalit farmers maintained that they had been paying their share on time. One woman from the group stated that the group had collectively paid NPR 4,000 for six months of irrigation. However, another woman pointed out discrepancies in payment structures, stating that she personally paid only NPR 500–600 annually for year-round irrigation on five *kattha* of land. This raised suspicions that the group was being overcharged for irrigation costs that also included Sarita's own farm usage.

Their frustration was compounded by their lack of formal education, which they felt made them vulnerable to financial exploitation. As one Dalit group member lamented:

> *'We are compelled, the poor are killed.' (Field interview, Saptari, August 2023)*

This statement reflected their perception of being trapped in a situation where economic and social vulnerabilities intersected, limiting their ability to contest unfair practices.

6.3.7.11 Attempts to Organise and Overcome Structural Barriers

Recognising the need for greater autonomy, the Dalit group discussed the possibility of acquiring its own electric meter. They estimated that if each of the eight members contributed NPR 600, they could cover the necessary costs. However, they were unsure about the procedural steps required to obtain a meter. A woman who was better informed about the process advised them on how to proceed, emphasising the importance of working closely with the landowner, since the electric meter ultimately had to be registered under the landowner's name.

Despite their willingness to organise this, bureaucratic and logistical challenges remained. The landowner, who had expressed willingness to facilitate the process, resided 150 kilometers away in Biratnagar. The Dalit farmers faced difficulties in reaching her and securing a firm commitment to move forward with the meter application. This geographic and administrative gap further delayed their ability to reclaim control over their irrigation infrastructure.

6.3.7.12 The Solar Pump as an Alternative and its Limitations

While struggling with restricted access to the electric pump, the Dalit group attempted to rely on a smaller solar pump for irrigation. This pump had been useful during the initial three years of the project, but its limitations became apparent over time. Unlike the electric pump, the solar pump had a lower capacity and was ineffective during the winter months due to insufficient sunlight.

Eventually, the solar pump broke down, further exacerbating the irrigation crisis. Repairing it proved to be a significant challenge, as solar pump maintenance services were not readily available locally. Unlike the electric pump, which could be serviced at a nearby workshop just one kilometer away, solar pump repairs required consultation with technicians in Biratnagar. The financial burden of transporting the pump for repairs, coupled with uncertainty about its restoration, rendered it non-functional.

Figure 21 A Non-Functional Solar Pump, Now Lying on the Ground Near its Original Installation Site

The Dalit farmers sought advice from Tira, who told them the only option was to have the pump inspected in Biratnagar. Ironically, Tira was also known for manipulating irrigation services for his own benefit, raising concerns about the reliability of his guidance.

6.3.7.13 Escalation of Conflicts and Emerging Power Struggles

The Dalit group's grievances with Sarita intensified as they noticed that she was not only controlling their access to the pump but also renting out irrigation services to other farmers. This significantly reduced the availability of water for Dalit farmers, further aggravating their frustrations. When asked why Sarita had authority over the pump, a group member responded that she claimed ownership of the motor and justified her control by pointing to her name on the electric meter.

Despite their efforts to negotiate with her, discussions remained unproductive. When they attempted to organise meetings with her family to resolve the conflict, the family refused to engage. Sarita continued to assert that she would relinquish control once the Dalit group secured its own meter, but she was aware that they lacked land ownership, which made this solution unattainable.

Beyond the immediate issue of irrigation access, the Dalit group faced an additional threat: the possibility of losing their leased farmland altogether. With improved irrigation infrastructure in place, the once undesirable land had become attractive to other farmers willing to pay higher rental rates.

Previously, the land's poor condition had deterred tenants, but with installation of the electric pump, it was now in higher demand. The Dalit group feared that landlords might prioritise wealthier tenants who could offer better leasing terms. As one member noted:

> *'If not today, then in future seasons, others will outcompete us for this land. If someone else offers more rent, what will we do? We improved this land, but we have no security. We could lose everything.' (Field interview, Saptari, November 2023)*

The group lives in constant fear that their tenure is precarious, particularly because their lower social status makes them more vulnerable to displacement. While they were in ongoing conversations with the landowner regarding the electric meter, securing their right to long-term land use remained uncertain.

6.3.7.14 Landowner's Rent Ploy

Table 40 Land Rent Rates in Farmer Collectives During and After the Project Period

Group name	**Land rent during the project (2015-2019)**	**Land rent after the project (after 2019)**
Kanakpatti Group 1	14 kg of paddy per *kattha*	increased by 40 kg per *kattha*
Kanakpatti Group 2	14 kg of paddy per *kattha*	increased by 40 kg per *kattha*
Kanakpatti Group 3	14 kg of paddy per *kattha*	increased by 40 kg per *kattha*
Fishery Group	15,000 per year	35,000 per year

Note: On irrigated land, it is 1 maan (local unit of measurement, approx. 40 kg of paddy) per kattha

After the project installed irrigation infrastructure, landlords significantly increased the land rent across all groups. For the three Kanakpatti groups, the rent nearly tripled, rising from 14 kg of paddy per *kattha* during the project (2015-2019) to 40kg per *kattha* after 2019. One farmer explained:

> *'The landlords justified this increase because of the irrigation facilities now available on the land.' (Field interview, Saptari, August 2023)*

However, they maintained that this new rate was still favourable, as the local market rate for irrigated land was higher at one *maan* per *kattha*.

Similarly, the fishery group experienced a substantial increase in its annual rent, rising from NPR 15,000 to NPR 35,000. This new pond rate was levied by the landlord and agreed to by Tira and his allies, to be paid annually.

The irrigation pump, initially intended as a shared resource, had become a site of power struggles and exclusion. While Sarita justified her control over the pump on financial grounds, her actions led the Dalit group to lose its agency over a critical resource. The lack of formal education, legal ownership, and bureaucratic knowledge placed the Dalit farmers at a significant disadvantage, making it difficult for them to contest the shifting power dynamics.The Dalit group's experience reveals the mechanism by which institutional exclusion is transferred rather than eliminated. The Dalit farmers were originally excluded from the subsidised electric meter by a bureaucratic eligibility rule, land documentation, that the programme worked around by registering the meter in Sarita's name. The rule was not changed; its exclusionary effect was temporarily deflected. However, in deflecting it, the programme created a new dependency: the Dalit farmers now required Sarita's consent to access a resource they had helped finance and maintain. The formal exclusion reproduced by the state's eligibility framework was replaced by an informal exclusion mechanisms reproduced through social hierarchy. Ferguson's (1990) anti-politics machine operates precisely through such mechanisms: the political-economic condition that produced the problem: the intersection of landlessness, caste and tenure insecurity, was not addressed by the intervention; it was rerouted through it, emerging at the other end in a new form that the programme's success metrics could not capture.

Moreover, the situation illustrates how technological interventions in agriculture are not merely about infrastructure but are deeply embedded in social, economic, and caste-based hierarchies. Without addressing these underlying inequities, such interventions risk reinforcing existing structures of marginalisation rather than alleviating them. As the Dalit group continues to seek alternatives, they remain in a precarious position negotiating with landlords, navigating bureaucratic hurdles, and contending with the ever-present threat of displacement. Their struggle highlights the broader reality that access to irrigation technology is not just about water; it is about power, control, and survival within an unequal social order.

6.3.8 Discussion

Access to irrigation technology in Shambhunath is not a discrete adoption event but an unfolding process structured by the interlocking layers of material, social, and institutional filters. The evidence from the Kanakpatti collectives show that the question is not whether development interventions can produce equitable irrigation access but under what structural conditions they are capable of doing so, and this chapter has documented the conditions that systematically prevent them: land tenure insecurity that makes individual investment rational only for landowners, eligibility requirements that encode those tenure relations into access criteria, project timelines too for institutional development, and the structural advantages of better-positioned actors that translate into programme advantages when the playing field is left formally equal. Li (2007) argues that the will to improve Is not wrong in its intentions but in its rendering of political-economic conditions as technical ones. The Kanakpatti evidence shows what follows from that rendering interventions that shift the form of exclusion without altering its structural determinants.

For development practitioners working in this context, the practical response is not to avoid engagement but to change its form. Within the bundled architecture of access framework, a productive starting point would combine three elements: participatory programme design in which landless and tenant farmer representatives formally shape eligibility criteria from the outset; a minimum five-year engagement commitment before assessing programme outcomes, with equity monitoring built into the first cycle; and systematic documentation and transfer of institutional knowledge to communities before withdrawal, so that governance capacity accumulates beyond the boundary of the individual programme. Where these conditions cannot be met, the evidence from Kanakpatti suggests that short-cycle infrastructure projects may, over time, deepen rather than reduce the cynicism that makes genuine collective action harder to sustain. Committing to longer engagement horizons, being explicit with communities about what a programme can and cannot deliver, building in community-controlled review mechanisms, and designing exit strategies that transfer institutional capacity rather than assets alone are not aspirational additions to programme design, they are preconditions for avoiding the expectation-disappointment cycle that this chapter has documented (Lam, 1998; Merrey & Cook, 2012; Cleaver et al., 2021).

6.3.8.1 Control and Continuity

The introduction of groundwater technologies, such as tubewells, electric pumps, and solar units, was intended to address water scarcity and promote collective ownership. However, these infrastructures

became embedded within local power relations. The social construction of technology (SCOT) perspective helps explain this outcome. As Oosterlaken (2011) note, infrastructure mediates human agency; it carries within it the capacity to both enable and constrain. In these farmer collectives, irrigation infrastructure was not a neutral tool. It operated as a social artefact, shaped by and shaping relations of control.

Initially, the formation of collectives suggested an egalitarian ethos, shared wells, equal contributions, and cooperative management. Yet, the principle of equality was gradually displaced by the consolidation of authority among a few actors with the necessary capital, bureaucratic familiarity, or political patronage. Over time, the collectives evolved into hierarchies in which access to water was contingent upon social proximity and compliance.

This process resonates with Ribot and Peluso's (2003) framing of access as the ability to benefit, rather than mere ownership. They argue that access is mediated through social and institutional mechanisms that define who can translate resource availability into meaningful use. Within the irrigation groups in my research, owning or belonging to a collective was insufficient. Real control rested with those who could navigate administrative procedures, maintain records, and leverage the local network.

The case of Tira, the husband of the president of Group 1, provides a concrete example of this cumulative control. As an early supporter of group initiatives, his role gradually shifted toward monopolising decision-making. By managing financial records and controlling pump access, he transformed the collective's infrastructure into an instrument of authority. Decisions about irrigation schedules and fee collection became vehicles for reproducing loyalty and dependency. Similar processes unfolded in other collectives, where individuals with higher caste status or access to institutional channels positioned themselves as indispensable intermediaries.

This concentration of authority reflects how the material filter – infrastructure location, energy connection, and technical maintenance – intersects with the social filter of hierarchy and legitimacy. A tubewell located on a dominant farmer's plot, for instance, granted the farmer physical control over the resource. Simultaneously, institutional systems, meter registration, subsidy verification, and inspection procedures served as institutional filters, legitimising control by those who could meet documentation requirements. Exclusion, therefore, was not a single event but a multi-layered outcome of material location, social hierarchy, and bureaucratic recognition. The concept of the equity deficit

is instructive here (Dobai & Riemer, 2024). Technological interventions designed to promote inclusion often leave intact the structural asymmetries that define access. As Coeckelbergh (2018) argues, technology evolves within existing social systems, carrying their moral and political dimensions forward. In the collectives I have studied, rather than transforming power relations, technology became a conduit for stabilising prior inequalities.

Gendered exclusions reinforced this pattern. Women were active contributors to farming and group activities, yet in some cases their participation was procedural rather than substantive. They attended meetings and appeared in membership records but later found it difficult to exercise decision-making power over resource allocation or technical maintenance. Agarwal's (2001) concept of participatory exclusion captures this paradox, where institutional inclusion masks deeper forms of control. Within these irrigation systems, women's presence fulfilled expectations of participation while leaving the material and institutional levers of power in male hands, as explained in the case of Tira, Radhe, Madhav in groups comprised largely of women members.

In this case, women's participation in the group was not always curtailed by land ownership, mobility, or technical capacity. Women were able to attend meetings, hold membership, and engage with the irrigation system alongside men. Yet, access remained fragile because it was mediated through layered social and institutional arrangements beyond the household. Even when women were formally included in collective structures, the conditions under which access was sustained were shaped elsewhere, through group politics, land reorganisation, and shifting alliances, rather than through individual capability alone.

The broader implication is that irrigation interventions must engage directly with the layered conditions that shape continuity of access. If collective arrangements are to move beyond symbolic inclusion, they require institutional designs that redistribute control rather than merely extend membership (Brown et al., 2019). This means locating infrastructure in ways that do not concentrate physical authority, simplifying administrative procedures so they are not monopolised by a few, and building transparent rules for scheduling, fee collection, and dispute resolution that are visible and enforceable by all members. It also requires recognising women and marginal farmers as decision-makers, not only as participants, by embedding safeguards that protect their voices when group priorities shift. Without such attention to the architecture of access, farmer-group-based irrigation

risks reproducing the very inequalities it seeks to address, offering technology without the conditions for equitable and sustained use.

6.3.8.2 The Duality of Power, Shifting Positions within the Architecture

Power within irrigation systems is fluid, circulating across the layers of material, social, and institutional relations. Individuals may hold influence in one context and experience subordination in another, depending on how the filters around them align. Within the bundled architecture of access, no actor occupies a single, permanent position; positionality is relational and dynamic.

The cases of Sarita and Tira reveal this fluidity. In Kanakpatti Group 3, Sarita controlled the electric pump, holding authority over irrigation schedules and meter payments. Her control stemmed from owning land and being the registered electricity account holder, with both institutional and material advantages. Yet, this authority was partial. Her leadership was limited to her immediate group, and her influence remained constrained by gender norms and caste boundaries that operated at higher levels of society.

In contrast, Dalit farmers who depended on Sarita's pump were structurally disempowered by landlessness and a lack of documentation, rendering them invisible to the state's eligibility frameworks. Their inability to register for electricity connections exemplified how the institutional filter amplifies exclusion rooted in the material and social layers. Still, these same farmers were indispensable for the system's functioning, providing labour and technical support during pumping seasons. Their contribution, though essential, was rendered invisible within the collective hierarchy.

This interplay between dependency and control captures the dual nature of power. Individuals can occupy both dominant and subordinate positions simultaneously, depending on how filters intersect. Sarita's authority over pump access coexisted with her vulnerability to male-dominated institutional spaces. Her experience echoes Nightingale's (2011) argument that power is relational and continuously reconfigured through social and material practices. Similarly, Pfaffenberger (1992) describes technology as a domain through which social relations are enacted and contested, rather than a neutral tool of progress.

The case of Tira also reflects this complexity. In the fishery group, he used financial management and bureaucratic connections to assert control. Yet, in another collective, his authority was constrained by rival elites occupying stronger institutional positions. This undulation between control and constraint emphasises that power is contingent upon the specific configuration of the access architecture. When

an actor's material, social, and institutional positions align, dominance is reinforced; when they diverge, power becomes unstable.

Gender and caste intersect strongly in shaping these shifts in position. Sarita's control emerged partly as a defensive strategy, reflecting the internalisation of hierarchical practices as a means of self-preservation (Elmhirst, 2011; Sultana, 2011). Having experienced exclusion in one group, she reasserted authority in another by adopting similar patterns of control. This reproduction of inequality across scales, and even within the same household, reveals how the architecture of access perpetuates itself through everyday interactions.

Within this framework, irrigation technology becomes a medium through which relational power circulates. Actors draw upon their positions within the architecture caste identity, land rights, and bureaucratic visibility to assert control in one context and negotiate dependence in another. Access is therefore not fixed but contingent, shaped by shifting alignments across layers. The duality of power reveals that technology, rather than redistributing authority, often redistributes the forms through which control is exercised.

6.3.8.3 Networks and the Uneven Durability of Access

Access to irrigation technologies is sustained through networks, relationships of trust, reciprocity, and brokerage that connect individuals to infrastructure, institutions, and each other. However, not all networks perform equally. Their resilience depends on how deeply they are embedded within the bundled architecture of access.

In the Shambhunath collectives, self-initiated networks, formed through shared labour, kinship, and local trust, tended to persist, while externally imposed networks often disintegrated after project withdrawal. This difference reflects the extent to which social and institutional filters align with material arrangements. Networks built from within what Cleaver (2007) calls institutional bricolage draw strength from pre-existing relationships that already carry local legitimacy (Lahiri-Dutt, in press). In this context, farmer groups, by contrast, rest on administrative criteria such as landholding size or project quotas, producing temporary alignment without social embeddedness.

Rogers' (2003) diffusion theory helps explain this divergence. The spread of innovation depends on compatibility with social systems and values. When collective irrigation structures are infiltrated by caste hierarchies, gender norms, and trust networks, they struggle to endure. In Kanakpatti, the farmer groups collapsed once the project facilitators were no longer present, while locally organised sharing

systems continued through informal rotation and reciprocity. The difference was not in farmers' motivation but in the coherence of the architecture that sustained their access.

Within these networks, brokerage emerged as a critical mechanism of control. Farmers like Tira acted as intermediaries, linking the group to bureaucratic institutions, providing translation of rules and facilitating eligibility. Such brokers operated across filters, materially through control of equipment, socially through reputation, and institutionally through connections. Their power derives from formal titles and from advantages arising from the intersection of multiple layers. As Berry (1993) describes in the context of African agrarian systems, resource control is often negotiated rather than absolute, sustained through flexible alliances and informal authority.

However, the dependence on brokers also reproduced hierarchy. The institutional filter, which required documentation and bureaucratic literacy, amplified the value of brokerage for those excluded from direct participation. Dalit and tenant farmers often had access to irrigation only through these intermediaries, who could simultaneously enable and constrain their use.

Gendered asymmetries further shaped network performance. Women's participation in groups was often mediated by male relatives or dominated by men who leveraged cultural legitimacy to assume leadership. Radhe, for instance, exercised authority within a predominantly female collective, not through technical expertise but through his ability to navigate patriarchal expectations. This pattern reflects Meinzen-Dick and Zwarteveen's (1998) observation that participation without recognition of women's authority reproduces inequality rather than transforming it.

These findings point to the need to work with, rather than around, the social architectures that sustain access. Farmer group-based irrigation cannot rely solely on formal membership or technical provision; it must be built upon relationships that already carry local legitimacy. This requires creating space for groups to evolve from existing practices of reciprocity, labour sharing, and informal coordination, and designing collective arrangements that recognise how authority and trust are organised on the ground. Attention to who brokers access, how leadership emerges, and whose voices carry weight is central to this process. When material infrastructure, social legitimacy, and institutional rules are aligned from within, rather than assembled only through external templates, collectives are better able to adapt, redistribute control, and sustain access over time.

6.3.8.4 Making Access Endure

Comparative work in irrigation and common-pool resource governance suggests that collective systems rarely emerge fully formed. They are built through extended processes of negotiation, conflict, and institutional learning. Studies of long-enduring irrigation systems in South Asia and elsewhere show that equity is not achieved through initial design, but through repeated cycles of adjustment in which rules, roles, and rights are contested and reworked (Ostrom, 2010; Lam, 1998; Boelens & Vos, 2014). In such cases, collective capacity is not the starting point of intervention but its outcome.

Where external actors have remained engaged over longer periods, not as managers but as facilitators of institutional maturation, farmer groups have been able to renegotiate internal authority, broaden participation, and stabilise shared control over infrastructure (Mosse, 2004; Cleaver, 2010). These experiences suggest that inequality is not simply an obstacle to collective irrigation, but a condition that must be worked through. Collective systems endure not by bypassing hierarchy, but by gradually reconfiguring it.

Read in this light, the Shambhunath cases show that collective irrigation is possible. They reveal what is required for it to become durable. The bundled architecture of access cannot be dismantled through a single intervention. It can only be reshaped through time, through relationships, and through repeated engagement with the material, social, and institutional layers that govern who controls water. What appears as failure in short project cycles may, under longer horizons, become the early and necessary turbulence of institutional formation.

6.4 Conclusion

Three dynamics together reveal irrigation access as a layered process embedded in a bundled architecture of access. The first dynamic is that control over technology translates into long-term authority when material and institutional filters align. The second demonstrates the fluidity of power, where positionality shifts as actors move across contexts and configurations. The third emphasises the role of networks in sustaining or eroding collective capacity.

Across these dynamics, (in)equality is not incidental but cumulative. Material infrastructures enable control, social hierarchies legitimate it, and institutional systems stabilise it. Together, they form an architecture in which access must be continuously negotiated.

The next chapter zooms out to the institutional landscape from which these dynamics originate. It examines the irrigation support programmes existing in the study area and how they interact with local

access architectures. While this chapter has traced how farmers navigate irrigation in everyday practice, Chapter Seven turns to how access to irrigation support itself is established, mediated, and distributed. It follows irrigation support from its point of entry into the village, tracing the roles played by farmers, and shows how institutional pathways both open and foreclose possibilities for inclusion.

7 Chapter Seven: Agency Subsidies, Elite Gains: Irrigation Infrastructure Support Politics

7.1 Introduction

During my fieldwork in 2023 in Ward 4 of Shambhunath Municipality, Saptari, a Dalit woman farmer shared her silent yet profound frustrations over the unequal distribution of irrigation support. Her voice carried the weight of generations of marginalisation as she described how development resources intended for marginalised farmers under Nepal's agricultural programmes sometimes failed to reach those who needed them most.

> *'Support comes for the poor, but the rich capture it. If anything arrives, we are not even informed. The wealthy people in the village take it for themselves.' (Field interview, Saptari, August 2023)*

Her words reveal a persistent experience in rural irrigation governance, where access to technology and resources is mediated through entrenched power structures. While irrigation schemes, supported by both government and non-governmental organisations, are framed as inclusive and equitable, their implementation sometimes reflects a different reality. Those wielding multiple forms of power – land ownership, social influence, and institutional connections – successfully claim benefits, while the most marginalised remain excluded from both resources and information networks.

When asked whether she had ever spoken against this inequity, she responded not with defiance but with fear, an emotion deeply ingrained in communities where challenging the status quo carries tangible risks:

> *'The motor (tubewell) has already been constructed, but we are not allowed to raise our voices. If we bring issues up, they might even come to beat us.' (Field interview, Saptari, November 2023)*

Her words tell of a practice in which silence is enforced through intimidation, and in which those at the margins are denied not only resources but also the right to protest their exclusion. Not all farmers articulate exclusion through explicit fear of violence, yet many remain unable to challenge those in power. Some quietly accept the status quo, as influential farmers with access to information, bureaucratic connections, and social capital continue to monopolise irrigation support. Their control operates through networks that normalise exclusion and render resistance private and often futile.

Through the experiences of three farmers, this chapter shows that access to irrigation infrastructure is rarely straightforward. Farmers rely on social networks, land relations, and political affiliations to secure support, but these same factors determine who is left out. While some gain access through ties with local leaders and development agencies, others, lacking such connections, remain excluded. To situate these dynamics institutionally, the chapter outlines the key agencies providing irrigation support in the study area, traces the flows of infrastructure, and examines who secures these interventions and how farmers engage with them in practice.

7.1.1 Status of Farmer and Water User Group Membership

Opening with my survey data from Wards 2 and 4 of Shambhunath Municipality (N=401), my findings reveal stark disparities in institutional participation and access to irrigation resources. A key contrast emerges in farmer and water user group membership: while 13.4% of respondents in Ward 2 reported membership in such groups, participation in Ward 4 was nearly non-existent (0.50%). Moreover, within Ward 2, most members (77.78%) hold general positions, while a smaller fraction (22.22%) occupy executive roles; a limited subset of the population.

On the gender front, the unequal distribution of power is visible within these groups. In Ward 2, men and women attend farmer group meetings at similar rates (44.44% male; 40.74% female), yet decision-making remains overwhelmingly male-dominated, with 85.19% of leadership roles held by men. In Ward 4, the disparity is even more pronounced, as a few men hold 100% of the decision-making positions. This disconnect, between formal participation and actual influence, suggests that attendance at meetings does not necessarily translate into meaningful decision-making power. The absence of female-led leadership in Ward 4 and its limited presence in Ward 2 (14.81%) highlight the persistent gender inequalities embedded in irrigation governance structures.

Access to irrigation-related resources and information also varies significantly between the two Wards. A key example is the distribution of electricity subsidies for groundwater access. Despite eligibility, fewer than half (44.9%) of surveyed households successfully accessed these benefits, suggesting administrative barriers, a lack of awareness, or even ineligibility to apply for the support given land ownership barriers. In fact, more than half of households in both Wards (51.2% in Ward 2; 59.0% in Ward 4) reported being unaware of these subsidies. Gender disparities in electric meter registration further reinforce these inequalities, with meters registered in men's names (31.1%) far exceeding those

registered in women's names (13.9%), which affects who can formally apply for, control, and manage electrified irrigation connections.

Patterns of irrigation support distribution follow three distinct trends: shared group resources (43.8%); combined individual and group support (43.8%); and purely individual support (12.5%). While individual allocations appear low in survey data, qualitative engagements with communities suggest that a select few farmers repeatedly benefit from these resources over time. This pattern, explored in later sections, reveals how specific individuals maintain privileged access despite the nominally collective nature of resource distribution.

Survey data suggest that while formal mechanisms for irrigation access through farmers and water groups exist, they are still limited.

Table 41 Distribution of Farmer/Water User Group Membership, Participation Patterns, and Resource Access in Wards 2 and 4, Shambhunath Municipality, Nepal

	Ward 2 (N)	**Ward 2 (%)**	**Ward 4 (N)**	**Ward 4 (%)**	**Total (N)**	**Total (%)**
Total Households (N)	**201**	**50.12%**	**200**	**49.88%**	**401**	100.00%
Membership (Farmer/Water user group)	**27**	**13.43%**	**1**	**0.50%**	**28**	6.98%
Individual	27	100.00%	1	100.00%	**28**	100.00%
Household						
Group Membership						
General Member	21	77.78%	0	0.00%	**21**	75.00%
Executive member	6	22.22%	1	100.00%	**7**	25.00%
HH Meeting participation	**27**	**100.00%**	**1**	**100.00%**	**28**	100.00%
Male attendance	12	44.44%	1	100.00%	**13**	46.43%
Female attendance	11	40.74%			**11**	39.29%
Both	4	14.81%			**4**	14.29%
Decision-Making Patterns						
Male led	23	85.19%	1	100.00%	**24**	85.71%
Female led	4	14.81%			**4**	14.29%
Joint Household	0	0%				0%
Resource Access[26]						
Group supported by the agency	17	62.96%	0	0.00%	**17**	60.71%
Member supported by the group	16	59.26%	0	0.00%	**16**	57.14%
Support received						

[26] Resource access here includes support in the form of irrigation, input, and machinery support accessed by farmer groups through external agencies (for example, pumps, tubewells, pipes, seeds, tractors, sprayers, and harvesters). See Table 42 and Table 47 for reference.

	Ward 2 (N)	Ward 2 (%)	Ward 4 (N)	Ward 4 (%)	Total (N)	Total (%)
Individually	2	12.50%			**2**	12.50%
Shared by the group	7	43.75%			**7**	43.75%
Both	7	43.75%			**7**	43.75%
Awareness about the electric subsidy						
Yes, I am aware	98	48.76%	82	41.00%	**180**	44.89%
No, I am not aware	103	51.24%	118	59.00%	**221**	55.11%
Applied for an electricity subsidy						
No, I have not applied for the subsidy	47	47.96%	52	63.41%	**99**	55.00%
Yes, I have applied for and availed the subsidy	44	44.90%	28	34.15%	**72**	40.00%
Yes, I have applied for but have not yet availed of the subsidy[27]	7	7.14%	2	2.44%	**9**	5.00%
Electric meter registration for household members						
Male member	34	34.69%	22	26.83%	**56**	31.11%
Female member	15	15.31%	10	12.20%	**25**	13.89%
Not applied	49	50.00%	50	60.98%	**99**	55%

Despite the limited presence of formal farmer/water groups in Wards 2 and 4 of Shambhunath Municipality, a select group of individuals repeatedly position themselves at the centre of multiple organisations, allowing them to access and control irrigation resources more than others. These individuals have established themselves as key figures in securing support, leveraging their institutional knowledge, bureaucratic connections, and leadership roles to navigate irrigation assistance. Their ability to strategically engage with multiple farm groups, including water user groups, ensures they remain well-positioned to benefit from available resources, often at the expense of less-connected farmers.

Among these influential figures, three farmers – Nilu, Parbat and Bhanu[28] – stand out for their ability to channel irrigation support to themselves and their networks. Nilu, a female farmer in her 40s from Ward 2, is widely recognised for her deep institutional ties and ability to facilitate resource distribution. As the president of a farmer cooperative, she maintains strong connections with the Agriculture Knowledge Centre (AKC) and the Groundwater Resources Development Board (GWRDB), enabling her to secure group-related support repeatedly. Parbat, another influential farmer in his 70s from Ward

[27] This response includes cases where farmers had applied for a subsidy but had not received it, either because the application was rejected or because approval was still pending at the time of the survey.
[28] Direct names used throughout this thesis are fictitious.

2, has similarly positioned himself as a central figure in resource acquisition. As a commercial vegetable farmer and the president of multiple farmer groups, Parbat has extensive ties with AKC and the Prime Minister Agriculture Modernization Project (PMAMP), which he has leveraged to access irrigation-related assistance. Meanwhile, Bhanu, a fishery farmer (entrepreneur) from Ward 4, holds significant influence at both the provincial and local levels. His leadership as president of the Saptari Fishery Association, combined with his strong political and institutional connections, enables him to channel support for fisheries and irrigation-related resources.

These three trajectories illustrate the upper end of the bundled architecture of access in practice: farmers who have not merely navigated individual layers of the bundle but have turned institutional pluralism, the coexistence of multiple programmes with overlapping eligibility criteria into a cumulative access strategy. Where the bundle constraints marginalized farmers at every layer, it compounds advantages for those already positioned above its thresholds. Ribot and Peluso's (2003) concept of access illuminates this asymmetry: access is not a binary condition but a set of mechanisms, and the capacity to exploit multiple mechanisms simultaneously is itself a structural advantage that accrues to those who already have it. Ferguson (1990) and Li (2007) add a further dimension: each of these three farmers has successfully exploited the development apparatus's own internal logic, using programme language, network connections, and administrative literacy to position themselves as the kinds of farmers that programmes are designed to help, regardless of whether their resource endowments already place them above the threshold of need the programme was designed to address.

Now, after deep-diving into the institutional landscape for irrigation support in Saptari District[29] (location of study Wards), I find it multi-layered, encompassing federal, provincial, and local administrative levels. Table 42 illustrates the irrigation-related support accessed by farmers in Wards 2 and 4, highlighting the various types of assistance available through different agencies. An analysis of the support distribution mechanisms across 6 key organisations reveals diverse approaches to resource allocation, subsidy structures, and targeting strategies.

[29] I present the agencies operating in Shambhunath Municipality, Saptari District, and Madhesh Province, which farmers in Wards 2 and 4 can access. Although the district is an older administrative unit, several government-affiliated agencies remain active there, and in many cases data were more readily available through these offices.

Table 42 Institutional Irrigation Support Details in Saptari District, Nepal

Organisation/programme	**Administrative Level**	**Target Farmers**	**Support Type Provided**	**Operational Status**
Prime Minister Agricultural Modernization Project (PMAMP), Kadma office	Federal with a branch office	Individual	Irrigation pump subsidies	Annually from (2016/17 to 2025/26 AD or 2073/74 to 2082/83 BS)[30]
Agriculture Knowledge Centre (AKC), Rajbiraj office	Provincial with a branch office	Individual & Group	• Tubewell construction • Irrigation pump subsidies • 85% subsidy provision, with 15% to be contributed by those receiving support	Annually
National Electricity Authority, Rupni office	Federal with a branch office	Individual	• Subsidised electricity rates for agricultural use	Annually
Alternative Energy Promotion Centre (AEPC), Kathmandu office	Federal with the central office	Individual	• Solar panel and pump • 70% subsidy, with 30% to be contributed by those receiving support	Annually
Groundwater Resource Development Board (GWRDB, Lahan office)	Federal with a branch office	Farmer Group	• Tubewell construction costs • Irrigation pump subsidies	Annually
Agriculture Development Section (Ward 2 and 4 offices)	Local at the Ward level	Individual	• Tubewell construction costs, Submersible pump subsidies 90% subsidy provision for both drinking and irrigation	Annually, following the Ward plan

Overall, at the federal level, institutions such as the PMAMP, Nepal Electricity Authority (NEA), Alternative Energy Promotion Centre (AEPC), and the GWRDB dominate the support framework. These organisations operate through centralised decision-making processes and primarily focus on providing technological infrastructure, including irrigation pumps, solar systems, and subsidised electricity access. The subsidy structures offered by these agencies vary significantly; for instance, AEPC provides a substantial 70% subsidy for solar installations, while NEA offers complete subsidies on electricity rates for agricultural use.

[30] Bikram Sambat (BS) is the official calendar used in Nepal and is approx. 56–57 years ahead of the Gregorian (AD) calendar.

At the provincial level, the AKC in Rajbiraj employs an 85:15 cost-sharing model for both individual and group-based supports, representing a hybrid approach to resource distribution. This model seeks to balance accessibility with stakeholder investment, yet questions remain regarding its effectiveness in reaching marginalised farmers who may struggle to meet the required contributions.

Local implementation through the Agriculture Development Sections of Ward offices shows the highest subsidy rate, reaching up to 90%, with support covering both submersible irrigation pumps and tubewell construction, aimed at meeting irrigation and drinking water needs. This high subsidy rate indicates an acknowledgment of local water security challenges; however, the annual plan-based distribution may inadvertently create temporal barriers to access, limiting farmers' ability to secure support when needed. In the following section, I outline the specific irrigation support provided by each agency listed in Table 42.

A notable pattern emerges regarding targeting strategies. While most federal and provincial programmes accept both individual and group applications, their operational mechanisms and subsidy structures may inadvertently favour better-resourced farmers who can fulfil matching contribution requirements. Consequently, this institutional framework exposes potential tensions between the policy intentions of inclusive support and the practical barriers to access faced by marginalised farmers.

At the same time, this mapping of the institutional landscape reveals is not a set of individual programme failures but a structural pattern. Across federal, provincial, and local tiers, each programme independently encodes the same eligibility logic: land documentation as proof of farming status, minimum landholding thresholds as conditions for subsidy qualification, and registration in formally recognized groups as the gateway to institutional support. The convergence is not coincidental. Each programme designer reached independently for the same solution because land documentation is the only proxy for farming status that the bureaucratic system can verify. The result is a multi-programme landscape that, despite variation in auspices, budgets, and stated priorities, consistently produces the same distributional outcome: marginal farmers with informal tenure, tenants, and landless households are excluded at the depolitisation of development: not that individual officials make biased decisions, but that the institutional architecture systematically encodes political inequality as procedural neutrality (Ferguson, 1990; Platteau, 2004; Li, 2007).

7.1.2 Irrigation Support by Wards

7.1.2.1 Ward 2

Ward 2 provides irrigation support through investments in groundwater access infrastructure, focusing primarily on submersible pump subsidies and electricity infrastructure development. Since 2018, the Ward has procured 100 submersible pumps, with financial assistance from both provincial and municipal authorities. These pumps serve dual purposes: irrigation and drinking water provision, under a subsidy structure requiring a 10% farmer contribution and 90% Ward financing. While the pump distribution is documented, the application and selection processes remain largely informal, with farmers submitting requests directly to the Ward Chair for approval.

The Ward makes a substantial financial commitment to agricultural and irrigation infrastructure construction through consistent budgetary allocations. In 2023, approximately NPR 20 lakhs of the total Ward budget of NPR 50 lakhs was designated for agriculture and irrigation development. The fiscal allocations that year included NPR 15 lakhs for electricity infrastructure and NPR five lakhs specifically for tubewell construction.

The Ward has supported tubewell installations between 2018 and 2023, with annual distributions of each installation comprising a set of submersible pumps and tubewells of 10, 16, 10, 12, 16, and 6, respectively. These installations primarily serve individual farmers and seven farmer groups engaged in irrigation activities throughout the Ward.

Submersible pump installations in Ward 2 entail significant technical requirements based on local hydrological conditions. According to a Ward officer, drilling typically extends from 100 to 200 feet, depending on groundwater availability and geological characteristics. The systems use deep tubewells operating at 13 Hz, with submersible pumps ranging in diameter from 4 to 8 inches to accommodate varying water depths.

The financial cost of submersible pumps is a significant barrier to independent farmers for private installations. Individual pumps cost between NPR 19,000 and 22,000 while drilling costs are approximately NPR 200 per foot, and most installations require a minimum depth of 80 feet. The Ward provides financial support of approximately NPR 100,000 per unit; however, total installation costs frequently exceed this amount, creating a substantial financial gap, especially for resource-constrained farmers.

Another irrigation project in Ward 2, funded through provincial financial support, involved installing a 209-foot tubewell to facilitate mango cultivation. However, construction remains incomplete due to a rocky subsurface aquifer at the drilling site. Accessing a non-rocky aquifer would require additional financial investment, which was not accounted for in the initial budget. As a result, the tubewell remains non-operational, leaving nearby farmers unable to utilise the water source and expressing disappointment over the unfulfilled promise of improved irrigation access.

Farmer testimonies present a contrasting narrative regarding the incomplete tubewell infrastructure, suggesting systematic misappropriation rather than budgetary constraints. Primary interview data reveal that local stakeholders perceive these implementation failures as deliberate instances of fund diversion rather than legitimate resource shortages. A farmer shared:

> *'It is not really about lacking funds... The officials brought this money for their own benefit. This whole story about insufficient funds is just their excuse. We understand what actually happened here.' (Field interview, Saptari, August 2023)*

The distribution of submersible pumps also reveals a similar discontent among the farmers. While Ward officials and those in leadership roles publicly acknowledge the need to support irrigation for resource-constrained farmers, empirical evidence from farmer interviews indicates a systematic pattern of politically motivated resource allocation. The distribution of submersible pumps appears to be closely tied to political patronage networks, with access predominantly granted to constituents who demonstrate party loyalty.

One farmer's testimony exemplifies this politically contingent distribution:

> *'He gives all the motor (pumps) to his party people. When we asked, he said, "You did not vote for me, why should I give you?"' (Field interview, Saptari, November 2023)*

Further, even the distributed pumps face substantial operational challenges that compromise their long-term use despite significant financial investments. Farmers noted that among the Ward-funded submersible pumps, only four remain operational. The majority have failed due to technical problems stemming from inadequate and fluctuating electricity voltage or rapidly declining groundwater levels. A persistent technical impediment affecting pump operation is an inconsistent electrical voltage supply, which frequently causes pump failures. Many farmers operate submersible pumps without voltage stabilisers that are essential for managing power fluctuations. Despite the relative affordability of these protective devices, investment in stabilisers remains limited among farmers. When pump

failures occur, maintenance costs create additional financial burdens, with repair expenses for malfunctioning submersible pumps ranging from NPR 2,000– 3,000, an additional expenditure for small-scale farmers.

Recognising the necessity of a stable electricity supply for the operation of submersible pumps, the Ward Chair prioritised the construction of a higher-capacity transformer in 2023. This commitment is reflected in the allocation of NPR 20 lakhs for expanding the electricity infrastructure. The plan includes installing 100-kilowatt (kW) capacity transformers in two settlements, Kanakpatti and Kahirbana, with the projected benefit of serving approximately 500 households. These installations aim to improve the reliability and consistency of the local power supply.

The governance of irrigation support in Ward 2 is notably fragmented, with limited integration among various government programmes operating at different administrative levels. The Ward Chair acknowledged the lack of formal coordination with national initiatives, such as the PMAMP, despite initial efforts to establish collaborative links.

In contrast, Ward 2 has maintained functional relationships with the GWRDB, which provides direct irrigation support to farmers. Within the institutional arrangement, the Ward primarily serves as an intermediary by issuing referral letters that connect farmers with technical and financial resources. Vegetable producers represent the primary beneficiaries of this support structure, reflecting an emphasis on high-value crop production. The Ward Chair acknowledges that equitable access to irrigation for marginalised farmers, particularly landless and Dalit communities, remains a significant challenge in Ward 2.

7.1.2.2 Ward 4

Ward 4 has comparatively fewer irrigation support programmes than Ward 2, with much of its agricultural support focused on electrification rather than direct irrigation infrastructure development. The Ward has prioritised agricultural electrification, allocating approximately 30%-35% of its total annual budget, which increased from NPR 50 lakh to NPR 70 lakh in the 2022-2023 fiscal year, toward the expansion of electrical poles, according to the Ward Chair. Additionally, NPR 2 lakh has been earmarked for farmer training programmes to promote commercial crop cultivation. However, this initiative remains in the planning phase, with implementation strategies still under discussion. The Ward leadership acknowledges significant limitations in coordinating with higher-level agricultural

initiatives, including a complete disconnect from the PMAMP and minimal engagement with the GWRDB.

Although the Ward Chair estimates that approximately 50% of farmers now have access to electricity for irrigation purposes, this figure is not based on official records, which remain inaccessible for verification. Field observations and structured interviews reveal, however, patterns of preferential infrastructure deployment, suggesting that electrification expansion follows networks of political and personal interests rather than systematic planning for equitable distribution. As one farmer observed during a field interview:

> *'These electrical poles were installed last year, prioritising the Ward Chair's agricultural land... The electrification has been completed exclusively in their fields.' (Field interview, Saptari, July 2023)*

Amid such electrification efforts, Ward 4 does not independently support the construction of tubewells or pumping infrastructure; instead, it relies on external agencies to facilitate groundwater access. The Agricultural Knowledge Centre (AKC) has provided limited support, primarily benefiting a small number of commercial fish farming enterprises and a few well-connected farmers with the procedural knowledge to navigate application processes. The Ward coordinator openly acknowledged this gap, stating:

> *'I have worked as a coordinator here for five years; I have not yet heard of training organised by AKC.' (Field interview, Saptari, July 2023)*

Ward officials recognise that inadequate dissemination of information about available support programmes further restricts farmers' access to irrigation resources. Public notices are primarily displayed on Ward office bulletin boards; however, literacy constraints limit their accessibility for a significant portion of the agricultural population. Traditional radio-based announcements, which previously served as the primary communication channel, have become less effective as media consumption patterns shift with mobile phone adoption. As one Ward member explained:

> *'The information is pasted on the noticeboard of the Ward, but people are not literate, and so they do not read the board. There used to be information passed through the radio as well, but due to the increased use of mobile phones, people have stopped listening to the radio as they used to before.' (Field interview, Saptari, July 2023)*

Structural inequalities further shape irrigation access in Ward 4, disproportionately disadvantaging smaller farmers cultivating less than one *bigha*. The same Ward member acknowledged this disparity, stating:

> *'Farmers with land less than one bigha who are smaller farmers do not normally get irrigation support in the Ward.' (Field interview, Saptari, July 2023)*

Ward officials attribute this exclusion to several interrelated factors, including information asymmetries, procedural complexities, and resource limitations that hinder smaller farmers' access to available support. Additionally, fragmented land ownership patterns pose a significant challenge to the effective implementation of irrigation infrastructure. As the Ward member articulated:

> *'Someone has two kattha here and four kattha there. If one borehole is supported in one place, it is still hard to irrigate. If the land were consolidated in one place, one tubewell could irrigate all the land.' (Field interview, Saptari, July 2023)*

Despite these acknowledgments, direct irrigation support has not been prioritised at the Ward level. Constraints such as limited budget allocations, institutional limitations, and dependence on higher-tier governmental and external agencies for groundwater access have led the Ward to focus primarily on expanding preferential agricultural electrification rather than initiating irrigation-specific programmes.

7.1.3 NEA Subsidised Electric Meter

The Nepal Electricity Authority (NEA) is responsible for the generation, transmission, and distribution of electricity across Nepal, with a mandate to expand energy access and support economic development. NEA is responsible for the electric energy supply for agriculture, including for irrigation. As part of its efforts to support affordable electricity for agricultural use, the NEA has introduced a subsidised electric meter programme, enabling farmers to use irrigation powered by electricity-based systems.

The NEA Rupni office is located three kilometers from Ward 2 and seven kilometres from Ward 4, serving agricultural communities in Shambhunath Municipality. This Rupni NEA branch, which operates as a subsidiary of the Rajbiraj office, located 15 kilometers away, is located closer to Shambhunath Municipality. The decision to establish this office in proximity to key agricultural areas was made to reduce logistical challenges for farmers seeking electrical services.

Farmers applying for an electric meter must complete a structured application process, which requires several official documents presented in Figure 22 below. These include: a recommendation letter from the local Ward and municipality; a completed application form; proof of citizenship; and either a land ownership or rental certificate. Additionally, applicants must provide two recent photographs and construct a designated meter house on their farmland to ensure proper installation and prevent non-agricultural usage. NEA officials emphasise the need for these requirements to maintain transparency and ensure that subsidised meters are used as intended.

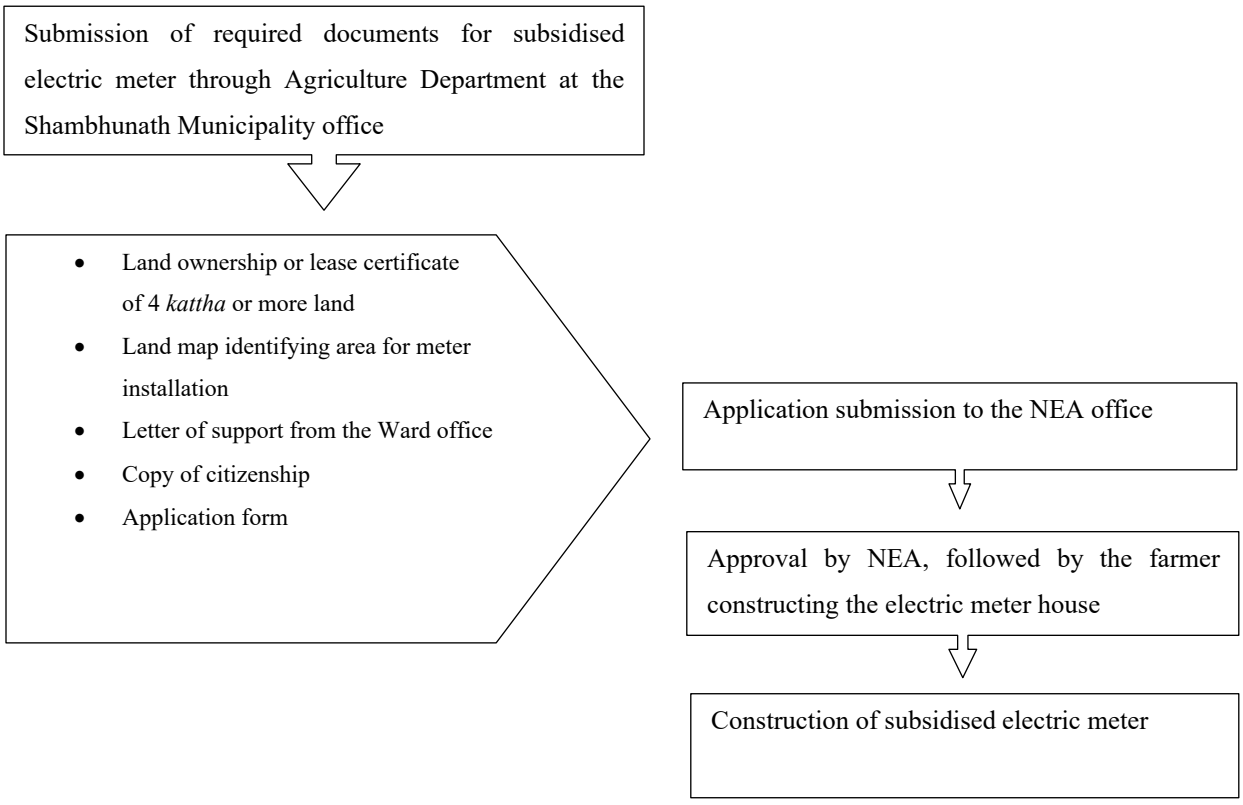

Figure 22 Process of Obtaining a Subsidised Agriculture (Krishi) Meter in Shambhunath Municipality

Upon receiving an application, the NEA office verifies the payment history of previously issued meters within the applicant's family, to assess compliance with existing regulations. Notably, there are no restrictions on the number of electric meters a farmer can obtain, allowing flexibility for those with higher irrigation needs. Once approved, applicants are notified and must complete the installation process within seven days of payment. Delays beyond this timeframe prompt inquiries from higher provincial authorities, reinforcing NEA's commitment to procedural accountability and timely service delivery.

Installing an electric meter is a relatively simple process that typically takes about 15 minutes. However, NEA officials expressed concerns regarding inconsistencies between recorded electricity consumption and corresponding revenue collection, suggesting potential inefficiencies or unauthorised usage within the system. Another concern is that these meters are procured from Janakpur (province), and delays in receiving meter boxes from the head office occasionally disrupt supply chains, affecting installation timelines.

The cost of a single-phase electric meter was set at NPR 4,153.50 and includes the meter itself, the meter box, a seal for the meter box, service charges, and a 13% value-added tax (VAT). For larger agricultural operations, a three-phase meter (priced at NPR 20,133) offers a capacity of 25 kilovolt-ampere (kVA) and 25 kW, making it more suitable for high-power irrigation systems. According to NEA officials, approximately 98% of farmers rely on single-phase meters, while commercial-scale farmers prefer three-phase meters due to their higher capacity. Improvements in electricity availability and reduced power outages have encouraged greater use of electric-powered irrigation systems, according to officials.

Despite these advancements, significant challenges persist for marginal and tenant farmers, particularly regarding the eligibility criteria for obtaining an electric meter. A key barrier is the requirement to own at least four to five *kattha* (0.167 ha) of land, which excludes many smallholders and tenant farmers from accessing electricity-based irrigation. In some cases, farmers with as little as one *kattha* have successfully acquired meters, although this has not been consistently implemented across different localities. Additionally, tenant farmers without land ownership face difficulties in securing subsidised rates for meter installations, further limiting their ability to get electric irrigation.

The regular electricity tariff ranges from NPR 12 to 14 per unit, but with a subsidised meter, the cost drops to NPR 2.5 per unit. Further, NEA provides a 7% discount available if payment is made within seven days of the meter reading. This incentive structure was designed to encourage timely payments among farmers. Because of this, officials often report that farmers take the initiative to monitor their electricity usage by photographing the meter readings and subsequently visiting the electricity office to process their payments. During the monsoon paddy cultivation season, when paddy is the principal crop, average electricity consumption typically ranges from 6 to 7 units per billing period, resulting in total electricity costs of less than NPR 20. Subsidised electric meters ensure that farmers pay less per unit charge when using electricity for agricultural purposes.

The demand for installations typically peaks in June and July, coinciding with heightened reliance on groundwater for irrigation because surface water sources are limited. According to the NEA Rupni office:

> *'The electric meter mostly operates during the paddy season, with some usage during the wheat season, leading to payments being made in Baishak/Jestha (April).' (Field interview, Saptari, July 2023)*

In the study area, electric meter readings are scheduled for four specific months: Baishak/Jestha (April and May); Mangsir/Poush (December and January). This schedule ensures that 99% of electric meters are accurately read and aligns those readings with the fiscal-year financial transactions. However, concerning the installation of new electric meters in Ward 2, the readings are conducted on pre-determined days each month. Farmers must then submit their electricity payments by the specified due date.

The electric meter reading officer raised farmers' awareness of their agricultural electricity subsidy. As farmers increasingly recognise the role that affordable electricity plays in their water access, applications for electric meters are on the rise. Despite the increase in meter applications submitted, the officer noted that while progress is being made in expanding electricity coverage, achieving complete coverage across all farms remains a significant challenge.

Municipal support is playing an important role in improving the affordability and accessibility of irrigation electricity. Municipalities provide financial reimbursements for subsidies allocated to farmers, assist the NEA Rupni office in verifying the authenticity of electric meter applications, and invest in infrastructure development, including the construction of electric poles to expand agricultural electricity coverage. However, the level of municipal support varies across different administrative units in Saptari. For instance, Rupni Municipality fully covers the cost of electric meters for agricultural purposes, while Shambhunath Municipality has not adopted this practice, according to NEA Rupni officers.

To ensure that electricity meters are allocated for agricultural rather than residential use, the NEA Rupni office relies on references from Ward representatives when there is uncertainty about the authenticity of applications. This process also accommodates farmers' preferences for meter placement, ensuring installations align with their irrigation needs. Additionally, municipalities allocate funds for constructing electric poles as part of efforts to improve the reliability of the electricity supply for agricultural activities.

Despite these efforts, meeting the growing demand for electricity remains a challenge. NEA officials have noted that the existing transformer capacity is insufficient to support increasing load, necessitating joint investments by NEA and municipalities to address the issue. When voltage fluctuations affect the electricity supply, the local NEA office conducts inspections and, when necessary, upgrades transformer capacity to accommodate up to 100 kW. The installation of new transformers follows a formal request process that requires a reference from the Ward and documented evidence from at least 8 to 10 individuals citing specific voltage issues. If sufficient funding is available, transformer installations are completed within the same fiscal year; otherwise, requests may be postponed to the following year.

Infrastructure improvements also include installing dedicated agricultural transformers. For example, a fish farmer in Ward 4 of Shambhunath Municipality received provincial assistance to install a dedicated transformer. However, challenges persist, as another agricultural transformer in another location of Ward 4 remains non-operational due to technical, financial, or administrative constraints. The annual budget allocated for transformer installations for NEA Rajbiraj is approximately NPR 8 million, with funds distributed based on community needs. Municipalities also contribute to co-funding transformer installations. However, the extent of municipal involvement varies; while Rupni Municipality benefits from higher government funding programmes for electricity infrastructure, similar support has yet to be extended to Shambhunath Municipality.

The installation of electric poles in Wards 2 and 4 has encountered challenges related to fund utilisation and technical oversight. In certain cases, municipalities have awarded construction contracts based on personal affiliations rather than technical merit, resulting in substandard infrastructure that fails to meet established specifications. As a result, some transformers installed for irrigation purposes in both study Wards in the Shambhunath Municipality remain inactive due to incomplete work. In response, according to NEA officials, official communications have been sent to municipal authorities, emphasising the need to adhere to technical standards and involve the electricity office in monitoring construction progress, before authorising payments.

The increasing demand for irrigation meters has also raised concerns about voltage fluctuations. During peak electricity demand periods, such as the paddy-growing season, transformers can effectively supply electricity within a 2-kilometer radius. However, when meters are connected beyond this range, voltage levels weaken, affecting irrigation pump performance. This issue highlights

a broader challenge: municipalities often overlook technical specifications when implementing electricity projects, according to NEA Rupni staff. Ideally, decisions on installing single-phase or three-phase transformers should be based on capacity requirements to ensure a reliable electricity supply. However, due to budgetary constraints, municipalities frequently install one- or two-phase transformers, resulting in mismatches between the capacity of electric meters and the transformers. Such mismatches have resulted in power supply inconsistencies in Shambhunath Municipality, causing irrigation pumps to malfunction.

Municipalities are still refining their strategies to improve electricity coverage and have received feedback from farmers about voltage fluctuations while operating irrigation pumps. These issues are often attributed to technical oversights in municipal installations, as they occur before coordination with the NEA.

Farmers in Shambhunath Municipality, where agricultural landholdings are typically fragmented across multiple locations, face significant challenges in utilising electricity meters under existing regulatory provisions. Current NEA policy mandates that each electric meter be installed in a designated meter house and fixed to a single plot to ensure accurate measurement of electricity consumption. However, due to the dispersed nature of landholdings, many farmers have resorted to transporting their meters between different plots, despite this practice being explicitly prohibited by NEA regulations. My own field observations confirmed multiple instances of farmers physically moving meters, which undermines the intended monitoring and regulation of electricity usage. NEA officials expressed concerns to me that when meters are not securely installed, they may fail to accurately register electricity consumption, leading to billing discrepancies. Despite these regulations, I found that some farmers continued to circumvent the policy by unhooking and reconnecting meters at different locations, a practice observed on multiple occasions during my fieldwork. While technically unauthorised, this practice is driven by the practical necessity of irrigating scattered agricultural plots. Farmers have developed informal strategies to overcome these constraints, including use of bamboo poles to extend electrical connections between fields, enabling irrigation pumps to operate across multiple locations. Although this practice poses safety risks, including the risk of electric shock, it remains widespread due to the lack of alternative solutions that accommodate fragmented landholdings. Farmers frequently justified these practices by pointing to gaps in official provisions, with one farmer stating:

'Farmers are cleverer than the officers.' *(Field interview, Saptari, July 2023)*

While electric meters remain traceable through their registration numbers, these improvisations highlighted a broader policy misalignment with the realities of smallholder farming.

7.1.4 Agricultural Knowledge Centre (AKC): Bridging the Gap in Irrigation Support

The Agricultural Knowledge Centre (AKC) serves as an important provincial government entity under the Ministry of Land Management, Agriculture, and Cooperatives in Madhesh Province. It provides essential technical and financial assistance to farmers in Saptari District, particularly in Shambhunath Municipality. The AKC is located in Rajbiraj, approximately 15 kilometers from Ward 2 and six kilometers from Ward 4. However, access from Ward 4 to Rajbiraj can be challenging due to poor road conditions, making it difficult for farmers to seek support.

The AKC addresses significant irrigation challenges faced by local farmers, over 60% of whom engage in agricultural activities, many of whom *own less than 0.1 hectare of land.* The head of the AKC emphasised the need for irrigation support, stating:

> *'Irrigation facilities are a significant problem for farmers because existing surface irrigation infrastructure in Saptari, such as the Chandra Nahar canal and the Koshi pump, often run dry during the dry months, compelling farmers to depend on groundwater and ponds for irrigation.' (Field interview, Saptari, July 2023)*

In recent years, the AKC has shifted its focus from overall agricultural productivity to promote agricultural mechanisation and establishing shallow tubewells (STWs) for irrigation, including provision of training for farmers. The centre is engaged in various initiatives, including riverbed farming, oilseed production, and vegetable farming, all designed to support agricultural practices. Furthermore, the AKC has undergone significant changes since the introduction of federalism in Nepal. Previously functioning as the District Agriculture Development Office (DADO), the AKC's scope of work has diminished, along with staffing levels. Historically, district agricultural offices employed 50 to 60 officials. However, since 2017, the redistribution of these positions across municipalities has left the AKC with only 15 officials.

To facilitate irrigation support, the AKC employs two distinct subsidy models. The first model offers a 100% subsidy for the construction of STWs, allowing farmers to pay a deposit of NPR 15,000 that is refunded upon the successful installation of the irrigation infrastructure. The second model provides

an 85% subsidy, requiring farmers to contribute 15% of the costs upfront. This financial structure is specifically designed to alleviate farmers' burden while promoting the installation of irrigation systems.

The AKC has implemented a structured application process for these subsidies, which begins with the issuance of public notices that invite farmers to submit their requests within a 21-day window. Individual applicants must provide various documents, including a land certificate confirming ownership of at least two *bighas*, a recommendation letter from their local Ward or municipality, and proof of citizenship. Additionally, farmer groups and cooperatives must submit extra documentation, such as group registration certificates and meeting minutes that discuss the support being sought. The construction of the tubewells is managed through a tendering process, ensuring that all parties involved adhere to the required protocols. Similar to individual applicants, farmer groups must also possess at least two *bighas* of land to qualify for support.

In Wards 2 and 4 of Shambhunath Municipality, the AKC has extended direct support to individual farmers and organised groups. This support includes installing STWs and a fish farm in Ward 4. Additionally, the cooperative Shree Mahila Utthan Jansewa in Ward 4 received funding for large-scale farming. Mechanisation support has also been significant, with six farmer groups participating in the New Block Development Programme and receiving power tillers and mini tillers to alleviate labour shortages. Beyond infrastructure, the AKC aids farmers, groups, and cooperatives in marketing linkage and management, ensuring that local farmers can effectively sell their produce.

Despite the AKC's efforts, significant challenges remain in meeting the irrigation needs of the local farming community. The head of the AKC expressed frustration regarding the disparity between demand and available resources, stating:

> *'If we had enough money to fulfil all irrigation demands, we could then focus on other agricultural mechanisation projects*.' *(Field interview, Saptari, July 2023)*

Historically, the AKC supported 150 to 200 irrigation pumps per year, but budget cuts in 2023 significantly reduced that number. Currently, demand for over 500 irrigation pumps per year contrasts sharply with the AKC's capacity to support only five, highlighting a substantial gap between need and availability. Budget constraints further exacerbated these challenges; the annual budget for irrigation programmes was drastically reduced from NPR 1 crore to NPR 10 lakh in 2023. The head lamented the delays in budget allocation, explaining:

'The financial year starts in June/July, but it is already December, and we still have not received our budget.' (Field interview, Saptari, July 2023)

Such delays hinder the timely delivery of essential irrigation support, making it difficult for farmers to access the resources they need. Further, planning and budgeting become challenging because although funds are allocated, the budgeting process takes two to three weeks. This delay can significantly impede the infrastructure construction timeline.

In addition to budget constraints, the AKC faces challenges when working with landless farmers, who encounter unique barriers to accessing irrigation resources. Although the AKC allows applications through *'manjurinama',* a land-use agreement that facilitates collaboration with landowners, the process remains complex. One of the field officers shared:

'It is challenging to work with farmers without land, but it depends on how they organise and come forth to ask for support.' (Field interview, Saptari, July 2023)

Many landless farmers struggle to navigate the bureaucratic system, often lacking access to crucial irrigation facilities. Furthermore, the AKC addresses bureaucratic inefficiencies in municipal budget allocations.

The recent reduction in budgetary allocations has necessitated that the AKC pursue collaborations with local governments, including municipalities, and engage with initiatives such as the PMAMP. However, these collaborations often lack formalisation, which poses significant challenges to operational effectiveness. In addition to financial constraints, the AKC must navigate a complex landscape of bureaucratic and political obstacles when implementing agricultural programmes. A notable concern is the ambiguity of municipal governments' budget allocations. Although municipalities are mandated to allocate funds to agriculture, veterinary services, and women's programmes, these funds are often consolidated into a single, centralised fund under the mayor's oversight. Additionally, municipal leaders' commitment levels vary widely; some mayors actively participate in planning meetings and consultations, while others show little engagement, complicating the implementation of agricultural initiatives. Furthermore, while the PMAMP focuses primarily on paddy, mango, and buffalo farming, the absence of formal programmatic coordination between the AKC and PMAMP results in a fragmented agricultural support system. This lack of integration underscores the pressing need for greater collaboration to ensure that farmers receive comprehensive, cohesive assistance.

Overall, the AKC plays a vital role in facilitating agricultural development and irrigation initiatives in Saptari District, particularly within Shambhunath Municipality. AKC officials acknowledge the various challenges they face, including budgetary constraints and bureaucratic inefficiencies; nevertheless, the centre remains committed to enhancing farmers' access to essential resources.

7.1.5 Irrigation Support Under PMAMP

The Prime Minister Agriculture Modernization Project (PMAMP) is Nepal's leading initiative for agricultural transformation, implemented under the Ministry of Agriculture and Livestock Development with a budget of NPR 130 billion (2016/17–2025/26). In Shambhunath Municipality, PMAMP plays a crucial role in promoting mango and paddy cultivation and in providing targeted irrigation support to farmers facing water scarcity. The PMAMP district office, located in Kadma, is approximately 40-45 kilometres from Wards 2 and 4 of Shambhunath, making accessibility to institutional support a challenge for many farmers. Ward 2 is designated as a mango zone, reflecting its agro-ecological suitability for fruit farming, while paddy zones are concentrated in the northern region of the Mahendra Highway.

As a domestically designed and funded initiative, PMAMP serves as the key implementation mechanism of Nepal's Agriculture Development Strategy (ADS). It focuses on enhancing irrigation infrastructure, providing subsidies for tubewell installation, and ensuring institutional capacity-building within local farming communities. Despite these efforts, challenges remain in equitable resource distribution, particularly in the accessibility of irrigation support for smallholder farmers.

7.1.5.1 Process of Accessing Irrigation Support

PMAMP primarily delivers irrigation support through registered farmer cooperatives and groups, ensuring that resources are allocated within formally recognised agricultural networks. Private commercial agricultural firms are also eligible for assistance, provided they are officially registered with the relevant authorities. In Saptari, overall, over 100 farmer groups are currently registered, receiving irrigation support primarily for mango and paddy farming.

The application process for irrigation subsidies follows a structured annual cycle, designed to ensure systematic planning and distribution of resources:

1. Call for Applications: Each year, around July-August (Shrawan), PMAMP announces available irrigation subsidies and invites applications from eligible farmer groups.

2. Submission & Verification: Farmers submit detailed requests specifying their irrigation needs, including the type and scale of support required. The PMAMP district office conducts site inspections to verify the feasibility of each application.
3. Approval & Agreement Signing: After evaluation, selected applicants are invited to sign agreements, outlining the terms and conditions, before the implementation phase begins.
4. Implementation & Final Payment: The installation of irrigation infrastructure is carried out, and final subsidy payments are disbursed in April, marking the completion of the annual cycle.

Previously, PMAMP allowed farmers to purchase and install irrigation equipment independently, reimbursing costs upon submission of bills. However, this reimbursement model was discontinued two years ago due to fraudulent claims, in which some farmers claimed subsidies without installing the required equipment. To address these issues and enhance transparency, PMAMP now directly supplies irrigation equipment, ensuring pumps are used appropriately for their intended purpose.

7.1.5.2 PMAMP's Irrigation Subsidy Allocation

In 2023, PMAMP allocated subsidies for 68 irrigation pumps to support farmers in Shambhunath and surrounding areas. The selection of tubewells and pumps is based on a combination of tubewell depth and pump support, ensuring that the support given does not exceed the allocated NPR 40,000 to 45,000 per unit irrigation support.

Table 43 PMAMP Subsidy Structure for Tubewells and Pumps

Depth of Tubewell	**Pump (Motor) Type**	**Subsidy Rate**	**Farmer Contribution**	**Additional Notes**
40 feet	2-inch motor	85%	15% manual labour cost	Farmers request installation via farmer groups/cooperative or private commercial farm
60 feet	1-inch motor	85%	15% manual labour cost	Inspected before approval
90 feet and above	Not provided	85%	15% manual labour cost	Farmers are not provided with pumps for deep tubewells, as the 85% subsidy applies only to tubewell construction, which is significantly more costly.
General cost per tubewell and pump	NPR 40,000 – 45,000[31]	Covered under subsidy	Farmers pay labour costs	The payment is capped at NPR 45,000 and the process takes months

[31] Indicative cost for construction of tubewell

To qualify for irrigation subsidies under PMAMP, farmers must submit a set of documents verifying their eligibility. The documents listed in the table below are verified during the application process.

Table 44 PMAMP Documentation for Subsidy Application

Required Document	**Description**
Farmer group/cooperative registration or commercial farm documentation	Proof that the applicant is part of a registered farmer group/cooperative or private commercial farm
PAN number	Tax registration number of the farmer group or cooperative
Citizenship certificates	Citizenship documents of all the farmer group members or the cooperative
Land ownership certificate	Proof of land ownership for the proposed irrigation installation site (of 2 hectares and above)
Ward-level recommendation letter	Issued by the Ward office to confirm the applicant's need for support
Bank account details	Bank account of the farmer group/cooperative for subsidy transactions
Confirmation of non-duplication	A declaration stating that the applicant has not received similar support from other programmes

The eligibility criteria for PMAMP irrigation support encourage support distribution through groups. A minimum land certification of two hectares is generally required for a single irrigation unit. However, recognising the needs of farmers working in smaller plots, PMAMP has expanded access to plots as small as two *kattha*, provided that farmers form shared-use agreements within registered groups.

For tenant farmers who do not hold landownership certificates, ward-level verification was described by PMAMP officials as a proxy mechanism to confirm farming status and enable eligibility for irrigation support. This arrangement was presented as an administrative adaptation to Nepal's land tenure context, intended to allow farmers with smaller or non-certified holdings to apply. However, this provision did not emerge in practice during fieldwork, as none of the interviewed tenant farmers reported accessing irrigation support through ward-level verification, which is why it was not discussed earlier.

7.1.5.3 Challenges in PMAMP's Irrigation Support

Despite its extensive support, PMAMP's irrigation interventions encounter significant barriers that hinder equitable access to resources. PMAMP officers share that wealthier, larger landholders are better positioned to benefit from the programme, leaving smaller farmers and tenant cultivators at a disadvantage. As a PMAMP officer acknowledges:

'Mostly, those with bigger landholdings receive support, while small farmers often do not. Monitoring is necessary.' (Field interview, Saptari, July 2023)

The PMAMP officer's observation that larger landholders consistently benefit over small farmers does not reflect a programme design flaw that could be corrected through better targeting criteria alone. It reflects a structural feature of how large-scale subsidy programmes interact with agrarian inequality. Larger landholders have advantages that are cumulative and self-reinforcing: they are more likely to be connected to the networks through which programme announcements circulate informally before they reach public noticeboards; they have the bureaucratic literacy and documentation to complete application requirements; they can afford the upfront costs (transport, fees, opportunity time) of navigating multi-stage application processes; and their prior programme participation gives them the procedural knowledge that transforms subsequent applications from a challenge into a routine. Each of these advantages derives directly from their position in the agrarian hierarchy. Mansuri and Rao (2013) show that community-driven development programmes consistently reproduce the capture patterns of the communities they work within unless institutional design actively counteracts those patterns from the outset, which requires acknowledging them as structural rather than incidental features. PMAMP's standard application cycle, public not announcements, and group registration requirements do none of this. Then apply formally equal rules to structurally unequal participants (Platteau, 2004; Mansuri & Rao, 2013; Thapa et al., 2023).

Additionally, the concentration of irrigation support remains a recurring issue. Many farmers who have previously received assistance continue to reapply each year, which reduces opportunities for new beneficiaries. A PMAMP technician highlighted this challenge, stating:

'To support new farmers, PMAMP needs to expand its interventions to additional Wards. Unfortunately, we work in the same areas every year.' (Field interview, Saptari, July 2023)

To ensure that resource-rich farmers do not repeatedly receive support, coordination with municipal and Ward offices is essential. The officers believe local governments that provide verification and recommendations for applicants are positioned to facilitate a more equitable distribution of resources. Furthermore, they note that improved monitoring is necessary to prevent duplication of resources and ensure fair access to support. The technician warns:

> *'Clever farmers are strategic - they sometimes seek subsidies from multiple agencies for the same tubewell installation. There needs to be stricter oversight to prevent corruption.' (Field interview, Saptari, July 2023)*

The dynamics within the groups supported by PMAMP also reflect varying degrees of participation among male and female farmers. Although women contribute significantly to farming activities, decision-making predominantly rests with men. The technician observes:

> *'In training sessions, women participate, but it is mostly men who speak. Women rarely ask questions, even though they perform most of the agricultural labour.' (Field interview, Saptari, July 2023)*

Amidst these realities, one of the officers notes an ongoing transition in crop choices in Saptari. Farmers in northern Saptari, where irrigation difficulties are more pronounced, are increasingly shifting land from paddy to mango farming. This transition is primarily driven by mango's lower water requirements and higher market value. However, it predominantly benefits wealthier farmers with larger landholdings.

> *'Those who earn more can establish mango orchards and buy rice from the market, but poor farmers without land face significant hardships.' (Field interview, Saptari, July 2023)*

The Kadma office staff at PMAMP share a long-term vision that includes exploring the feasibility of installing deeper tubewells to address chronic water shortages in Saptari. However, such decisions depend on federal budget allocations and policy directives, which are beyond the control of local branch officers.

Ultimately, while PMAMP plays a crucial role in facilitating irrigation infrastructure in Saptari and Ward 2 of Shambhunath Municipality, the officers recognise that access disparities persist. These disparities tend to favour well-connected and vocal farmer groups over marginalised farmers.

Furthermore, the institutional landscape documented in this chapter demonstrates that the patterns of differential access identified in Chapter Four are not produced by individual programme failures or institutional incompetence. They are the cumulative output of a system in which formally neutral procedures: land documentation, group registration, public notice announcements, interact with an agrarian structure in which the relevant resources are already unequally distributed. Across federal, provincial and local tiers, each programme independently applies the same procedural logic to the same structured inequality and independently reproduces the same distributional outcome. This is the

anti-politics machine operating across an institutional ecosystem rather than within a single project: each institution treats irrigation access as a technical allocation problem; none treats it as a political-economic problem rooted in the agrarian structure the programmes simultaneously depend on and reinforce. The implication for policy is direct: piecemeal programme reform that adjusts targeting criteria at the margin will not fundamentally alter distributional outcomes as long as the structural conditions that advantage better positioned farmers across all programme interfaces remain unaddressed. Equitable irrigation requires not mere better programme management but different institutional arrangements, ones designed from the outset to counteract rather than encode the agrarian inequalities through which they operate.

7.1.6 Groundwater Resources Development Board (GWRDB) Irrigation Support

The Groundwater Resources Development Board (GWRDB) operates its Lahan office as the primary institution for groundwater development in eastern Nepal's Terai region, encompassing Saptari district. Established under a federal mandate in 1976, this office implements programmes to identify and develop groundwater resources, with a specific focus on the use of both shallow and deep aquifers for irrigation. GWRDB's jurisdiction over the Shambhunath Municipality positions it as one of the actors in supporting local irrigation infrastructure development. However, its operational capacity is often constrained by institutional limitations and an increasing demand for groundwater access. Notably, the GWRDB office is located approximately 60 kilometers from Wards 2 and 4 of Shambhunath municipality.

GWRDB primarily engages with registered farmer groups to facilitate irrigation support by constructing tubewells. The board categorises tubewells into two types: shallow tubewells (STW), which are up to 50 feet deep; and deep tubewells (DTWs), which are deeper. The construction of these tubewells is fully mechanised, employing power drills for STWs.

Farmers are responsible for purchasing materials for tubewell construction and coordinating with others in need of irrigation support. Currently, GWRDB supplies six-inch Polyvinyl Chloride (PVC) or Unplasticised Polyvinyl Chloride (UPVC) tubes, as well as Mild Steel (MS) options in areas with challenging soil conditions. A single four-inch tubewell is estimated to irrigate approximately four hectares, while a DTW is designed to irrigate around 40 hectares. To qualify for subsidies, farmers must apply through their respective groups and show landholdings of 4 *bighas* or more.

Table 45 Tubewell Types and Subsidy Requirements

Tubewell Type	Depth	Diameter	Irrigation Capacity	Farmer Group Requirement	Documents Required
Shallow Tubewell (STW)	Up to 50 feet	Up to 6 inches	Approximately 4 hectares	Minimum four *bighas* of land	Registration of the farmer group/cooperative, tax land receipts, and the land ownership certificate
Deep Tubewell (DTW)	More than 50 feet	Up to 6 inches	Approximately 40 hectares	Minimum four *bighas* of land	Registration of the farmer group/cooperative, tax land receipts, and the land ownership certificate

In the pre-federalism era, hydrogeologists conducted direct assessments of farms to determine water needs. However, GWRDB has transitioned to a tender notification system, requiring farmers to apply for tubewell construction. Under this system, GWRDB staff members monitor the installation of both STWs and DTWs. At the same time, farmers are responsible for the actual construction of the infrastructure by hiring contractors. The application process begins with demand collection, which occurs during Jestha and Aashad (approx. May and June). During this period, GWRDB compiles data on demand, submits to the province, reviews previous applications, and assesses new requests. Subsequently, the province allocates specific locations for pump installations, after which GWRDB announces tenders for construction.

To construct a DTW, farmers must submit several documents, including a payment of NPR 20,000, land tax receipts, details of the farmer group registration, and a land ownership certificate for the proposed installation site.

Table 46 GWRDB Application and Construction Process

Process Step	Description
Demand Collection	Farmers submit requests in Jestha and Aashad (May and June) for tubewell construction
Application Submission	GWRDB compiles demand data and reviews previous applications before allocating locations for pump installations
Tender Notification	Once locations are assigned, GWRDB announces tenders for construction
Construction	Farmers construct the tubewells themselves, with GWRDB staff monitoring the installation process
Documentation	Farmers must provide necessary documents, including proof of land ownership and group registration, before construction begins

The GWRDB office in Lahan, which oversees both Saptari and Siraha districts, receives approximately 1,500 requests annually. However, GWRDB faces significant challenges in handling

the volume of applications, as it can accommodate only 100 requests per year. Subject to budget availability, the office offers both tubewell construction support and pumps as part of its assistance. A GWRDB officer notes:

> *'Now, if possible, we provide pumps as well if the budget allows. If we do not have enough funds, we focus on tubewell construction*.' *(Field interview, Saptari, July 2023)*

Farmers are expected to apply as a group; however, many are unaware of this requirement and often come to the office seeking support individually. The GWRDB officer adds:

> *'A lot of times, perhaps due to lack of information, farmers come individually*.' *(Field interview, Saptari, July 2023)*

The officers note that tenant farmers often struggle to receive support due to the requirement for land documentation.

> *'When submitting documentation, land ownership must be verified. If one is part of a group, they can access support, but receiving assistance officially is not possible.' (Field interview, Saptari, July 2023)*

Historically, GWRDB supported irrigation in smaller landholdings, such as one or two *bighas*, which previously qualified for smaller tubewells. However, the requirement has now shifted to a minimum of four *bighas* of land to receive support for larger tubewells, which deters smaller farmers from applying.

To obtain support, a land certificate is required that indicates the name under which the land is registered. Access to subsidies is easier for landless farmers when they are part of a group; however, obtaining official support without proper land documentation remains a significant barrier.

Each farmer group can typically apply for about four tubewells, but GWRDB aims to limit allocations to two per group. This approach aims to maximise coverage across multiple groups while considering the varied demands of numerous farmers.

Additionally, implementing deep tubewell projects can take several years, as budget allocation often takes considerable time.

> *'Once the budget arrives, it can take 4-5 years to implement a deep tubewell plan.' (Field interview, Saptari, July 2023)*

Despite their technical expertise, GWRDB staff members lack decision-making authority over tubewell location selection. Their responsibilities include only measuring and monitoring installations, determining the required materials, and arranging for the necessary equipment.

The recent shift in decision-making authority to the provincial government has affected the selection process for support applications. Farmers with connections to politicians and bureaucrats tend to be favoured in resource allocation. The Lahan office receives directives from the provincial government regarding which applications will receive support.

> *'Everything has become political. Support allocation comes from above. Provincial-level decisions are based on who they know. Sometimes, the applications we send are not allocated. The province makes arrangements based on whom they know, and they get the subsidy. We are facing such issues.' (Field interview, Saptari, July 2023)*

Support allocation is influenced by established relationships, with decisions based on whom individuals know, rather than solely on need.

Even farmers who are aware of available support face conflicts within their groups, which complicates their access to water. The officer reflects on the challenges encountered in resolving these conflicts:

> *'In Nepal, when groups are formed, it can be cumbersome with four to five people. Sometimes we have to engage in discussions, and other times we cannot find solutions at all.' (Field interview, Saptari, August 2023)*

To address such issues, the officers note that coordination with Ward offices is essential for addressing the challenges that arise within farmer groups. The GWRDB informs local Wards whenever it provides support to farmers, ensuring that local governance structures are actively engaged in the process.

Within farmer groups, there is a requirement to ensure gendered participation, stipulating that 33% of group members must be women. However, GWRDB officers report that actual female participation remains low, at around 10%. Many women face multiple responsibilities and are often unaware of the opportunities available to them.

7.2 Patterns of Resource Distribution and Elite Capture in Agricultural Support

Figure 23,

Figure 24, and Figure 25 show the expensive solar pumps, provided for irrigation support, used for non-irrigation purposes. Tragically, these photos are small examples of the implementation of irrigation support programmes and the realities of resource distribution. Resourceful farmers managed to secure support, but when a technical mismatch occurred, these technologies became non-functional.

Figure 23 A Solar Panel, Initially Intended for Irrigation, was Repurposed[32] as a Window Shield at a Fishery Farm in Ward 4, Shambhunath Municipality.

Figure 24 A Non-operational Solar Panel Installed in Ward 4, Shambhunath Municipality, Now Repurposed for Storing Paddy Hay - Photo from Behind

Figure 25 A Non-operational Solar Panel Installed in Ward 4, Shambhunath Municipality, Now Repurposed for Storing Paddy Hay - Photo from Front

[32] The term repurposed is used deliberately here. The solar pump was originally installed for irrigation on the farm of a relatively well-resourced farmer who already owned multiple irrigation technologies, including shallow tubewells and diesel pumps. As the pump was not essential for meeting irrigation needs, it was subsequently used as a window shield at the fishery site.

Similarly, in Wards 2 and 4 of Shambhunath Municipality, while multiple agencies offer substantial support for groundwater irrigation, fundamental structural barriers persist in their delivery systems. The land ownership requirement emerges as the primary constraint across agencies, including GWRDB, PMAMP, and Ward-level programmes, creating an insurmountable barrier for landless farmers. This prerequisite effectively excludes a significant portion of agricultural producers who, despite their active role in food production, lack formal land entitlements.

The financial structures of support programmes, despite their seemingly inclusive design, present significant challenges for economically marginalised farmers. Even minimal contribution requirements, such as the 10% Ward-level contribution (close to NPR 100,000) for submersible pumps, become substantial barriers for resource-constrained farmers. NEA's electrical infrastructure support, while offering comprehensive coverage through subsidised agricultural electricity rates, remains inaccessible to farmers unable to meet the baseline financial requirement of NPR 5,000. This reveals a critical gap between programme design and the economic realities of resource-poor farmers.

Further, the distribution of irrigation resources reveals patterns of political influence and dynamics of social capital. Local government support, particularly evident in Ward-level implementations, shows systematic bias toward politically connected individuals. Field evidence indicates concentrated installation of irrigation infrastructure on lands owned by Ward chairs and their networks, highlighting how political affiliation often supersedes need-based allocation. This politicisation of resource distribution is creating parallel access systems that operate independently of formal eligibility criteria, further marginalising farmers without political connections.

District-level implementation faces additional complexities, as acknowledged by staff across AKC, GWRDB, and PMAMP. These institutions recognise systematic issues, including the repeated allocation of resources to select farmer groups, male dominance in group leadership, and limited inclusion of marginalised farmers. However, the institutions' capacity to address these issues is constrained by rigid budgetary processes, top-down political interference in beneficiary selection, and limited institutional autonomy. This creates a situation in which staff carrying out implementation recognise systemic inequities but lack the authority or mechanisms to effect meaningful reforms. The resulting institutional paralysis perpetuates cycles of exclusion, despite awareness of system failures.

When we shift focus to the distribution patterns of irrigation support in Shambhunath Municipality, Table 47 systematic disparities in resource allocation are revealed (Table 47). An examination of the

AKC's fiscal year 2078/79 BS (2021/22) records reveals concentrated patterns of support distribution, in which specific individuals consistently secure resources. This phenomenon is exemplified through three prominent cases: the Shambhunath Fish Farm (owned by Bhanu); Parbat Chaudhary's vegetable committee; and the Shree Mahila Utthan Jansewa Krisi Sahakari (led by Nilu). All have repeatedly accessed support from multiple agencies, including PMAMP and AKC.

These beneficiaries have successfully secured various forms of irrigation infrastructure, particularly shallow tubewells (locally known as 'motors') and associated agricultural inputs, through multiple institutional channels. While official documentation from AKC and PMAMP provides formal evidence of this support pattern, qualitative research through in-depth interviews reveals that their access to resources extends beyond these two agencies, suggesting a broader network of institutional support. This concentration of benefits among select recipients indicates the emergence of what can be termed resource capture 'specialists': actors who have developed strategies to navigate bureaucratic systems and secure agricultural support.

The success of these beneficiaries in repeatedly accessing support can be attributed to their cultivation of extensive institutional networks, particularly through strategic relationships with agency personnel and decision-makers. This pattern of resource distribution highlights how social capital and institutional connections become crucial determinants of access to agricultural support, potentially superseding formal criteria for resource allocation. The following section provides detailed case studies of Bhanu, Nilu, and Parbat, examining their specific strategies for securing support and the broader implications of their success for agricultural resource distribution systems.

Table 47 List of Beneficiaries and Types of Agricultural Support Provided (by Year and Category)

S.N.	Name	Address	Support Type	Individual/Group	Year Support Extended (AD & BS)
1	Shambhunath Fish Farm	Shambhunath Ward 4	Shallow tubewell (locally called motor)	Individual	2021/22 AD (2078/79 BS)
2	Sunita Devi Sah	Ward 4	Shallow tubewell construction (85% subsidy)	Individual	2020/21 (2077/78)
3	Radhe Shyam Sah	Ward 4	Shallow tubewell construction (85% subsidy)	Individual	2020/21 (2077/78)
4	Hari Chaudhary	Ward 4	Shallow tubewell construction (85% subsidy)	Individual	2020/21 (2076/77)

S.N.	Name	Address	Support Type	Individual/Group	Year Support Extended (AD & BS)
5	Subhalal Sah	Ward 4	Shallow tubewell construction (85% subsidy)	Individual	2020/21 (2076/77)
6	Laxman Ram	Ward 2	Tubewell and pump construction (85% subsidy) for 10 *kattha* land	Individual	2020/21 (2076/77)
7	Lalo Devi Chaudhary	Ward 2	Tubewell and pump construction (85% subsidy)	Group	2020/21 (2076/77)
8	Shambhunath Fish Farm	Ward 4	Tubewell and pump construction (85% subsidy) for 1 *bigha* land	Group	2020/21 (2076/77)
9	Rajgadi Farmers Group	Ward 2	Tubewell and pump construction (85% subsidy) for 1 *bigha* land	Group	2020/21 (2076/77)
10	Khado Khola Farmers Group	Ward 2	Tubewell and pump construction (85% subsidy) for 15 *kattha* land	Group	2020/21 (2076/77)
11	Shree Dina Bhadri Fish and Animal Farm	Ward 4	Tubewell and pump construction (85% subsidy) for 10 *kattha* land	Group	2020/21 (2076/77)
12	Shree Mahila Utthan Jansewa Krishi Sahakari	Ward 4	Tubewell and pump construction (85% subsidy) for 6 *kattha* land	Group	2020/21 (2076/77)
13	Shree Mahila Utthan Jansewa Krisi Sahakari	Ward 4	Various support for vegetable farming via PMAMP	Group	2021/22 (2078/79)
14	Samjhana Kumari Chaudhary	Ward 4	Commercial model farming	Individual	2021/22 (2078/79)
15	Malti Devi Sah	Ward 4	Banana farming support (model farming)	Individual	2021/22 (2078/79)
16	Saroj Kumar Chaudhary	Ward 4	Onion farming support (model farming)	Individual	2020/21 (2077/78)
17	Manoj Kumar Chaudhary	Ward 4	Vegetable farming	Individual	2020/21 (2076/77)
18	Parbat Chaudhary via Shree Kanak Ladhu Udhami Tarkari Block coordination committee	Ward 2	PMAMP: seeds, shallow tubewells, etc.	Individual/Group	2020/21 (2076/77)
19	Parbat Chaudhary via Shree Kanak Ladhu Udhami Tarkari Block coordination committee	Ward 2	Group vegetable farming support (not received)	Group	2075/76 (2019/20)
20	Parbat Chaudhary via Shree Kanak Ladhu Udhami	Ward 2	Farmer *haat* (weekly market) improvement programme	Individual/Group	2021/22 (2077/78)

S.N.	Name	Address	Support Type	Individual/Group	Year Support Extended (AD & BS)
	Tarkari Block coordination committee				
21	Parbat Chaudhary	Ward 2	Reaper	Individual	2022/2023 (2078/79)
22	Shree Mahila Utthan Jansewa Krisi Sahakari	Ward 4	Block support part of the PMAMP fertiliser cooperative	Group	NA

(AKC, 2023)

7.2.1 Bhanu, a Fishery Entrepreneur in Ward 4

Bhanu, a 46-year-old fish farmer, is a prominent entrepreneur in Ward 4. Originally engaged in the brick factory business, he transitioned to fish farming a decade ago due to the high labour demands and time-consuming nature of brick production. He is not a native of Ward 4 but from a neighbouring village. His decision to shift to the fishery was driven by higher profit margins compared to traditional paddy and agricultural farming.

In 2014, Bhanu leased 14 *bighas* of land for fish farming in Ward 4, initially starting with just five *bighas*. He secured the lease from local landowners he was acquainted with. Over time, recognising the profitability of the fishery compared to other agricultural ventures, he expanded his lease to 14 *bighas*, now secured for 15 years.

Bhanu's fish farm meets the demand of Saptari district, where approximately one quintal (South Asian unit for 100 kilograms) of fish is imported daily from outside the district. His farm alone supplies 100 kilograms of fish per day, ensuring a consistent market with high demand. He cultivates six fish species and maintains steady sales year-round.

His land lease agreement stipulates a rental payment of three to four *maan* per *kattha*, which remains stable for the entire 15-year rental period. Bhanu has entered into a formal land lease agreement with the landowner, maintaining stability as a commercial entrepreneur. He acknowledges that formal land lease agreements provide security and prevent arbitrary actions by landowners. Furthermore, in case of any disputes, he can appeal to the entrepreneur association, which strengthens his tenure security, unlike tenants and marginal farmers in Wards 2 and 4, who are riddled with tenure insecurity under their informal leases.

7.2.1.1 Government Support and Incentives

Bhanu has received substantial government support to improve his fishery operations, including various forms of financial assistance and subsidies. The Veterinary Office has provided essential training programmes and fingerlings to improve his fishery practices. Additionally, the AKC assisted him by supplying a tubewell and pump with an 85% subsidy, significantly reducing his initial investment costs. The Provincial Ministry of Agriculture facilitated the installation of a deep tubewell and pump, at a total cost of NPR 1.4 million, thereby expanding Bhanu's water access.

Moreover, Bhanu has successfully lobbied through the Ward government to increase the capacity of his transformer to 100 kW. This transformer, which he can use exclusively for his fishery operations, provides him with a stable electricity supply, free of intermittent power issues. He also received support for a solar pump installation through collaborations with Sabal Nepal and the Alternative Energy Promotion Centre (AEPC).

Currently, Bhanu operates six tube wells, comprising three shallow tubewells (STWs) and three deep tubewells (DTWs). The STWs, with diameters ranging from three to four inches, have depths of up to 60 feet. In addition, the DTWs, equipped with 6-inch diameter pumps, reach depths of 340 feet, 175 feet, and 155 feet. One of these tubewells was provided by the GWRDB in Lahan. Bhanu's ability to secure substantial funding and technical support puts him in a better position than many smaller farmers, who often face challenges in accessing similar assistance.

Previously, Bhanu relied on diesel-powered pumps because the electricity supply was unreliable, available for only four hours per day (7 to 11 PM). This necessitated continuous diesel pump operation, which was economically unsustainable given high fuel costs. With the current stable electricity supply, Bhanu exclusively uses electric pumps, eliminating diesel expenses. He highlights the cost difference: while the electricity tariff for agricultural meters is subsidised at NPR 8 per unit, diesel costs NPR 150 per Liter, making electric pumping significantly more economical. Bhanu operates under a commercial electricity meter and pays approximately NPR 150,000 annually.

7.2.1.2 Patronage Politics in Agricultural Subsidies

Despite receiving significant support, Bhanu acknowledges that government assistance is often distributed based on political affiliations rather than genuine agricultural needs. He asserts that under the central government, resources are allocated to farmers impartially, but at the provincial level, political favouritism is prevalent. He recounts receiving a deep tubewell from GWRDB while his

brother was an elected politician in 2017. However, following the 2022 elections, when his brother was not re-elected, he observed a decline in support and an increase in patronage politics.

He states:

> *'Relatives of politicians receive support, while many farmers face difficulties; I personally have not faced such issues extensively…Political recommendations are excessive.' (Field interview, Saptari, August 2023)*

7.2.1.3 Issues with AEPC-Supported Solar Pump Installation

In 2017, Bhanu received a solar pump through AEPC and Sabal Nepal. However, he faced significant challenges due to contractor mismanagement. While the subsidy agreement specified the installation of a submersible pump, the contractor provided a surface-level pump, which was unsuitable for his farm's water table. Bhanu protested but was assured that if the pump failed, a replacement would be provided. However, after installation, the contractor did not return, and AEPC did not respond to his complaints. He paid NPR 60,000 (15% of the total cost) but never received a working system.

Bhanu expressed his frustration:

> *'They cheated a lot…It seems like everyone is complicit. I called him (the contractor), but he did not come. I wrote a complaint, but no one addressed it…No one came, they did not provide an estimate, and it all collapsed.' (Field interview, Saptari, August 2023)*

Bhanu's role as a fishery entrepreneur in Ward 4 serves as a pertinent example of the concentration of political favouritism and resource allocation among a select group of influential farmers in Saptari. Although he is reticent to openly discuss the political advantages he has received, his position as chair of the Saptari Fishery Association grants him significant access to opportunities that remain largely unavailable to his peers. This role facilitates direct communication with fisheries offices, enabling Bhanu to swiftly access various forms of government support. The implications of these connections are substantial, positioning him as a key player in capturing agricultural resources within his community.

The support Bhanu has garnered over the years, including funding for deep tubewells and multiple subsidies, contrasts sharply with the experiences of tenants and marginal farmers, particularly those in Ward 2. For marginal farmers, the challenges of securing access to land and essential agricultural resources often culminate in unsuccessful attempts. In contrast, Bhanu navigates these systems with

relative ease, benefiting from favourable land leases and institutional support. This disparity reinforces a narrative of privilege that is both economic and social, highlighting the systemic inequalities that exist within the allocation of agricultural support.

Bhanu's confidence in his ability to protest and seek institutional support is a significant advantage, allowing him to operate from a position of relative security. This confidence starkly contrasts with the realities faced by tenant farmers in the study area, who often lack the resources or knowledge to advocate effectively for their rights. Bhanu's experience exemplifies how privileged socio-economic status can shape different power dynamics between farmers and landowners, with less privileged farmers frequently feeling disempowered in negotiations. Moreover, Bhanu's ability to secure formal land leases exemplifies the disparity. While tenant farmers often face exploitative conditions and insecure arrangements, Bhanu has successfully secured a stable agreement that affords him greater security and opportunity.

However, this narrative is not without contradictions. His achievements are often juxtaposed with instances of mismatched support, such as his experience with a solar pump provided by the AEPC. Although the pump was intended to enhance his access to groundwater, its non-functionality reveals significant systemic flaws in the implementation of agricultural support programmes. Nevertheless, Bhanu's access to six other pumps funded by various agencies ensures he maintains diversified water access, a privilege that remains out of reach for smaller-scale farmers lacking similar institutional backing.

Furthermore, Bhanu's reluctance to sell water to neighbouring farmers reflects a prioritisation of his own resource use. For an individual of his affluence, the prospect of selling water at seven rupees per Liter appears marginal.

Complicating Bhanu's narrative further are allegations from farmers in Ward 4 that he formed a fictitious farmer group to secure additional pumps from the GWRDB. Such actions highlight a willingness to exploit systemic vulnerabilities for personal gain, reflecting a broader pattern of behaviour prevalent within agricultural support networks. Interviews with GWRDB personnel reveal that access to resources is often determined by political connections, highlighting patronage politics in the Saptari water space.

In conclusion, Bhanu's case illustrates the systemic inequalities that characterise agricultural support systems, in which access is frequently contingent on social capital. His story raises important questions about equity and the ethical considerations that should guide resource allocation.

7.2.2 Nilu, a Farmer Cooperative President

Nilu, a member of the Chaudhary caste and president of the Shree Mahila Utthan Jansewa Krishi Sahakari, is another central player acquiring and distributing agricultural resources to a select few in Ward 4. As the president of the cooperative, she has been instrumental in securing irrigation support and other agricultural subsidies, often positioning herself at the centre of navigating bureaucratic structures, cultivating political networks, and strategically expanding funding opportunities. However, her involvement is also marked by controversy, with accusations of mismanagement of resources and preferential allocation.

Nilu's engagement with the cooperatives began well before her marriage, shaped by early exposure to training programmes facilitated by the village development committee and district agriculture office. Encouraged by her mother, she participated in various livelihood-oriented training sessions, which familiarised her with institutional mechanisms for agricultural support. This background proved crucial when she moved to Ward 4 after marriage and sought to establish herself within the local agricultural community.

Her family's ownership of three *bighas* of land provided a degree of economic security, but her prior experience with farming groups enabled her to take on leadership roles. She quickly became active in the cooperative.

The cooperative originated as a smaller farmers' group registered in the District Agriculture Development Office (DADO) (pre-federal structure). Between 2008 and 2010 (2065–67 BS), Nilu led a group of 25 women in initiating onion farming, with each contributing NPR 50 from their savings. She had identified a district-level support programme targeting women farmers and mobilised the group to secure NPR 20,000 in government funding.

Around this period, DADO introduced an incentive programme of NPR 100,000 for farmer groups willing to transition to farmer cooperatives. Recognising the financial and institutional benefits, Nilu pushed for the group's formal conversion into a cooperative in 2011 (2068 BS). However, this transition was fraught with internal conflicts, as several members opposed the formalisation process

due to the costs involved. Registration required NPR 25,000, half of which could be covered by group savings. When existing members resisted the transition to a formal cooperative, Nilu dissolved the farmers' group and sought new members willing to contribute financially.

Once the cooperative was formally established, it successfully secured NPR 100,000 in government support. Despite her success in securing funding, Nilu's leadership soon became the subject of controversy. While the NPR 100,000 incentive was intended for cooperative development, DADO agricultural officers reportedly demanded a NPR 30,000 facilitation fee. After covering registration costs, NPR 50,000 remained available for cooperative use. Nilu advocated for reinvesting this amount into cooperative activities, such as setting up a shop for agricultural inputs. Several members pushed to have the funds distributed among themselves for personal use. This disagreement escalated tensions within the cooperative, ultimately leading to allegations against Nilu, including claims of financial mismanagement and the unauthorised sale of irrigation equipment for personal gain.

From 2006 onwards, even before the formal conversion of the farmers' group into a cooperative, Nilu had started seeking irrigation support through various institutional channels. Between 2005 and 2006 (2065–2066 BS), she submitted multiple applications for support for deep tubewells. In parallel, she was affiliated with *Muthiya Bachat*, a savings initiative under the Global Cooperative, where she organised and managed women's savings groups within the village. This involvement was expanding her connections with key institutions in Saptari.

Leveraging her ties with AKC and GWRDB, she filed numerous applications for tubewell support, each costing NPR 3,000. To maximise access to resources, she established fictitious farmers' groups under fabricated names, securing five tubewells through this process.

Tensions within the cooperative escalated as allegations of fund mismanagement and the acquisition of tubewells through fictitious farmers' groups created widespread resentment against Nilu. Discontent among cooperative members reached its peak when a legal complaint was filed at the Chief District Office (CDO), demanding that she return NPR 100,000. According to Nilu, a competitor (the neighbouring village cooperative president) orchestrated a police intervention, sending officers to her home, an event that severely damaged her reputation. During the legal proceedings, a police officer advised her to seek political backing, implying that institutional support could influence the case's outcome. Acting on this advice, she sought assistance from officials at the DADO, some of whom had themselves benefited from the cooperative's funds. By mobilising political allies, she secured a

favourable resolution that did not incriminate her. An investigation by DADO and the Village Development Committee (VDC), institutions that were themselves implicated in financial mismanagement, found no concrete evidence of misconduct. However, they directed her to continue cooperative operations rather than distribute funds among members.

Despite the controversies, Nilu continued to expand her agricultural support networks. Her ability to navigate and overcome legal challenges reinforced her confidence in the power of institutional and political networks. She eventually secured a dealership for agricultural inputs under the cooperative, though the process was not without obstacles. Obtaining dealership rights required official recommendations, which she initially struggled to secure. However, a personal connection with a senior agricultural officer at DADO facilitated the approval process, allowing her to establish a foothold in the agricultural supply chain.

Within her household, Nilu's increasing public role and the controversies surrounding her activities elicited mixed reactions. While her husband expressed reservations, her father-in-law offered pragmatic support, reassuring her with a local proverb:

> *'When an elephant walks to the market, many dogs will bark but have to continue doing the right work.' (Field interview, Saptari, December 2023)*

In the broader community too, Nilu found strong backing from wealthier land-owning farmers (locally referred to as *Sauji*), particularly those involved in *Muthiya Bachat*. These individuals were willing to co-finance tubewell installations at reduced costs. Although these pumps and tubewells were intended to be made accessible to farmers at a 15% subsidy, Nilu retained and resold them for profit. A farmer who purchased a subsidised pump reported that, while the market price was NPR 18,000, he paid NPR 12,000 to Nilu. However, he later expressed disappointment when he realised the pump was not Nilu's to sell. He initially believed he was benefiting from a lower price than if he had purchased the pump privately at full cost. She retained a commission from the irrigation infrastructure support she facilitated, a practice that sustained her operations but also attracted scrutiny.

A farmer from a Dalit household in Ward 4 shared that individuals like Nilu, who have knowledge of irrigation support programmes, tend to share information and support only with those within their close networks. The farmer noted that Nilu primarily facilitated access to irrigation support for members of the Chaudhary caste and suggested that this might be driven by caste loyalties. Expressing this sentiment, the farmer stated:

'She fills bellies of her own caste.' (Field interview, Saptari, November 2023)

When the PMAMP introduced a pocket programme for subsidised onion saplings, villagers accused her of manipulating the distribution process for personal gain. Formal complaints were lodged with agricultural officers, but once again, no institutional action was taken against her.

In response to mounting complaints, Nilu was advised to consolidate her control over the cooperative. Initially holding 25 shares, she withdrew shares from other members and, following recommendations from agricultural officers, increased her stake to 51%. This move granted her decision-making authority and, according to her, helped stabilise conflicts within the cooperative. By 2023, the cooperative's total fertiliser transactions amounted to NPR 3.6 million (36 lakh), yielding a profit of NPR 600,000 to 700,000 (six to seven lakh), which she claimed she would reinvest in the cooperative. She maintained that she had not personally profited from the cooperative's funds, emphasising that she sold agricultural inputs at designated prices, in contrast to the widespread black-market practices among other cooperatives.

Nilu's access to irrigation infrastructure primarily stemmed from the GWRDB, with fewer tubewells and pumps secured through the AKC. She noted that AKC required farmers to deposit NPR 12,000 upfront to receive support equivalent to NPR 100,000, covering tubewell construction and equipment costs. The reimbursement process, however, was often complex and time-consuming, making it difficult for farmers to reclaim their initial deposits. In contrast, she found GWRDB's procedures more straightforward, requiring only a single visit to their office in Lahan, thereby eliminating bureaucratic delays. Over time, however, GWRDB has shifted its focus from providing smaller pumps to larger, six-inch tubewells, which she found less practical for local agricultural needs. As a result, her reliance on GWRDB's programmes is diminishing.

Nilu has not only facilitated irrigation support through her farmers' cooperative and micro-credit initiatives but has also built alliances with other farmers to access additional resources. Unlike Bhanu, the fishery entrepreneur who remained discreet about his use of fictitious farmer groups, Nilu was more forthcoming. She openly admitted collaborating with Bhanu to secure a deep tubewell (DTW) from GWRDB.

During one of my interactions with Nilu, she shared that her morning had been spent at Bhanu's fishery pond, where an official from GWRDB Lahan had arrived to inspect the site for the DWT installation. Bhanu had submitted the application, and while Nilu was certain she would not personally

benefit from the irrigation infrastructure, she remained involved in the process. When a tubewell application is approved, GWRDB officers conduct site inspections before disbursing funds. In this case, Bhanu successfully secured financial support equivalent to NPR 10 million (one crore) for the DTW, with the funds released in installments. On the day of the visit, Nilu recalled witnessing a cheque of NPR 1.3 million (13 lakh) being handed over to Bhanu. However, she was unexpectedly asked to sign a document related to the transaction, a request that made her uneasy, as she feared the implications of her signature being recorded in an official capacity.

While Nilu was nominally involved in the application process, she was fully aware that the deep tubewell support, intended for shared use by a farmers' group, was being appropriated for Bhanu's private fishery operation. To fulfil the eligibility criteria for government support, Bhanu created a farmers' group on paper, designating Nilu as the treasurer to lend credibility to the application. She even had to travel to Lahan, located in a different district, to complete the application process for the so-called group. Although she had been led to believe she would receive some form of compensation for her participation, she ultimately received nothing.

The GWRDB officers, unaware of the underlying arrangement, believed that the deep tubewell would be utilised by a collective of farmers. However, Bhanu had no intention of sharing the water, having specifically requested the pump for private use. Furthermore, the contractor responsible for installing the deep tubewell was Bhanu's brother-in-law; he, too, leveraged his network to manipulate state resources and concentrate benefits within a select group of individuals.

Despite her involvement in Bhanu's irrigation scheme, Nilu recognised that GWRDB's annual budget allocation for such projects presented an opportunity, and she hoped to secure one in the following year's funding cycle (2025). She was particularly interested in the additional benefits of high-capacity deep tubewells, including a dedicated transformer and ongoing maintenance support from GWRDB in the event of breakdowns. If she were to receive the infrastructure, she planned to install it on a plot of one to two *bigha*, with the capacity to irrigate 15 to 20 *bigha*.

Nilu has leveraged support for irrigation, navigating relationships with organisations and with people in the Ward with whom she can build alliances. These relationships at external agencies help her retain support. When she gets them, she selects powerful people to provide irrigation support so she can build a network that will support her in any crisis, such as a legal complaint against her.

She is one of the few women who are as open in the community, as she is traveling to AKC and GWRDB often for irrigation support and other agronomic support. She relied on her caste identity, leaning into them as they are landowners who are powerful in the area, who can be of benefit to her.

It is also interesting that she allies with powerful figures like Bhanu. Although she was promised something in exchange for joining the fake farmers' group, she had not received it. It goes to show that someone who misappropriates funds gets misappropriated as well.

She has sound knowledge and sells pumps that are of good quality. The sad thing is that the officers who provide this support are unable to implicate her because they themselves are involved in malpractice. Other poorer farmers do not have such elaborate knowledge and connections, and she makes use of these connections.

In one of the initial interviews in Ward 4, I was assigned to interview farmers through Nilu. It was helpful that the Ward Chair extended this support, and Nilu helped me with this. However, during the interview, when I asked questions to farmers about what types of pumps in their experience are easier to use, Nilu would often interrupt the answers the farmers gave by saying:

'You should say the electric pump is easier.' (Field interview, Saptari, November 2023)

7.2.3 Parbat, Founder of Multiple Farmers Groups

Parbat, a farmer in his 70s from Ward 2, owns approximately 2.5 *bighas* of land and has long been notorious for exploiting agricultural support programmes by forming fraudulent farmers' groups. During my fieldwork, several farmers alleged that he had systematically secured aid through his deep-rooted connections with officials from the AKC and the PMAMP. His influence dates back to the pre-federalism era when DADO was responsible for agricultural support, and he has since maintained these relationships under the federal structure, where many DADO staff were absorbed into AKC.

Farmers recalled an incident from 20 to 25 years ago when Parbat collected photocopies of their citizenship and land-ownership documents, claiming he needed them to apply for agricultural aid on their behalf. After securing the necessary paperwork, he later returned the documents, falsely assuring them that no support was granted. However, farmers eventually discovered that he had used their identities to obtain irrigation equipment, such as pumps, which he installed on his own land. While initial complaints were muted, resentment grew over time as Parbat continued to receive disproportionate aid while other farmers were excluded. Although farmers no longer trust Parbat with

their documents, they suspect he still possesses copies and continues to use them to secure new irrigation and agricultural support without the farmers' knowledge or consent.

Parbat's exploitation extends beyond manipulating bureaucratic processes; he has also engaged in direct financial misconduct. When he was approached to form a farmers' collective (mentioned in Chapter Six) under an ACIAR-funded project, he initially expressed interest. However, project officers discovered that he had been charging illicit commissions. In one case, the actual cost of digging a project-supported tubewell was NPR 40 per foot, but Parbat negotiated with the contractor to inflate the price to NPR 60 per foot, pocketing the excess NPR 20 per foot as a commission. Upon learning of this, the project personnel stopped working with him. A project officer remarked that many stakeholders had negative experiences with Parbat due to his corruption, which made it difficult to form genuine farmer collectives.

Parbat understands the procedures for distributing agricultural support, leveraging this knowledge to manipulate support programmes. When new initiatives are announced, he quickly organises groups, informs farmers about potential benefits, collects money from them, and then extracts commissions from the process. His ability to navigate these systems, coupled with his established relationships with officials, ensures that he remains a recurring beneficiary despite widespread awareness of his actions.

When asked why Parbat continues to receive support despite his reputation, one farmer, clearly frustrated, shared:

'We shut our eyes and cover our ears and leave him be.' (Field interview, Saptari, July 2023)

Another farmer revealed that Parbat's tactics extend beyond agricultural aid fraud. They described an incident involving his daughter-in-law, whose family had once been part of a farmer group Parbat led. Despite her participation, she never received any direct support. The farmer's daughter-in-law recounted contributing funds to the group but struggling to access benefits due to administrative mismanagement and favouritism that prioritised Parbat's close associates.

Beyond his fraudulent activities in agricultural programmes, Parbat has also faced legal consequences for electricity theft for irrigation. He has been caught twice by the electricity office for unauthorised connections, leading to fines and the confiscation of equipment.

Parbat's ability to continuously exploit support programmes, despite his notorious reputation, reflects systemic weaknesses in monitoring and accountability within agricultural and irrigation aid

institutions. His case highlights how entrenched relationships with AKC and PMAMP officials enable certain individuals to repeatedly manipulate resources, reinforcing inequalities in the distribution of agricultural support. Addressing these vulnerabilities requires stronger oversight mechanisms, increased transparency, and stricter enforcement to ensure that assistance reaches genuine beneficiaries, rather than being concentrated among a select few with the knowledge and influence to exploit the system.

7.3 Discussion: Elite Appropriation, Institutional Mediation, and Technological Closure

Access to irrigation infrastructure support in Shambhunath is mediated through overlapping layers of material, social, and institutional processes that together form a bundled architecture of access. Within this structure, power is exercised through the selective interpretation of technical rules, the mobilisation of social and positional identities, and the stabilisation of dominant technological forms. These layers do not act in isolation; rather, they intersect and reinforce one another, determining who can access, control, and sustain irrigation support and whose claims remain peripheral.

7.3.1 Interpretive Flexibility and Elite Appropriation

The irrigation support landscape of Wards 2 and 4 reveals how the interpretive flexibility of technological interventions enables local elites to align irrigation programmes with their own interests. This flexibility, the space for multiple, socially contingent interpretations of technology, creates opportunities for actors with influence to transform interventions designed for collective welfare into mechanisms of control and accumulation (Bijker et al., 2012). This pattern reflects a broader dynamic in water governance, where infrastructure and subsidy programmes intended for public benefit are frequently appropriated by socially and politically powerful actors through rent-seeking, procedural influence, and control over information (Aleu et al., 2022; Li et al., 2025; Fanaian, 2025).

Government institutions conceive of irrigation technologies as neutral tools for improving productivity. Yet, elite farmers reinterpret these same interventions as routes for resource consolidation, while marginalised farmers experience them as sites of exclusion. This pattern reflects what Ribot and Peluso (2003) term the mechanisms of access, in which knowledge, institutional recognition, and financial capital become resources that structure the distribution of benefits. As mentioned previously, a Dalit woman reflects that:

'Support comes for the poor, but the rich capture it.' (Field interview, Saptari, July 2023)

This encapsulates this reality: technological support framed as pro-poor often deepens inequality when mediated through uneven social hierarchies.

Empirical evidence from Shambhunath shows how elite farmers actively navigate institutional systems to exploit such flexibility. The formation of 'ghost' farmer groups to access GWRDB subsidies exemplifies Cleaver's (2007) notion of institutional bricolage, the adaptive recombination of formal procedures and informal norms to serve local power holders. Through bureaucratic familiarity, social ties, and political brokerage, elites manipulate programme requirements to secure public resources for private accumulation. The process converts infrastructural interventions into pathways of exclusion rather than inclusion.

Research on participatory water governance shows that such asymmetries routinely undermine formal inclusion frameworks, allowing dominant actors to monopolise decision-making and benefits, even in programmes designed as community-based or pro-poor (Aleu et al., 2022; Shunglu et al., 2022). Institutional fragmentation amplifies this effect. The coexistence of overlapping agencies – AKC, PMAMP, AEPC, and Ward-level offices – creates interpretive gaps that better-connected actors exploit. Farmer Parbat's practice of applying simultaneously to multiple agencies for similar support reflects Von Benda-Beckmann's (1981) concept of forum shopping, where actors selectively engage institutions most favourable to their claims. Asymmetrical access to information further intensifies exclusion: limited literacy, opaque public notices, and politically selective dissemination ensure that subsidy opportunities remain concentrated among the informed and networked. As Ward officials conceded, 'literacy constraints limit [public notices'] accessibility', effectively institutionalising asymmetry as a gatekeeping mechanism.

Within the bundled architecture of access, these processes align across layers. The material layer, the physical infrastructure, and its placement are captured by elites who command resources to meet co-financing requirements. The social layer, informal networks, caste, and political alliances legitimise the elites' entitlement to benefit. The institutional layer, rules of eligibility, and bureaucratic documentation confer formal recognition. Together, these layers consolidate advantage and transform ostensibly redistributive programmes into instruments that reproduce agrarian hierarchy.

Institutional fragmentation also enables what Pinch and Bijker (1984) describe as interpretive flexibility gaps, where divergent interpretations coexist across agencies. In Shambhunath, elite actors

exploit these gaps to multiply benefits, while marginalised farmers lack both the information and the procedural literacy to navigate the same terrain. Knowledge, in this context, functions as an exclusionary resource, one of the most decisive yet least visible filters in the architecture of access (Ribot & Peluso, 2003).

Interpretive flexibility extends beyond institutional navigation into the physical transformation of technology itself. Instances in which solar panels are converted into window shields or used for hay storage exemplify Akrich's (1992) concept of user reconfiguration, in which technological artefacts are adapted to serve local needs or to display social status rather than their designed function. These acts of reinterpretation reveal how technologies circulate through layered social worlds, acquiring meanings that diverge from official purposes.

Yet, the institutional response to such reconfiguration often reinforces closure around elite interpretations. Officials aware of misuse acknowledge systemic issues but cite budget rigidity, political interference, and limited autonomy as constraints on corrective action. These conditions stabilise elite control, producing what Pinch and Bijker (1984) term closure mechanisms, the dominance of one interpretation of technology over all others. As a result, irrigation programmes evolve into stable yet exclusionary systems that reward administrative capacity and political alignment rather than need.

The consolidation of elite interpretations produces structural consequences. Technological support schemes, designed to be redistributive, become what Ferguson (1990) calls an anti-politics machine, a system that masks inequality behind technical rationality. Subsidy allocation framed as a technical process of 'verification' or 'land eligibility' obscures the political dimensions of inclusion and exclusion. The repeated allocation of infrastructure to the same beneficiaries converts access into entitlement, creating durable hierarchies of water control.

For marginalised farmers, exclusion is reinforced not only through bureaucratic mechanisms but also through intimidation and fear. The Dalit woman's statement, *"If we bring issues up, they might even come to beat us"*, reveals how coercion and silence maintain technological closure. Violence, both symbolic and physical, extends institutional power, enforcing the legitimacy of elite control over water infrastructure.

In this context, resistance takes subtle and often hidden forms. Farmers excluded from formal channels turn to informal negotiation, small collective leasing arrangements, or seasonal cooperation as acts of

quiet resilience. These practices do not dismantle the bundled architecture of access, but they open temporary cracks within it, spaces in which marginalised actors renegotiate their constrained agency. They echo what Cleaver and Whaley (2018) describe as institutional bricolage: the everyday work through which people adapt, bend, and recombine rules to make systems liveable without overturning the structures that govern them.

These dynamics also foreground the limits of technocratic reform. As Lemos et al. (2018) argue, technical systems that are not co-produced with social actors and institutions systematically misread how access and authority are constituted. Models, infrastructures, and programmes designed as if social relations were external to them inevitably fail to grasp the relational and political nature of access. Without explicit attention to the mechanisms of power that mediate irrigation support, well-intentioned reforms risk reproducing exclusion.

Meinzen-Dick (2014) similarly cautions that policy adjustments, such as granting water rights, are insufficient unless accompanied by institutional capacity-building that enables marginalised groups to exercise those rights in practice. In this vein, Upadhyay and Bastola (2024) argue that agricultural strategies, such as Nepal's Agriculture Development Strategy, must be subjected to systematic gender impact evaluations to assess whether they meaningfully address Gender Equity and Social Inclusion (GESI) concerns in food security, employment, and climate change adaptation. They further stress that policy intent alone is not enough; programmes must be examined against concrete budgetary commitments to determine whether stated equity goals are institutionally enabled and materially realised.

Therefore, if interpretive flexibility is the terrain on which elite appropriation occurs, then equity-oriented reform must work by reshaping how that flexibility is governed rather than eliminating it. What is required is not a tighter technical specification alone, but institutional arrangements that redistribute interpretive authority. This includes: transparent, publicly accessible beneficiary lists; rotating and externally audited selection committees; and mandatory disclosure of repeat beneficiaries across programmes. Crucially, interpretive discretion must be reoriented toward inclusion by embedding social criteria such as tenancy, caste, and gender into eligibility frameworks in ways that are binding rather than advisory. Without such institutional counterweights, flexibility will continue to function as a resource for those already positioned to exploit it. Equity in irrigation support,

therefore, depends on transforming interpretive space from a site of elite manoeuvre into a field of accountable public reasoning.

7.3.2 Strategic Mobilisation of Class, Position, and Networks

The appropriation of irrigation infrastructure support in Shambhunath does not arise from a single category of 'elite' but from the intersection of multiple forms of advantage – economic, positional, and relational. These elites operate within the bundled architecture of access by aligning material, social, and institutional resources in ways that reinforce their privilege while sustaining systemic inequality.

Economic elites, grounded in class advantage, draw upon landholding and financial capital to secure disproportionate access to irrigation technologies. Empirical research from Nepal confirms that access to agricultural subsidies is unevenly distributed and systematically shaped by farmers' resource endowments and institutional positioning. Thapa et al. (2023) show that ethnicity, cooperative membership, and contact with extension services significantly influence who receives public support, while Brown et al. (2021) demonstrate that subsidy-supported mechanisation in the Terai disproportionately benefits better-resourced farmers who can meet co-financing and procedural requirements. The case of farmer Bhanu shows how ownership of 'three *bighas* of land' functions as both a productive resource and collateral, enabling participation in multiple subsidy programmes. This dynamic aligns with Bourdieu's (2002) notion of the convertibility of capital, where economic resources translate into institutional power and social legitimacy. By repeatedly accessing subsidised irrigation infrastructure across six installations in different programmes, Bhanu consolidates his material control and institutional recognition. His case reveals how the material filter (land and capital ownership) enables movement through institutional gates that remain closed to smaller farmers.

Positional elites, such as Ward officials and cooperative leaders, leverage authority embedded in their formal roles to direct support flows. The case of Nilu, president of the Shree Mahila Utthan Jansewa Krishi Sahakari, reflects how positional authority converts into privileged access to irrigation support. Her dual role as an elected representative and cooperative leader situates her at the junction of institutional and social filters, granting early access to information, influence over beneficiary selection, and control over programme execution. National evidence reflects this dynamic. Timsina et al. (2023) show that access to agricultural services and technologies in Nepal is mediated through extension systems and institutional intermediaries, while Thapa et al. (2023) find that organisational

membership and training exposure significantly increase the likelihood of receiving subsidies. Positional authority thus converts into informational privilege and procedural advantage. As Mosse (2004) observes, development interventions often sustain rather than disrupt the authority of those who administer them, reinforcing the legitimacy of positional elites even when outcomes appear participatory.

Network elites such as Parbat exemplify how relational capital substitutes for formal authority. Through social connections with PMAMP and AKC officials, Parbat secures multiple installations across agencies, using personal networks to mediate between bureaucratic procedures and local needs. These networks act as informal extensions of the institutional filter, translating knowledge, procedural fluency, and institutional proximity into opportunity. Evidence from Nepal shows that farmers embedded in organisational and informational networks are far more likely to access public support than those operating outside these circuits (Timsina et al., 2023; Thapa et al., 2023).

The interaction between class, position, and network power is cumulative. Elites rarely rely on a single form of capital; rather, they combine multiple advantages to maintain dominance. Bhanu, for example, uses his land-based wealth (material advantage), leadership position (institutional advantage), and reputation (social legitimacy) to sustain privileged access across changing programme structures. This strategic blending of identities enables what can be described as positional assemblage, the practice of selectively emphasising different aspects of one's status to align with varying institutional criteria. When applying for PMAMP funds, elites present themselves as 'progressive innovators', while for GWRDB support, they portray themselves as 'representatives of community interest'. This adaptive representation, which could be called strategic simplification, allows elites to meet eligibility requirements without overtly violating the rules.

The temporal dimension of elite resource capture reveals how advantages consolidate over time. Repeated programme access across fiscal years (2020/21 and beyond) creates a cycle of cumulative privilege, in which early beneficiaries become specialists in resource capture. Institutional staff recognise these patterns but lack mechanisms to disrupt them, constrained by rigid budget cycles, limited discretion, and political interference. This produces what Mosse (2004) describes as institutional stabilisation, a condition in which systems reproduce inequality not through active bias but through habitual governance routines, as observed by Ali (2020) in Pakistan's irrigation bureaucracy.

This reading of elite behaviour moves beyond a static understanding of 'capture'. It positions rural elites as adaptive actors whose power is sustained through continuous negotiation within the bundled architecture of access. Their dominance rests on their ability to align economic resources, social networks, and institutional legitimacy, each reinforcing the others.

The strategic mobilisation of class, positional authority, and networks shows that inequality is not accidental but actively produced through layered advantage. Addressing this requires policy designs that recognise cumulative privilege and intervene across time, not only at the point of application. Mechanisms such as caps on repeat participation, progressive subsidy structures that decline with successive benefits, and explicit priority windows for first-time applicants can disrupt cycles of accumulation. Equally important is the institutionalisation of countervailing power through farmer facilitation units, support wings at Wards for tenants, and embedded field mediators who work with marginalised groups to navigate bureaucratic processes. Redistribution cannot be achieved by neutral procedures alone; it requires organisational forms that actively rebalance asymmetries in knowledge, confidence, and institutional legibility.

7.3.3 Closure Mechanisms and the Institutionalisation of Inequality

The appropriation of irrigation support in Shambhunath is sustained through closure mechanisms that stabilise elite interpretations of technology and foreclose alternative pathways to access. These processes – rhetorical, procedural, and technical – align across the material, social, and institutional filters, creating durable systems of privilege that appear neutral but are socially produced.

Rhetorical closure occurs when eligibility criteria and technical justifications redefine political questions of access as administrative necessities. The land-based criteria for irrigation subsidies, such as the minimum 'four to five *kattha'*[33] requirement for electricity meter applications, function as an exclusionary gate masked as procedural formality. Officials describe these conditions as 'verification requirements', transforming a political question of entitlement into a technical problem of documentation. This reflects what Pinch and Bijker (1984) term the technological frame: the bounded discourse that defines which solutions appear logical and legitimate (see also Li, 2007; Wyborn et al., 2023). By framing land ownership as a pre-condition for efficient subsidy management, institutions normalise exclusion, rendering it invisible within the logic of bureaucracy.

[33] According to respondents, eligibility for a subsidised electric meter typically required a minimum land ownership of four to five *kattha.*

Procedural closure embeds inequality in documentation requirements and layered approval processes. This pattern is consistent with national evidence from Nepal showing that access to agricultural subsidies is strongly shaped by organisational membership, extension contact, and administrative visibility, systematically disadvantaging smallholders and socially marginal farmers (Thapa et al., 2023; Bharati et al., 2024). Access to irrigation support demands a bundle of certifications, citizenship, land title, tax receipts, Ward endorsements, and cost-sharing commitments and documents that few marginal farmers can provide, particularly where subsidy designs presume upfront liquidity and procedural capacity. Studies of mechanisation and subsidy regimes in Nepal's Terai show that such design features systematically privilege better-resourced farmers who can absorb co-financing costs and navigate bureaucratic processes (Brown et al., 2021; Thapa et al., 2023). This documentation regime privileges those already visible to the state, systematically excluding tenants, sharecroppers, and landless households. The requirement for repeated verification across agencies multiplies these barriers, reinforcing Scott's (2020) notion of the legibility trap (see also Aleu et al., 2022; Fanaian, 2025).

Institutional fragmentation further entrenches closure by dispersing accountability. Overlapping mandates among the GWRDB, PMAMP, and AEPC allow each agency to defer responsibility for equitable outcomes, stabilising elite control through diffusion rather than explicit exclusion. Officials acknowledge inequity but cite procedural rigidity and political pressure as reasons for inaction. In this way, institutions reproduce inequality not through overt discrimination but through bureaucratic inertia.

Once physical infrastructure is installed on elite-owned land, it produces a durable form of closure that extends beyond documentation. The spatial fixity of deep tubewells, electric meters, and solar arrays anchors technological benefit in place. Physical installation transforms social advantage into material permanence. The resulting landscape of solar panels glinting atop the farms of Ward chairs and cooperative leaders embodies inequality in visible form.

The technical specifications of these infrastructures reinforce the same effect. The selection of high-capacity pumps or deep tubewells requires extensive land privileges, among those with capital and acreage, marginalising smaller-scale holders whose needs could be met by alternative technologies (Kafle et al., 2022). The lock-in effect is both technical and institutional: once investment standards, training programmes, and spare-parts supply chains align around elite configurations, alternatives

such as shallow wells or shared solar units become administratively invisible and financially unsupported. Evidence from Nepal shows that subsidy programmes increasingly standardise around particular equipment profiles and farm types, marginalising smaller or collective configurations that do not fit prevailing technical templates (Brown et al., 2021; Bharati et al., 2024).

These intertwined closure mechanisms reveal how the bundled architecture of access stabilises inequality through everyday governance. At the material layer, elite control over infrastructure creates durable advantages. At the social layer, caste, gender, and positional hierarchies legitimise these advantages as deserved or inevitable. At the institutional layer, bureaucratic procedures, eligibility rules, and fragmented accountability ensure that exclusion persists under the guise of administrative rationality.

Closure operates by translating political questions of access into technical routines that appear neutral. Reopening these closures requires redesigning infrastructure support as a process of staged inclusion rather than a single threshold event. This could involve decoupling eligibility from formal land title through recognised tenancy certificates, enabling shared or cooperative infrastructure models, and legitimising intermediate technologies that match the material realities of marginal farmers. Equally, institutional mandates must be restructured so that agencies are evaluated not only on expenditure and installation targets but on distributive outcomes. When accountability is tied to who benefits rather than how efficiently funds are disbursed, bureaucratic routines can begin to align with social justice objectives. Without such shifts, closure will continue to harden inequality into the physical and administrative landscape.

7.4 Conclusion

The irrigation support space in Wards 2 and 4 of Shambhunath Municipality illustrates how technical interventions are deeply embedded within existing power structures. These programmes exhibit significant interpretive flexibility, enabling powerful social groups to manipulate ostensibly neutral technological initiatives to reinforce hierarchies rather than promote equitable water access. The documented repurposing of costly solar panels exemplifies the gap between policy intentions and implementation realities, as these technologies are often diverted from their intended uses.

The appropriation of irrigation resources occurs through diverse elite types, class-based elites (wealthy landowners), positional elites (Ward chairs and institutional leaders), and network elites (those with bureaucratic connections) who strategically and repeatedly mobilise overlapping identities

to secure disproportionate benefits. The experiences of Bhanu, Nilu, and Parbat illustrate how these resource-capturing elites navigate institutional channels and employ strategies, such as creating fictitious farmer groups and leveraging political connections, to repeatedly access resources.

Barriers such as land ownership requirements and contribution thresholds effectively exclude resource-constrained farmers from participation, while implementing agencies acknowledge these systemic failures, yet, remain limited by rigid processes and political interference. For marginalised farmers, these inequalities are reinforced through structural exclusion and intimidation that suppress dissent.

Unless these fundamental power dynamics are addressed, irrigation support programmes will perpetuate the very socio-economic hierarchies they aim to dismantle, resulting in a system where, as one respondent aptly noted: *"Support comes for the poor, but the rich capture it."*

8 Chapter Eight: Conclusion

This dissertation has pursued a central question: How are farmers differentially positioned to access and benefit from groundwater irrigation technology within an agrarian system structured by intersecting axes of land tenure, caste, gender, class, and migration? At its core, the study explains that irrigation technology in Nepal's Terai cannot be understood as neutral infrastructure that automatically delivers productivity and poverty reduction. Instead, technologies are embedded in social and political architectures that determine who can access, control, and benefit from them, and who remains excluded or subordinated. By asking not how to maximise adoption rates but how positionality shapes the very possibility of access and use, the dissertation has shown that the celebrated 'groundwater revolution' in Nepal remains deeply uneven and, in many cases, reproduces rather than alleviates historical inequalities.

This question was addressed through three analytically connected lines of inquiry that foreground farmers' differential positioning within Nepal's agrarian system. First, the research examined how land tenure status, landholding size, caste identity, gender, and household migration shape access to and ownership of groundwater irrigation technologies. Second, it explored how farmers located in marginal positions experience, negotiate, and respond to unequal conditions of groundwater access in their everyday livelihoods. Third, it analysed how formal institutions and development interventions mediate irrigation access, showing how social position conditions programme uptake and how elites consolidate advantage through bureaucratic and political processes. Together, these lines of inquiry reframe irrigation not as a technical input but as a socio-material process shaped by power, institutional practice, and everyday negotiation. This chapter synthesises the empirical findings, theoretical contributions, methodological insights, and policy implications of the dissertation, situating the research within broader debates in agrarian change, political ecology, and science and technology studies.

The research presented three central empirical insights that answers the research questions. First, irrigation access is cumulative and layered, a process I conceptualise as 'bundled architecture of access'. The result of my survey of 401 households, together with qualitative testimonies in Saptari, shows that each layer of technology – from land tenure security to tubewell installation and pump acquisition – builds on the conditions created by the previous layer, with subsidised electric meter connections constituting an additional institutional layer that stabilises and reduces the cost of electric

irrigation. This layering multiplies inequality: larger-scale landowners move through the bundle with relative ease, while marginal farmers, tenants, and the landless encounter structural barriers at each stage. The regression results indicate that once landownership is established, access to fixed irrigation rises sharply beyond the marginal scale, and that tubewell access is closely linked to subsequent uptake of cheaper alternatives, such as electric pumps and electric meters. These patterns make visible how agrarian hierarchies are not simply reflected in irrigation infrastructure but are actively reproduced through it.

Second, irrigation technology is experienced differently across social positions, reflecting its interpretive flexibility. The same electric pump symbolises empowerment for a woman landowner asserting independence through an electric meter, yet exclusion for landless Dalit tenants who cannot meet bureaucratic documentation requirements. Ethnographic cases documented how tenants depend on landlords' discretion for water, and how women affected by male out-migration take on increased burdens of irrigation management in practice, without necessarily gaining greater authority or control over assets. Technology here is not a stable artefact but a socially constructed one, its meaning and effects shaped by positionality.

Third, irrigation support interventions are infiltrated by elite capture in this study, leading to exclusion. Externally funded irrigation projects and subsidy schemes in Saptari consistently fell prey to elite capture. Larger-scale farmers and politically connected households leveraged their networks, bureaucratic literacy, and resources to meet co-financing requirements and secure programme benefits. Marginalised farmers were formally included through quotas, but, in practice, were substantively excluded. Externally imposed networks of 'beneficiary groups' were often difficult to sustain beyond project completion, while organic, self-initiated networks based on kinship and local trust appeared more durable in practice. Yet these networks were frequently exclusionary, reinforcing existing social hierarchies rather than overcoming them. Durability, in this sense, did not equate to equity. These findings point to the need for future research and policy efforts to identify institutional arrangements that are both durable and equitable, and that can sustain irrigation access over time without reproducing caste-, class-, and gender-based exclusions. Institutions, as the research established, are not neutral channels of resource distribution but arenas of contestation where power is performed and reproduced.

These three findings together explain irrigation not as apolitical technical input, but as a force that actively drives agrarian differentiation. For well-positioned farmers, access to irrigation enables commercial intensification, higher yields, and accumulation of land and capital. For poorly positioned farmers, irrigation becomes a driver of dispossession, raising land values and rental rates beyond their reach, and often relegating them to labouring on others' fields. Irrigation is thus a mechanism of both empowerment and subordination, simultaneously producing winners and losers in rural Nepal.

Equitable irrigation development in the Madhesh context is not simply a matter of distributing more technology more widely, or of correcting discrete programme failures through better targeting. The evidence points toward what would need to change structurally for access to become meaningfully equitable. Nepal's own history of long-enduring farmer-managed irrigation systems, studied by Lam (1998), demonstrates that durable equitable arrangements are possible: they require rule makers who are subject to the rules they make, collective monitoring with genuine accountability, and accessible conflict resolution. Translating these principles in the groundwater context means, at minimum: eligibility criteria that do not require formal land title, accepting instead witnessed cultivation agreements, Ward endorsed rental contracts, or group guarantees; genuine representation of landless and tenant farmers in programme governance from the design stage, with not merely consultative but decision-making authority; infrastructure that accounts for the seasonal water table dynamics documented in this study, so that investments do not systematically fail for the poorest users in March and April; and programme timescales of ten to fifteen years rather than three to five, sufficient for the institutional capacity that equity requires to actually develop (Lam, 1998; Merrey & Cook, 2012).

This dissertation advances theory in three ways. First, it develops the concept of a bundled architecture of access framework. This framework integrates insights from political ecology, agrarian change scholarship, and science and technology studies. It conceptualises access not as a singular event but as a cumulative process, layered across economic (land, labour, capital), social (caste, gender, networks), and techno-institutional (infrastructure, bureaucratic rules, subsidy schemes) architectures. These layers mutually reinforce each other, producing compounded advantage and exclusion. The framework helps explain why irrigation inequality persists even in the presence of subsidies and new infrastructure.

Second, building on established intersectionality scholarship, the research applies an intersectional approach to agrarian political economy. By showing how land tenure, caste, gender, and migration

intersect, it moves beyond single-axis analyses. The lived experience of a Dalit woman tenant farmer, for example, cannot be reduced to 'Dalit disadvantage' plus 'gender inequality' plus 'tenancy insecurity'; it is a distinct configuration of subordination shaped by the overlap of all three. In this sense, the dissertation offers an empirically grounded illustration of how intersectionality operates in shaping differentiated agrarian change.

Third, the dissertation extends the social construction of technology framework into agrarian studies. It shows how irrigation technologies acquire divergent meanings across social positions and how closure mechanisms stabilise particular forms of irrigation (for example, individually owned electric pumps for landowners) while foreclosing alternatives (for example, collectively managed systems, tenant-friendly arrangements). In this way, it contributes to the growing scholarship that treats technologies as socially constructed, contested, and politically embedded rather than as neutral instruments of development.

Methodologically, the research demonstrates the value of explanatory sequential mixed-methods in resource governance research. The quantitative survey identified structural patterns of inequality, while qualitative ethnography explained the mechanisms and lived experiences behind those patterns, and visual documentation captured embodied and spatial dimensions of access. By integrating these methods, the dissertation offers a model for future studies of complex socio-technical systems.

Equally important is the reflexive methodological stance. As a researcher with particular positionality – educated, rural born, later educated in an urban educational institution, and associated with institutions of power – I engaged continuously with questions of representation, trust, and accountability. Recognising my role in shaping research encounters, I sought to foreground farmers' voices while situating them within broader theoretical debates. This reflexive orientation strengthens both the rigor and the ethical grounding of the research.

The findings carry important implications for policy and practice. First, irrigation policy must move beyond the assumption that technology is a neutral input. Pumps, tubewells, and meters are embedded in social relations and distributed through institutional channels that reproduce the access inequalities they are meant to address. Providing subsidies or credit alone does not guarantee equitable outcomes. Practically, this means redesigning subsidy eligibility criteria to accept alternatives to formal land title, including municipality-witnessed cultivation agreements, Ward-endorsed rental contracts, or group guarantees, so that tenant and landless farmers can access the same programmes as landowners. It

means mandatory disaggregated reporting of beneficiary profiles by caste, land tenure, and gender from the first programme cycle, with defined equity triggers if profiles deviate from the community population. And it means simplifying multi-stage documentation requirements that disproportionately disadvantage households without formal sector integration (Platteau, 2004; Mansuri & Rao, 2013).

Second, equity in irrigation requires confronting land inequality. Without addressing land tenure insecurity, particularly for Dalit and women farmers, subsidies and technology promotion risk reinforcing existing hierarchies. Practically, this means implementing Nepal's existing tenancy legislation to formalise verbal lease agreements and reduce documentation insecurity; piloting group-based tubewell and pump ownership models that do not require individual land titles; and expanding policies that promote joint land ownership for women. These recommendations build on evidence that women's ownership of land strengthens their bargaining power and participation in household decision-making (Allendorf, 2007), while more recent research from Nepal shows that women who own land report greater confidence, enhanced participation in household and community decision-making, and improved socio-economic standing, although awareness and implementation of land ownership policies remain uneven across social groups (Koirala, 2022). The three-stage conditionality of water access, land enabling institutional eligibility, technology enabling extraction capacity, and aquifer conditions determining actual water availability, means that land reform alone is not sufficient, but it remains the prerequisite stage without which the other two cannot be reached by the most excluded farmers.

Third, irrigation and water access support must integrate supportive networks. Supporting and scaling up organic, self-initiated farmer networks that sustain irrigation access may be effective through longer-term engagements built on accountability, monitoring, and trust.

Fourth, elite capture must be addressed directly. Monitoring processes that focus solely on quantitative delivery targets (e.g., the number of pumps installed) obscure distributive outcomes. Equity-sensitive metrics and participatory oversight could help redirect benefits toward marginalised farmers (Al-Zu’bi et al., 2025).

Finally, irrigation policy and practice must be situated within broader debates on climate adaptation and justice. As climate change intensifies water stress in Nepal, ensuring equitable access to irrigation is not only a question of productivity but of resilience and justice. Recognising that marginalised

farmers face the most significant climate risks, yet the steepest barriers to irrigation access, equity is an urgent adaptation priority.

The research is not without limitations. It focuses on two Wards in Shambhunath Municipality, a site chosen for its theoretical significance but not statistically representative of Nepal as a whole. The findings, therefore, require cautious generalisation. The focus on access and control may underplay cultural and symbolic dimensions of irrigation technology. Moreover, the bundled architecture of access framework, while useful, risks reifying layers of exclusion as fixed rather than dynamic. Future refinements should attend more closely to how architectures shift over time and under new political-economic pressures.

Building on these limitations, the dissertation opens pathways for future research. Comparative studies across different districts of Nepal and South Asia could test the robustness of the bundled architecture of access framework. Longitudinal studies could trace how irrigation access and agrarian differentiation evolve, especially in relation to migration and climate change. Research could also examine alternative irrigation arrangements, such as cooperatives or public provision, to explore possibilities beyond elite-dominated individual ownership. Finally, future work could integrate hydrological and ecological data with social analysis to advance a more holistic understanding of irrigation sustainability.

At the heart of this dissertation is a question posed by a tenant farmer:

> '*…Tell me, what good is a technology that we cannot control?' ... (Field interview, Saptari, August 2023)*

Her words cut through policy optimism and technical abstractions, revealing the lived contradiction of irrigation in Nepal's Terai. Groundwater may lie beneath the soil, pumps may stand in the fields, and electricity poles may tower overhead, but, without secure access and control, technology offers little liberation. Instead, it becomes a mirror of inequality, reflecting and reinforcing the hierarchies of land, caste, gender, and class.

This research has shown that irrigation is much more than water or pumps. It is about power, farmers' positionality, and justice. To reimagine irrigation in Nepal as a driver of equitable agrarian change requires more than installing infrastructure. It requires confronting the deep structures of inequality

that shape who can access, control, and benefit. Only by centring these questions can the promise of irrigation move from a revolution, perpetually overdue, to a transformation genuinely shared.

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