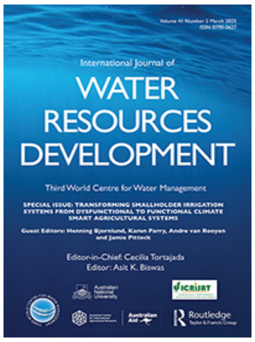

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Climate change adaptation benefits from rejuvenated irrigation farming systems in Mozambique

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ABSTRACT

Smallholder irrigation in sub-Saharan Africa suffers from the impacts of flooding and droughts, which are predicted to increase in frequency and severity. This increases the need to improve farmers' adaptive capacity to climate change. This paper explores how agricultural innovation platforms and nutrient monitoring tools impact farmers' adaptive capacity in a smallholder irrigation scheme in Mozambique. Through qualitative and quantitative data, we assess the impacts across four domains of adaptation: farm, household, community/scheme and markets. The multi-faceted interventions improved farmers' productivity, irrigation practices, scheme maintenance and livelihoods, thereby enhancing resilience and adaptive capacity to climate change in all assessed domains.

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SUSTAINABLE DEVELOPMENT GOAL
SDG 1: No poverty

Introduction

Mozambique is one of the most exposed countries to climate-related risks in Africa and the frequency of these events is expected to increase significantly in the coming years. More than half of the population lives in low-lying coastal areas, putting communities and key resources at risk (World Bank, 2023). Temperatures could rise by 2–2.5°C by 2050 and 5–6°C by 2090, with rainy and dry seasons becoming wetter and drier, respectively (Instituto Nacional de Gestão de Calamidades [INGC], 2009; Tadross, 2009). The risk of flooding will increase in the south, while the Cahora Bassa area in the western part of the centre will be heavily impacted by intense cyclones and drought.

Since agriculture is the main source of income for over 70% of the population in Mozambique, this sector is critical for food security and sustaining rural livelihoods (International Fund for Agricultural Development [IFAD], 2022). The predicted climatic changes will significantly impact the production of agriculture – including staple crops,

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such as maize and cassava – and reduce infrastructure and water access and people's livelihoods and health. This will undermine Mozambique's overarching goal of reducing extreme poverty (Arndt et al., 2011; Artur & Hilhorst, 2012; de Sousa et al., 2017). The extent to which Mozambique's vulnerability will increase depends on its adaptive capacity (INGC, 2009).

To cope with the adverse effects of climate change, the National Adaptation Programme of Action (National Adaptation Programme of Action [NAPA], 2007) was one of the immediate programmes to strengthen farmers' capacity to deal with climate variability and identify key adaptation areas related to agriculture, water resources management and land use. The National Strategy for Adaptation and Mitigation of Climate Change (ENAMMC) 2013–2025 (Ministério para a Coordenação da Acção Ambiental [MICOA], 2012) constitutes Mozambique's most recent response to reducing the risks associated with climate change. Actions arising from this strategy focus on protecting livelihoods and assets, such as increasing water resources management capacity and the resilience of the agriculture sectors and vulnerable people, and safeguarding adequate levels of food security and nutrition (Sustainable Trade Initiative [IDH], 2019).

Given the frequency of a partial or total failure of crops due to scarce and unreliable rainfall (INGC, 2009), sectoral plans focus on the expansion and intensification of irrigated agriculture to take advantage of the relatively abundant blue water in the country. The country's recent plans estimate a growth rate of irrigated areas between 1050 and 15,000 ha per year (Programa Nacional de Irrigação [PNI], 2016). However, existing irrigation schemes in sub-Saharan Africa, including Mozambique, have a history of underutilisation, underperformance and failure, highlighting the need for innovative approaches to enhance adaptive capacity amidst the challenges posed by climate change (Bjornlund et al., 2017). Several factors are currently hindering smallholder farmers' adoption of climate change adaptation mechanisms in Mozambique, including: access to credit and financial services, information gaps, education and training, irrigation infrastructure deficiencies, transportation and market access, price volatility, limited access to quality inputs, insecure land tenure, and gender inequality (International Center for Tropical Agriculture [CIAT] & World Bank, 2017).

Farmers' adaptive capacity determines their ability to maintain food security, income and livelihoods, while facing changes in climate and socio-economic conditions (Kandlikar & Risbey, 2000). Several factors have been identified in the literature that enhance farmers' capacity to adapt to climate change: (i) land access determines farmers' ability to adopt specific strategies and technologies (Nyanga et al., 2011; Smit & Skinner, 2002); (ii) access to finance determines the ability to access fertile lands, irrigation water and inputs (Tangonyire & Akuriba, 2021); (iii) household demography (size, age distribution, gender composition, education level, income level, occupation, ethnicity and location) impacts the capacity to choose effective adaptation options, with non-farm income particularly important as it is less sensitive to climate change (Belay et al., 2017); (iv) access to markets, extension, technology and farm assets (labour, land and capital) help farmers access resources and knowledge on different adaptation strategies (Hassan & Nhemachena, 2008); (v) access to climate change related information and training, influence farmers' choice of adaptation strategies (Mequannt et al., 2020); (vi) supportive institutional environment (laws and regulations) and efficient service delivery systems, ensure effective climate change adaptation and resilience strategies (Zeleke et al., 2022); and vii) social capital (trust and reciprocity, relationships, norms, culture, values, and information flow), enables farmers to learn and access information, knowledge and support from established social networks (Agrawal, 2010; Nyanga et al., 2011; Smit & Skinner, 2002).

Several current initiatives in the agriculture sector aim to build the resilience of smallholder farmers, but they have been poorly coordinated resulting in a lack of communication and an overlap in coverage. Consequently, lessons are rarely shared and learned, and synergies are not explored (CARE & ACTIONAID, 2017). There have also been several more specific climate smart agriculture-related initiatives, led by governmental and non-governmental actors, such as: crop diversification, intercropping, use of short season varieties, sustainable water and fertiliser management practices, conservation farming, organic farming, and integrated pest management (International Center for Tropical Agriculture [CIAT] & World Bank, 2017). However, there is a noticeable scarcity of studies reporting on the implementation, impact or success of these initiatives. Further, the breadth of challenges that hinder the ability to adapt and the factors required to enhance this capacity are complex and interconnected, making it crucial to intervene in a holistic way. This includes engaging local communities in the planning and execution of initiatives to ensure root causes and interconnected challenges are addressed. In the context of smallholder irrigation schemes, capacity building of the local farming community with respect to soil and moisture conservation is also critical to support adaptation (Sustainable Trade Initiative [IDH], 2019). We argue that it is crucial to address these interconnected challenges to ensure long-term and sustained climate change adaptation and mitigation. Hence, there is a need for research that reports on innovative institutional and technological interventions and how these can improve farmers' capacity to adapt to climate change.

Agreeing with IDH (2019), this study focuses on farming households and contributes to filling this gap, by reporting on outcomes from the 'Transforming small-scale irrigation in southern Africa' (TISA) project, which ran from 2013 to 2023. The TISA project adopted a two-pronged approach, making an institutional and technological intervention, agricultural innovation platforms (AIPs) and soil moisture and nutrient monitoring tools, to improve farmers productivity and profitability and thereby support the reinvigoration of existing irrigation schemes (Pittock et al., 2020, 2018). While the focus of TISA was on increasing profitability, the impacts experienced during the ten-year project suggest that the two-pronged approach also increased farmers' capacity to adapt to shocks to their production systems, such as COVID-19, and left them better positioned to adapt to climate change. This paper provides an ex-post analysis of TISA outcomes drawing on data collected on the outcomes during the TISA project, including three household surveys across the ten-year timeframe. While it is always possible in ex-post research to identify additional data that would improve an analysis, the variety of data presented is a strength of the paper. The project capitalised on the opportunity presented by COVID-19 to collect additional data about COVID-19 impacts from a scheme not engaged in TISA. This paper explores the following research question: Have TISA's two-pronged approach improved farmers' adaptive capacity and resilience to climate change with respect to the seven factors identified in the literature? We hypothesize that the answer is in the affirmative.

The first section provides background information about the scheme and the region, explains the two main TISA interventions, the approach used to assess the impact on the adaptive capacity within four domains and the quantitative and qualitative data used to measure this impact on the seven factors identified in the literature. This is followed by the results section, which first reports farmers' perceptions of the importance of the AIP activities and the adoption of learnings from the tools followed by an analysis of how the AIP activities and the tools have improved farmers' water management, productivity and livelihood within the four domains. The discussion analyses how these improvements have changed farmers' capacity to adapt to climate change, assessed against the seven factors identified in the literature.

Background

The irrigation scheme and its climate change vulnerability

This paper is based on the analysis of changes taking place within the 25 de Setembro irrigation scheme located in Boane District (Figure 1). The scheme is located approximately 30 km south of Maputo city, the capital of Mozambique, and is a government-built and supported scheme. It was constructed in 1975 with an area of 38 ha and was legally established as a registered Farmer Association in 1981. The selection was based on its potential to improve or address agronomic practices, institutional capacity, and market barriers, and factors such as site accessibility, research cost, crop diversity and the willingness of the district authority to collaborate (de Sousa et al., 2017).

The scheme had 56 farmers when established, but when the study commenced in 2013 there were only 38 farmers (22 male and 16 female). At that time, the average age of household heads was 57 and the average household size was 6.8. With respect to

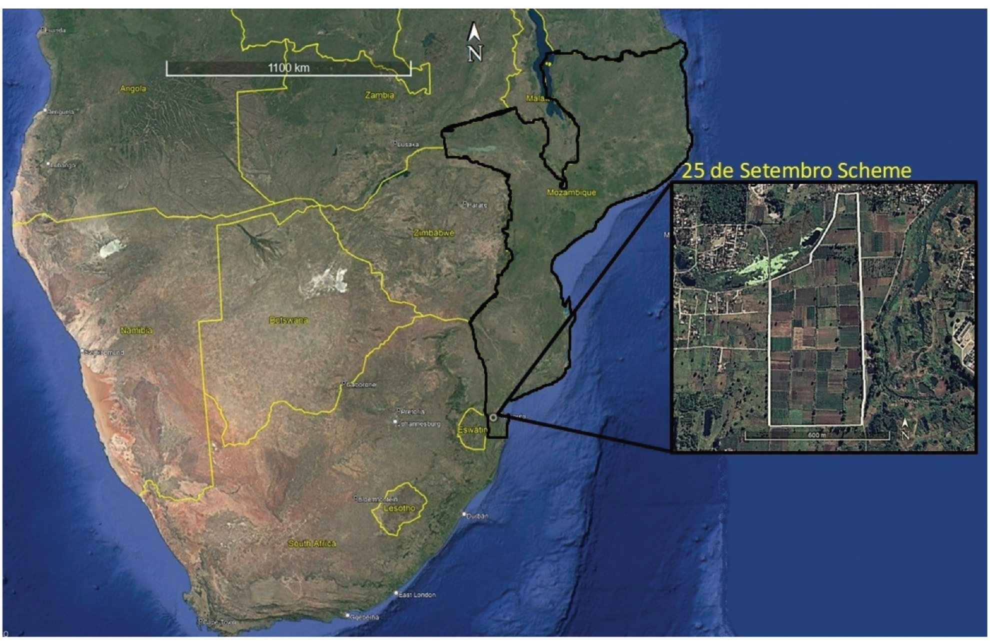


Figure 1. Location of the 25 de Setembro irrigation scheme, Mozambique, based on satellite imagery from Google.

education, 32% had no formal education, 37% had attended/completed primary school, and 31% had attended/completed secondary school. The average farm area was 1.1 ha, and the main crops grown were green maize (71%) and cabbage/tomatoes/cowpea (29%) (de Sousa et al., 2017). Hence, the scheme had a group of aging farmers, many recently deceased farmers and many farmers had left the area due to low productivity, resulting in many unused plots (Chilundo et al., 2020).

Both men and women participated in most farm work. However, men were responsible for building and supplementing household income by off-farm work, while women were responsible for most domestic work (de Sousa et al., 2017). Extension services are critical to provide crop management advice and its provision is the responsibility of the government. Nevertheless, extension officers had little influence in the scheme, with only 28% of farmers accessing an extension officer during the two years prior to the commencement of TISA in 2013 (Wheeler et al., 2017).

The Boane district has a hot-wet season from October to March, with high temperatures and heavy rainfall. This period is favourable for rainfed agriculture as precipitation exceeds half of the evapotranspiration (Reddy, 1984). The period from mid-March to the end of October is cooler and drier and irrigation is essential (Ministério de Administração Estatal [MAE], 2005; Reddy, 1986). The total annual rainfall is around 699 mm (Instituto Nacional de Meteorologia [INAM], 2012; Climate Data, 2022), with an average annual temperature of 22.7°C, the maximum in February (26°C) and the minimum in July (19°C). The average annual relative humidity is 67%, with minimum and maximum values of 58% and 75% observed in August and January, respectively (INAM, 2012; Climate Data, 2022).

The Boane district is crossed by the Umbelúzi River, which is the most important source of water for irrigation and provides drinking water for Maputo and Matola cities and the Boane district (Government of Boane District, 2016). The 25 de Setembro scheme extracts water from the Umbelúzi River using a 40 hP diesel pump delivering 125 l/s. Water is distributed by gravity through a canal system and applied into the fields using furrow irrigation. Irrigation scheduling is subject to constant negotiations among the members, with water supplied every six to seven days prior to the commencement of TISA (Chilundo et al., 2020). The soil texture ranges from sandy clay (86%) to clay (14%) (de Sousa et al., 2017).

Due to its location downstream of the Umbelúzi international basin, agriculture in the Boane area is vulnerable to climate change. The area is highly exposed to frequent hazards, especially severe floods and cyclones during the hot-wet season and droughts during the cold-dry season. As an example, the region was affected by severe drought in the period 2016–2018, forcing the suspension of irrigation activities (CARE, 2016). In February 2023, flood-related disruptions negatively impacted the harvest, threatening the food security of approximately 99,000 people in Boane (Wansi, 2023).

TISA interventions

The TISA project adopted a two-pronged approach to transform small-scale irrigation schemes. The project introduced AIPs and soil moisture and nutrient monitoring tools with the aim of improving household and scheme productivity. The project was implemented in two phases: Phase I from 2013 to 2017 (TISA I) and Phase II from 2017 to 2022 (TISA II).

TISA I implemented the approach with a small number of schemes and TISA II focused on out-scaling to a larger number of schemes with a lower level of project staff, transitioning staff roles to local stakeholders. Activities at the scheme were seriously affected by the onset of COVID-19 around April 2020. After COVID-19 was declared a 'national disaster' and a subsequent 'state of emergency' in Mozambique, the agricultural sector faced substantial challenges. Movement restrictions had a significant impact on the supply chain and farmers' access to markets. Moreover, market closures and restricted trading hours hindered farmers' ability to sell their produce, resulting in significant income losses.

Agricultural innovation platforms

An AIP aims to facilitate interactions and engagement among stakeholders in irrigated agriculture and associated value chains. Many studies have reported on the performance of AIPs in various countries (e.g., Ayantunde et al., 2016; Makini et al., 2018; Schut et al., 2018b; Van Paassen et al., 2014). Overall, the literature supports the claim that AIPs generate enthusiasm and bring together stakeholders to effectively address specific problems; thus, achieving impact. However, they should be demand-driven, participatory and involve committed stakeholders to be successful (Schut et al., 2018a).

In the TISA project, the AIP process brought together all the stakeholders with an interest in the irrigation scheme (Chilundo et al., 2020), creating an environment in which everyone understood their role in the network. As described by van Rooyen et al. (2017), the steps associated with the AIPs were:

(1) a visioning exercise during which irrigators assess the existing situation and develop a vision of how their scheme would look in five years;
(2) identifying barriers that needed to be overcome to achieve the vision, which were mainly factors affecting the productivity and profitability of farming such as marketing and value-adding opportunities;
(3) identifying solutions to overcome the barriers; and
(4) identifying stakeholders to implement the solutions.

Across the ten-year period, a total of nine AIP meetings were held. This included one district-level AIP meeting (14 May 2019), with approximately 50 participants and including representative farmers from two other schemes. Furthermore, many informal meetings took place to address issues outside the formal AIP meetings. To implement the solutions, the AIP initiated several activities during TISA I, which are discussed later and listed in Table 3.

Soil moisture and nutrient monitoring tools

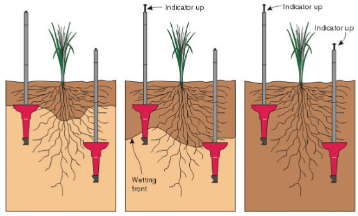
Two soil monitoring tools were introduced: Wetting Front Detectors (WFDs) and Chameleon soil moisture sensors and readers, which are described in Table 1.

Method

Assessing the ability of farmers to adapt to climate change

This study explores whether the TISA approach to improve profitability has also increased farmers' resilience and their ability to adapt to climate change across the seven factors

Table 1. Soil monitoring tools deployed at irrigation schemes in Mozambique (data source: Stirzaker et al., 2017).

Tool	Full Stop Wetting Front Detector	Chameleon Soil Moisture Sensor
		
Measures	• Depth of wetting front in soil. • Salinity and nitrate levels of water samples collected in WFDs.	• Availability of soil water for crops
Feedback and learning	• When over-irrigation takes place fertilizer leaches below the root zone. • Optimal irrigation volumes by detecting the wetting front reaching a desired depth.	• Illustrates distribution of soil moisture through the profile using intuitive readings: blue = wet, green = desirable moisture, and red = dry. • Optimal timing and volume of irrigation by identifying if the soil is sufficiently wet and no irrigation is needed, or if the soil is dry in the root zone. • Combined with the WFD, farmers learn that when the chameleon is consistently blue, fertilizer leaches below the root zone and is lost to the plants.

identified in the literature to enhance farmers' adaptive capacity, namely: land access; access to finance; access to markets, extension, technology and farm assets; access to information and training; service delivery and institutional environment; and social capital.

The paper assesses the impact on farmers' adaptive capacity, using measures reflecting the seven factors and across four domains of adaptation: farm, household, community/scheme and markets (Table 2). In performing this assessment, we analyse TISA's data on change, drawing on the data and changes that align most closely to the seven factors.

Data sources

Household surveys

Three household surveys were undertaken to collect a broad range of data including change in farming practice (irrigation, crops grown) and farmers' perceptions of their circumstances. While efforts were made to interview all farmers and, where possible, the same households across the surveys, this was not always feasible due to changes within the farmer population and the expansion of the scheme. Nonetheless, each survey successfully interviewed a substantial proportion of the population, providing a reliable basis for the survey findings. The questionnaires included a consistent set of questions across the surveys to facilitate longitudinal analysis, alongside questions tailored to the specific focus of each survey period. The three surveys were: i) a baseline survey conducted in 2014 with 25 out of 38 households in the scheme, which provided data on baseline conditions and farmers' perceptions of changes over the previous four years; (ii) an end-of-phase I survey, conducted in 2017 with 28 out of 38 households, which allowed for an analysis of practice change and how farmers perceived changes in their

Table 2. Measures assessed across the four domains and the corresponding data sources.

Measures for four domains	Indicators	Data source[1]
Farm/field		
Changes in irrigation practices	Changes in irrigation frequency and duration Reasons for change	Household survey
Changes in yield and water productivity	Green maize yield Duration and frequency of irrigation events	Farmer field books Household surveys
Change in crops grown	New crops grown	Household survey
Access to finance	Ways access was facilitated and number of farmers accessing credit	Field observations Focus group discussions
Household		
Changes in household income	Perceptions of change in farm and off-farm income Gross margins	Household survey Farmer field books and workshops
Changes in well-being	Perceptions of changes in household food security, health and education	Household survey
Community and scheme		
Governance aspects:		
Conflict at scheme level	Perceptions of changes in conflict within and between sections/blocks	Household survey Focus group discussions
Equity of water allocation	Perceptions concerning water supply: fairness, reliability of supply	Household survey
Willingness of farmers to participate in scheme	Perceptions of participation in scheme maintenance and willingness to pay for water	Household surveys
Collaborative activities	New collaborative activities	Records of AIP meetings, TISA publications, field observations, Focus group discussions, workshops
Impact on disadvantaged groups	Allocation of plots to young farmers Changes in balance of decision-making	Field observations Citing other TISA research
TISA approaches contributing to enhanced resilience to shocks (COVID-19)	Perceptions of COVID-19 impacts	Household surveys (TISA & non-TISA)
Market		
Linkages between farmers and other value chain actors	Activities to strengthen links to input and output markets Perceptions on inputs and outputs: process, range, price	AIP records Household survey

Note: [1]All data sources are for TISA scheme unless noted otherwise.

circumstance during TISA I and enabled an assessment of the impact of TISA interventions; and (iii) an end-of-phase II survey that was conducted in late 2020/2021 with 40 households (including two active farmers who were not formally registered but were recognized by the association as part of the scheme), providing data on practice change and how farmers perceived changes in their situation and facilitating an analysis of the impact of TISA II and the perceived effects of the COVID-19 pandemic on the outcomes.

Non-TISA scheme survey (2021)

This was conducted with 106 out of 244 households from a non-TISA scheme to evaluate the impact of the COVID-19 pandemic on farmers who were not engaged with TISA. This supported an assessment of the extent to which TISA interventions had enabled farmers to cope better with shocks such as COVID-19 compared to non-TISA farmers. The TISA and non-TISA scheme, located approximately 3 km from 25 de Setembro, shares several key production characteristics: both utilize a furrow irrigation system to irrigate about 40 ha, draw water from the same source (the Umbelúzi River) using a pump and produce similar crops, including green maize, cabbage, tomatoes, potatoes and beans. These similarities formed the basis for selecting the scheme for comparison. However, we acknowledge that plot sizes were smaller at the non-TISA scheme. And that these differences may influence farmers' adaptive capacities. Since the non-TISA scheme was not engaged with the TISA project, we have less background context on this scheme, including the functionality of scheme governance and how this and other influences might have created and supported capacity among households.

Farmers' field books and gross-margin workshops

During TISA I, 18 farmers who received the tools committed to maintain field books, while the remaining farmers were encouraged to do so voluntarily. These field books captured detailed, real-time quantitative data on farm operations, including irrigation schedules, input use and costs, volumes of produce harvested, and commodity prices received. This data enabled the computation of gross margins and yields, which were discussed during end-of-season workshops with the farmers maintaining the field books (Chilundo et al., 2020). The gross margin is the difference between income and variable costs. In research on crop production, it is generally expressed in monetary value per land use area. The full description of its computation can be found in Chilundo et al. (2020). The detailed observations from the field books offered rich quantitative data that validated the household survey data.

Supplementary qualitative data

Field observations were made by the project's field officers and researchers during site visits, which provided additional context. The code FO is used in the results section to show where data relates to field officer observations. Discussion and outcomes of the AIP meetings were recorded and provided a rich source of information on developments taking place during TISA. Additionally, 13 focus groups/workshops were held over TISA's 10-year timeframe with between eight and 32 participants, depending on the purpose of the meeting. During these meetings various topics were discussed: mapping the scheme; cropping strategies; market access and commodity pricing; business plan development; and financial access and credit (Chilundo et al., 2020). Key points from all discussions were recorded on flip charts and later summarized in reports and provided insights into farmers' strategies and challenges. Participants in the meetings and focus groups included farmers and other relevant stakeholders, and the code FGD is used in the results section to show where data is from these discussions.

Data analysis

The quantitative data was analysed using descriptive statistics and validated through triangulation with information from focus groups, observations and farmers field books. One limitation of the survey approach is the inherent subjectivity of the measures and the potential for recall bias, given the time lapse between the occurrence of an event and the survey. There is also the potential for invigilator inconsistencies and recording errors. To mitigate these limitations, we employed a maximum recall period of three years, ensured consistency in the questions asked across different time points, provided comprehensive training for enumerators and implemented rigorous data validation procedures. Additionally, the second and third surveys were conducted using tablets to reduce transcription errors and further improve consistency. Furthermore, reporting on farmers' field book data provides a measure of triangulation with the survey data, which minimizes the risks associated with these methodological limitations of household surveys. The qualitative data has been drawn on to a lesser extent than the surveys and farmers' field books. Focus group and field officer records were examined as aides to reflection on project implementation and outcomes, and interpretation of quantitative findings.

We acknowledge that enhancing the adaptive capacity of irrigation schemes is inherently tied to strengthening the governance structures of these schemes. However, this topic lies beyond the scope of the present paper and represents an important area for future research. In the context of the TISA project, we have addressed governance aspects in greater detail in previous and forthcoming papers, including van Rooyen et al. (2020), Mdemu et al. (2023), and Bjornlund et al. (2020, 2021, forthcoming).

Ethics declaration

For this study, ethics approval for the three surveys and focus groups was follows: (i) 2013/14 survey and focus groups – The University of South Australia's Human Research Ethics Committee, protocol name was 'Increasing irrigation water productivity in Mozambique, Tanzania, and Zimbabwe through on-farm monitoring, adaptive management and agricultural innovation platforms', protocol number was 0000032704; and (ii) 2016/17 and 2020/21 surveys and focus groups – The University of South Australia's Human Research Ethics Committee, the protocol was called 'Transforming smallholder irrigation into profitable and self-sustaining systems in southern Africa', protocol number was 2017/263.

All research participants provided their consent to participate prior to the data collection process. Consent was obtained after providing an introductory statement to informants, which explained the background of the research, the use of the information and how their personal data would be handled.

Results

The results section is divided into two sub-sections. The first describes the implementation of the two TISA interventions, and the actions taken by the AIP and how they were perceived by farmers. It then analyses the changes in irrigation water management that resulted from the use of soil-water and nutrient monitoring tools. The second sub-section reports the combined outcomes emanating from both the actions taken by the AIP and the monitoring tools, with outcomes reported at field, household. scheme and market domains.

Implementation of the two TISA interventions

The AIP

The primary goal of AIPs is to facilitate interactions and engagement among stakeholders in irrigated agriculture and associated value chains to overcome barriers to increased profitability. The assumption of the project was that increased profitability

Table 3. Activities identified and implemented by the AIP and households' perceptions of their importance (data source: surveys).

Activity/outcomes (2013–21)	% of households aware of the activity	% of households ranking each activity 1–3 in order of importance		
		1	2	3
Collaborative mapping	70	58	3	3
Business plan	85	13	65	5
Gross margin workshop/training	45	3	0	35
Experiential demonstration plots	53	5	5	13
Introduction of new high-value crops	60	5	0	20
Improved input market linkages	53	5	13	0
Improved output market linkages	35	0	0	5
Improved linkages to financiers	40	5	0	3

would increase farmers' ability and willingness to pay for and participate in scheme maintenance, to buy farm inputs, and adopt new farming practices. It was anticipated these outcomes would increase farmers' resilience and the sustainability of their farms and schemes. In Mozambique, the AIP facilitated the identification and discussion of several critical barriers that farmers were facing and initiated a range of activities to overcome them. Table 3 lists the activities explored in the survey and their relative importance as perceived by the farmers, while Table 4 shows why farmers perceived each activity to be important.

In addition to the activities explored in the survey, the AIP facilitated two interventions to address the issues identified as most urgent during the first AIP meetings. First, the AIP collaborated with farmers and a key stakeholder, the National Irrigation Institute, to design a project aimed at improving irrigation infrastructure (Chilundo et al., 2020). This included lining the main supply canal, implementing some laser grading, building a new pump house, and convincing the government to fund the project. This was critical for farmers, as they paid for diesel to pump water into the canal. The canal lining increased the speed of water delivery and reduced leaching, thereby, lowering farmers' pumping cost. Another AIP stakeholder facilitated contact to a Japanese aid organization, which replaced the scheme's aging tractor and truck. This enabled the farmers to retain the benefits from using this equipment and maintain its rental income from non-scheme farmers (Chilundo et al., 2020; de Sousa et al., 2017).

Collaborative mapping was ranked as the most important activity by most farmers (58%) (Table 3). This activity improved farmers' understanding of the boundaries and sizes

Table 4. Households' assessment of importance of AIP activities (data source: surveys).

What did this mean for households (% of those aware of activity):	Collaborative mapping	Business plan	Gross margin workshop	Demonstration plots	New high-value crops	Input market linkages
Improved crop selection	22	56	0	50	8	78
Increased yield	11	56	75	67	100	78
Increased gross margin	0	36	0	25	17	22
Increased food security	0	28	0	0	0	44
Increased household income	0	48	25	0	8	22
Reduced conflicts within the scheme	89	20	0	0	0	44
Increased willingness to pay for water and participate in scheme maintenance	11	16	50	33	0	33

of their plots and proved to be a major tool to improve farmers' empowerment and ownership (Mdemu et al., 2023). Farmers perceived that this had reduced conflicts within the scheme and increased their willingness to participate in the scheme management (Table 4).

The highest ranked activities, aside from collaborative mapping, include the business plan, gross-margin workshops, introduction of new high-value crops, and improved input market linkages. The business plan was rated the most or second most important by 78% of households, as it was perceived to improve farmers' crop selection, yields, gross margin, and household income. The introduction of new high-value crops was considered most important by 5% and third most important by 20%, as it was perceived to lead to increased yields, gross margins and household income and improved crop selection. Gross margin workshops – rated most important by 3% and third most important by 35% – were perceived to increase yield, willingness to pay water fees and household income. This finding highlights the role of these workshops in fostering a greater understanding of the value of irrigation and, hence, the importance of investing in scheme maintenance. The surprising relative importance of high-value crops on yield, gross margins and increased income might be related to the fact that the high value crops were associated with the use of more expensive improved seeds and other high quality inputs, which increased yield but also increased cost. Improved input market linkages were deemed most important by 5% and second most important by 13%, and are perceived to improve crop selection and yields (78% each), as well as increased food security and reduced conflicts (44% each). Improved output market linkages were less known, with only 35% being aware of this being an activity of the AIP, and none of the farmers ranking it as most or second most important. This highlights potential room for improvement in the scheme's marketing strategies.

The tools

At the commencement of the project in 2013, 20 farmers received and started learning from using the tools. As shown in Figure 2 and Table 5, there is evidence of ongoing and sustained learning, leading to subsequent changes in irrigation practices throughout the scheme. By the end of TISA I, 35% of all scheme farmers had changed their irrigation practices. These changes were sustained during TISA II, with 80% of farmers continuing to practice the changes they made prior to 2017. The majority (88%) reported that they continued to learn from using the tools; hence, 77% made further changes during TISA II, and 50% of those not changing during TISA I, did so during TISA II. By 2021, 75% of all scheme farmers had made changes. This is clear evidence of the effectiveness of the intervention and that the changes were long-lasting and on-going. Most farmers with tools (74%), reported that they had learned enough from using the tools so that if they were no longer available, they would be confident to continue their newly adopted irrigation regimes. Furthermore, farmer-to-farmer learning was a significant factor in this process, with 64% of those changing practices during TISA II reporting that they did so because they had observed and talked to their neighbour. Hence, there is strong evidence of sustained and ongoing experimentation and learning from using the tools.

Farmers reported that training on the functionality of the tools was essential to facilitate an understanding of how to use them (FGD; Table A1, where A indicates online supplemental material). Farmers who mastered the use of the tools led the

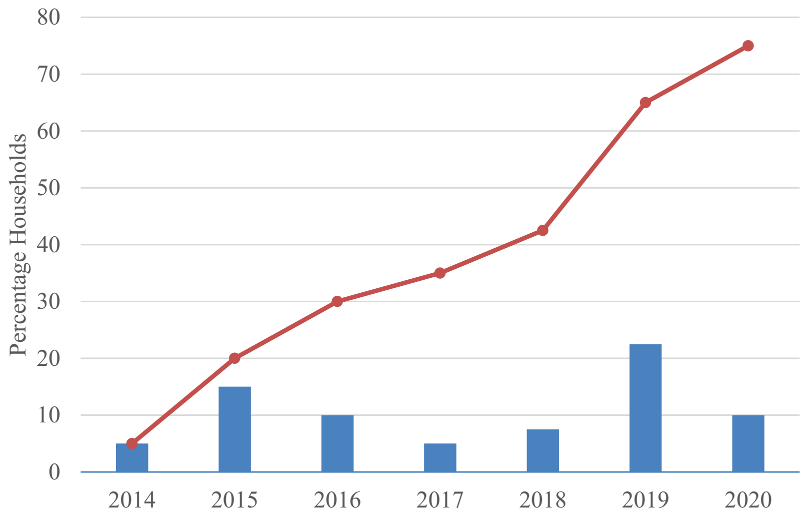


Figure 2. Uptake of learning accumulated over time (each year in blue bar, cumulative in orange line) by all the 40 scheme farmers included in both the 2017 and 2021 survey at 25 de Setembro irrigation scheme (data source: surveys).

Table 5. Changes to timing of irrigation and duration of events (data source: surveys).

	% households
Reasons for changes and usefulness of tools	
Changed irrigation practice prior to 2017 due to learning from the tools	38
Still practising changes made prior to 2017	80
Still learn new things from the information from the tools	88
Made further changes to irrigation practices: % of those making changes prior to 2017	77
Changed irrigation practices since 2017	50
Irrigation practices changed since 2017	
Reduced irrigation frequency (%)	86
Irrigation frequency before (days)-mean	5
Irrigation frequency now (days)-mean	12
Reduced duration of irrigation event (%)	23
Hours of irrigation before (mean)	5
Hours of irrigation now (mean)	3
What prompted the changes?	
Continued monitoring the tools and learning	32
Neighbour or other farmers doing it	64
Demonstration plot	4
What would happen if the tools were no longer available?	
Have learned enough from using the tools to have confidence in maintaining the new irrigation regime	74

training in their fields for those who did not have the tools (FO). Focus groups facilitated and strengthened farmer-to-farmer learning by creating forums for farmers, with and without the tools, to discuss and share their experiences and learning. As a result, irrigation was no longer based on a visual observation of the soil, but on the availability of water in the soil for the plants. Due to the simplicity of the operation of the tools, farmers stated that it was easy even for illiterate farmers to learn from the tools and realize the advantages from using them (FGD).

Changes in the field/farm domain

Irrigation frequency and duration

Farmers changed their irrigation management primarily by extending the time between events and shortening their duration (Table 5). Most changes focused on irrigation frequency (86%), with irrigators more than halving the number of irrigation events and almost halving the duration of each event. These changes significantly reduced water use, time, pumping cost, and fertilizer leaching. Figure 3 provides further evidence of farmer-to-farm learning. Initially, farmers with the tools learned and extended irrigation intervals, and those without the tools followed closely in making the change. Around 2020, this trend reversed, indicating widespread learning. In utilising the tools, farmers gained awareness of the importance of water and soil nutrient dynamics, improving fertilizer and water application for improved crop productivity.

Based on farmers' records, the number of days between irrigation events peaked in 2019 with farmers using the tools irrigating only every 18 days (Figure 3). In this year, six of the nine farmers changing their irrigation practices were young farmers that had recently become scheme farmers and received the tools (FO). Hence, this final increase could be a result of the entrance of young and enthusiastic farmers.

Changes in yields

Significant increases in crop yield for both groups (Figure 4) were achieved alongside reductions in irrigated water use, reflecting the reduction in fertilizer leaching. While those with the tools initially reported larger and more rapid yield increases, those without the tools showed a similar improving trend. This provides further evidence of farmer-to-farmer learning. The increases were particularly in the earlier period of tool usage (2015/16 to 2017/18 seasons). Both groups then experienced a decline in yields during the 2018 and 2018/19 seasons. However, farmers without the tools, experienced sharper declines than those with the tools (26% versus 16%). During the next two seasons, yields for those with the tools were relatively stable, while those without the tools increased their yields.

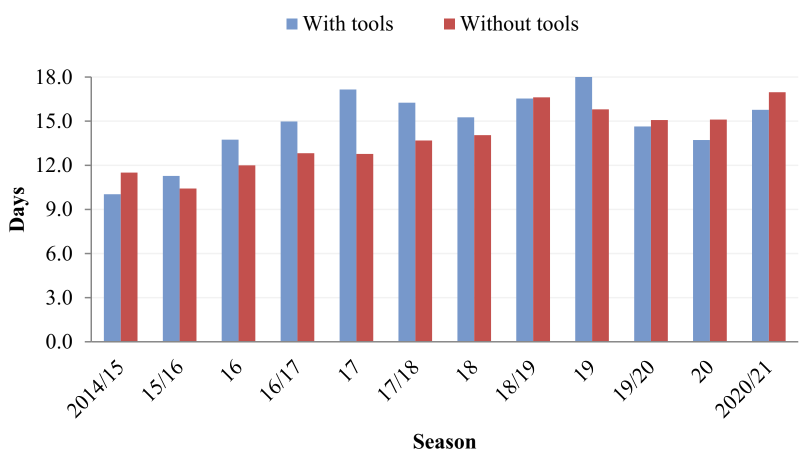


Figure 3. Changes in irrigation intervals for farmers with or without the tools. (data source: Farmers' field books).

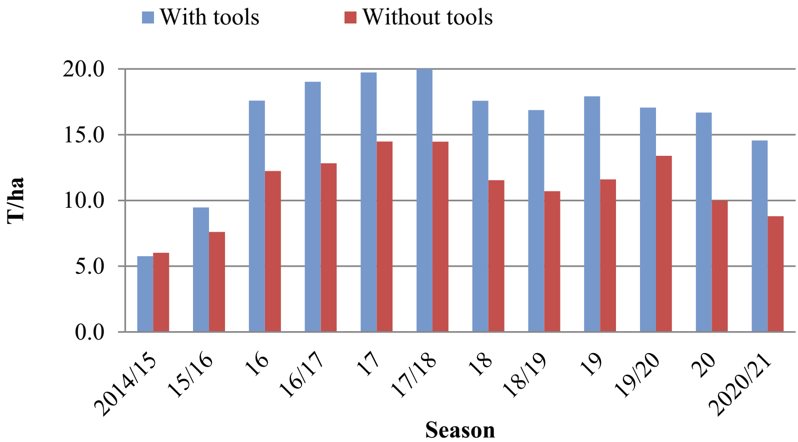


Figure 4. Green maize yields (tonnes/ha) from 2014 to 2021 at 25 de Setembro irrigation scheme. (Data: farmers field books).

After the onset of COVID-19 in April 2020 (2020 and 2020/21 seasons), both groups experienced a reduction in yields, which was more pronounced for farmers without the tools than those with the tools (34% and 15%, respectively). This drop in yields is in response to movement restrictions, which reduced access to and increased the prices of farm inputs (Bjornlund et al., 2024). We speculate that farmers with the tools were in a better financial position following the preceding year's yield increases, and hence could better afford the higher input costs.

Changes in water productivity

While we have not carried out a thorough evaluation of water productivity due to the absence of reliable rainfall data, we argue that the reduction in irrigation events during the season and the duration of each event combined with increasing yields, must mean that water productivity has increased. Evidence from a TISA scheme in Zimbabwe, where there was access to rainfall data and similar changes in irrigation practices were achieved, supports our argument (Moyo et al., 2024, 2020). In this case, water productivity of grain maize increased from 0.2 to 1.28 kg/m^3 from 2013/14 to 2016/17, before declining to 0.98 kg/m^3 in 2020/21. The decline likely reflects the challenges farmers faced in accessing inputs and coping with rising prices during the COVID-19 pandemic (Bjornlund et al., 2024; Moyo et al., 2024). This increased water productivity reflects how tools can help farmers optimize water use. Additionally, the contribution of rainfall to total water use increased significantly from 20% in 2013/14 to 65% in 2020/21, with irrigation as a share of total water use decreasing from 80% to 35% over the same period (Moyo et al., 2024).

New crops grown

The AIP process strengthened linkages with value chain actors and increased the information flow to farmers about market demand and desired crop specifications. This resulted in many farmers deciding to produce certain crops for the first time. The number of farmers doing so, and the diversity of these crops, demonstrates the capacity of farmers to change. This indicates that the AIP process had a positive impact on farmers' ability to

Table 6. Irrigated crops grown by farmers for the first time in the past four years (data source: surveys).

What new irrigated crops were grown last four years (2014–2017)?

Crops	TISA I (%)	Crops	TISA I (%)
Grain maize	5	Onion	15
Green maize	65	Cucumber	23
Irish potato	8	Sweet pepper	13
Sweet potato	8	Okra	8
Tomato	10	Eggplant	10
Sugar beans	33	Pumpkin	8
Other legumes	5	Carrot	5
Other vegetables	10	Garlic	5
Fruits	3	Sugarcane	5
Cabbage	48	None	23

adapt to changing market demands, adopting new crops, and to collectively agreeing on minimum prices for various crops. New irrigated crops were adopted such as green maize (65%), cabbage (48%), sugar beans (33%) and cucumber (23%) (Table 6). The high proportions reported for each of these crops were initially surprising given the crops grown prior to TISA. However, the findings reflect the influx of new farmers into the area during TISA I, replacing aging and deceased farmers and activating previously unused plots (Chilundo et al., 2020). These farmers opted to cultivate new crops in response to market signals (FGD; Table A1).

Access to finance

The AIP also facilitated farmers' access to credit for inputs. An agreement was made with the company *Tecnologia e Consultorias Agro-Pecuária, SA* (TECAP) – an agricultural technology and consulting agency, which provides services and supplies various products for agriculture, livestock and agribusiness – to provide technical assistance to develop production plans. These were crucial for obtaining access to finance from *Gabinete de Apoio a Pequenos Investimentos* (GAPI) – an agricultural development finance entity, that operates along the entire agribusiness value chain, providing services to strengthen links between players in the value chain, technical assistance for agricultural production and financing. This is evidence of how the AIP fostered interactions among a group of relevant stakeholders that perform different but complementary roles in sustainable development. As a result, 15 farmers accessed credit to invest in high-quality inputs, such as certified seeds, pesticides and fertilizers (Chilundo et al., 2020).

Changes in the household domain

Income

Most farmers reported that on- and off-farm incomes improved during TISA I. This was especially the case for off-farm work, which reflected the reduced time spent on irrigation. These off-farm income levels were mainly retained during TISA II and, critically, remained largely stable after the onset of COVID-19 (Table 7). The proportion reporting declining off-farm income has changed little since 2014.

The perceived increases in farm income were very strong during TISA I, with 83% reporting increases. This trend was not retained during TISA II, especially after the onset of

COVID-19, with many farmers reporting declining or stable farm income. COVID-19 had a significant impact on access to and prices of inputs and restricted access to output markets (Table A2). This affected both the physical and economic access to farm inputs and hence reduced yields and farm income.

Farmers with the tools consistently experienced higher gross margins than those without. However, their gross margins followed the same trend with an initial significant increase during the first six seasons, which then dropped slightly and again increase slightly during the few years prior to COVID (Figure 5).

Perceived changes in food security, health, and education

Within the scheme, the proportion of households that experienced food shortages between 2014 and 2020 decreased from 16% to 5% and then increased significantly to 53% after the onset of COVID-19. These findings are consistent with farmers' perception of changes to their food security (Table A3). At the end of TISA I, 67% of households perceived that their household's food security had improved over the last four years. This trend continued during TISA II, with 85% of farmers perceiving improved or stable household food security before COVID-19. This reflects improved farm production and household income. However, 55% of households experienced a decline in food security following the onset of COVID-19, which was probably due to the decline in farm and off-farm income (Table A3).

Similar trends can be observed when it comes to farmers' perceptions of the health of their household and their capacity to pay for their children's education. A large proportion of farmers (61%) perceived improved capacity to pay for their children's education during TISA I. This capacity continued to improve and then stabilized, with a large proportion (45%) experiencing a decline in their capacity to pay after the onset of COVID-19. The trend in the perceived health of their family was identical to that experienced for capacity to pay for children's education until the onset of COVID-19. However, farmers did not perceive the same drop in their health, with most (72%) reporting it to remain unchanged. This could indicate that health is considered of primary importance.

These findings suggest that TISA interventions have significantly improved households' ability to pay for critical components of their livelihood. Further, they have retained and built on these improvements after the end of TISA I when the level of intensity of TISA project staff engagement reduced significantly.

Table 7. Changes in households' perceived farm and off-farm income from 2014 to 2021 (data source: surveys).

	2014–17 (%)	2017–20 (%)	2020–21 (%)
How would you rate your off-farm income:			
Much worse	10	0	8
Worse	15	18	15
The same	15	78	73
Better	55	5	5
Much better	5	0	0
How would you rate your farm income:			
Much worse	–	3	8
Worse	11	33	58
The same	7	30	33
Better	62	30	0
Much better	21	5	3

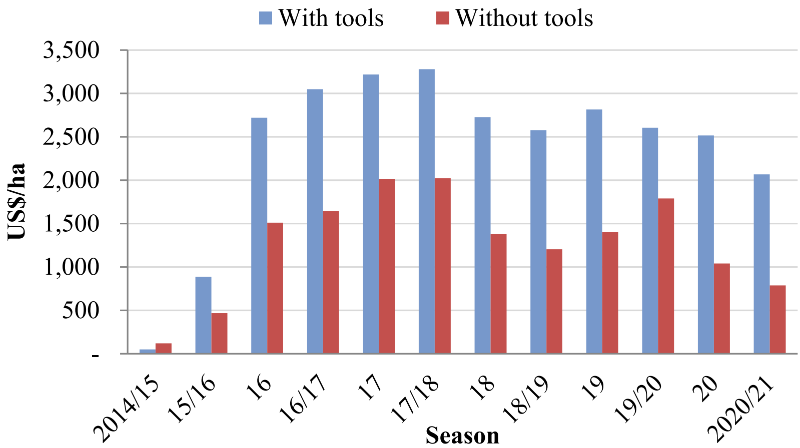


Figure 5. Green maize gross margins per hectare for farmers at 25 de Setembro with and without soil monitoring tools from season 2014/2015 to 2020/2021. Data: Based on analysis of real time observations in farmers field books and computed with extension officer during end of season workshops.

Impacts in the community/scheme domain

The reduction in water use during TISA I (Chilundo et al., 2020) is likely to have caused the perception of increased equity in water allocation (2014–17) and increased reliability of water supply after 2017, even after the onset of COVID-19 (Table A4). These changes in perception of water supply, combined with increases in household income, are likely to have caused the increased willingness to participate in scheme maintenance and pay water fees. The willingness to collaborate was not only maintained but continued to increase for some time during TISA II, confirming a sustained impact. As more experienced farmers began to provide mentorship to new and younger farmers joining the scheme, the community was further strengthened, and a supportive environment was fostered (FGD; Table A1). The increase in trust and willingness to collaborate were essential in building social capital, enhancing adaptive capacity, and reducing conflicts (Table A5). At the governance level, the AIP took proactive steps to optimize land use through activation of unused plots and by identifying nearby dryland that could be irrigated. This led to collaboration between the SDAE, District Farmers Union and Farmers Association to reallocate land to young farmers (Chilundo et al., 2020).

Impact on disadvantaged groups

Two initiatives were made to make plots available for young people. The AIP, through the collaborative mapping process, identified four hectares of unused land within the scheme. After a plenary discussion among the scheme community, two additional hectares were identified that could potentially be irrigated (Chilundo et al., 2020). These areas were then allocated to the youth (eight women and five men). Under both initiatives, the young farmers were linked up with an experienced farmer as a mentor. This allowed 13 young farmers to start irrigated farming. Of these, seven took up the four hectares of unused land already connected to the scheme infrastructure, while the other six were accommodated on the additional two hectares not connected to the scheme infrastructure. These farmers were able to attract microfinance to support their purchase of a pump to bring water to the highest point and from there apply water to their fields by gravity using pipes and furrow irrigation (FO and FGDs).

The impact of the TISA interventions differed markedly between men and women farmers. For overall production decision making (decisions about dryland and irrigation crops, cattle and small stock, for example, Parry et al. (2024) report an increase in female household members making decisions and a decrease for males between 2016/17 and 2020/21: from 20% to 37% for females; and from 28% to 20% for males. Additionally, women have been equally active in participating in community activities and have a strong role in accessing farming information (Parry et al., 2024). This suggests that women have increased their role in production decisions.

The proportion of households reporting that female household members made the decisions about cattle farming increased from 14% in 2016/17 to 38% in 2020/21, joint decision making increased from 14% to 33%, and the proportion reporting that decisions were made by males decreased from 71% in 2013/14 to 28% in 2020/21 (Parry et al., 2024). This suggests a significant shift from male to joint and female decision making. This change is interesting as cattle keeping has been mostly male-dominated in Mozambique (Porsani et al., 2020). Similarly, for small livestock keeping, the percentage of female farmers making decisions increased from 8% in 2016/17 to 33% in 2020/21. For decisions about household expenditure, more than half of households reported these decisions were made by female household members.

Impact of COVID-19

Analysing the COVID-19 pandemic's impact on households provides insights into their resilience to shocks. Comparing the impact of COVID-19 on TISA schemes with non-TISA schemes demonstrates how improved water management, crop productivity, and market and community linkages can improve adaptive capacity to shocks.

A much higher proportion of farmers at 25 de Setembro reported that COVID-19 restrictions had no impact than those in the non-TISA scheme (43% versus 21%) (Table A6). Additionally, a much higher proportion of farmers from the non-TISA scheme reported moderate to severe negative impacts than farmers within the TISA scheme (48% versus 25%). This suggests that agricultural and social systems in the farm, household, and community domains were better able to adapt to shocks at the TISA schemes.

The specific impacts of COVID-19 restrictions on farming operations also differed between TISA and non-TISA schemes. Overall, more farmers within the non-TISA scheme reported they were affected by access to input (58% versus 23%) and output markets (38% versus 15%) and access to labour (16% versus 10%) (Table A6). This suggests that improved market linkages through the AIP process improved resilience to market shocks. The TISA farmers reported marginally greater impact from restrictions in the areas of access to information and finance institutions. This suggests that the TISA interventions have created increased demand for and access to quality information and finance through increased extension services, workshops, demonstration plots and access to finance for inputs.

Overall, the findings related to the impact of COVID-19 restrictions, suggest that farmers at the 25 de Setembro scheme were better able to adapt to the shocks brought about by the pandemic. This was due to stronger market and community linkages. We speculate that this adaptive capacity should translate into improved resilience to climate change. The ability of the TISA approach to cope with the COVID-19 shock is investigated further in Bjornlund et al. (2024).

Impacts in the market domain

The aim of the AIP interventions was to strengthen linkages between supply chain actors and farmers to improve the buying and selling processes within the agricultural system. The AIP took several steps in this regard. Importantly, it facilitated a farmer agreement that farmers would only accept to sell green maize within certain price ranges. Meetings held between 25 de Setembro's Farmer Association and representatives of TECAP enabled the joint design of a strategic model that facilitated access to certified agricultural inputs within the irrigation scheme through a TECAP mobile store. The farmers collectively bought certified inputs (e.g., seeds, fertilizer and pesticides) and had access to free technical assistance at the same price as in the city and with no added transport cost. This arrangement reduced spending on transport and the time required to visit a physical store, further illustrating the positive impact of AIP interventions on the agricultural supply chain.

The adoption of new crops and improved farming practices initiated by the AIP increased the demand for specific and higher-quality inputs. While these improved practices are beneficial, it made inputs more expensive and difficult to access, with COVID-19 movement restrictions further complicating access to input and output markets. Reflecting this, 43% of farmers reported input prices had increased during TISA II and before the onset of COVID-19 (Table A2). Farmers reported that their ability to afford the increases in input prices were exacerbated by a perceived reduction in output prices, with 42% of farmers reporting output prices decreased during TISA II both before and during COVID-19.

In TISA I, AIP activities led to a noticeable increase in both buyers of farm produce and sellers of agricultural inputs (such as seeds, fertilizers, and pesticides). Hence, 86% of farmers perceived an expansion in the range of input sellers (Table A2). The increased availability of inputs resulted in 67% of farmers reporting that the buying process had become easier during TISA I. However, this changed during TISA II. While 43% of farmers still observed an increase in the range of input sellers, 48% either reported a stable or decreasing range of input sellers.

These changes in input/output price and supply/demand dynamics contributed to the challenges farmers faced in accessing inputs for their farming activities. Despite the new mobile input shop that became available during TISA II, 55% perceived that the buying process had become more difficult. This increased to 67% after the onset of COVID-19.

Discussion

This study finds that social institutions such as AIPs can facilitate the development of climate-smart agriculture for smallholders by identifying local knowledge and adaptation experiences in a participatory manner, which is consistent with Müller et al. (2018) and Zeleke et al. (2022). Participatory learning and innovation interventions introduced by the

AIP, such as collaborative mapping, played a pivotal role in producing positive outcomes, reducing conflict among farmers over access to land and water resources.

Prior to the TISA interventions in the 25 de Setembro scheme, there were several uncertainties and conflicts over access to land, especially for young male and female farmers (de Sousa et al., 2017). We argue that the collaborative mapping process and the allocation of vacant plots to young farmers will have a profound impact on the operation of the irrigation scheme and help ensure its long-term sustainability. By reducing conflicts and establishing clearer land access, the scheme's overall governance was strengthened, leading to more efficient and coordinated use of resources. The introduction of young farmers, supported by mentoring from experienced members, ensured the sustainability of operations. This collaborative approach fostered a more cohesive community, improving water management practices and enhancing the overall productivity of the irrigation scheme. These efforts significantly enhanced access to land and increased social capital, both of which have been found to bolster farmers' resilience and ability to adapt to climate change (Childress et al., 2022; Nyanga et al., 2011; Shikwambana & Ntokozo, 2022; Smit & Skinner, 2002) .

Training in business plan development, gross margin computation, demonstration plots and improved market linkages, were also identified by farmers as contributing positively to improved crop selection, increased yields, gross margins and household income, which improved the capacity of farmers to pay for farm inputs, food, education and health. These findings are consistent with the literature, which argues that access to training, extension services and accessible technology are key pillars supporting farmers to access information and knowledge on different strategies for climate change adaptation (Hassan & Nhemachena, 2008; Tangonyire & Akuriba, 2021). The positive outcomes related to food, education and health are also critical outcomes, as better nutrition and health increases households' capacity to work and children's capacity to learn, and more education paves the way for improved livelihoods and resilience (Chilundo et al., 2020).

The results underscore the positive influence of TISA's institutional and technological interventions on farmers' capacity to adapt to changing market demands; thereby, enhancing their overall resilience. The increased level of trust and willingness to cooperate is exemplified by farmers collectively agreeing on the selling price of their produce and purchasing of farm inputs, and preventing individual farmers from accepting lower prices from buyers. By fostering better relationships between value chain actors and farmers and increasing information flow, the AIP process has empowered farmers to adapt, which has been found to be critical factor in building resilience to economic, environmental, and external shocks (Kandlikar & Risbey, 2000). These improved relationships have played a pivotal role in achieving enhanced productivity, diversification and therefore resilience across the farm, household, community and market domains. This paper therefore argues that these systemic changes have enabled improvements in the capacity to adapt to climate change to extend beyond the farm and irrigation scheme domains.

The incorporation of soil moisture and nutrient monitoring tools into farmers' irrigation decision making, combined with the infrastructure improvements, has contributed to a reduction of irrigation frequency and duration, leading to a reduction in water use and nutrient leaching. This has translated into increased yields, which combined with reduced water use has increased water productivity, reduced labour, fuel costs and conflicts over water use, and increased off-farm income. Given households have more time available, this can be used for other activities, such as secondary employment, skills development or entrepreneurial ventures. These technological enhancements illustrate the positive impact of adopting advanced practices in agriculture. Nevertheless, and consistent with Toole and Baum (2019), technology adoption alone will not secure the sustainable benefits. The positive outcomes should be viewed in the context of the holistic activities initiated by the AIP.

Notably, the positive changes reported in the scheme during TISA I have proven to be sustained and ongoing during TISA II. This highlights that in the context of the AIP, farmers can sustain meaningful changes in their practices, even with reduced involvement from TISA staff. Such sustainable practices have intensified agriculture and enhanced irrigation practices, contributing collectively to increased food production with reduced water application. As suggested by Cassman (1999), these improvements bolster farmers' resilience to climate change.

In response to improved market information flow, farmers have increased their market engagement and responded by growing new and higher value crops, which enhanced overall food value chain resilience. This demonstrates farmers' ability and willingness to adapt and their ability to manage the risk associated with shocks to their production systems, such as those caused by COVID-19 and climate change. This is consistent with findings by Hassan and Nhemachena (2008) and Labeyrie et al. (2021). In addition, farmers have been able to increase their off-farm income and thereby diversify their income stream due to the time saved irrigating. Diversification of household income through low climate-risk income sources has been associated with increased overall household income and resilience (Manero, 2017). This aligns with findings in Nicaragua, where income diversification beyond agriculture led to increased income, consumption and protection from shocks (Toole & Baum, 2019).

Access to resources and social capital has been widely recognised as enhancing household resilience and adaptive capacity to external shocks, including the COVID-19 pandemic (Egamberdiev et al., 2023). Households in the 25 de Setembro scheme reported less severe impacts from COVID-19 restrictions compared to non-TISA farmers. This highlights their improved capacity to respond and adapt to shocks, and this paper argues this includes shocks stemming from climate change. However, it is important to note that differences in plot sizes and household composition between the two schemes may also have influenced these outcomes.

These findings suggest that the TISA interventions have significantly contributed to the implementation of government strategies for climate change adaptation, including the National Strategy for Adaptation and Mitigation of Climate Change (MICOA, 2013). This study demonstrates that TISA's key outcomes respond directly to the identified strategies, including the need for improved water resources management, better water distribution, increased agricultural sector resilience, and the promotion of low carbon emissions through energy-efficient agricultural activities.

While this study touched on many governance issues, it did not provide a comprehensive analysis of the role of governance in improving the adaptive capacity of small-scale irrigation schemes, which was outside the scope of this study. We therefore recommend further studies into this important aspect of improving the adaptive capacity to climate change.

Conclusions

TISA's multi-faceted interventions have delivered substantial benefits to smallholder farmers in four domains of adaptation: farm, household, community/scheme, and markets. Smallholder farmers and their households have significantly improved their resilience and hence their capacity to adapt to climate change. Relationships, trust and information flows have improved between households and between value chain actors, with farmers diversifying and being better able to adapt to changing market demands.

The AIPs activities brought significant positive changes for farmers. Collaborative efforts, like mapping and training, empowered farmers, boosting their understanding of land and water use. These changes enhanced trust among farmers, reduced conflicts, improved social bonds and increased farmers' willingness to engage in collective actions. A key lesson was that involving farmers in decision making processes and enabling them to share experiences led to remarkable progress.

Incorporating advanced tools for soil and water monitoring led to farmers learning about soil moisture and nutrient dynamics, which helped them use resources more efficiently and reduced water usage and increased yields; thereby, improving water productivity. This technology, combined with market insights and improved linkages, enabled farmers to adapt to changing demands. The AIP approach not only increased agricultural productivity and profitability, but also diversified income sources. This enhanced overall household wellbeing and highlights the critical link between profitability, resilience, adaptive capacity and sustainability.

Despite challenges like the COVID-19 pandemic, farmers in the programme demonstrated remarkable adaptability and resilience suggesting an increased ability to bounce back after encountering shocks such as COVID-19. This paper argues that this extends to other shocks such as climate change. The AIP's impact extended beyond individual farms, creating stronger community ties and enhancing the entire agricultural system's resilience. The success of the project was not just about introducing new technology; it was about building lasting relationships, facilitating knowledge exchange, and fostering a sense of community ownership.

The outcomes align with broader climate change adaptation strategies and support the implementation of the Mozambican Strategy for Adaptation and Mitigation of Climate Change. The study suggests that prioritising participatory interventions at the local level can realise benefits beyond the point of intervention and help the government improve smallholders' capacity to respond to shocks, achieve critical development goals (food security, poverty reduction and agricultural sustainability), and contribute to international climate change obligations. The study also emphasizes the need to shift some of the current research and development focus on yield increases to developing ways of improving smallholders' profitability.

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