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India's depleting groundwater: When science meets policy

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Abstract

A commonly applied policy to India's ongoing depletion of groundwater is feeder separation. Introduced in Gujarat as the Jyotigram Yojana (JGY) scheme, it provides a separate and rationed electricity supply to farmers and an unrationed power supply to non-agricultural users. JGY is claimed to increase groundwater storage. By using Gujarat district-level data from 1996 to 2011 and by separately applying difference-in-differences and Bayesian regressions, we find that groundwater storage has continued to *decrease* with JGY. We contend that our empirical results show that JGY has been implemented without adequate consideration of (1) a publication bias whereby researchers have a greater likelihood of having their results published if they are statistically significant and show a positive outcome and (2) a 'barrier' effect such that communicating evidence across science and policy divides means that evidence may not be accepted, even when true, and this limits policy advice and options.

KEYWORDS

Bayesian regression, difference in differences, disciplinary divides, energy-water nexus, groundwater, Jyotigram Yojana

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As scientific facts become more important in public policy, democracy has become more dependent on scientists for factual information. This vulnerability has made publicizing tortured versions of facts a favorite tactic for influencing policy. (Kantrowitz, 1993, p. 102)

1 | INTRODUCTION

More than half of India's total area suffers from high baseline water stress (India Water Tool, 2017) and very low water storage (including reservoirs and groundwater) per capita (Subhadra, 2015). India uses some 230 km^3 of groundwater per year, making it the world's largest user of groundwater (World Bank, 2012). In India, about 90% of the groundwater extracted is used by irrigation—a much higher proportion than the global average of some 40% (Siebert et al., 2010).

Overall, some 60% of the irrigated land in India is supported primarily by groundwater supplies, and approximately 90 million rural households are directly dependent on groundwater irrigation (World Bank, 2012; Zaveri et al., 2016). Importantly, more than 80% of the addition to net irrigated area in India since the Green Revolution has been supported by groundwater use (World Bank, 2010b) whereas the area in South Asia equipped for irrigation has tripled since 1950 (Siebert et al., 2015).

The increased use of groundwater for agriculture has been supported by supply-driven policies that provide farmers free or heavily subsidized grid electricity and pumps (Dubash, 2007; Shah, 2014; Zaveri et al., 2016). This is contributing to an unfolding water crisis (Biswas & Hartley, 2017) from the depletion of groundwater sources (World Bank, 2010b). Groundwater development (GWD), the ratio of the annual groundwater extraction to the net annual groundwater availability from recharge (a higher ratio means greater extraction), for all of India, increased from 58% in 2004 to 62% in 2011 (Suhag, 2016). Decadal fluctuation in groundwater level for all of India between 2001 and 2011 reveals that groundwater level declined in 42% of observation wells with 7% wells showing a fall of between 2 and 4 m and nearly 5% wells showing a fall of less than 4 m (Central Ground Water Board, 2011). Satellite-based estimates of groundwater (Rodell, Velicogna, & Famiglietti, 2009) from three states of India—Rajasthan, Punjab, and Haryana (including Delhi)—show that irrigation may have contributed to about half of India's annual groundwater extraction between August 2002 and October 2008.

Groundwater regulation in India operates through state-level policies with states adopting different strategies and combinations of instruments (Narasimhan, 2008; Shah, 2014). The federal government affects groundwater regulations through the promotion of "Model" forms of groundwater regulation that operate both on the demand and on the supply side (Birkenholtz, 2017; Foster, Tuinhof, Kemper, Garduño, & Nanni, 2003). On the demand side, direct state regulation includes mandatory registration of bore-well owners, permission for sinking new bore wells, restriction on the depth of bore wells, and establishment of protection zones (India Water Portal, 2017). These direct regulations are administratively difficult to monitor and remain weakly implemented or unenforced in several states (Shah, 2014). Direct groundwater regulation also includes promoting water-saving agricultural technologies and community management of groundwater (Kumar, 2000; Narayanamoorthy, 2004).

On the supply side, groundwater policy measures have included constructing groundwater recharge structures and also making surface irrigation more accessible (Foster et al., 2003). Although many demand and supply-side approaches have been applied to respond to this groundwater crisis (Shah, 2005), and some such as groundwater recharge and community-managed projects have potential (World Bank, 2010b), there continues to be serious and substantial ongoing groundwater depletion across India.

1.1 | Indian groundwater-energy nexus

In 2013, agriculture was estimated to consume 18% of the power generated in India (International Energy Agency, 2015, p. 84), and the estimate for 2015–2016 was 17% (Ministry of Statistics and Programme Implementation, 2017, p. 43). Over the period 2000–2013, estimated agricultural power demand almost doubled from 84.7 terawatt hours (TWh) to 152.7 TWh (IEA, 2015; Indiastat, 2018, p. 84). Agriculture, however, contributes a much lower proportion of the revenues to electric utilities (Ghosh & Agrawal, 2015) than the power it consumes because of longstanding policies to subsidize the price of electricity to farmers (World Bank, 2001). Power subsidies persist because charging a tariff to farmers is politically unpopular in India (Chindarkar, 2017; Mukherji et al., 2009).

An energy policy implemented since 2001 in India is the separation of agricultural and non-agricultural power uses in rural areas combined with restrictions as to when, and for how long, electricity is supplied to farms. The key objective of this policy is to increase the level of rural electrification: Some 220 million Indians in rural areas lacked access to power in 2013 (IEA, 2015, p. 29). This feeder separation policy has been implemented in several Indian states (World Bank, 2013) including Andhra Pradesh, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Punjab, and Rajasthan, combining a population of about half a billion people.

1.2 | Gujarat and Jyotigram Yojana (JGY)

Gujarat, with a population of 66 million in 2016, was the first state in India to implement feeder separation and farm power rationing. The state contributes about 7% of India's gross domestic product (Government of Gujarat, 2015) and has one of the highest rates of electricity access, at 94% in 2013 (IEA, 2015). Much of the state falls under arid, semi-arid, and dry subhumid climatic zones, and it receives an average rainfall between 500 and 1,200 mm across its various climatic zones (Government of Gujarat, 2013). Geographic conditions, and poor access to alternate irrigation sources and technologies, have led to farmers in the state to rely heavily on groundwater for irrigation.

In 2004, the state-wide average GWD in Gujarat was 76%, substantially higher than the national average of 58% (Suhag, 2016). In the same year, around half the districts in the state were declared as being over exploited (less than 100% GWD), critical (90–100% GWD), or semicritical (70–90% GWD) in terms of groundwater extraction (Central Ground Water Board, 2004).

It is estimated that around 70% of groundwater extraction in Gujarat occurs from electric-powered farm tube wells (Shah, Bhatt, Shah, & Talati, 2008). The unsustainable use of groundwater accompanied with poor electricity access in rural areas and weak financial condition of the state electricity board, prompted state policymakers to introduce the “Jyotigram Yojana” or “lighted village scheme” in October 2003. This scheme was fully implemented in the state by March 2008.

JGY involves the physical separation of the agricultural and non-agricultural electricity feeders through installation of specially designed transformers, high-tension lines, low-tension lines, electricity poles, electricity conductors, and polyvinyl chloride cables. As part of the JGY policy, farm electricity supply has been rationed to 8 hr/day according to a predetermined schedule, which is adjusted for peak periods of moisture stress (Shah et al., 2008).

Farm electricity rationing under JGY only involves restricting hours of supply. JGY provides high-quality power (supporting three-phase or 415 V electricity supply with limited variability in voltage and frequency) to farms, which is necessary to operate large electric groundwater pumps. Prior to implementation of JGY, nearly 80% of the population in Gujarat had at least some access to electricity, and there was no limit imposed on hours of farm electricity supply (Census of India, 2001; Chindarkar, 2017). Thus, before JGY, farmers did not have restrictions on hours of supply although they did suffer from the poor quality of the power supplied that included frequent power outages and voltage fluctuations. In turn, these power fluctuations caused damage to pump motors and added to farmers' repair and maintenance costs (Shah et al., 2008). Importantly, during JGY implementation (October 2003 to March 2008), there were no substantial increases in farm electricity tariffs (Chindarkar, 2017; Zilberman, Sproul, Rajagopal, Sexton, & Hellegers, 2008).

1.3 | Gujarat's JGY and groundwater extractions

Evidence of the effect of JGY on groundwater extraction is mixed. Studies based on descriptive analyses claim that JGY has reduced groundwater extraction because of an estimated 37% decline in the use of farm electricity to power tube wells (Mukherji, Shah, & Verma, 2010; Scott & Shah, 2004; Shah et al., 2008). Most recently, Bhanja et al. (2017) claim that reductions in the agricultural power consumption between 2001 and 2016 in Gujarat are associated with an *increase* in groundwater storage under the untested assumption that groundwater extraction is directly proportional to electricity usage in agriculture.

In a rebuttal to Bhanja et al. (2017) and Kumar and Perry (2017) outline uncertainties in relation to the finding that JGY increases groundwater storage and refer to Dave, James, and Ray (2017) who provide evidence of an increasing and significant (99.9% level) trend in monsoon rainfall in Gujarat equal to, on average, some 44 mm per decade over the past century. Here, using district-level data from Gujarat, we calculated that mean rainfall for all districts in Gujarat increased, on average, some 20% from before JGY implementation to post-JGY (see Section 2, Data S1). Kumar and Perry further observe there has been an increase in the groundwater-irrigated area in Gujarat since 2001 and a rise in electricity consumption in agriculture since 2006. Both of these trends are at odds with the prediction of Bhanja et al. that JGY, coupled with other policies, will "… probably start replenishing the aquifers by increasing groundwater storage in near future".

Rather than assume relationships with respect to state-level trends of agricultural power use or make simple comparisons between groundwater storage at different time periods, we utilized data on well observations, aggregated to the district level, to empirically test the effects of JGY on groundwater storage in Gujarat. We employed two different methods. We first undertook a difference-in-differences (DiD) analysis to empirically test the effect of JGY on groundwater storage, as measured by the depth or distance from the soil surface to

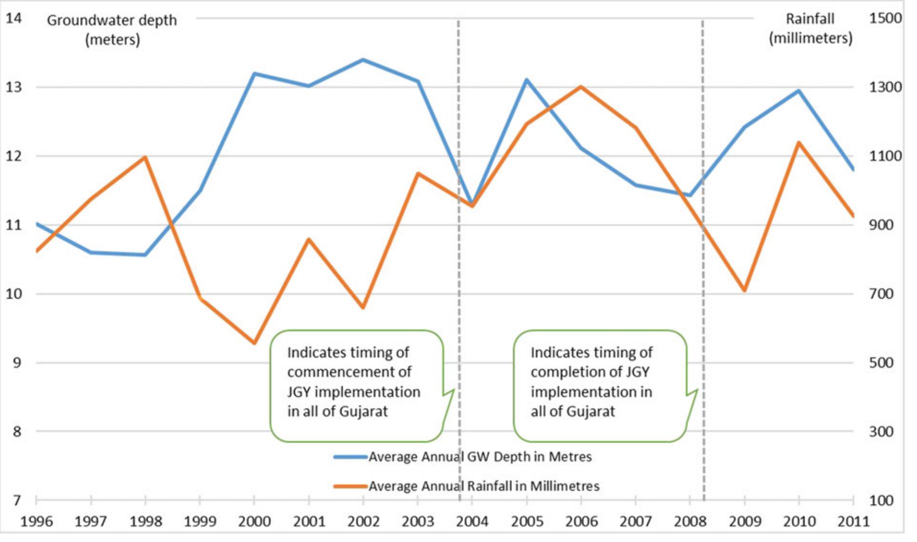

FIGURE 1 Trend of average annual depth to groundwater and rainfall in Gujarat from 1996 to 2011. JGY: Jyotigram Yojana

Source: Authors' analysis using depth to groundwater data from India-WRIS, administrative data on JGY implementation and rainfall data from ICRISAT VDSA

the groundwater aquifer.[1] We then separately estimated, using Bayesian methods, whether district-level implementation of JGY determines groundwater storage.

Figure 1 presents average annual depth to groundwater for all of Gujarat from 1996 to 2011. It indicates an increase in the depth from the soil surface to groundwater (decline in groundwater accessibility) until 2004 and, thereafter, a variable trend. While the depth from the soil surface to groundwater decline is coincident with the introduction of JGY, this trend was not sustained and the depth from the soil surface to groundwater *increased* from 2008 to 2010, about 2 years after JGY was fully implemented in Gujarat.

The causal impact of JGY on groundwater depth cannot be identified by correlations or trend analysis alone nor by the untested assumption of direct proportionality between groundwater extractions and electricity use. Here, and as far as we are aware, we are the first to empirically test for the possible effects of JGY on district-level average annual groundwater depth in Gujarat using either multivariate causal models or Bayesian methods.

1.4 | When science meets policy

A common presumption among researchers is that new scientific evidence, as soon as it has been properly explained to and understood by policymakers, will then contribute to better decision-making (Brooks, 1964). This is a “knowledge deficit” model whereby greater knowledge and scientific literacy by decision-makers and the public will result in better decisions

[1]An *increase* in depth to groundwater therefore reflects a *decline* in groundwater level and vice versa.

and outcomes (Scheufele, 2014). This description of the science-policy interface can also be characterized as the "linear model" whereby scientific discovery, application, and then societal benefit follow the use and insights from scientific advances.

The reality is that when scientific evidence is used by decision-makers to make a choice between competing actions, the decisions are not simply based on facts (Sarewitz, 2004). Indeed, policymaking is, typically, more of a values-driven than a science-driven process (Pielke, 2007). This does not necessarily result in poor policies, but it does mean that the role of science is, typically, subsidiary to values and interests in policymaking. Further, science can serve a political purpose even when the scientific evidence is provided honestly and competently (Fischhoff & Scheufele, 2013).

Science and its communication is complex. In part, this is because there can be large discrepancies between peer-reviewed studies that may even span orders of magnitudes. As a result, very different and even opposite policy decisions can be supported by different science-based evidence (Stirling, 2010). Thus, if there is divergence over the facts, it is difficult to have a good decision-making process (Dietz, 2013).

Overlaying the challenge of effectively communicating science is what facts are reported and used by decision-makers (Dietz, 2013). This is exacerbated by the problem of "publication bias" (Dickersin, 1990). This bias occurs because researchers have a greater likelihood of submitting results for publication and of having these results published, if they are statistically significant and show a positive outcome of a treatment effect than when results are statistically insignificant and/or with a negative or null treatment effect (Hopewell, Loudon, Clarke, Oxman, & Dickersin, 2009). The publication bias arises, in part, because of how statistical results are reported and because there is insufficient replication of existing studies to confirm positive findings are not random (Prinz, Schlange, & Asadullah, 2011).

A publication bias effect exists in many disciplines (Ioannidis, 2005) and even in the world's most prestigious journals (*Nature* and *Science*). Indeed, based on an interpretation of findings from multiple disciplines, the lower and upper bound for the average reproducibility of results could be between 35% and 75% (Camerer et al., 2018). The implications of this bias for Indian groundwater policy is that statistically significant results, especially those that support existing policies but are not replicated, need to be treated with caution. At the very least, it demands an acknowledgement of the scientific uncertainties and the need for ongoing replication of results reported to be statistically significant.

Another effect that challenges effective science-policy interface is barriers to communication between scientists and policymakers (Pielke, 2007), and also across disciplines (*barrier effect*). These barriers include differences in language and terminology, interpretation of results, scale of effects, and methods of analysis (Grafton & Robin, 2005, p. 194). Disciplinary distance can mean that evidence from one domain is overlooked, ignored, or dismissed in other domains (Simis, Madden, Cacciatore, & Yeo, 2016). A consequence is that evidence becomes "compartmentalized" with relatively few links across disciplinary divides. In the context of Indian groundwater policy, the barrier effect may mean that evidence based on causal statistical models that are widely employed in the social sciences are not viewed as acceptable evidence by a hydrogeologist whose preferred source of evidence is, say, remote sensing data. Thus, rather than "opening" the policy discussion over what are the facts and developing pluralistic policy advice (Stirling, 2010), a requirement for mitigating complex problems and even "wicked" problems (Grafton, 2017), the barrier effect tends to narrow policy options (Pielke, 2007).

2 | METHODS

We constructed panel data over a 16-year period from 1996 to 2011 from 18 districts in Gujarat. A district is the administrative unit below the state. Data on implementation of JGY were obtained from the public electricity distribution companies in Gujarat under the *Right to Information Act of India*, 2005. The administrative data enabled us to identify the year in which JGY was implemented in a particular district. Groundwater, rainfall, temperature, and agricultural data were extracted from publicly accessible sources. Groundwater depth data were sourced from the Water Resources Information System of India (India-WRIS) maintained by the Central Ground Water Board (2017). Agricultural and rainfall data were sourced from the Village Dynamics in South Asia surveys conducted by the International Crops Research Institute for the Semi-Arid Tropics (2015). Temperature data were extracted from the University of East Anglia Climatic Research Unit, et al. (2017).

We applied two different empirical approaches to test for the effect of JGY on groundwater depth in Gujarat. The first approach we employed was DiD that has been widely applied in "before and after" studies across different disciplines. It employs the frequentist approach when testing whether or not there is a statistically significant causal relationship in the data. Thus, in this approach, whether or not JGY affects groundwater depth is determined by the size, sign, statistical significance, and robustness of the estimated coefficient in relation to the JGY policy.

The second approach we employed is Bayesian estimation that, unlike classical statistics, begins with a prior, that is, the probability of JGY implementation and then estimates a posterior distribution using observed data. The posterior estimates, in turn, provide evidence as to whether the data are sufficiently influential to change beliefs about the relationship between JGY and groundwater depth.

A critique of the frequentist approach employed in DiD is that the test of significance for post-JGY is premised on the null hypothesis (Ho: post-JGY there is no change in trend of groundwater depth between treatment and control districts) being true. A common misunderstanding for a variable found to be statistically significant at the 5% level of significance ($p < 0.05$) is that this means there is only a 5% probability the null hypothesis is true conditional on observed data, which can be expressed as Pr (Ho|data). In fact, it means that *only when the null hypothesis is true*, there is a 5% probability that if two samples of a given size were drawn randomly from the same population, the statistical test would have yielded a statistic as large or larger than the one estimated conditional on observed data, which can be expressed as Pr (≥data|Ho). As shown by (R. A. J. Matthews, 2001, p. 46) for a p value of 0.05 to be interpreted as Pr (Ho|data) requires, under the assumption of normality, that there must be a prior belief that the probability of the null hypothesis being true is 10% (or probability null is not true is 90%). If the prior belief that the null hypothesis is true were to be 50%, under the assumption of normality, then Pr (Ho|data) is at least 0.22, and not 0.05 as is commonly interpreted (Berger & Sellke, 1987, p. 113).

The challenge of the frequentist approach is that, depending on the randomness of the data, the number of observations, data sampling, the nature of the null hypothesis, among other factors, a p value at or more significant than the standard level of significance (5%) may not be an acceptable level of scientific "proof" of a statistically significant effect. Indeed, physics journals accept statistical evidence for a "discovery" only when a variable's p value is more than 10,000 times more significant than the standard 5% level of significance used in most academic disciplines (R. Matthews, 2016, p. 175). Recognizing this potential "positive" bias in our own DiD results if we only focus on the p value of the post-JGY variable, we also employed a Bayesian regression approach.

In both the DiD and Bayesian approaches, we exploited the variation in the timing of JGY implementation across the 18 districts to test whether JGY influences groundwater depth. Here, "JGY implementation" refers to the proportion of villages that completed feeder separation in a given district in a given year and, in our hypothesis, is the key independent variable. The outcome or dependent variable is the average annual groundwater level (depth from soil surface to groundwater), in meters, at the district level. If there were to be a relationship between JGY implementation and groundwater depth, it can only be unidirectional (JGY causes groundwater depth and not groundwater depth causes JGY) because district electrification was implemented independently of the groundwater depth in each district.

The treatment or policy variable in the DiD estimation is "post-JGY" that equals 1 for the year in which JGY is fully implemented (100% of the villages are covered) in a district and for each subsequent year thereafter. The causal effect was identified from the difference (or change) over time in groundwater depth between districts that implemented JGY earlier (treatment districts) and those that implemented it later (control districts). The DiD estimated equation is provided in Equation (1) below.

$$
\begin{aligned}
Y_{dt} = {} & \alpha_0 + \alpha_1 PostJGY_{dt} + \alpha_2 \ln(TotalCA_{dt}) + \alpha_3 \ln(Rainfall_{dt}) + \alpha_4 \ln(MinTemperature_{dt}) \\
& + \alpha_5 \ln(MaxTemperature_{dt}) + \alpha_6 \ln(RoadLength_{dt}) + D_d + T_t + \varepsilon_{dt},
\end{aligned} \tag{1}
$$

where Y_{dt} is average annual depth to groundwater in district d in year t. $PostJGY_{dt}$ is a dummy, which equals 1 for t in the year of full implementation of JGY in district d and for each subsequent year. A positive coefficient on $PostJGY_{dt}$ would be interpreted as *decreasing* groundwater storage as it measures depth to groundwater. $TotalCA_{dt}$ is the total cultivated area under all crops; $Rainfall_{dt}$ is average annual rainfall; $MinTemperature_{dt}$ and $MaxTemperature_{dt}$ are, respectively, the average annual minimum and maximum temperatures, and $RoadLength_{dt}$ is road length. D_d and T_t are district and year fixed effects whereas ε_{dt} is the error term.

The challenge with Bayesian estimation is the determination of the prior because the choice of the prior affects the posterior estimates. Here, we selected the prior as the mean JGY implementation in all of Gujarat, that is, the proportion of villages that implemented JGY across all 18 districts. This prior varies over time: Until 2002, no districts had implemented JGY (prior = 0.0), and by 2008 all, districts had implemented JGY (prior = 1.0). These priors were chosen because (a) they are based on observed data rather than uninformed priors and (b) the empirical investigation is about whether JGY affects groundwater depth.

For the posterior estimation, we progressively updated our prior and used observed data from subsequent years. For instance, when the prior was the probability of JGY implementation, based on mean JGY implementation in 1996, we used data from 1997 to 2011 for the posterior estimation. Similarly, when the prior was the probability of JGY implementation, based on mean JGY implementation in 1997, we used data from 1998 to 2011 for the posterior estimation and so on. Although the posterior estimate and its credible interval[2] from each model are important, of greater relevance is whether an increase in the probability of the JGY implementation increases groundwater depth subsequent to estimation using observed data. In this case, we judged JGY to determine groundwater depth by comparing posterior estimates from models with increasing probability of JGY implementation.

[2]Credible interval and confidence interval have different interpretations. In Bayesian estimation, a parameter value is, typically, considered *not* to be credible if it lies outside the highest density interval that spans 95% of the posterior distribution.

Other factors may also affect groundwater depth. Thus, we controlled for the confounding effects of average annual rainfall (in millimetres); average annual maximum and minimum temperature (in degree Celsius); and total cultivated area (in ′000 hectares). We also controlled for the natural logarithm of the length of road (in kilometres) in each district to proxy for the general level of economic development and population growth (the Census is the only source that provides district-level population figures, but only 2 years of census data overlap with our time period of study, the years 2001 and 2011) that may have affected the speed of JGY implementation in a district.[3] In the DiD estimation, unobserved factors common to all districts in a given year were also controlled for through the use of year and district-level fixed effects. These unobserved factors may include changes in state-level agricultural or energy policies and unobserved factors that may vary across districts but remain the same for a given district over time such as soil type and the location, gradient, and structure of the aquifer.[4] In the Bayesian estimation, the priors for all the control variables were chosen using the same informed prior approach as the JGY implementation variable.

An expanded description of the methods used, including tests of robustness, is provided in Data S1 whereas summary statistics for all model variables are summarized in Data S1.

3 | RESULTS

The DiD estimates of the impact of JGY on groundwater level are presented in Table 1. On average, our estimates show that, post-JGY, the depth to access groundwater *increased* by approximately 3 m ($p < 0.05$) relative to the level prior to JGY implementation.[5] We also checked whether groundwater depletion was greater in districts with high GWD. The second column in Table 1 presents heterogeneous effect of JGY by districts that were classified as "exploited." An exploited district is defined as one in which groundwater development is greater than or equal to 90%. Post-JGY, the average increase in depth to groundwater in exploited districts, is nearly 9.5 m. Thus, contrary to previous findings (Bhanja et al., 2017) or past claims (World Bank, 2010a), there is evidence that JGY is associated with *greater*, not less, groundwater depletion, as indicated by surface to groundwater depth.

To test for the robustness of our DiD results, we undertook a series of checks. First, we reran the DiD regressions using total crop production and total irrigated area instead of the total cultivated area. Second, similar to Bhanja et al. (2017), we recomputed groundwater depth for a district by limiting the observations wells to those with at least three seasonal data points in every year. Third, we checked the sensitivity of our estimates by dropping the district of Dangs, which was the first and fastest to implement JGY. Fourth, we redefined JGY implementation as when 80% of the villages in a district had JGY implemented.[6] Fifth, as our sample size is relatively small, we used "bootstrapping" procedures to obtain the standard errors. Last, we used alternate specifications using quantile regression that assigns asymmetric penalties for

[3]Due to limited data availability, we proxy population growth. Annual district-level population data are unavailable for India.

[4]Soil type and the location, gradient, and structure of the aquifer can be assumed to be fixed as these hydrogeological factors are unlikely to change significantly over a time span of 15 years.

[5]A 1% increase in the mean average annual minimum and maximum temperature, in linear terms, represents a 0.21°C and 0.34°C increase, respectively.

[6]Computing annual cumulative JGY coverage at the end of a given year from monthly data produces a step function. We, therefore, test sensitivity at 80% cumulative JGY coverage, which is the mean coverage in 2005.

TABLE 1 Effect of JGY and other variables on average depth from soil surface to groundwater (annual GW depth) across districts in Gujarat

	Annual GW depth	Annual GW depth
	(1)	(2)
Post-JGY	3.009** (1.408)	−0.010 (1.819)
Post-JGY*Exploited district		9.463*** (1.935)
Exploited district		11.859*** (1.068)
Ln total cultivated area	−0.458 (2.471)	8.493*** (1.156)
Ln average annual rainfall	−0.688 (0.840)	1.638** (0.720)
Ln average minimum temperature	23.256 (60.646)	−23.985*** (8.225)
Ln average maximum temperature	146.277 (93.047)	0.810 (10.756)
Ln road length	0.381 (4.494)	−6.482*** (1.281)
District fixed effects	Y	N
Year fixed effects	Y	Y
Observations	288	266
R^2	0.881	0.880
Data coverage	1996–2011	1996–2011

Note. Difference-in-differences estimates from ordinary least squares regressions. Robust standard errors in parentheses. Annual GW depth = average annual district level depth (meters) from soil surface to groundwater for all observable wells. An exploited district is defined as one in which groundwater development level is ≥90%. Groundwater development is the ratio of the annual groundwater extraction to the net annual groundwater availability. Regression in column (2) does not include district fixed effects as they are perfectly collinear with "exploited district" status. JGY: Jyotigram Yojana.

*$p < 0.10$. **$p < 0.05$. ***$p < 0.01$.

overprediction and for underprediction; this is not the case with standard linear regression. Thus, quantile regression allows us to evaluate the robustness of our estimates to outliers in the data (see Data S1). In sum, our DiD results using frequentist statistical analysis provide empirical evidence that JGY has exacerbated rather than reduced groundwater depletion in Gujarat.

As a follow-up and an alternative to DiD estimation, we employed Bayesian methods and estimated 13 separate models for 13 different sample sizes beginning with model (1) where the prior is the probability of JGY implementation based on mean JGY implementation in 1996. For model (1), the posterior effect of JGY on groundwater depth is estimated using data from 1997 to 2011. Models (2) to (13) used the same approach but employed a prior for the year immediately before and progressively updated the prior on the probability of JGY implementation until the prior was 1 (100% probability) in 2008.

The Bayesian posterior estimates and corresponding credible intervals are summarized in Figure 2. Detailed posterior estimates are provided in Data S1, which includes the full set of control variables. The DiD estimates and corresponding confidence intervals are also included in Figure 2 for comparison. The posterior estimates from models (1) to (13) suggest that as the probability of JGY implementation increases, groundwater depth also increases. Thus, both the DiD estimates and the Bayesian estimates are consistent with each other.

In sum, we find (a) with Bayesian estimation, the effect of a low probability of JGY implementation on depth to groundwater is null, negative, or low in magnitude, which is counter

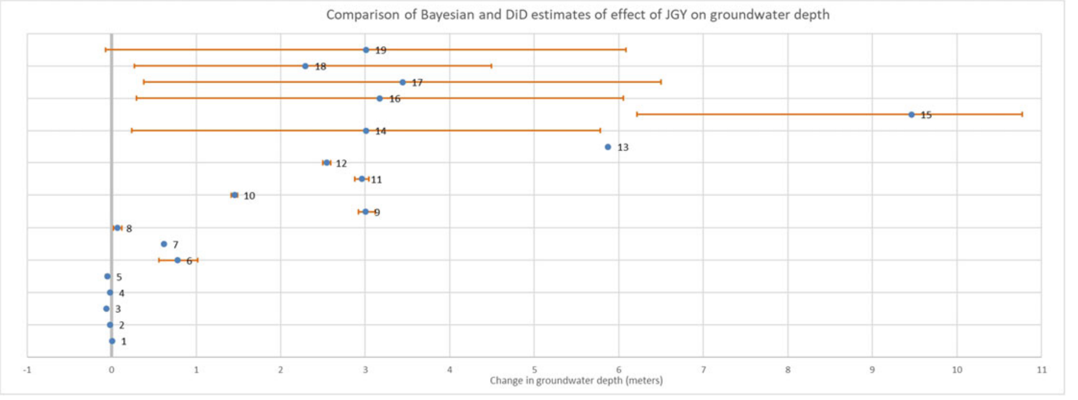

FIGURE 2 Comparison of Bayesian and difference-in-differences estimates of effect of Jyotigram Yojana on groundwater depth

Legend of Figure 2

Model		JGY implementation	Posterior/DiD	Credible/confidence interval	Sample
(1)	Bayesian	1996 JGY implementation as prior	0.007	[0.000, 0.013]	1997–2011
(2)		1997 JGY implementation as prior	−0.019	[−0.026, −0.014]	1998–2011
(3)		1998 JGY implementation as prior	−0.064	[−0.069, −0.058]	1999–2011
(4)		1999 JGY implementation as prior	−0.020	[−0.031, −0.010]	2000–2011
(5)		2000 JGY implementation as prior	−0.052	[−0.069, −0.034]	2001–2011
(6)		2001 JGY implementation as prior	0.778	[0.562, 1.020]	2002–2011
(7)		2002 JGY implementation as prior	0.619	[0.613, 0.623]	2003–2011
(8)		2003 JGY implementation as prior	0.067	[0.018 , 0.117]	2004–2011
(9)		2004 JGY implementation as prior	3.002	[2.920, 3.115]	2005–2011
(10)		2005 JGY implementation as prior	1.452	[1.417, 1.489]	2006–2011
(11)		2006 JGY implementation as prior	2.958	[2.878, 3.046]	2007–2011
(12)		2007 JGY implementation as prior	2.544	[2.498 , 2.591]	2008–2011
(13)		2008 JGY implementation as prior	5.874	[5.868, 5.880]	2009–2011
(14)	DiD	Post-JGY (100% JGY implementation)	3.009	[0.236, 5.782]	1996–2011
(15)		Post-JGY (100% JGY implementation in overexploited districts)	9.465	[6.217, 10.771]	1996–2011
(16)		Post-JGY (100% JGY implementation using data on wells with at least three seasonal observations)	3173	[0.294 , 6.051]	1996–2011
(17)		Post-JGY (100% JGY implementation excluding Dangs district)	3.443	[0.383, 6.503]	1996–2011
(18)		DiD post-JGY (80% JGY implementation)	2.293	[0.269, 4.316]	1996–2011
(19)		Post-JGY (100% JGY implementation with bootstrapped standard errors)	3.009	[−0.069, 6.087]	1996–2011

Note. JGY: Jyotigram Yojana; DiD: difference in differences.

to the claim that JGY reduces groundwater depth; (b) with Bayesian estimation, as the probability of JGY implementation increases beginning in 2004, there is a sustained increase in the depth to groundwater; and (c) with DiD estimation, we find a statistically significant

($p < 0.05$), robust, and positive effect for JGY on depth to groundwater under eight different model specifications. In sum, we find using multiple methods and controls, and with the publicly available data that JGY is statistically significantly associated with increased groundwater depth (or reduced groundwater storage).

4 | DISCUSSION

If JGY increases rather than reduces groundwater depth, or in other words, it decreases groundwater storage, then an explanation for this effect is required. We hypothesize that increasing the reliability and quality of the electricity supplied to farms, notwithstanding the temporal rationing, supports a "rebound effect" that increases groundwater use (Gómez & Pérez-Blanco, 2014). We contend this may have arisen because the cost per unit of electricity remained essentially unchanged, as there were no substantial increases in tariff, but the power supplied became more effective and reliable. Thus, the improvement in the quality of the power supplied increased the farmers' ability to extract groundwater per kilowatt-hour and, in turn, increased groundwater extractions. Indeed, in 2002–2003, just prior to JGY implementation, total electricity consumption for agricultural purposes in Gujarat was 12.97 TWh, and it increased to 13.34 TWh in 2009–2010, just after JGY was fully implemented in the state (Indiastat, 2018).

We evaluated changes in the types of crops grown post-JGY. We find some evidence that post-JGY irrigated area under cotton significantly increased suggesting a shift towards more water-intensive cash crops (see Data S1). Further, there is evidence that, post-JGY, farmers in Gujarat have substituted to higher capacity, submersible pumps that allow for an increased rate of extraction per hour (Kumar & Perry, 2018). Both observations are consistent with our finding that JGY is coincident with a decrease in groundwater storage. Further, we performed a Granger causality test between mean JGY coverage, that is, the proportion of districts in Gujarat that implemented JGY at the end of a given year, and average annual groundwater for all of Gujarat for the period 1996–2011. Our results show that JGY implementation Granger causes groundwater depth ($p < 0.01$), which is consistent with our DiD and Bayesian results.

As with any empirical investigation, it is not always possible to control for all confounding variables. One of these is an increase in new tube well connections prioritized and allocated to small farmers belonging to scheduled castes and scheduled tribes categories by the Gujarat state government (Shah, 2018; Shah & Chowdhury, 2017). Additional tube wells and the ease of extracting groundwater post-JGY may have jointly contributed to a decrease in groundwater storage.

Beyond our own findings, the results suggest that follow-up research is required to test for the possible effects of policies that promote solar irrigation pumps on groundwater depletion. This is because of similarities of these policies to JGY, namely, solar irrigation pumps have very low operating costs, ration power (by sunlight) and provide power of reliable quality. Further, there are large capital subsidies for their installation (Shah, Rajan, Rai, Verma, & Durga, 2018) so confirmation, or otherwise, of the effects of these subsidies on groundwater depletion is materially important from a policy perspective.

5 | CONCLUSIONS

Our results are restricted to Gujarat, but they are also relevant to other Indian states that have adopted feeder separation policies, such as neighbouring Rajasthan. Our DiD and Bayesian estimates provide evidence that the JGY feeder separation policy, combined with an improved quality in the power supply and no increase in the electricity tariff charged to farmers, has *reduced* groundwater storage. If correct, this is a matter of serious concern in a country that uses more groundwater than China and the United States combined and that has adopted JGY, in part, as a means to increase groundwater storage, supported by evidence from the World Bank (2010a, p. 53) and others (Zilberman et al., 2008).

Our findings are important, and not just because of the scale of the groundwater crisis in India that directly or indirectly affects hundreds of millions of people. The DiD and Bayesian results call into question the belief that JGY is increasing groundwater storage. Given the introduction of the Deen Dayal Upadhyaya Gram Jyoti Yojana scheme in 2015, which aims to implement feeder separation across India (Ministry of Power, 2018), our findings gain even more policy significance. The scientific challenge is to replicate both our findings and competing results that purport to show that JGY has increased groundwater storage.

The challenge for the science-policy interface is to mitigate or overcome confounding effects that can disconnect scientific evidence from policy actions, especially where scientific results are contradictory. These effects include (a) a publication bias whereby researchers have a greater likelihood of submitting research, and also having results published, that are statistically significant and show a positive outcome of a treatment effect; and (b) a barrier effect that hinders communication and consideration of alternative policy options, especially when evidence is developed with different epistemologies and is contradictory.

A practical response to the communication challenges when science meets policy is a "testing, replication and experimentation" collaboration. Such an approach does not guarantee better decision-making, but is likely to avoid "worst case" or "one-track" policies. It requires that alternative policies are tested, and where a statistically significant finding is obtained, the results are replicated. All policies successfully tested and replicated must then be included in experiments across multiple contexts, before they are scaled out.

Possible policy alternatives suitable for testing, replication, and experimentation in relation to their effects on groundwater storage include water recharge schemes (Shah, 2005), water law reform (Cullet, 2014), water metering, water accounting (Berbel & Mateos, 2014), and water pricing and incentives for water conservation (Fishman, Devineni, & Raman, 2015) subsidies for solar irrigation pumps (Shah et al., 2018). Where such policies are tested, replicated, and are also shown to be successful in multiple and different circumstances, they may be suitable to be upscaled to promote the long-term sustainability of India's groundwater resources.

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REFERENCES

Berbel, J., & Mateos, L. (2014). Does investment in irrigation technology necessarily generate rebound effects? A simulation analysis based on an agro-economic model. *Agricultural Systems*, *128*, 25–34. https://doi.org/10.1016/j.agsy.2014.04.002

Berger, J. O., & Sellke, T. (1987). Testing a point null hypothesis: The irreconcilability of *p* values and evidence. *Journal of the American Statistical Association*, *82*, 112–122.

Bhanja, S. N., Mukherjee, A., Rodell, M., Wada, Y., Chattopadhyay, S., Velicogna, I., … Famiglietti, J. S. (2017). Groundwater rejuvenation in parts of India influenced by water-policy change implementation. *Scientific Reports*, *7*, 7453. https://doi.org/10.1038/s41598-017-07058-2

Birkenholtz, T. (2017). Assessing India's drip-irrigation boom: Efficiency, climate change and groundwater policy. *Water International*, *42*, 663–677. https://doi.org/10.1080/02508060.2017.1351910

Biswas, A. K., & Hartley, K. (2017). From evidence to policy in India's groundwater crisis. In *The Diplomat*.

Brooks, H. (1964). The scientific advisor. In R. Gilpin, & C. Wright (Eds.), *Scientists and national policy-making*. New York: Columbia University Press.

Camerer, C. F., Dreber, A., Holzmeister, F., Ho, T.-H., Huber, J., Johannesson, M., … Wu, H. (2018). Evaluating the replicability of social science experiments in nature and science between 2010 and 2015. *Nature Human Behaviour*, *2*, 637–644. https://doi.org/10.1038/s41562-018-0399-z

Census of India. (2001). Census 2001. In: Office of the Registrar General & Census Commissioner,Ministry of Home Affairs, Government of India.

Central Ground Water Board. (2004). Dynamic groundwater resources of India. In: Central Ground Water Board, Ministry of Water Resources, Government of India.

Central Ground Water Board. (2011). Dynamic ground water resources of India. In: Central Ground Water Board, Ministry of Water Resources, Government of India.

Central Ground Water Board. (2017). Water Resources Information System of India (India-WRIS WebGIS) groundwater level database. In.

Chindarkar, N. (2017). Beyond power politics: Evaluating the policy design process of rural electrification in Gujarat, India. *Public Administration and Development*, *37*, 28–39. https://doi.org/10.1002/pad.1777

Cullet, P. (2014). Groundwater law in India: Towards a framework ensuring equitable access and aquifer protection. *Journal of Environmental Law*, *26*, 55–81. https://doi.org/10.1093/jel/eqt031

Dave, H., James, M. E., & Ray, K. (2017). Trends in intense rainfall events over Gujarat state (India) in the warming environment using gridded and conventional data. *International Journal of Applied Environmental Sciences*, *12*, 977–998.

Dickersin, K. (1990). The existence of publication bias and risk factors for its occurrence. *Journal of the American Medical Association*, *263*, 1385–1389. https://doi.org/10.1001/jama.1990.03440100097014

Dietz, T. (2013). Bringing values and deliberation to science communication. *PNAS*, *110*, 14081–14087. https://doi.org/10.1073/pnas.1212740110

Dubash, N. K. (2007). The electricity-groundwater conundrum: Case for a political solution to a political problem. *Economic and Political Weekly*, *42*, 45–55.

Fischhoff, B., & Scheufele, D. A. (2013). The science of science communication. *PNAS*, *110*, 14031–14032. https://doi.org/10.1073/pnas.1312080110

Fishman, R., Devineni, N., & Raman, S. (2015). Can improved agricultural water use efficiency save India's groundwater? *Environmental Research Letters*, *10*, 084022. https://doi.org/10.1088/1748-9326/10/8/084022

Foster, S., Tuinhof, A., Kemper, K., Garduño, H., & Nanni, M. (2003). Groundwater management strategies: Facets of the integrated approach. In GW•MATE Briefing Notes Series. Washington, DC: The World Bank.

Ghosh, A., & Agrawal, S. (2015). Sustainable solar irrigation. In *Business Standard*.

Gómez, C. M., & Pérez-Blanco, C. D. (2014). Simple myths and basic maths about greening irrigation. *Water Resources Management*, *28*, 4035–4044. https://doi.org/10.1007/s11269-014-0725-9

Government of Gujarat. (2013). Gujarat agricultural statistics. In D. o. A. Cooperation (Ed.).

Government of Gujarat. (2015). Socio-economic review 2014-15 Gujarat state. In D. o. E. a. Statistics (Ed.). Gandhinagar.

Grafton, R. Q. (2017). Responding to the 'wicked problem' of water insecurity. *Water Resources Management*, *31*, 3023–3041. https://doi.org/10.1007/s11269-017-1606-9

Grafton, R. Q., & Robin, L. (2005). Bridging the Divides. In R. Q. Grafton, L. Robin & R. J. Wasson (Eds.), *Understanding the Environment: Bridging the Disciplinary Divides*.

Hopewell, S., Loudon, K., Clarke, M. J., Oxman, A. D., & Dickersin, K. (2009). Publication bias in clinical trials due to significance of trial results. *Cochrane Database of Systematic Reviews*, *1*.

IEA. (2015). *India energy outlook*. Paris, France: International Energy Agency.

India Water Portal. (2017). An insight on legal aspect of groundwater use by industries and water tax/rate/fee. In (Vol. 2017).

India Water Tool. (2017). India water tool. In: World Resources Institute, Columbia Water Center.

Indiastat. (2018). State/region-wise consumption of electricity for agricultural purposes in India. In Indiastat.com (Ed.).

International Crops Research Institute for the Semi-Arid Tropics. (2015). Village Dynamics in South Asia (VDSA)—India Meso Dataset. In.

Ioannidis, J. P. A. (2005). Contradicted and initially stronger effects in highly cited clinical research. *Journal of the American Medical Association*, *294*, 218–228. https://doi.org/10.1001/jama.294.2.218

Kantrowitz, A. (1993). Elitism vs. checks and balances in communicating scientific information to the public. *Risk: Issues in Health & Safety*, *4*, 101–111.

Kumar, M. D. (2000). Institutional framework for managing groundwater: A case study of community organisations in Gujarat, India. *Water Policy*, *2*, 423–432. https://doi.org/10.1016/S1366-7017(00)00020-9

Kumar, M. D., & Perry, C. J. (2017). Comments on the article "groundwater rejuvenation in parts of India influenced by water-policy change implementation". https://www.nature.com/articles/s41598-017-07058-2#article-comments (accessed 7 December 2017).

Kumar, M. D., & Perry, C. J. (2018). What can explain groundwater rejuvenation in Gujarat in recent years? *International Journal of Water Resources Development*, 1–16. https://doi.org/10.1080/07900627.2018.1501350

Matthews, R. (2016). *Chancing it: The laws of chance and how they can work for you*. London: Profile Books Ltd.

Matthews, R. A. J. (2001). Why should clinicians care about Bayesian methods? *Journal of Statistical Planning and Inference*, *94*, 43–58. https://doi.org/10.1016/S0378-3758(00)00232-9

Ministry of Power, Government of India, (2018). Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) guidelines. In R. E. Corporation (Ed.). New Delhi.

Ministry of Statistics and Programme Implementation, Government of India, (2017). Energy Statistics. In. New Delhi.

Mukherji, A., Das, B., Majumdar, N., Nayak, N. C., Sethi, R. R., & Sharma, B. R. (2009). Metering of agricultural power supply in West Bengal, India: Who gains and who loses? *Energy Policy*, *37*, 5530–5539. https://doi.org/10.1016/j.enpol.2009.08.051

Mukherji, A., Shah, T., & Verma, S. (2010). Electricity reforms and their impact on ground water use in states of Gujarat, West Bengal and Uttarakhand, India. In J. Lundqvist (Ed.), *On the water front: Selections from the 2009 world water week in Stockholm*. Stockholm: Stockholm International Water Institute.

Narasimhan, T. N. (2008). Groundwater management and ownership. *Economic and Political Weekly*, *43*(21–23), 25–27.

Narayanamoorthy, A. (2004). Drip irrigation in India: Can it solve water scarcity? *Water Policy*, *6*, 117–130. https://doi.org/10.2166/wp.2004.0008

Pielke, R. A. J. (2007). *The honest broker making sense of science in policy and politics*. New York: Cambridge University Press. https://doi.org/10.1017/CBO9780511818110

Prinz, F., Schlange, T., & Asadullah, K. (2011). Believe it or not: How much can we rely on published data on potential drug targets? *Nature Reviews Drug Discovery*, *10*, 712.

Rodell, M., Velicogna, I., & Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. *Nature*, *460*, 999–1003. https://doi.org/10.1038/nature08238

Sarewitz, D. (2004). How science makes environmental controversies worse. *Environmental Science & Policy*, *7*, 385–403. https://doi.org/10.1016/j.envsci.2004.06.001

Scheufele, D. A. (2014). Science communication as political communication. *PNAS*, *111*, 13585–13592. https://doi.org/10.1073/pnas.1317516111

Scott, C. A., & Shah, T. (2004). Groundwater overdraft reduction through agricultural energy policy: Insights from India and Mexico. *Water Resources Development*, *20*, 149–164. https://doi.org/10.1080/0790062042000206156

Shah, T. (2005). Groundwater and human development: Challenges and opportunities in livelihoods and environment. *Water Science and Technology*, *51*, 27–37. https://doi.org/10.2166/wst.2005.0217

Shah, T. (2014). Groundwater governance and irrigated agriculture. In *Global Water Partnership Technical Committee (TEC) Background Paper No.19*. Stockholm, Sweden: Global Water Partnership.

Shah, T. (2018). Personal communication between Dr. Tushaar Shah and Professor Quentin Grafton. In P. Q. Grafton (Ed.).

Shah, T., Bhatt, S., Shah, R. K., & Talati, J. (2008). Groundwater governance through electricity supply management: Assessing an innovative intervention in Gujarat, western India. *Agricultural Water Management*, *95*, 1233–1242. https://doi.org/10.1016/j.agwat.2008.04.006

Shah, T., & Chowdhury, S. D. (2017). Farm power policies and groundwater markets: Contrasting Gujarat with West Bengal (1990–2015). *Economic & Political Weekly*, *52*, 39–47.

Shah, T., Rajan, A., Rai, G. P., Verma, S., & Durga, N. (2018). Solar pumps and South Asia's energy-groundwater nexus: Exploring implications and reimagining its future. *Environmental Research Letters*, *13*. https://doi.org/10.1088/1748-9326/aae53f

Siebert, S., Burke, J., Faures, J.-M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T. (2010). Groundwater use for irrigation—A global inventory. *Hydrology and Earth System Sciences*, *14*, 1863–1880. https://doi.org/10.5194/hess-14-1863-2010

Siebert, S., Kummu, M., Porkka, M., Döll, P., Ramankutty, N., & Scanlon, B. R. (2015). A global data set of the extent of irrigated land from 1900 to 2005. *Hydrology and Earth System Sciences*, *19*, 1521–1545. https://doi.org/10.5194/hess-19-1521-2015

Simis, M. J., Madden, H., Cacciatore, M. A., & Yeo, S. K. (2016). The lure of rationality: Why does the deficit model persist in science communication? *Public Understanding of Science*, *25*, 400–414. https://doi.org/10.1177/0963662516629749

Stirling, A. (2010). Keep it complex. *Nature*, *468*, 1029–1031. https://doi.org/10.1038/4681029a

Subhadra, B. (2015). Water: Halt India's groundwater loss. *Nature*, *521*, 289. https://doi.org/10.1038/521289d

Suhag, R. (2016). *Overview of groundwater in India*. New Delhi, India: PRS Legislative Research.

University of East Anglia Climatic Research Unit, Harris, I. C., & Jones, P. D. (2017). CRU TS4.01: Climatic Research Unit (CRU) Time-Series (TS) Version 4.01 of High-Resolution Gridded Data of Month-by-Month Variation in Climate (Jan. 1901- Dec. 2016). In C. f. E. D. Analysis (Ed.).

World Bank. (2001). *India: Power supply to agriculture, volume 1. Summary report*. Washington DC: World Bank.

World Bank. (2010a). *Deep wells and prudence: Towards pragmatic action for addressing groundwater overexploitation in India*. D.C.: Washington.

World Bank. (2010b). *Deep wells and prudence: Towards pragmatic action for addressing groundwater overexploitation in India*. World Bank: In. Washington DC.

World Bank. (2012). India groundwater: A valuable but diminishing resource. http://www.worldbank.org/en/news/feature/2012/03/06/india-groundwater-critical-diminishing (accessed 25 October 2017).

World Bank. (2013). Lighting rural India: Experience of rural load segregation schemes in states. In. Washington, DC: World Bank.

Zaveri, E., Grogan, D. S., Fisher-Vanden, K., Frolking, S., Lammers, R. B., Wrenn, D. H., ... Nicholas, R. E. (2016). Invisible water, visible impact: Groundwater use and Indian agriculture under climate change. *Environmental Research Letters*, *11*. https://doi.org/10.1088/1748-9326/11/8/084005

Zilberman, D., Sproul, T., Rajagopal, D., Sexton, S., & Hellegers, P. (2008). Rising energy prices and the economics of water in agriculture. *Water Policy*, *10*, 11–21. https://doi.org/10.2166/wp.2008.049

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