Irrigation in Transition: Changing Patterns of Groundwater Use in Nepal

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June 20, 2026

Abstract

Irrigation in the Eastern Gangetic Plains is changing fast in water use and energy. Focusing on Nepal's Terai, we provide an updated assessment of irrigation patterns, with attention to irrigation assets, costs, and access. Three findings stand out. First, irrigation is shifting from surface water to groundwater and from diesel to electric pumps. Second, despite cheaper electric pumping and rapid grid expansion, access remains uneven, with regional differences in ownership and rental markets shaping both cost and timeliness. Third, renters face higher irrigation costs and longer delays than owners. These patterns reveal persistent disparities in irrigation access despite ongoing transitions.

Keywords: Groundwater irrigation, water market, rural electrification, irrigation access, Nepal

JEL: Q12, Q15, Q25, O13

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Introduction

Over the past decade, the Eastern Gangetic Plains (EGP), spanning Bangladesh, eastern India, and Nepal's Terai, have seen a rapid expansion of electric irrigation (Kishore, 2019). By replacing diesel-based pumping with lower-cost electricity, this transition could substantially reduce irrigation costs and raise agricultural productivity. In Nepal, this shift is already visible. The number of grid-connected irrigation consumers nearly tripled between 2011/12 and 2019/20, from 53,165 to 152,485, while electricity sales to irrigation and water supply rose from 65 to 182 gigawatt hours. This expansion has been supported by a favorable irrigation tariff of NPR 4.30 per unit, less than half the rate paid by typical household consumers (Nepal Electricity Authority, 2021).

These rapid changes raise a basic question: as electricity reaches more households, does groundwater irrigation actually become more accessible? Cheaper energy should make irrigation more affordable and more widely available, but the link is neither automatic nor uniform. Evidence from West Bengal in eastern India shows that changes in electricity pricing and supply shift groundwater use, yet they do not translate mechanically into improved access or agricultural outcomes (Meenakshi et al., 2012; Modak, 2021). Who benefits also depends on the political economy of irrigation infrastructure and energy provision (Mukherji and Das, 2014; Srinivasan and Kulkarni, 2014). More recent evidence indicates that the impact of electrification reforms depends critically on the structure of groundwater markets: when markets are competitive and relatively thick, lower energy costs translate into broader access and higher irrigation use, whereas in thin markets, gains may accrue primarily to pump owners (Mukherji et al., 2020).

These concerns are highly relevant in Nepal's Terai, where groundwater has become increasingly central to irrigation. Between 2011 and 2021, the share of irrigated land served by groundwater rose from 30 percent to 42 percent, while the share of surface water declined over the same period (Chakraborty et al., 2023). Earlier studies in Nepal show that smallholders often rely on pump rental markets for irrigation (Bhandari and Pandey, 2006), and that irrigation costs vary by ownership status, fuel source, and pumping duration (Foster et al., 2019). Tenant and resource-poor farmers can therefore face especially high irrigation burdens (Sugden, 2015). Despite these insights, there remains limited up-to-date evidence on recent trends in groundwater irrigation and on how the ongoing shift toward electric pumping is reshaping groundwater access, rental market functioning, irrigation costs, and delays across regions and farmer groups in Nepal.

This paper addresses these gaps using recent household and national datasets, including the CSISA Landscape Diagnostic Survey, the Nepal Living Standards Surveys, and CHIRPS rainfall data. It focuses on three related questions. First, how are irrigation patterns in Nepal's Terai changing as groundwater becomes more important and electric pumping expands? Second, how do asset ownership, pump type, and regional differences in groundwater market structure shape farmers' access to irrigation, including its cost and timeliness? Third, what do these patterns suggest about the broader distribution of the benefits of irrigation transition across regions and farmer groups?

The rest of the paper is organized as follows. Section 2 describes the data and methods. Section 3 presents the main results. Section 4 discusses the findings, their policy implications, and concludes.

Data and Methods

We combine multiple datasets to provide a comprehensive picture of irrigation practices in Nepal. A timeline summarizing their collection periods is presented in Appendix Figure A1 . The first source is the Landscape Diagnostic Survey (LDS) Rice 2019–2020, collected under the Cereal Systems Initiative for South Asia (CSISA) program led by International Maize and Wheat Improvement Center, a member of the Consultative Group for International Agricultural Research. This survey gathered detailed information on rice production practices, including irrigation use, pump and tubewell ownership, water costs, and delays, from 2,917 households in 2019 and 2,122 households in 2020 across Feed the Future districts (Karki et al., 2020). Input use was recorded for the largest rice plot cultivated by each household, which is particularly relevant since most farmers operate multiple plots. This dataset provides detailed information on irrigation behavior and the functioning of informal water markets. Most Terai districts are represented in the sample, as shown in Appendix Figure A2 .[1]

We also use data from the three most recent rounds of the Nepal Living Standards Survey (NLSS II–IV), conducted by the Central Bureau of Statistics in 2003/04, 2010/11, and 2022/23 (Central Bureau of Statistics, Nepal 2004; Central Bureau of Statistics, Nepal 2011; National Statistics Office, Nepal. 2023). Each round employed a multistage stratified sampling design to ensure national representation across ecological zones and rural–urban areas. The 2003/04 survey covered about 4,000 households, the 2010/11 round (NLSS III) expanded to roughly 7,200 households, and the most recent NLSS IV surveyed over 8,000 households nationwide. Together, these datasets provide consistent information on irrigation status and sources allowing for analysis of long-term trends in irrigation coverage and the shift from surface to groundwater use.

Finally, we incorporate rainfall estimates from the Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS), which combines satellite imagery with ground-based observations to produce high-resolution time-series data. These estimates allow us to account for spatial and temporal variation in rainfall across Nepal, providing an important environmental context for irrigation outcomes. Rainfall patterns are shown in Appendix Figures A3 and A4.

Our analysis relies primarily on descriptive statistics and comparisons across regions, years, and farmer groups. Using the NLSS rounds, we document long-term trends in irrigation coverage and irrigation sources across Nepal's ecological regions. Using the CSISA rice surveys, we examine patterns of groundwater access, irrigation asset ownership, pump type, irrigation costs, irrigation frequency, and irrigation delays among farmers in the Terai. Most results are presented using group means, proportions, and graphical comparisons disaggregated by region, year, ownership status, pump type, and landholding quartiles. Several figures report predicted probabilities or group averages with 95% confidence intervals to illustrate differences across farmer groups. We also incorporate district-level rainfall estimates from CHIRPS to account for spatial and temporal variation in rainfall and to provide environmental context for differences in irrigation outcomes across years and regions. This approach allows us to systematically document recent changes in irrigation patterns and highlight key differences in groundwater access, costs, and constraints across regions and types of farmers.

Results

Regional and Temporal Patterns of Irrigation

We begin our analysis by documenting a key relationship: access to irrigation is strongly associated with higher rice yields, based on data from the 2019–2020 CSISA rice surveys conducted in Nepal's Terai region. Figure 1 shows that yields increase with the frequency of irrigation. The overall pattern is clear: more frequent irrigation is linked to higher production. This empirical pattern highlights the importance of understanding who has access to irrigation, how frequently they irrigate, and what factors enable or constrain their irrigation practices. We begin by examining the primary sources of irrigation used across regions in Nepal, with particular attention to how reliance on groundwater and surface water differs between the hills and the Terai.

Access to irrigation in Nepal is highly uneven across ecological regions, with the Terai far ahead of the hills and mountains. Figure 2 presents the percentage of plots in each district in 2022/23 (NLSS IV) that receive irrigation, whether seasonal or year-round. The spatial pattern indicates that Terai districts, located in the southern plains, exhibit the highest irrigation coverage, often exceeding 80 percent. In contrast, most hill and mountain districts have much lower irrigation coverage, reflecting the challenging terrain and the limited expansion of irrigation infrastructure in these areas.

Over time, Nepal has experienced a steady rise in irrigation coverage, alongside a major shift of irrigation source. Figure 3 shows that irrigation coverage increased notably in the Terai, the country's main agricultural belt, from about 55 percent in 2004 to nearly 80 percent in 2023, while remaining below 40 percent in the hill and mountain regions. Figure 4 shows a clear shift in the Terai's irrigation pattern from surface water to groundwater. By 2023, groundwater accounted for more than 60% of irrigated plots in the Terai, compared with less than 10% two decades earlier. In contrast, surface water still dominates in the hills and mountains, though its share fell from nearly 90% in 2004 to around 75% in 2023. Because the Terai now contains most of Nepal's irrigated area and agricultural production, the subsequent analysis focuses on this region. [2]

Irrigation assets

Understanding the ownership and access to irrigation assets provides key insights into how farmers engage with groundwater irrigation in Nepal's Terai. Among the 4,886 Terai farmers in the CSISA rice surveys from 2019 and 2020, 3,931 (80.45 percent) reported having access to some form of irrigation, while the rest relied solely on rainfall. Among irrigating households, the share relying exclusively on groundwater increased from about 49 percent in 2019 to 54 percent in 2020. Since irrigation assets such as tubewells and pumps are primarily used for groundwater irrigation, we restrict the analysis in this section to farmers who rely on groundwater sources.[1] [3]

While most irrigating farmers in Nepal's Terai own or share tubewells and pumps, renting is essential for meeting demand. As shown in Figure 5, asset ownership is more common in the Western Terai (73%) than in the Eastern Terai (58%). Consequently, reliance on rental markets is higher in the East, where the practice increased from 23% to 27% between 2019 and 2020. In the West, renting declined slightly from 22% to 18% during the same period. Overall, irrigation asset ownership is more prevalent in the West, whereas reliance on rental markets remains more pronounced in the East.

The likelihood of owning or sharing a tubewell is strongly correlated with a farmer's land size. As Figure 6 demonstrates, the probability of tubewell ownership or sharing

[1]Only about 5 percent of farmers who mainly depend on surface irrigation also use tubewells, and around 15 percent use pumps.

increases sharply across landholding quartiles, rising from about 52–53% among farmers with less than 0.3 hectares (quartile 1) to 82–90% among those with more than 1.3 hectares (quartile 4), with a persistent ownership advantage in the Western Terai. Beyond landholding, tubewell access increases with education (82% for those with postsecondary schooling vs. 65% for illiterate farmers) and is slightly higher among women than men (77% vs. 72%), as shown in Table A1. Regionally, Figure A5 shows tubewells are deeper in the West (29 m) than the East (23 m).

Pump ownership and sharing in Nepal's Terai are concentrated among wealthier, better-educated, and female farmers, especially in the Western region. Figure 7 shows that the likelihood of owning or sharing a pump, compared to renting, increases steadily with land size and remains higher in the West, with very little change between 2019 and 2020. As shown in Table A1, ownership also increases with education, rising from 64% among illiterate farmers to 84% among those with postsecondary education, and is slightly higher among women (78%) than men (70%). Together, these patterns show that irrigation asset access is closely linked to existing socioeconomic advantages.

Electric pump use is expanding in the Western Terai and remains limited in the East, with adoption concentrated among more educated and female farmers. As shown in Figure 8, nearly 70% of farmers in the West used electric pumps in 2020, up from 65% in 2019. In contrast, diesel pumps were used by roughly 70% of farmers in the Eastern Terai in 2020. This regional divide indicates a gradual shift toward electricity-based pumping in the West, likely driven by better grid connectivity and lower operating costs. While likelihood of using an electric pump, visa-a-vis a diesel pump, does not vary by land size (Figure 9), it does vary by education level and gender. Adoption increases from 49% among illiterate farmers to 62% among those with postsecondary education, and is more common among female farmers (69%) than male farmers (49%). These adoption patterns also have important consequences for irrigation costs, which we examine next.

Irrigation cost

Irrigation is one of the largest production expenses for farmers in Nepal's Terai, encompassing fuel, pump or tubewell rental fees, labor, and equipment transport. Using data from the CSISA rice survey for 2019–2020, the mean groundwater irrigation cost per hectare per irrigation application is NPR 1,462, with a median of NPR 700. Irrigation costs differ sharply by pump technology, with median per-hectare costs substantially lower for electric pumps (NPR 300) than for diesel pumps (NPR 1,350).

Figure 10 highlights three key patterns in irrigation costs. First, per-hectare irrigation costs are slightly lower in the Eastern Terai than in the Western Terai, likely reflecting the greater prevalence of pump renting in the East, as shown in Figure 5. Second, diesel-pump users face higher irrigation costs than electric-pump users across both renters and owners or sharers. Third, renters incur substantially higher irrigation costs than farmers who own or share pumps.

These differences are driven by distinct fuel and non-fuel components of irrigation costs. We decompose total irrigation costs into fuel costs and non-fuel costs, which include pump rental fees, transport, labor, and other expenses. Figure 11 shows that fuel costs per hectare per irrigation application are nearly identical for renters and owners, as expected given uniform fuel prices. However, fuel costs are much higher for diesel pumps, at roughly NPR 1,000 per hectare, compared to about NPR 400 for electric pumps, reflecting the higher unit cost of diesel relative to electricity. Figure 12 shows that non-fuel costs are substantially higher for renters, who pay two to three times more than owners or sharers due to rental fees. These rental fees account for most of the gap in total irrigation costs between renters and owners, completing the explanation for the patterns observed in Figure 10.

Figure A6 shows that irrigation costs per hectare do not vary with pump horsepower among owners, indicating limited efficiency gains from larger pumps. In contrast, renters face consistently higher costs, reflecting rental fees. Among renters, irrigation costs do not decline with horsepower for electric pumps, but are lower for higher-horsepower diesel pumps, likely because smaller diesel pumps command higher rental premiums due to ease of transport and higher demand among smallholder farmers.

Irrigation Access and Constraints

Understanding how often farmers irrigate their fields provides important insights into irrigation access, rental market dynamics, and rainfall dependence in Nepal's Terai. Using the full CSISA rice sample for 2019 and 2020 (N=4,886), roughly 80% stated that they irrigated their rice fields. Figure 13 shows irrigation frequency by pump ownership, region, and year.

Two notable patterns are observed. First, across regions and years, pump owners consistently irrigate more frequently than renters, though the gap narrows in 2020 relative to 2019. This likely reflects higher rainfall during the 2020 rice season compared to 2019, as shown in Figures A3 and A4, with slightly greater rainfall in the Eastern Terai in both years. Higher rainfall reduces irrigation demand and may ease rental market constraints, helping to explain the smaller ownership gap in irrigation frequency in 2020 and in the Eastern Terai.

Second, irrigation frequency varies more widely among renters, particularly in the Western Terai, suggesting more uneven access within this group. Rental markets are more active in the Eastern Terai, where a larger share of farmers depend on rented pumps due to lower ownership rates. The slightly higher irrigation frequency observed in the East may therefore reflect a more active rental market that allows farmers to irrigate when needed, despite higher costs and continued dependence on diesel pumps.

Timely access to irrigation remains a persistent constraint for farmers in Nepal's Terai. Among the 80% who irrigated their fields, about 14.6% reported experiencing delays, with an average waiting time of five days—a substantial lag given that farmers in Nepal typically irrigate only when crops are in urgent need of water. Figure 14 shows that renters were significantly more likely to face delays than owners or shared users across both regions and years. The gap in waiting probability between renters and owners was smaller in the Eastern Terai, where tubewell and pump rentals are more common (see Figure 5), suggesting that rental markets in the region may function more efficiently despite the higher cost of diesel pump rentals. Waiting probabilities were lower in 2020 than in 2019, likely due to improved rainfall that year. The most frequently cited reasons for delays were having to wait for pump or tubewell access, canal drying, and equipment breakdowns.

A smaller but notable share of farmers either did not irrigate or were unable to irrigate their fields. In 2019, this share was 18% in the Western Terai and 8% in the Eastern Terai, while in 2020 it rose to about 27% in both regions. Figure 15 shows that the increase in 2020 was associated with sufficient rainfall, consistent with higher precipitation that year (Figure A4). Given the high cost of irrigation, many farmers may choose not to irrigate when they believe rainfall is sufficient for their crops to survive. Other reasons include distant or non-functioning water sources and financial constraints, such as the inability to afford irrigation equipment, which are more common in the Western Terai.

Discussion and Conclusion

Irrigation in Nepal's Terai is undergoing two simultaneous transitions. The first is a shift in water source: surface irrigation, which dominated two decades ago, has increasingly given way to groundwater, which now supplies more than 60% of irrigated plots. The second is a shift in energy source: diesel pumps are being replaced by electric pumps as grid coverage expands and operating costs decline, substantially reducing the cost of groundwater extraction. These transitions mirror broader patterns across the Eastern Gangetic Plains, where rural electrification has lowered the marginal cost of pumping and facilitated the expansion of groundwater irrigation (Kishore, 2019; Urfels et al., 2020). However, the benefits of this transition aren't distributed evenly. Access to tubewells and pumps remains strongly associated with landholding size, education, and location, leaving smallholders and tenants disproportionately dependent on irrigation rental markets. Consequently, the distribution of gains from electrification depends not only on the availability of cheaper energy but also on the balance between irrigation asset owners and renters. This balance varies markedly across Nepal's Terai: farmers in the Western Terai are substantially more likely to own or share irrigation assets and to use electric pumps than their counterparts in the East. Our findings suggest that electrification alone does not guarantee equitable access to irrigation. Rather, its benefits are mediated by existing patterns of asset ownership and local water market institutions. This interpretation is consistent with evidence from West Bengal, where electrification reforms improved irrigation and agricultural productivity, but much of the resulting benefit accrued to pump owners, with limited gains for pump renters (Banerji et al., 2012; Mukherji et al., 2020).

Rental markets help narrow the irrigation access gap, but imperfectly. Renters pay two to three times more per hectare per irrigation than owners or sharers, irrigate less frequently, and are more likely to face delays—about five days on average. Higher per-irrigation costs that renters face come largely from the rental fees they pay for tubewells and pumps.[4] Earlier work in Nepal and Bihar makes a similar point: irrigation costs and delays depend not only on energy prices, but also on how local water markets are organized. This includes who owns irrigation assets, how rental terms are set, and how coordination problems are resolved (Bhandari and Pandey, 2006; Foster et al., 2019; Srivastava et al., 2021).

The functioning of rental markets varies across the Terai, and this variation has important consequences for farmers' access to irrigation. In the Eastern Terai, where fewer farmers own pumps but the rental market is more active, renters get water faster and more predictably, even though they pay more for fuel because most pumps still run on diesel. However, in the Western Terai, where ownership is higher and electric pumps more common, rental markets are thinner, and renters face longer and more dispersed delays despite cheaper electricity. These contrasts suggest that an active rental market matters as much as the type of pump or the price of fuel. This pattern is consistent with evidence from India, where denser groundwater markets have been shown to function better for smallholders, with more competitive pricing and more reliable access (Manjunatha et al., 2011; Mukherji et al., 2020). Electrification alone will not help all farmers equally if rental markets remain thin and slow.

These findings have implications for future research and policy. On the research side, three questions are especially important. First, more work is needed to explain why some rental markets function better than others, and for whom. This would require transaction-level data on rental terms, market density, and bargaining between pump owners and renters, which existing household surveys rarely capture. Second, while we document a positive association between irrigation frequency and rice yields, it remains unclear how groundwater access affects broader farm outcomes. Future research could examine whether improved irrigation access changes crop choice, increases cropping intensity, strengthens resilience to drought and heat stress, or raises farm incomes. This would require well-stratified farm- and landscape-level evidence from Nepal's Terai. Third, the sustainability of growing groundwater use remains uncertain. Nepal still lacks the aquifer monitoring needed to assess seasonal and long-term changes in groundwater levels. Following Sekhri (2014), future work could examine whether seasonal water-table declines, especially below the depth at which cheaper centrifugal pumps can operate, affect water access, rental markets, and farmer welfare.

On the policy side, two broad policy implications follow. First, irrigation policy could focus on both pump ownership and rental markets. Most Terai farmers depend on water markets for irrigation, but these markets work differently across regions. In the Western Terai, rental markets are thinner. Policies that lower barriers to pump and tubewell ownership, or support reliable irrigation service providers, may help smallholders and socially disadvantaged farmers. In the Eastern Terai, rental markets are more active. There, support for better irrigation rental services and faster expansion of electrification may bring larger gains. Across both regions, the key issue is equity. Irrigation expansion may reinforce existing inequalities if access to pumps and water markets remains tied to land ownership and social status.

Second, Nepal's groundwater transition needs to be paired with stronger monitoring and planning systems. Groundwater use is expanding, but data on groundwater storage, aquifer health, and seasonal water-table changes remain limited at the spatial scale needed for policy. Existing efforts by the Groundwater Resources Development Board, the Department of Water Resources and Irrigation, and the Cereal Systems Initiative for South Asia provide an important foundation, but they require sustained investment. As drought risk and rainfall variability increase, groundwater cannot be treated as a stand-alone solution for agricultural resilience. Policy will need to link irrigation expansion with groundwater monitoring, farmer income needs, and competing water demands from agriculture, industry, and other sectors. This requires stronger agro-hydrological planning and closer coordination among line ministries, universities, researchers, and policymakers.

Data availability statement

The Nepal Living Standards Survey data are available from the National Statistics Office of Nepal, formerly the Central Bureau of Statistics, subject to its data access procedures. The Cereal Systems Initiative for South Asia survey data are publicly available through the Cereal Systems Initiative for South Asia Data Repository, and Climate Hazards Group InfraRed Precipitation with Station data are publicly available from the Climate Hazards Center at the University of California, Santa Barbara.

Disclosure statement

No potential conflict of interest was reported by the authors.

Generative AI declaration

ChatGPT (OpenAI) was used to support language refinement during manuscript preparation. The authors take full responsibility for the content of the article.

Funding statement

This research received no specific grant from any funding agency.

Tables and Figures

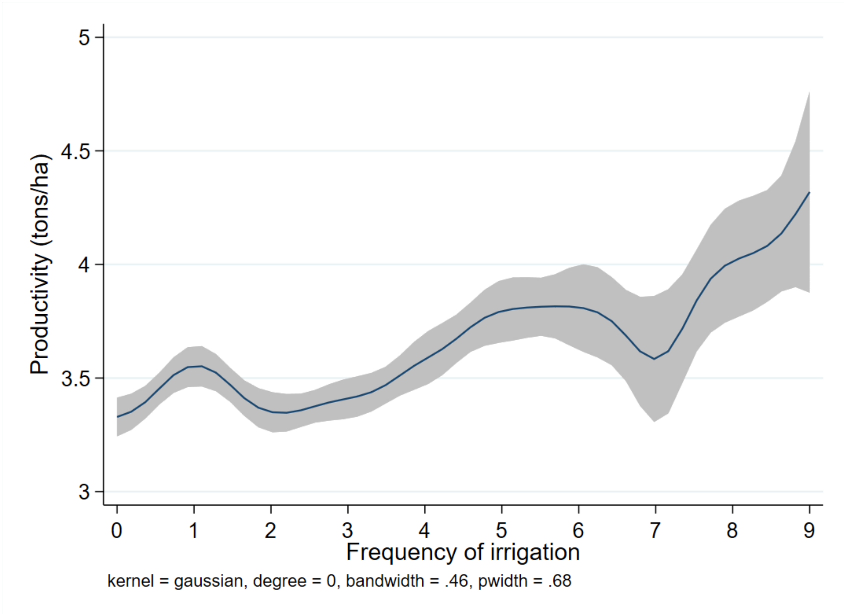

Figure 1: Non-parametric relationship between irrigation frequency and rice yield in Nepal's Terai, 2019-2020. The figure plots the fitted relationship. Shaded areas indicate 95% confidence intervals. [Back]

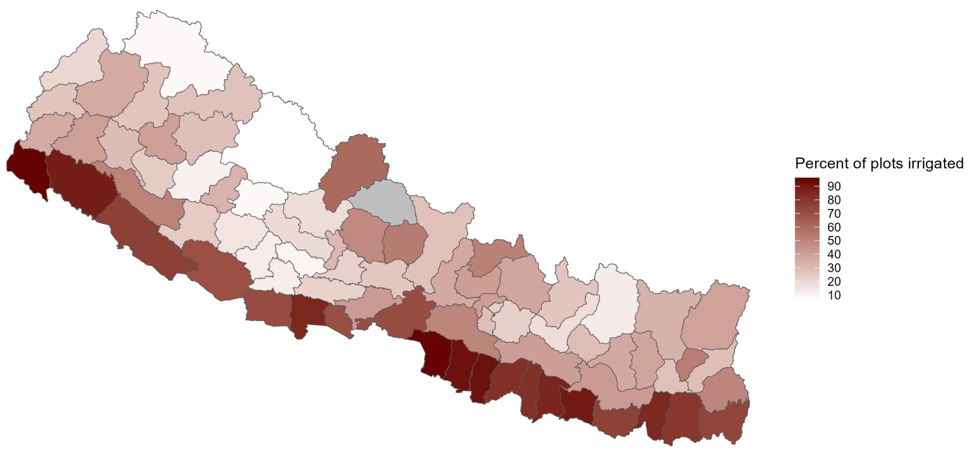

Figure 2: Share of plots with seasonal or year-round irrigation in 2022/23 across Nepalese districts. Manang district is shown in grey because data were unavailable. [Back]

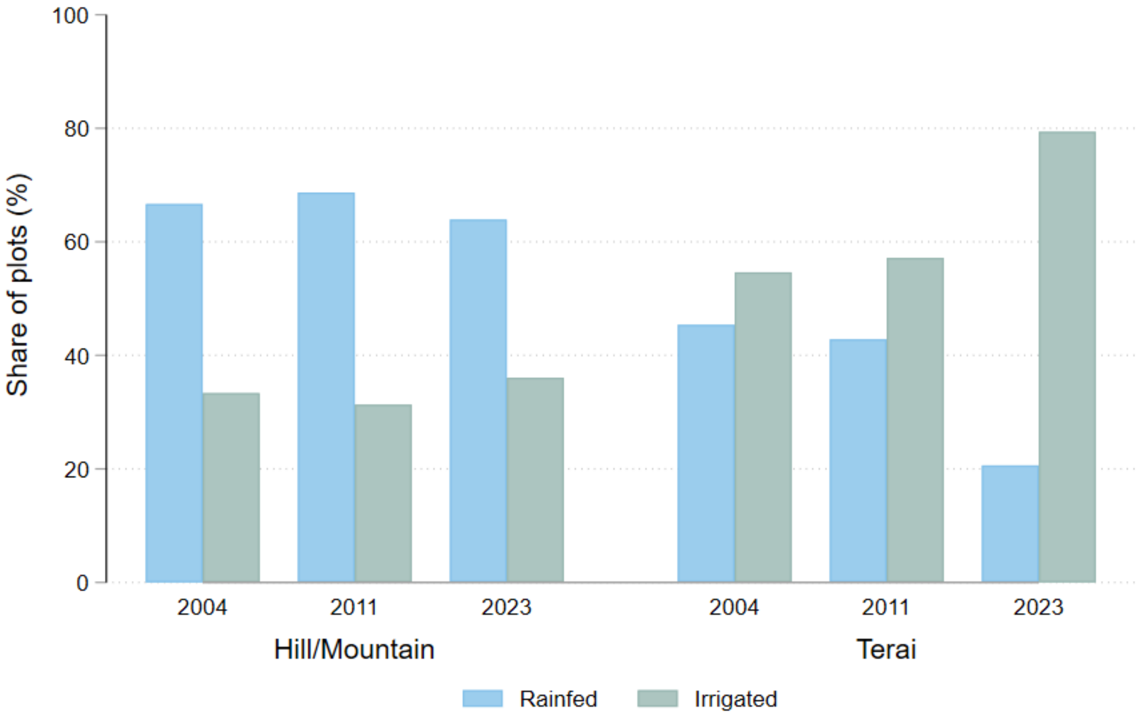

Figure 3: Share of plots with access to irrigation across Nepal's ecological regions over time. [Back]

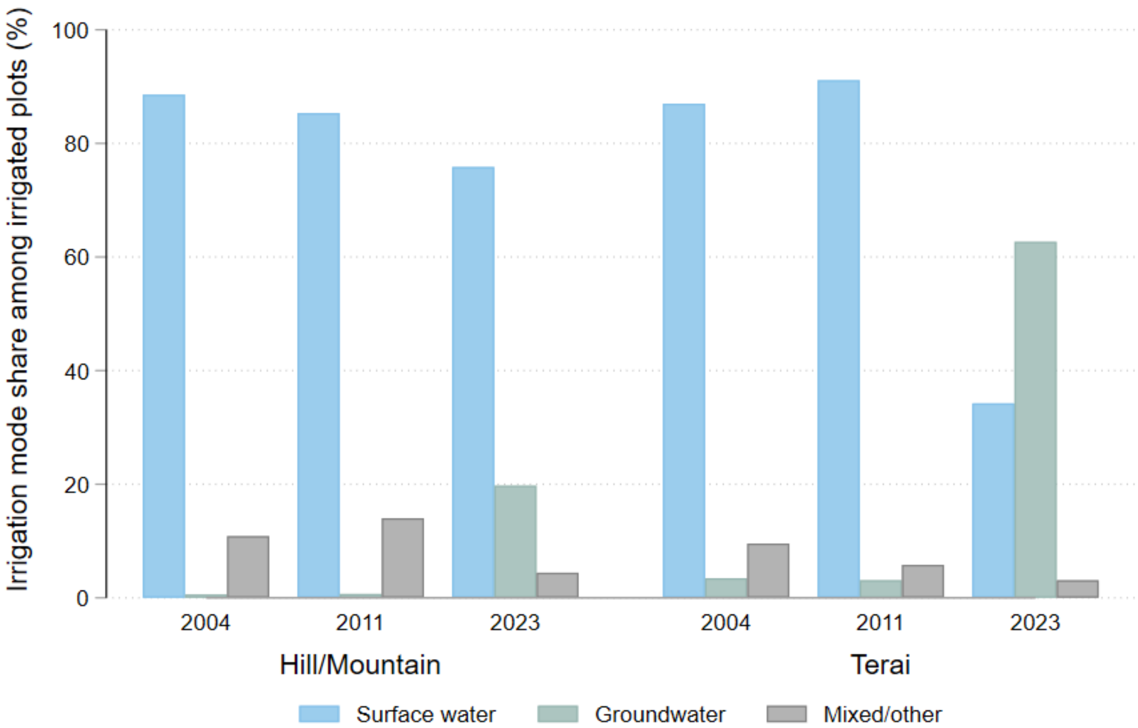

Figure 4: Source of irrigation across Nepal's ecological regions over time. [Back]

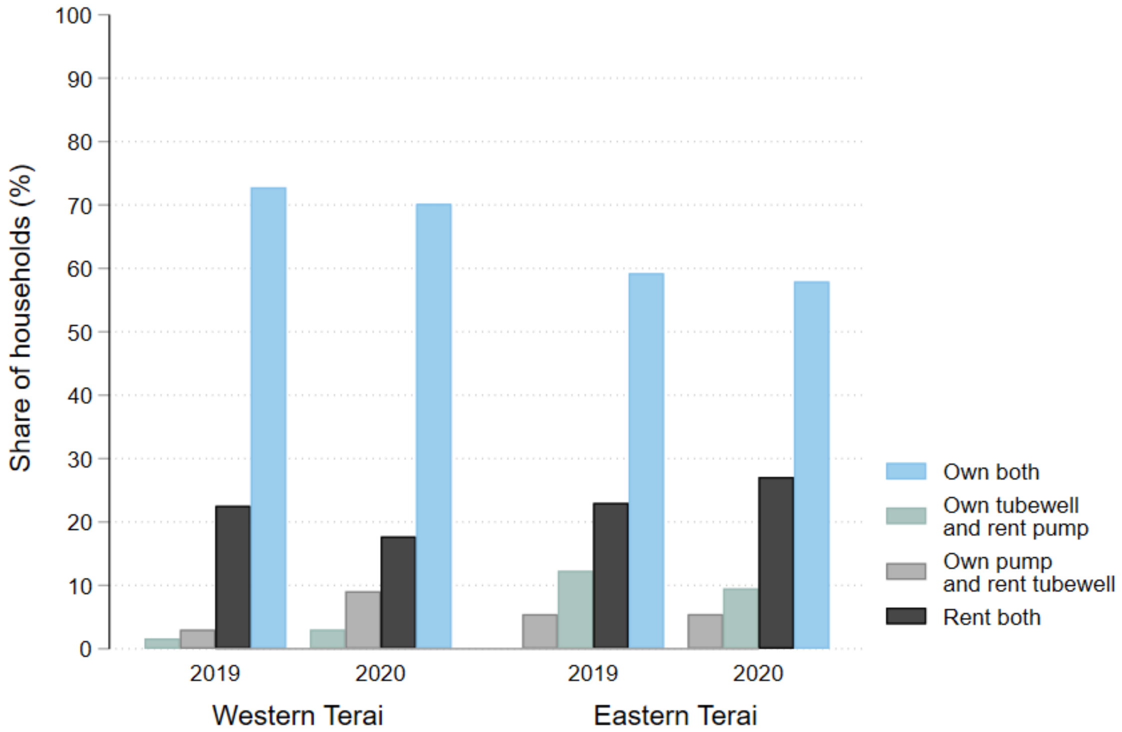

Figure 5: Distribution of tubewell and pump ownership among households who reported irrigating their field using groundwater in 2019 and 2020. [Back]

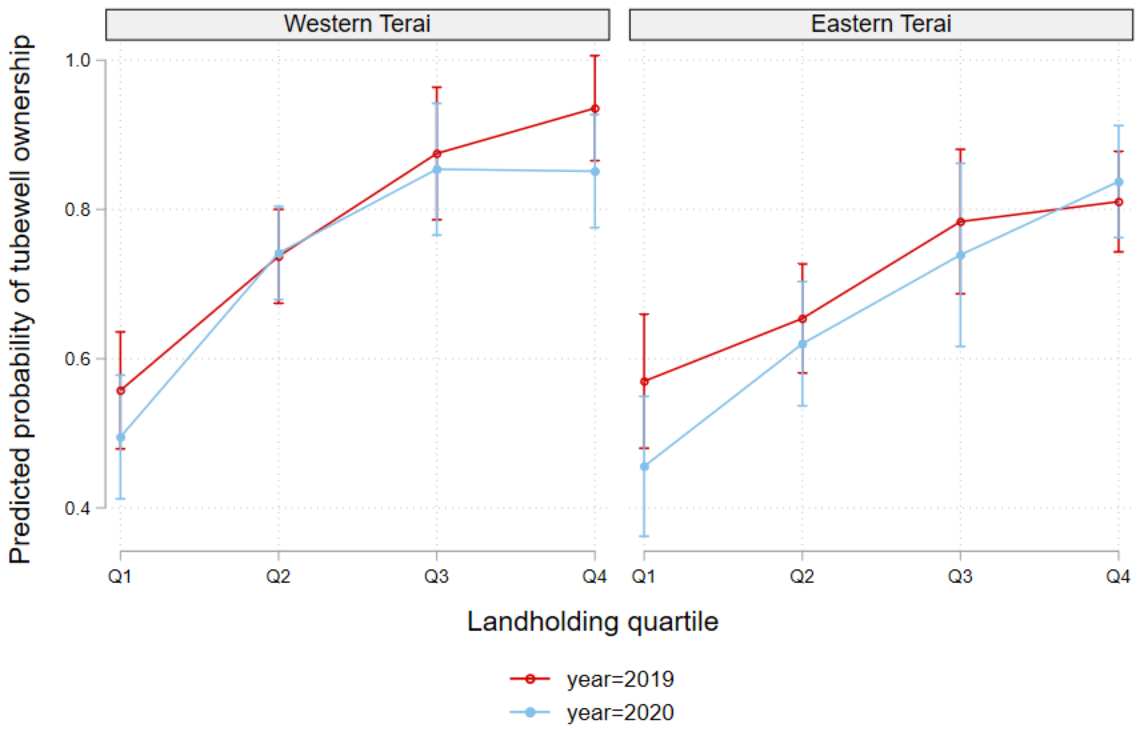

Figure 6: Predicted probability of owning or sharing a tubewell by landholding quartile and region in 2019 and 2020. Error bars show 95% confidence intervals. [Back]

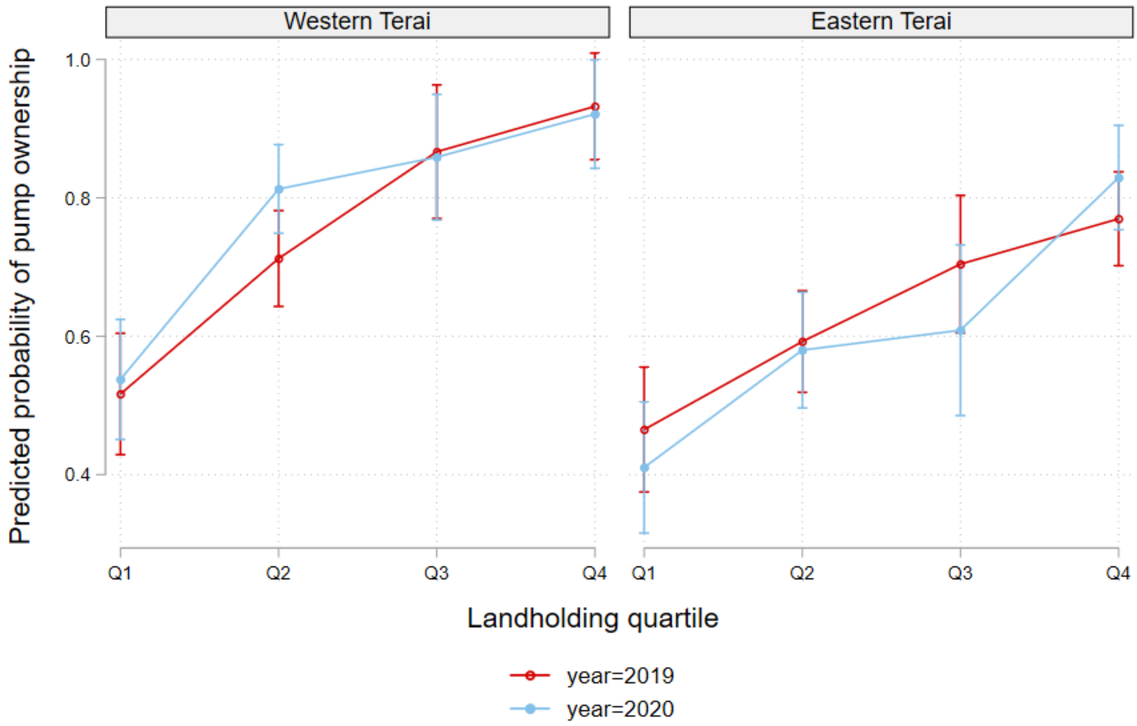

Figure 7: Predicted probability of owning or sharing a pump by landholding quartile and region in 2019 and 2020. Error bars show 95% confidence intervals. [Back]

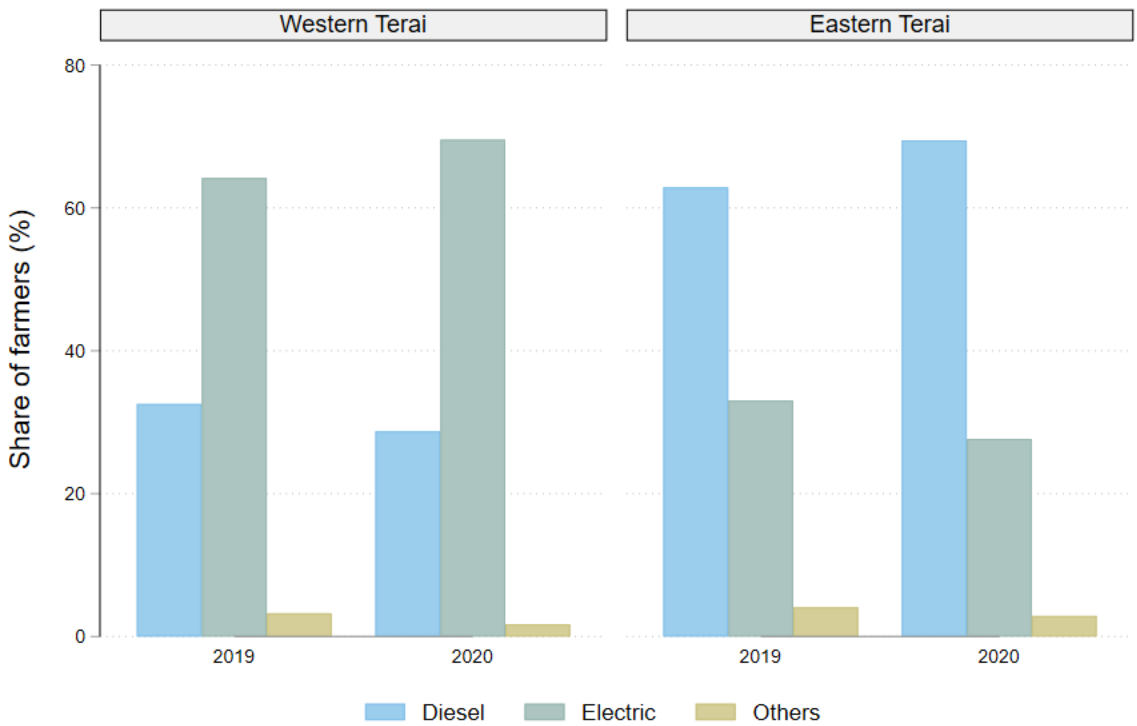

Figure 8: Share of farmers using different pump types across regions in 2019 and 2020. [Back]

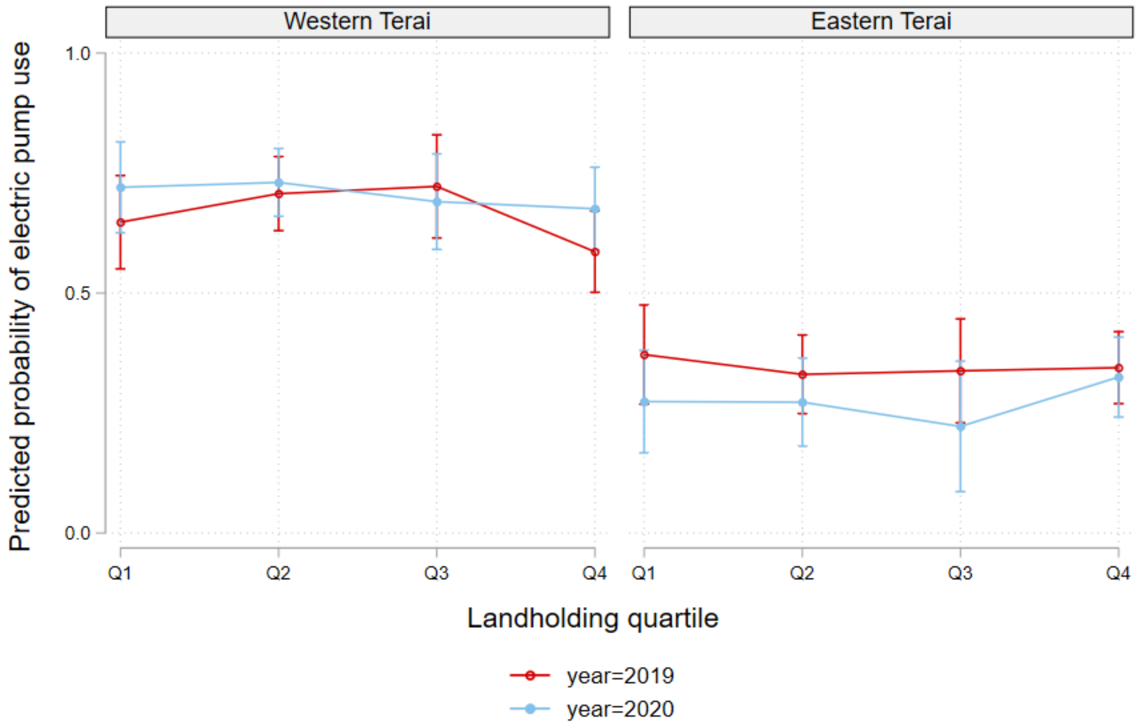

Figure 9: Predicted probability of using an electric rather than a diesel pump by landholding quartile and region in 2019 and 2020. Error bars show 95% confidence intervals. [Back]

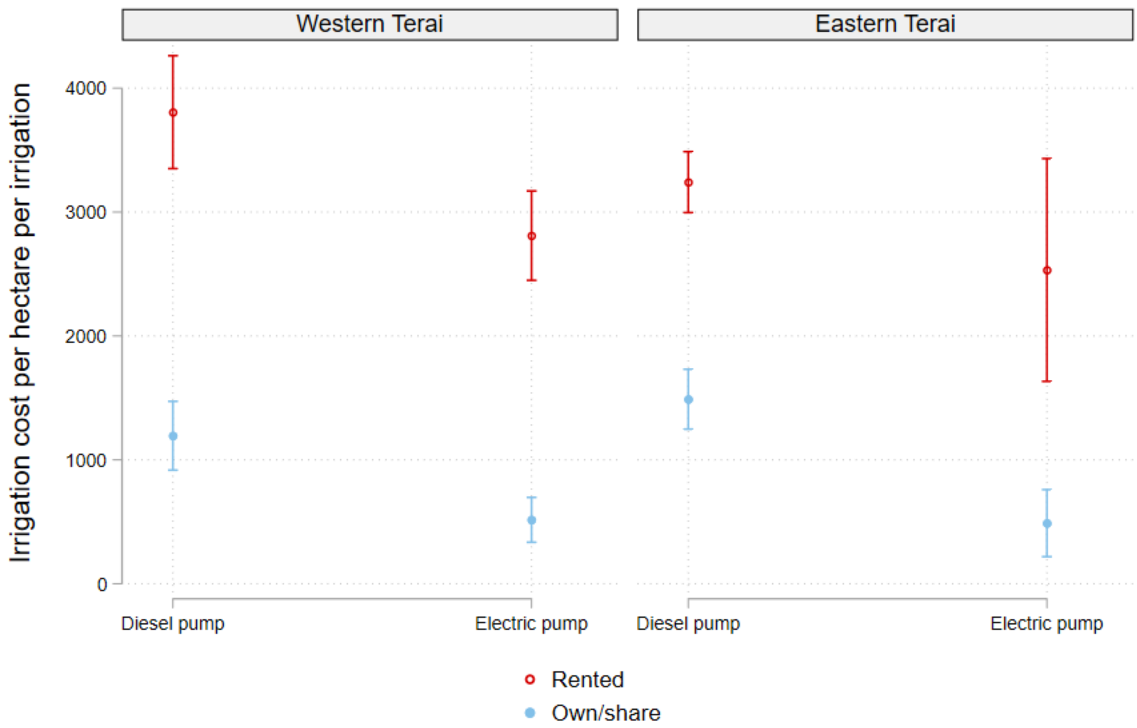

Figure 10: Irrigation cost per hectare per application by pump type and ownership status in the Eastern and Western Terai, 2019 and 2020. Error bars show 95% confidence intervals. [Back]

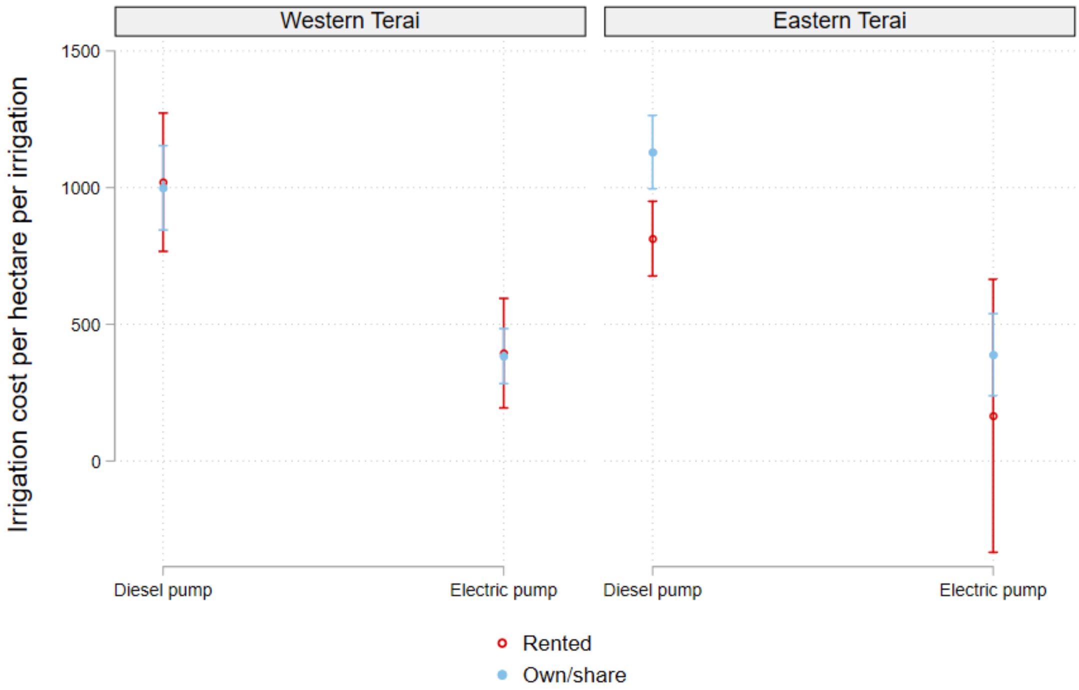

Figure 11: Irrigation fuel cost per hectare per application by pump type and ownership status in the Eastern and Western Terai, 2019 and 2020. Error bars show 95% confidence intervals. [Back]

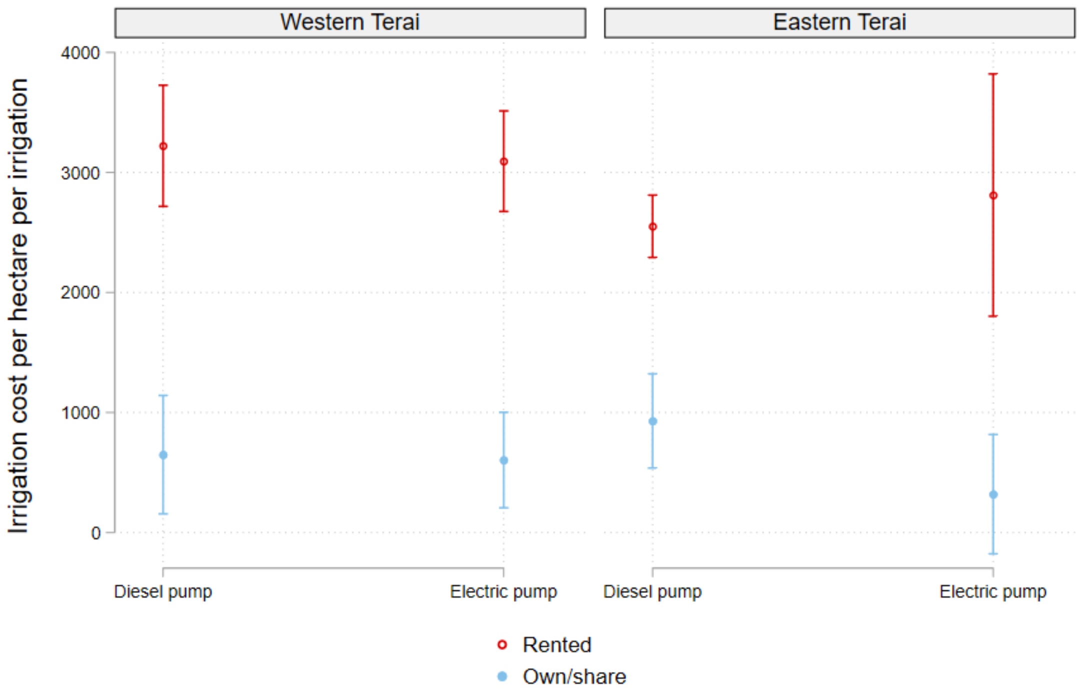

Figure 12: Other irrigation costs per hectare per application by pump type and ownership status in the Eastern and Western Terai, 2019 and 2020. Error bars show 95% confidence intervals. [Back]

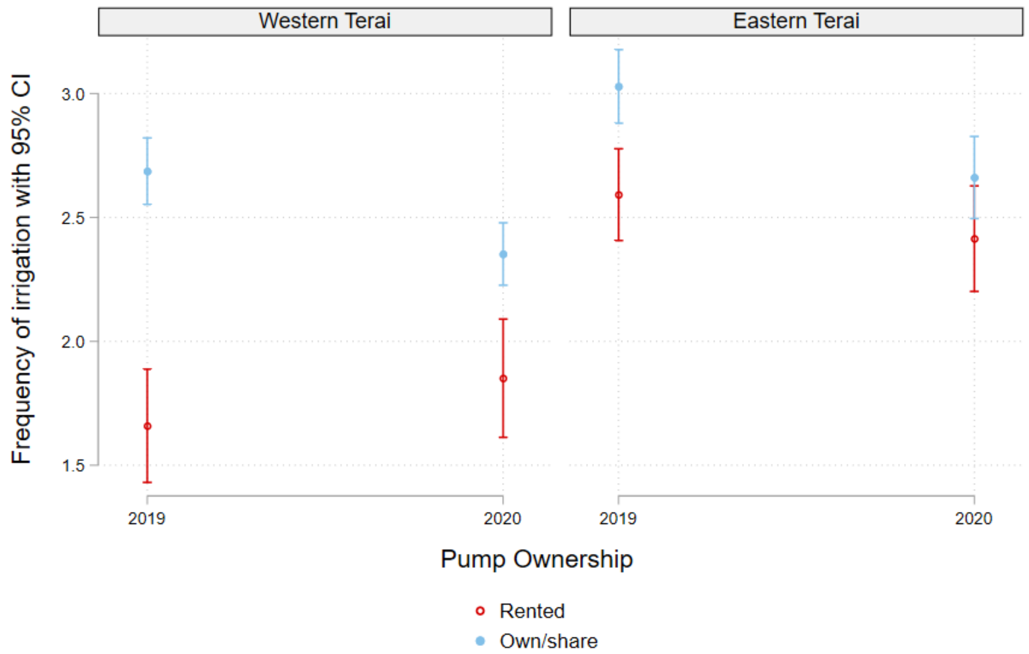

Figure 13: Average number of irrigation applications by pump ownership status in the Eastern and Western Terai, 2019 and 2020. Error bars show 95% confidence intervals. [Back]

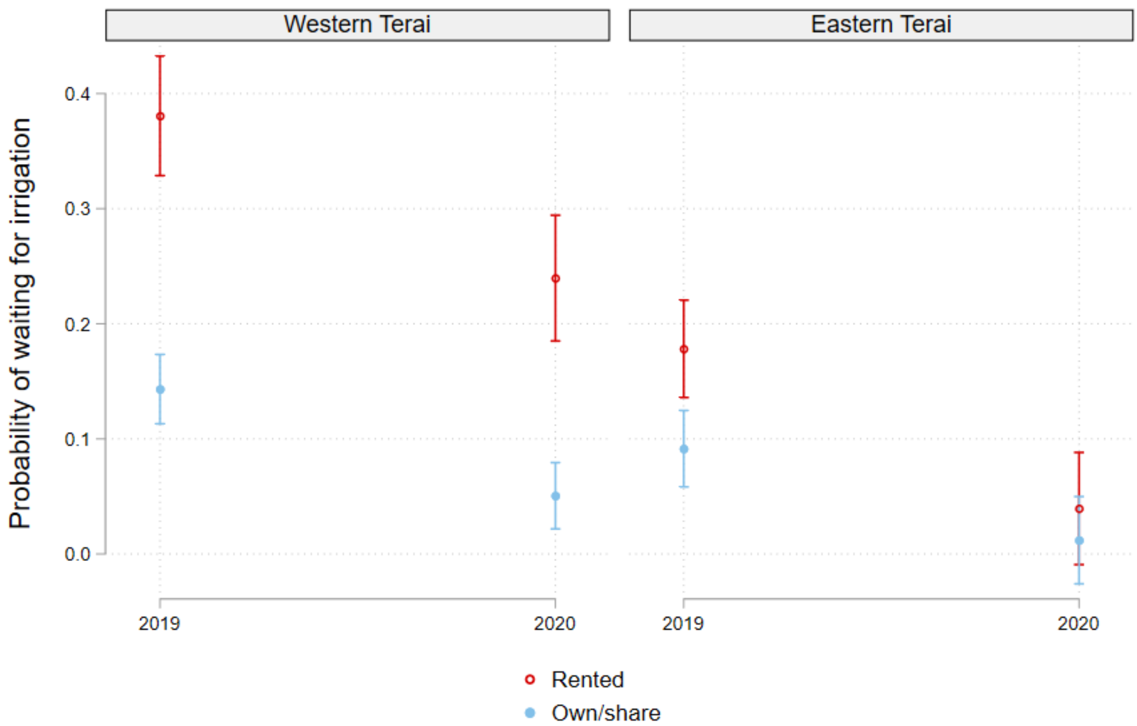

Figure 14: Factors influencing probability of waiting for irrigation in 2019 and 2020. [Back]

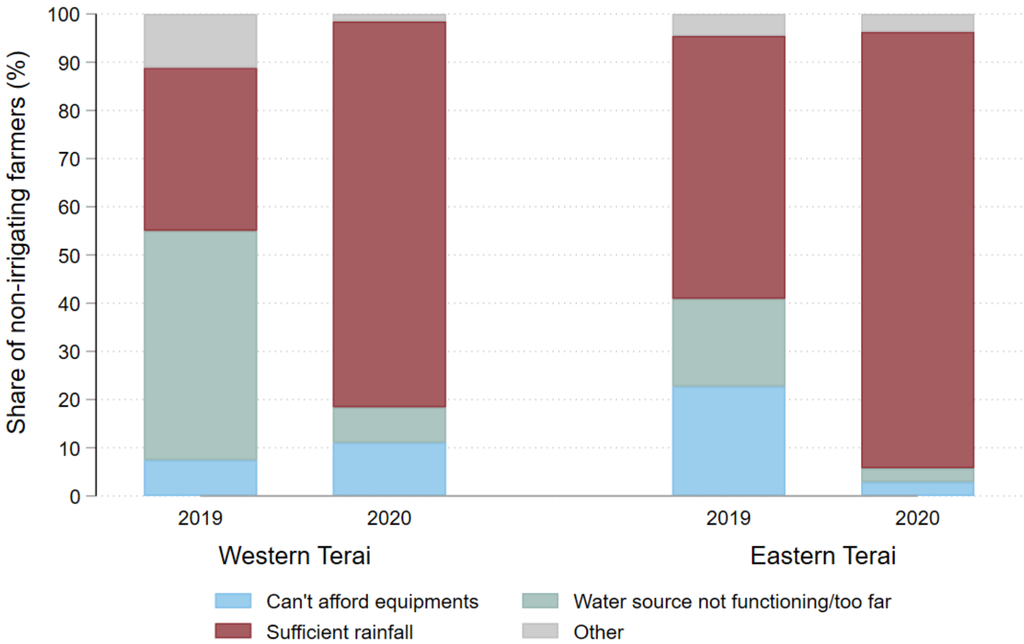

Figure 15: Reasons for not applying irrigation in 2019 and 2020. [Back]

Notes

[1]The districts included are Banke, Bardiya, Chitwan, Dang, Jhapa, Kailali, Kanchanpur, Kapilvastu, Morang, Rautahat, Rupandehi, Sarlahi, Siraha, and Sunsari. Three hilly districts—Gorkha, Parbat, and Pyuthan—were excluded because they only had data for 2019 and together account for less than 3 percent of the total observations.

[2]The CSISA rice surveys primarily cover the Terai, with less than 3 percent of observations from hill districts. Excluding these districts therefore leads to minimal data loss. In addition, data for 2020 are available only for the Terai region.

[3]Tubewells draw water from underground aquifers, and pumps are used to lift and distribute this water to the fields.

[4]If anything, our estimates are conservative, since they capture rental fees and fuel cost but likely miss other expenses, such as transport and incidental charges for irrigation.

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Appendix

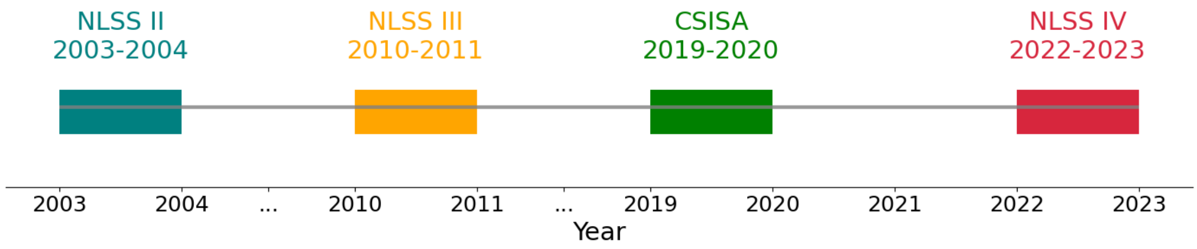

Figure A1: Timeline of datasets used in the study [Back]

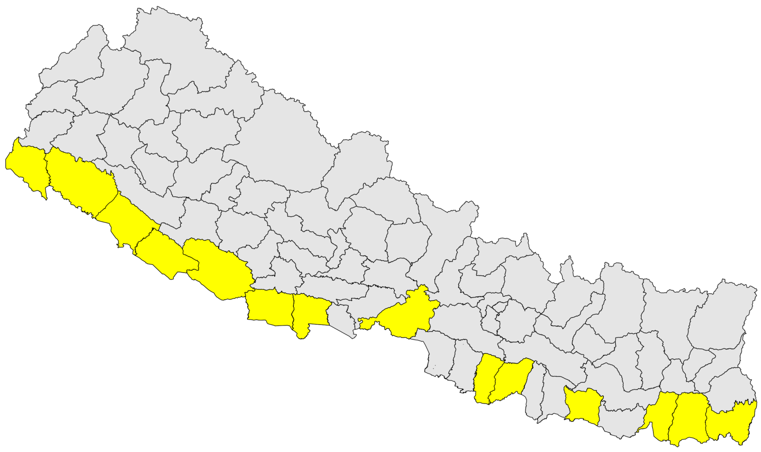

Figure A2: Districts surveyed in CSISA 2019-2020 data. The districts included are Banke, Bardiya, Chitwan, Dang, Jhapa, Kailali, Kanchanpur, Kapilvastu, Morang, Rautahat, Rupandehi, Sarlahi, Siraha, and Sunsari.[Back]

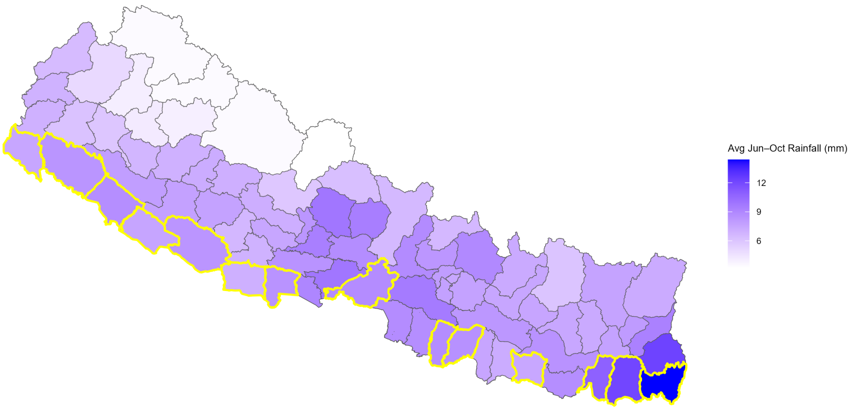

Figure A3: Mean monthly rainfall from June to October 2019, averaged across the five monsoon months to obtain a single annual measure for each district. Districts with yellow boundaries indicate surveyed areas for CSISA 2019-2020 data. [Back]

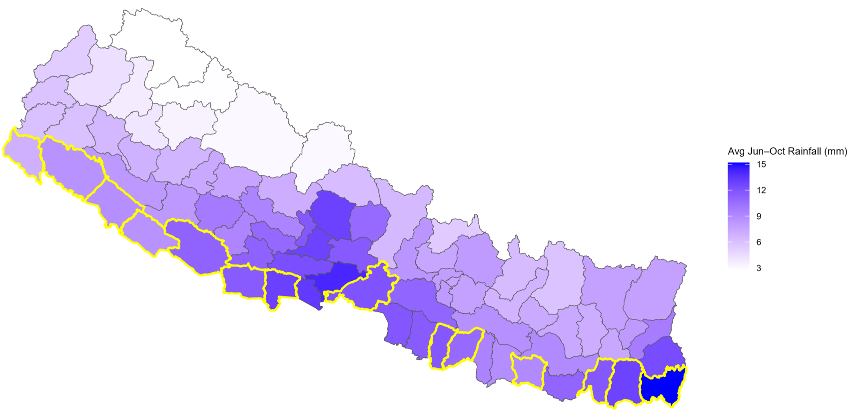

Figure A4: Mean monthly rainfall from June to October 2020, averaged across the five monsoon months to obtain a single annual measure for each district. Districts with yellow boundaries indicate surveyed areas for CSISA 2019-2020 data. [Back]

Table A1: Tubewell and Pump Ownership by Education and Sex [Back]

Category	Group	Tubewell Rented	Tubewell Own/Share	Pump Rented	Pump Own/Share
Education	Illiterate	34.54%	65.46%	35.93%	64.07%
	Primary	25.58%	74.42%	28.34%	71.66%
	Secondary	21.99%	78.01%	24.60%	75.40%
	Post-secondary	18.14%	81.86%	16.41%	83.59%
Sex	Female	22.53%	77.47%	22.41%	77.59%
	Male	27.63%	72.37%	29.67%	70.33%

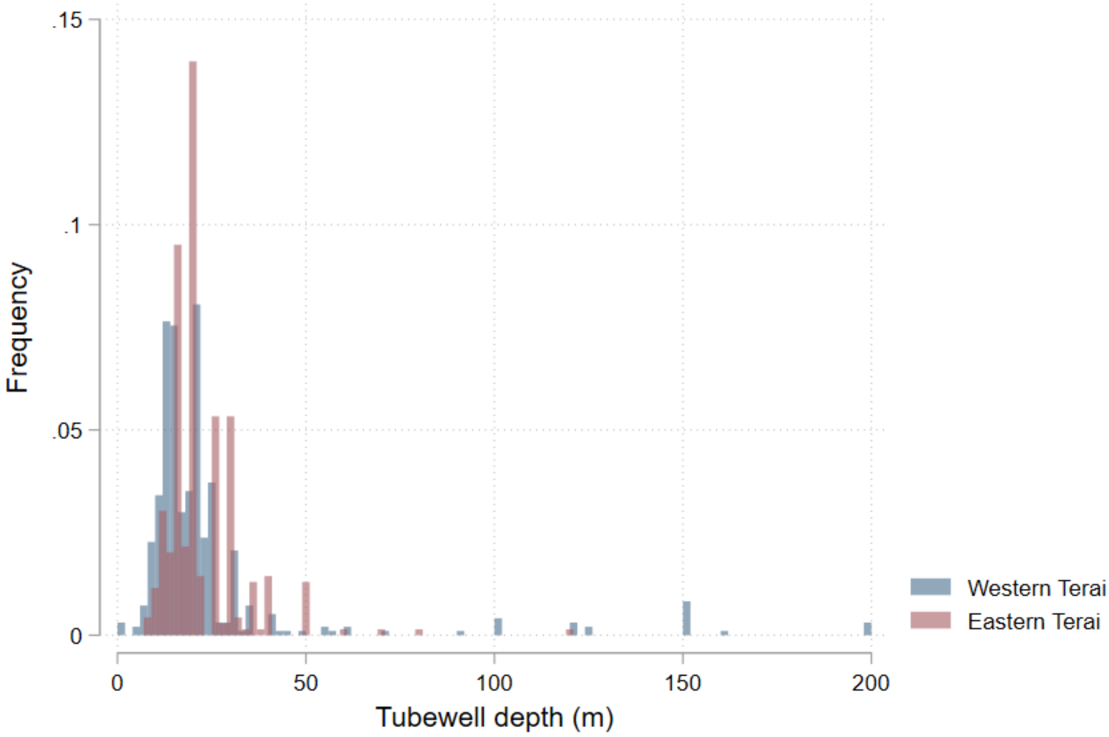

Figure A5: Overlaid histogram of tubewell depth by region. Tubewell that were deeper than 200 m (beyond the 99th percentile) were excluded for improved visibility.[Back]

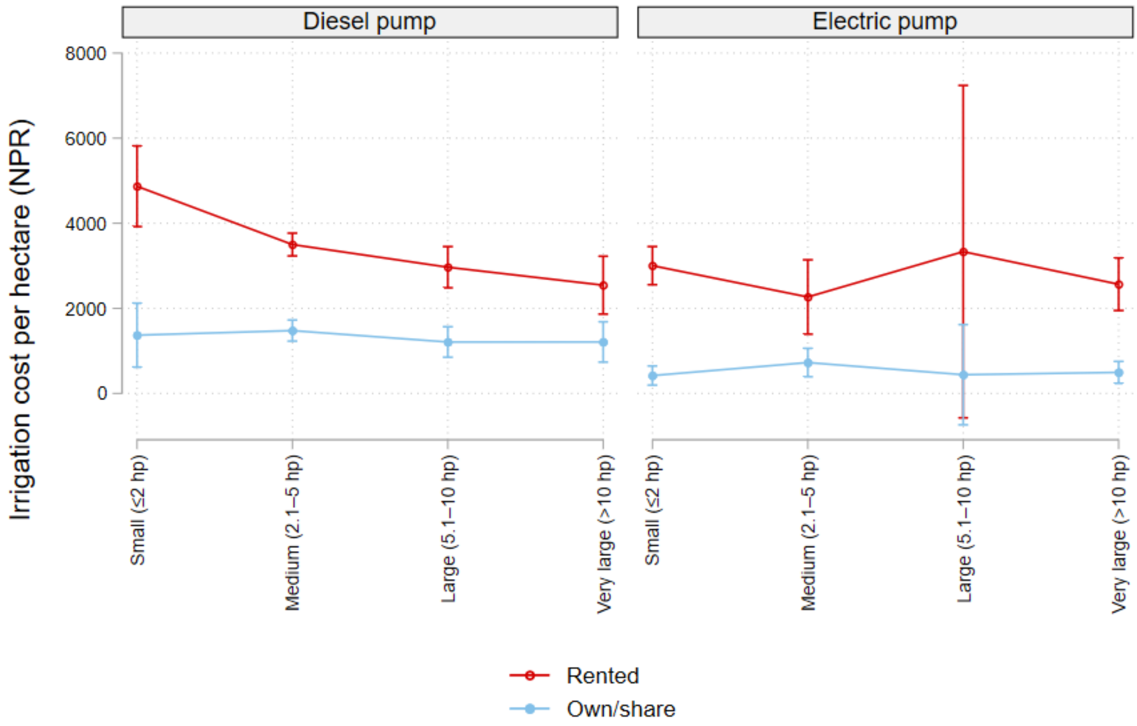

Figure A6: Irrigation cost per hectare per application by pump horsepower in 2019 and 2020. [Back]