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A comparative study of electricity, irrigation and cropping pattern in three villages of Uttar Pradesh, India

REKHA GUPTA[1,♥], JYOTI TRIPATHI[2,♥♥]
[1]Department of Economics, University of Allahabad. Senate House Campus, University Road, Old Katra, Prayagraj-211002, Uttar Pradesh, India. Tel./fax.: +91-532-2461083, ♥email: rekhaeco@gmail.com
[2]Department of Economics, Government Degree College, Kuchlai, (Affiliated to University of Lucknow, Lucknow). Sitapur – 261303, Uttar Pradesh, India. Tel.: +91-9415170204, ♥♥email: 93jyotis@gmail.com

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Abstract. *Gupta R, Tripathi J. 2025. A comparative study of electricity, irrigation and cropping pattern in three villages of Uttar Pradesh, India. Asian J Agric 9: 103-111.* India's economy, particularly Uttar Pradesh, one of its most agriculturally dependent states, heavily relies on agriculture. In the modern world, electricity plays a crucial role in every aspect of the economic and social life of the masses, and it became more vital in an agriculturist economy like India. Agriculture production and other agriculture-related activities have become increasingly dependent on the supply of electricity in recent times. Policymakers have expressed a strong desire to improve farming's certainty and reliability with improved electricity supply and by reducing reliance on monsoons for irrigation. The present work highlights this issue by elucidating how the electricity supply influences agriculture production, investment in agriculture, employment structure, and the living standards of women within an economy or community. The present study, based on a comparison of three villages in Pratapgarh District, Uttar Pradesh, India, has explored several deeper questions associated with the impact of electrification on irrigation facilities, groundwater access, and cropping patterns. The study is mainly based on primary data that has been collected during the agricultural crop year 2019-2020. Major findings of the study indicate that villages with healthier electricity supplies had higher investment in irrigation, profitable cropping patterns, and reasonable water prices. Villages with a healthier electricity supply had a higher number of groundwater irrigation sources as well as two to three times more investment in irrigation facilities than villages with a poorer electricity supply. The healthier electricity supply also has a positive impact on the employment structure of the surveyed villages and the living conditions of women.

Keywords: Agricultural production, cropping pattern, electricity supply, irrigation, water prices

INTRODUCTION

Agriculture is considered the backbone of an economy like India. Two-fifths of Indians spend over two-thirds of their earnings on food and allied commodities, which indicates the importance of the agrarian sector in India (Jha 2020). The agriculture sector has also occupied a prominent position in the Indian economic system since independence (Yadav and Gupta 2021), to which an agrarian state like Uttar Pradesh contributes more. Uttar Pradesh, being a populous state in India and having an agricultural economy, places greater importance on this sector. The agriculture sector contributes about 24% of Uttar Pradesh's Gross State Domestic Product (GSDP), and around 65% of its population depends on it for their livelihood. Uttar Pradesh is considered the top producer of food grains in the country (RBI 2023). The provision of reliable, sufficient, and affordable electricity not only plays a crucial role in agriculture production and productivity but also influences crop diversity and cropping patterns, ultimately affecting the nation's food security. Large-scale crop diversification significantly impacts the micro- and macro-food security of the rural and urban poor (Chakrabarti 2014). The debate over electricity supply and groundwater management in the farming sector is quite rich. Land and water are considered key factors for the sustainable agricultural development of a nation (Osama et al. 2017).

A number of studies can trace water charges, power reform, and water management in farming. Energy as a resource and electricity as an amenity are no exception (Nathan 2014). Studies indicate that irrigation and agriculture production are strongly associated with electricity supply. An increase in the cost of electricity adversely affects the agricultural land types (Sridharan et al. 2020) and production. Electricity subsidies have increased the production and productivity of the agriculture sector in Punjab state (Sarkar and Das 2014). Since the adoption of the green revolution policy, the government of India at the national level and the governments of different states at the local level have promoted groundwater irrigation facilities, free electricity, and subsidized irrigation equipment to increase agriculture production and productivity. The implementation of the electricity reform has led Punjab's cropping pattern to shift toward water-intensive crops such as rice and wheat (Sarkar and Das 2014).

Uttar Pradesh's cropping pattern exhibits a wide variety due to its geographical location in the fertile Gangatic plain and its ample monsoon rainfall zone. For a long time, agricultural irrigation in the state was largely dependent on the river's monsoon. However, in recent times, the state has transitioned from relying on the monsoon to groundwater irrigation, with the development of more dependable and adaptable irrigation sources. The Uttar Pradesh government has given considerable importance to the development of groundwater irrigation; therefore, groundwater extraction has rapidly increased since the adoption of the green revolution policy. Initially, the state promoted the groundwater extraction policy without any electricity reform, forcing farmers to use diesel engines. Over time, the expansion of the power sector and the rapid increase in diesel rates have led to the replacement of diesel engines with submersible engines. In Uttar Pradesh, there has been a significant shift from diesel engines to submersible engines for both irrigation and domestic purposes. In addition to irrigation, many other agricultural activities, such as sowing and harvesting, have become dependent on electricity in recent times. Many states of India have adopted a free or flat electricity policy, which has increased agriculture production and crop diversity in the respective states. Literature indicates a strong association between electricity supply, water charges, irrigation facilities, cropping patterns, and rural electrification. These factors not only enhance agricultural production and productivity but also enhance non-agricultural variables, leading to an increase in employment opportunities, household per capita income, expenditure, and living conditions (Chakravorty et al. 2014; Khandker et al. 2014; Sarkar and Das 2014; Chatterjee 2015; Dev 2016; Fishman et al. 2016; Osama et al. 2017; Xie and Su 2019). Numerous studies have mapped the relationship between electricity supply, water prices, irrigation sources, cropping patterns, and the positive impact of electricity reform policy on agricultural production and productivity as well as non-agricultural variables at the macro level, i.e., state level or national level. However, studies at the micro level, i.e., village level, are scarce, which is crucial for a large and populus state like Uttar Pradesh. Therefore, the present study aims to provide a micro-level perspective, which is crucial for developing bottom-up policies.

MATERIALS AND METHODS

Sample selection and data collection

The study is mainly based on the comparison of three villages in Uttar Pradesh, India (Figure 1). Villages have been selected using a purposive sampling method. Given our understanding, soil type and other factors such as distance from urban areas and groundwater depth significantly influence agriculture production and cropping patterns, so the selected villages for the survey have the same soil type, nearly equal groundwater depth, and are within a 5 km radius from the urban area. Three survey villages (Tardaha, Bijemau, and Pure Keshavrai) are in the Pratapgarh District of Uttar Pradesh. It is the south-eastern part of Uttar Pradesh and lies on the Allahabad-Faizabad highway. According to the Central Statistical Organization, India, the district has an area of 3730 square kilometers. The district primarily relies on agriculture as its primary source of livelihood. There are three cropping seasons in this area. The Khareef season is the first of the year. Main crops of the first season are paddy, *arhar*, maize, *till*, *chari*, black gram (*urad*), and millet. The second season is considered the rabi season, and the main crops are wheat, mustard, gram, and *matar*. Farmers primarily sow vegetables during the third season, known as *zayed*. *Arhar* and sugarcane are annual crops of the district.

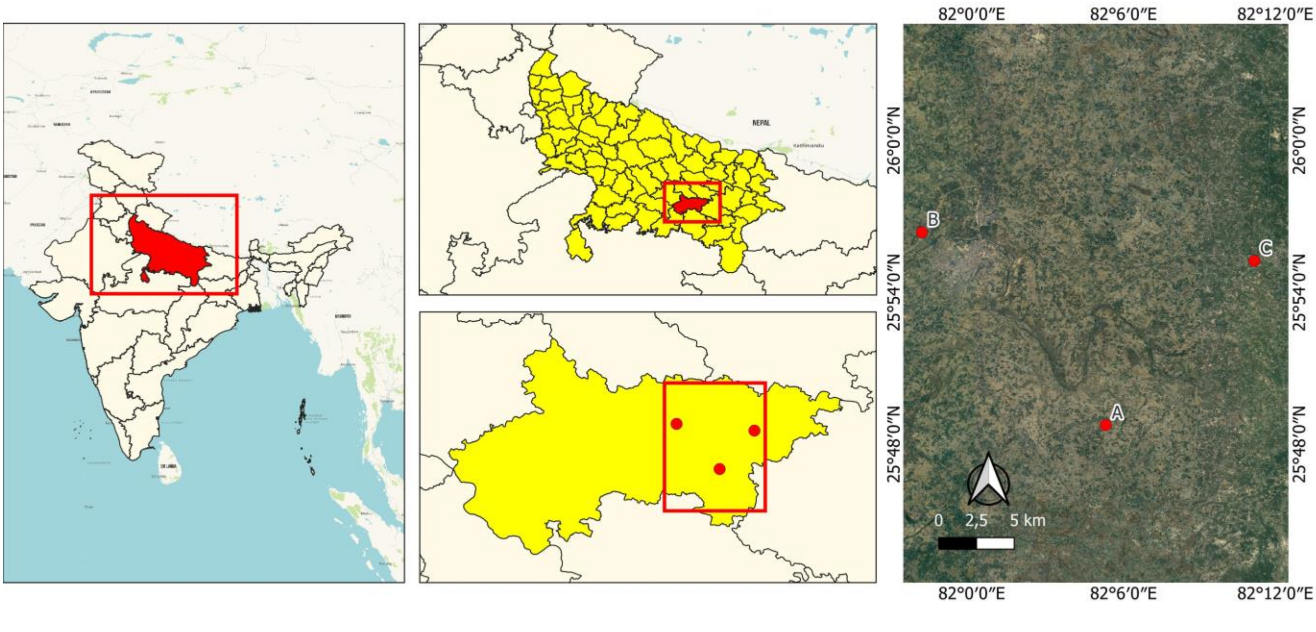

Figure 1. Study area of three villages in Uttar Pradesh, India. A. Bijemau Village, B. Pure Keshavrai Village, C. Tardaha Village

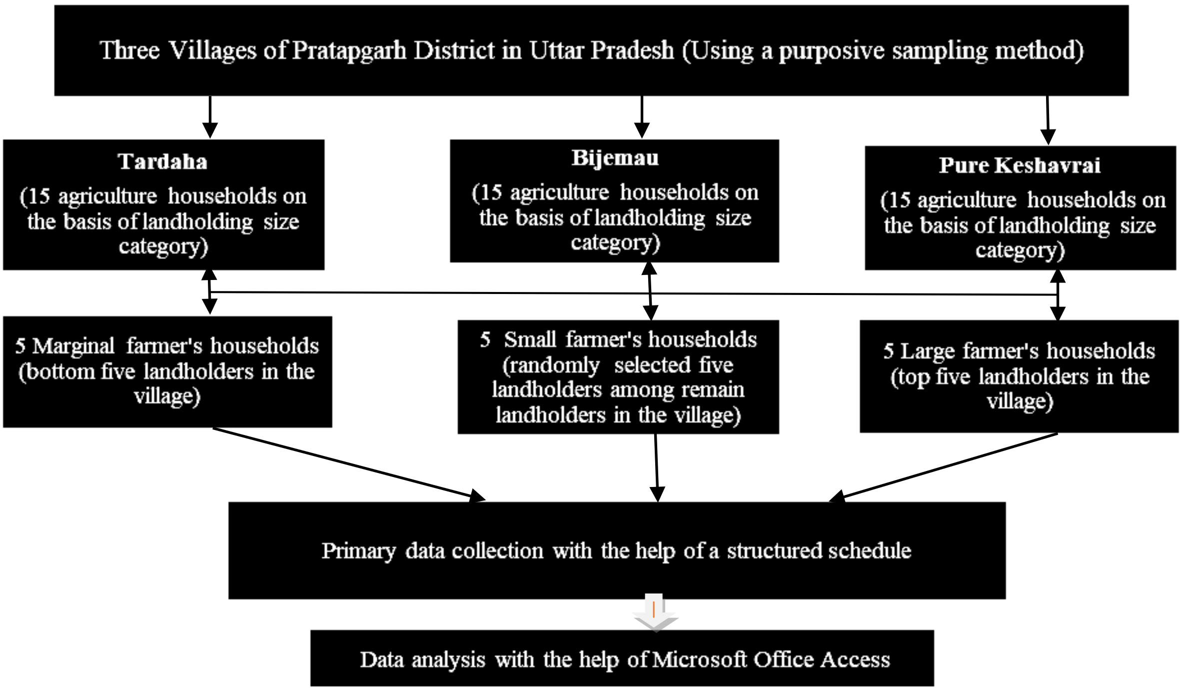

Figure 2. Summary of the primary data collection method

One of three selected villages, Tardaha, has sufficient electricity supply hours with full voltage. The second village, Bijemau, provides a 15-18 hours electricity supply, albeit at a very low voltage. At the time of survey, Pure Keshavrai, the third village, lacked full electrification. A rapid rural survey has been conducted to identify the sample villages, interviewing key informants about their electricity supply and irrigation sources. Furthermore, total 15 agriculture households have been selected from each village, representing various landholding size categories, and five from each landholding size category at the household level. All agriculture households of the village have been classified into three categories: marginal, small, and large farmer's households based on the size of their land holdings. The top five landholders in the village were considered large farmers, the bottom five as marginal farmers, and the remaining as small farmers. Among the small farmers, randomly selected five of them. For this research, primary data has been collected with the help of a structured schedule. The primary survey has been conducted during the agricultural crop year 2019-2020. A simple cross-tabulation method has been used for data analysis with the help of Microsoft Office Access. The following flowchart summarizes the primary data collection method (Figure 2).

RESULTS AND DISCUSSION

Basic information of the three sampled villages

Table 1 displays basic information about each of the three villages that were surveyed, including the number of households, their distance from the powerhouse, the number of electrified households, the depth of the groundwater, the type of soil, and the main occupation of households. This information comes from the primary survey and information gathered from the Gram Panchayats in those villages. Table 1 indicates that all three surveyed villages have almost the same (alluvial) soil type and nearly the same level of groundwater depth.

Tardaha is considered a small village with a population of only 1000 people (Table 1). The Brahmin caste, a general caste category, dominates the village. All the large farmers of the village belong to the Brahmin caste. Village has electricity connection with high voltage. Only 55 of the village's 158 households have access to electricity. The main occupations of the village are salaried jobs and self-employment; agriculture is considered a secondary occupation in the village. The village is located one kilometer away from the urban area. The village clearly demonstrates the benefits of its location. The village boasts a good school, college, hospital, petrol pump, and a well-connected road (*chakroad*) to the market. It has built a new power house in front of the village.

Bijemau is also considered a small village, with 371 inhabitants. The Brahmin caste also dominates this village (Table 1). The village has electrified 17 out of 35 households. The village has a low voltage supply. The main occupation of the village is salaried jobs, and agriculture is considered a secondary occupation in the village. The village is located 5 km from the main market, or *tahseel*, but has poor connectivity. An old powerhouse is situated in an urban area far away from the village, and only one transformer is in running condition in the village.

Table 1. Basic information of the three sampled villages in Uttar Pradesh, India, i.e. Tardaha Village, Bijemau Village, Pure Keshavrai Village

Information	Villages		
	Tardaha	**Bijemau**	**Pure Keshavrai**
Number of households	158	35	264
Electrified household	55	17	1
Voltage	High	Low	High
Distance from powerhouse	0 km	5 km	3 km
Number of transformers	1	1	0
Distance from urban area	1 km	5 km	5 km
Groundwater depth	120	165	165
Source of water	Groundwater	Groundwater	Groundwater & River
Prevalent soil type	Alluvial	Alluvial	Sandy Alluvial
Population	1000	371	3391
Main occupation	Salaried Job & Self Employment	Salaried Job	Agriculture
Secondary occupation	Agriculture	Agriculture	Labour
Dominant caste	Brahmin	Brahmin	Thakur

Pure Keshavrai can be considered a large village with a 3391 population and 264 households. The village is located on the banks of the Sai River. The river separates the village from the main city, which is only 5 kilometers away. The main occupation of the village is agriculture, and labour work is considered a secondary occupation in the village. The village has a high voltage supply but only one household has an electricity connection in the village (Table 1). Connectivity of village to urban area is very good, but other facilities are inadequate in the village. In Pure Keshavrai, there are no scheduled caste farmer's households. Only *thakur* (general caste category) and *vaishya* (backward caste category) households are in the village. None of the respondents from the all three surveyed village has reported any role of social caste or category for the quality and quantity of electricity supply.

Irrigation sources

Tardaha Village has 7 water extraction engines for irrigation purposes; Bijemau Village has 3 water extraction engines, one of which is a government electric engine for irrigation purposes, and Pure Keshavrai Village has only one water extraction engine for irrigation purposes. Surface water primarily feeds irrigation, while electricity powers it (Berardy and Chester 2017). The irrigation facility was appropriate in the Village of Tardaha. There was no government water supply in the village, but a reliable electricity supply provided irrigation source to the farmers. Each farmer had either his own diesel or electric engine or purchased power to buy water. Out of the 15 samples, 7 have their own personal water extraction source. Even marginal farmers, earning a monthly income of Rs 5,000 and living in poverty, possess their own water extraction engine. According to Master Data from Prayagraj Zone Uttar Pradesh Power Corporation, three large farmers in the village have their own agricultural electricity connection and personal tubewells. After constructing a new power house in the village, the farmers opted to use a 1-HP, 3-inch pipe machine known as a "submersible" for irrigation instead of purchasing water. Farmers in Tardaha Village reported that the cost of a 1 HP engine is approximately 9000-10000 rupees, which is comparable to the irrigation expenses for three khareef seasons.

Bijemau's Village condition appears slightly worse. The village has a government electric engine for irrigation, which runs on three-phase voltage. The village is located 5 km from the powerhouse, and it has a single operational transformer. The same engine also supplies electricity to nearby villages. The village reported approximately 15-18 hours of electricity supply but experienced significant voltage problems. In the survey year, there was not a single day when the engine delivered water. Among the 15 samples, only 2 have their own personal engine (a submersible engine that does not need a separate connection), and the rest of the farmers depend on the government electric engine. None of the farmers had an agriculture electricity connection. During the survey, voltage was so low that the 1 HP engine could not run. But in the rabi season (winter crop), voltage becomes normal and farmers get sufficient water.

The irrigation sources in Pure Keshavrai have been observed to be extremely bad. Neither government nor private irrigation sources were available in the village. Only one farmer out of the 15 had their own electricity connection and engine facility for irrigation, and there were no reports of an agriculture connection. The house of the farmers who had an electricity connection and an irrigation source was located on the main road of the village, while the remaining farmers resided within the village itself. So, it is tedious and near impossible to get water for irrigation from this engine inside the village. In spite of the village being located on the banks of the Sai River, no irrigation ways have developed to use river water as an irrigation source. The majority of farmers in Pure Keshavrai Village lack both a personal irrigation source and the ability to purchase water, so they mainly depend on rainfall for irrigation.

Investment on irrigation sources

The study indicates that power supply controls the investment in irrigation projects. In the Village of Tardaha, where power supply was good, farmers invested more in water extraction machines. Even the cost of maintenance was higher in Tardaha than in other villages. Despite the disparity in investment between small and large farmers, the study estimated the maintenance cost of old machines and investment in new equipment during the last 25 years. Among the marginal farmers in different villages, investment in water extraction machines was higher in Tardaha Village (Table 2). In Pure Keshavrai, only one farmer has invested 40,000 rupees in an engine. In Bijemau, there has been a notable lack of investment in irrigation projects. Farmers use government engines during periods of adequate electricity supply, but their personal engines become useless during periods of low voltage. Therefore, wealthy farmers who can afford large investments typically install only 1 or 5 horsepower (3-inch) pipe machines.

Groundwater access and water rate

Water is a common pool resource, and everyone should have the right to access groundwater. Equity in water resources can be measured in two ways. First, how many farmers get water, and second, how much they pay for it. For headcount measurement, cropping pattern is a useful indicator. If we compare the cropping pattern among farmers of different landholdings within a village, the same cropping pattern will show equality in water accessibility. But if resource-rich farmers choose water-intensive crops and marginal farmers cultivate dry crops, it will indicate unequal water distribution.

The study has observed a positive correlation between a reliable electricity supply and accessibility to groundwater. Tardaha was a well-developed and fully electrified village. All the farmers in the village, regardless of their size, were receiving irrigation water. Even marginal farmers prefer to set up a 1-hp small electric engine instead of purchasing water. If we compare the cropping pattern among the farmers of Tardaha Village, none of the farmers have found who had not shown the water-intensive crop paddy (Table 3). The survey reports indicate that Tardaha Village adopts the same cropping pattern not only due to cost-benefit considerations but also because animals play a significant role. Animals damage crops, leading farmers to choose the paddy cropping pattern, which is less susceptible to animal damage. However, the availability of ample irrigation water made this possible. To protect the crop from animals, some small farmers cultivated 100% paddy in the khareef season of the survey year. In Bijemau, only two farmers had personal water extraction machines. A scarcity of water prevented many farmers from cultivating paddy during the survey period. When comparing the cropping patterns of marginal, small, and large farmers in a village, it was found that the marginal farmers cultivated more dry crops than the small and large farmers. In Pure Keshavrai, the sole water seller resided on the village's main road, 500 meters away from the main tola. It became increasingly expensive and challenging to obtain water within the village. Marginal farmers in the Pure Keshavrai Village completely abandoned water-intensive farming practices. Only during the khareef season and only when the monsoon was good did the few farmers in the Pure Keshavrai Village engage in water-intensive farming. *Till*, *urad*, and millet were the main crops of the khareef season in the village. Only five farmers cultivated paddy in the survey year (Table 3).

Table 3 displays the number of farmers per category for various crop production. In Tardaha Village, all 15 farmers cultivated paddy. None of the small farmers has cultivated any other dry crop in the khareef season. Large farmers have diversified their cropping patterns more than small farmers. In Bijemau, the situation was slightly different. Large farmers were primarily responsible for paddy cultivation. Only one farmer was involved in paddy farming. In the winter season, the cropping pattern was the same in all landholding categories in both villages. In Pure Keshavrai, not a single farmer cultivated paddy during the khareef season. During the winter season, the crops produced by small and large farmers varied significantly. Water charges also measure groundwater accessibility. The irrigation water price is an indispensable element for the modernization of agriculture (Xiqin et al. 2022). Water charges across different categories and villages represent the accessibility of water in their own right. The study found that water charges were consistent across different categories of farmers but varied between villages. Table 4 attempts to capture the affordability of farmers in purchasing water. To maintain simplicity, we have excluded the cost of a self-user engine and only accounted for the water market prices. Tardaha Village holds a developed water market. The water charge for a 4-inch pipe with 5 horsepower was 120 rupees per hour for an electric engine and 150 rupees for a diesel engine. In Bijemau, only two farmers had a personal water extraction machine. They charged 100 rupees per hour for a 5-hp, 3-inch pipe engine. The water charges in Bijemau Village were significantly higher than those in Tardaha Village. In the Village of Pure Keshavrai, there existed a complete monopoly. In Pure Keshavrai, a solitary farmer operated as a seller, charging Rs. 210 per hour for a 5-horsepower, 4-inch pipe electric engine. The water charge in Pure Keshavrai Village was just 1.5 times that of Bijemau and Tardah. In Bijemau, the primary method of irrigation was through a government engine but with uncertainty. Farmers purchase water for irrigation only when power supply is not available. Therefore, the water charge in Bijemau was not particularly high. However, in Pure Keshavrai, farmers have limited options. This leads to a marked increase in the cost of water. Because of the high cost of water, poor farmers in Pure Keshavrai Village rely solely on the monsoon. Therefore, only a few farmers cultivate during the khareef season.

Table 2. Average investment on water extraction machines in the three sampled villages category-wise (in Rs.) in Uttar Pradesh, India, i.e. Tardaha Village, Bijemau Village, Pure Keshavrai Village

Category	Villages		
	Tardaha	**Bijemau**	**Pure Keshavrai**
Marginal	20,000	0	0
Small	40,000	0	0
Large	91,000	45,000	50,000
Total	1,51,000	45,000	50,000

Table 3. Category-wise number of farmers produce different crops in the three sampled villages in Uttar Pradesh, India, i.e. Tardaha Village, Bijemau Village, Pure Keshavrai Village

Crops	Tardaha			Bijemau			Pure Keshavrai		
	Marginal	Small	Large	Marginal	Small	Large	Marginal	Small	Large
Paddy	5	5	5	1	4	4	0	2	3
Till	0	0	3	3	0	4	5	4	3
Urad	0	1	3	4	5	4	1	2	4
Millet	0	0	2	4	5	4	0	3	5
Wheat	4	5	5	5	5	5	1	4	5
Mustard	0	2	5	4	4	5	5	4	3

Table 4. Number of water extraction machines and water rate in the three sampled villages in Uttar Pradesh, India, i.e. Tardaha Village, Bijemau Village, Pure Keshavrai Village

Indicator	Villages		
	Tardaha	Bijemau	Pure Keshavrai
Number of water extraction machines	7	3	1
Water rate (in Rs. Per hour)	120	100	210
Type of machine	4 inch/5 hp	3 inch/5 hp	4 inch/5 hp
Number of water sellers	5	2	1

Cropping pattern

Factors such as cost, benefit, and natural resources determine the cropping pattern. Natural resources directly influenced the cropping pattern in Tardaha Village. A full-voltage supply facilitates the extraction of water. Farmers have been cultivating paddy, a crop that is becoming increasingly profitable. Paddy is a more profitable crop, and animals inflict less damage on it than other crops, posing the biggest challenge in agriculture today. Each of the 15 farmers has cultivated paddy during the khareef season. Large farmers sow paddy on about 25% of their total agricultural land. Even small farmers cultivated only paddy during the survey year, despite the monsoon being late. The study encompassed 17.65 hectares of agricultural land, with approximately 57% of it dedicated to paddy cultivation in khareef season. Only the cost-return ratio influences cropping patterns in the rabi season. Farmers cultivate wheat, mustard, and pulses. Farmers cultivated wheat on approximately 58% of the total land and mustard on approximately 21%. On the remaining land, pulses are cultivated.

In Bijemau, the cropping pattern closely resembles that of the Village of Tardaha during normal years. But in the survey year, monsoon was late, and electricity supply was poor in the village. Farmers could not get sufficient water for irrigation. Due to the low groundwater level in the village, diesel engines were unable to extract sufficient water for irrigation. Large farmers cultivated paddy with *moong*, *urad*, *till*, and *arhar*, while marginal farmers who could not manage water for irrigation cultivated *urad*, *moong*, and *till*. The study encompassed 11.42 hectares of land in the village, with approximately 31% dedicated to paddy cultivation. The village cultivated about 20.13% *urad*, 8.40% *till*, and 18% *bajra*. According to the farmers' information, the cropping pattern during the last rabi season resembled that of the Village of Tardaha.

The cropping pattern in Pure Keshavrai Village was notably unique. Farmers were totally dependent on the monsoon for their agriculture. Among the 15 sampled farmers, only 5 had sown paddy. All the paddy farmers were considered marginal farmers. *Till*, *bajra*, and *urad* were the main crops during the khareef season. The study covered 4 hectares of village land, of which 10.12% contained *urad*, 16.17% *till*, 16% *bajra*, and only 29% paddy. During the rabi season, wheat and mustard were the main crops. The cropping pattern for winter crops was almost identical to that of Bijemau. Some farmers were farming only in the khareef season/rainy season (Figure 3).

Impact on employment structure and living conditions of women

In the modern world, electricity touches every aspect of life, directly or indirectly. It affects not only luxuries or electronic goods, but it also plays an important role in structuring society and the economy. The employment structure primarily impacts a society or economy. The electricity supply significantly influences the restructuring of employment opportunities. Electricity enhances business and self-employment opportunities in rural areas within the primary sector and other sectors. The quality of electricity increases the non-agricultural incomes of rural households (Chakravorty et al. 2014).

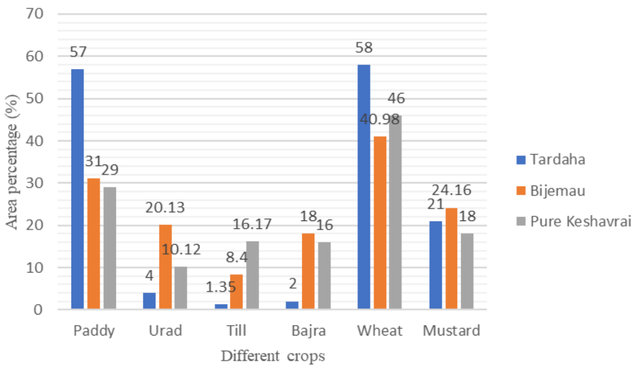

Figure 3. Area percentage (%) under different crops in the three sampled villages in Uttar Pradesh, India

In the Village of Tardaha, the employment pattern is diversified. Agriculture is a secondary source of income in the village. Among the 15 sampled households, 9 have either a regular job in the government or private sector, or they are self-employed. Many farmers owned rice mills, flour mills, and oil extraction machines, while some larger farmers also sold water. One farmer even owned a small cafeteria. Among large farmers, only one's primary occupation was farming. However, he was also involved in various agriculture-related businesses, such as cultivating straw and operating tractors. The overall analysis shows that the availability of adequate electricity has given villagers opportunities to explore self-employment. The occupational structure in Bijemau bears a striking resemblance to that of Tardaha. Bijemau is almost similar to Tardaha. The availability of electricity has significantly enhanced the employment opportunities in the village of Bijemau. The Agarbatti and Dhoopbatti factories were operating efficiently in the village, offering approximately 6-7 workers employment opportunities. Rich and large farmers earn approximately Rs 10,000 per annum from the sale of water. Two farmers operate a flour mill and a rice mill in the village. However, in Pure Keshavrai, the occupational pattern differed significantly. The majority of the farmers were engaged in agriculture. Among 15 sampled households, 11 households' main occupation was farming. The remaining households primarily engage in labor in urban areas of Uttar Pradesh or other states. Not a single farmer was associated with business or self-employment. Income levels among the villagers were very low compared to Tardaha and Bijemau Villages. Rural electrification increases household per capita income and expenditure (Khandker et al. 2014).

Electricity has a significant impact on women. In the Village of Tardaha, women recounted their experiences after the installation of a water extraction engine. The women from affluent families expressed that they no longer rely on male family members to fetch water from outside their homes. Households that had installed a handpipe within their premises reported that women were solely responsible for fetching water from the handpipe—a task that required significant time and energy. However, the installation of a water extraction engine has saved their time and energy. Women from scheduled castes have expressed that they no longer have to carry water from others homes, which can sometimes be embarrassing. Therefore, we can easily assert that a proper electricity supply contributes to the improvement of women's living standards and saves time and energy. In the Village of Bijemau, the situation was nearly identical. Only in the summer season, when electricity supply becomes poor, do women face the problem of water drawing from handpipes or wells. In Pure Keshavrai, only one household has a water extraction engine. None of the farmers has a personal hand pump, as the water table is low in the village. The village only has two government handpipes, known as *'Indiamarka'*, installed among 20-25 families. Needless to say, the water burden falls either on women or female children of the family.

Discussion

A brief comparison of three villages in Uttar Pradesh having a limitation of very small sample size, only three villages and fifteen households from each village, using purposive sampling, provides insight that different stages of electricity indicate the profound impact of electricity on the agriculture sector and non-agriculture variables like employment structure and living standard of women. The study found that electricity supply is highly associated with capital investment in irrigation sources, water prices, and cropping patterns. Villages with a healthier electricity supply had a higher number of groundwater irrigation sources, like Tardaha Village. Tardaha Village, with a healthier electricity supply, invests two to three times more in irrigation sources than Bijemau and Pure Keshavrai Villages, with a poorer electricity supply. In Tardaha Village, which has a healthier electricity supply, the water charges are also relatively low, further reducing the variable cost of farming. The study also demonstrates that government intervention in Bijemau Village maintains control over the water price market, but the supply of irrigation water remains uncertain due to inadequate electricity. In Bijemau, the primary irrigation source relied on a government engine, but it was fraught with uncertainty. The power house is located 5 km away and is shared with another village, resulting in a very poor quality of electricity supply in Bijemau Village. Due to the uncertainty of irrigation water, marginal farmers in Bijemau Village are less engaged in water-intensive crops such as paddy. Additionally, the area covered by paddy crops in Bijemau Village is smaller than that of Tardaha Village, which enjoys a healthier electricity supply. Bijemau Village is not experiencing better outcomes due to socio-political factors, but rather due to its poor electricity supply. Therefore, a bottom-up electricity reform policy necessitates that the government implement measures to regulate water prices and enhance irrigation sources to ensure a sufficient supply of water. This will protect marginal and small farmers from excessive irrigation expenses. An improvement in irrigation facilities can increase agricultural production and productivity (Yadav and Gupta 2023), and the impact of this is also evident in the cropping pattern. Villages with a healthier electricity supply, like Tardaha, tend to cultivate more profitable and water-intensive crops such as wheat and paddy, which provide farmers with significant benefits in terms of agricultural production due to their minimum support price and year-round demand.

The present study also found that not only does a healthier electricity supply benefit the agriculture sector, but it also positively impacts non-agricultural variables like employment opportunities and the living condition of women. Free electricity supply has a positive income effect in Andhra Pradesh, which may lead to increased expenditure on education and consumption rather than investment in agriculture (Chatterjee 2015). High production and productivity, with the help of healthier electricity supply, have a long-term impact. Villages like Tardaha, which enjoy a healthier electricity supply and higher income, actively explore new self-employment and business opportunities within their village. Whereas villages have poor electricity supply like Pure Keshavrai, people are forced to explore employment opportunities in the urban areas of the state or in other states. In the Village of Tardaha, women shared their experiences following the installation of a water extraction engine. They reported a reduction in their reliance on male family members for water, as well as a reduction in the time they spent fetching water.

Therefore, we can assert that a healthier and more efficient electricity supply plays a crucial role in agricultural production and productivity as well as non-agricultural variables like employment structure and the living conditions of women, but unregulated electricity supply also poses several challenges. Overuse of water for crop production is one of the main causes of water scarcity in major economies of South Asia (Mitra et al. 2017). Due to overexploitation, Punjab and Haryana states are facing severe water crises (Rosencranz et al. 2021; Gupta 2023; Khara and Ghuman 2024). The negative effects of the free electricity policy on underground water raise several questions about the effectiveness of both the free electricity policy and its reform. Research suggests that sustainable agriculture development requires electricity reform, but it also necessitates proper water management. The problem is not a shortage of water but the absence of proper mechanisms, distribution, and efficient use (Dev 2016). Efficient pricing of water and energy can lead to a more efficient allocation of water in developing countries, such as India (Fishman et al. 2016). Many studies indicate that in recent years, the adoption of proper water mechanisms, efficient water use through water-saving irrigation methods, and reasonable water pricing has increased the groundwater level. Due to the introduction of paddy as the main kharif crop, Punjab and Haryana became water-scarce states after the Green Revolution, but improvements in water use efficiency have increased the water level (Gill 2016). Due to a severe groundwater overexploitation problem in Hebei, the province of China has adopted a water-saving agricultural irrigation system and improved water use rights and water pricing systems (Lilia et al. 2020). The reform of agricultural water prices is essential for social stability and serves as a primary tool to encourage the rational use of water resources (Xie and Su 2019). The drip irrigation method, a water delivery method that slowly drips water into the soil or directly into the roots of plants, can be considered the most water-efficient for irrigation if managed properly (Reddy 2017). A number of studies also indicate that reasonable water pricing and monetary incentives reduce electricity consumption (Sudarshan 2017) and enhance water conservation. The reasonableness of the water price has a direct influence on people's attitude, behavioral decision regarding willingness to pay, and motivation for water conservation in China (Mu et al. 2019). Farmers of Punjab prefer the policy with a reward for consuming less electricity rather than the free and unmetered electricity policy (Kaur and Pollitt 2024).

Uttar Pradesh is a populous state of India, and the agricultural production demand, mainly for main and water-intensive crops like paddy and wheat, is not going to decline in recent times; even their demand will increase day by day. Therefore, the entire study emphasizes the need for a bottom-up policy (a policy from micro unit) that not only provides an efficient and reliable irrigation source along with a proper electricity supply and reasonable water prices but also equips farmers with proper irrigation management knowledge and training to prevent future water crises in the state.

In conclusion, the study concludes with the finding that the quantity and quality of electricity supply, water prices, and reliable irrigation sources play a vital role in increasing production and productivity of the agriculture sector with the help of groundwater extraction. It also helps to promote employment opportunities at the local level and improve the living conditions of women. Many of the agricultural states of India, like Uttar Pradesh, have used power reform policy as a tool to increase agricultural production, manage the cropping pattern, and control water prices. However, overextraction of underground water can lead to a water crisis. Therefore, it's crucial to use water efficiently to boost agricultural production and productivity, which can be achieved through appropriate bottom-up electricity reform policy, water-saving irrigation technology, and government intervention.

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