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RESEARCH ARTICLE

Impact of electrically operated tubewells on water use, water productivity and profitability of major crops in Gorai village, Samastipur district of Bihar

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Abstract

A field study was conducted in Gorai village of Kalyanpur block, Samastipur district, to evaluate the economic and water-use efficiency of electric versus diesel-operated tubewell irrigation systems across major crops. The study encompassed 20 farmers and analysed multiple parameters including water productivity, irrigation costs, crop profitability and water balance. The irrigation water productivity values were highest for *kharif* maize at 7.77 kg/m^3, followed by wheat (1.95 kg/m^3), *spring* maize (1.45 kg/m^3), *rabi* maize (1.01 kg/m^3) and paddy (0.79 kg/m^3). In terms of gross water productivity, wheat showed the highest efficiency at 1.69 kg/m^3, followed by *rabi* maize (0.95 kg/m^3), *spring* maize (0.89 kg/m^3), *kharif* maize (0.74 kg/m^3) and paddy (0.44 kg/m^3). Economic analysis revealed that diesel pump irrigation costs were substantially higher than electric pump costs, ranging from 30 to 37 times more expensive across crops. This cost differential significantly impacted profitability, with electric pump users achieving higher profits of 22 % more for paddy, 13 % for *rabi* maize, 7.8 % for wheat, 4 % for *spring* maize and 2 % for *kharif* maize. The study demonstrates that crop selection and irrigation technology choice are critical factors for optimizing both water use efficiency and farm economics. While electric tubewells demonstrate clear economic advantages, the extremely low electricity tariffs (₹ 0.75/unit) raise sustainability concerns regarding potential groundwater overextraction, necessitating integrated groundwater governance frameworks.

Keywords: CROPWAT model; coordinate method; gross water productivity; irrigation water productivity

Introduction

Irrigation is one of the important inputs for crop production. Groundwater is the major source of irrigation in India for crop production. The net irrigated area in the country is 79.31 m ha and the share of the tube wells irrigated area is 49.34 %. Groundwater is a vital resource for irrigation in India, with electrically operated tubewells playing a crucial role. This has been studied in various contexts, including the estimation of crop water requirements for rice-wheat and rice-maize cropping systems using the CROPWAT model (1). Bihar represents a unique case of economic development with significant agricultural challenges, despite its abundant natural resources. The state, with 90 % rural population and 94163 km^2 area, has a population density of 1365 persons/km^2, far exceeding the national average of 325 persons/km^2 (2). The region is predominantly underlain by Gangetic alluvium, covering 90 % of the geographical area, which creates favourable conditions for agriculture and groundwater resources (3). The state currently utilizes groundwater for approximately 65 % of its gross irrigated area, supported by 0.69 million shallow and 1700 deep tube wells according to the Central Ground Water Board (CGWB). The total annual groundwater recharge is 33.96 billion cubic meter (BCM), with a net availability of 30.72 BCM after accounting for natural discharge. The total groundwater draft was 13.75 BCM and the stage of groundwater development is about 41.66 %, compared to the national average of 59.26 %. This development has largely been driven by private farmer investment and the emergence of groundwater markets (4). The 6th Minor Irrigation Census indicates that the number of minor irrigation schemes in the state is 693634, with the majority of schemes 76.9 % (533615) schemes are using diesel pumps as the energy source, followed by electricity in 17.0 % (117590 schemes) (4). The high cost of irrigation has severely limited agricultural productivity in Bihar. Rather than irrigating their fields, farmers typically either let their land remain unused or rely on rainfall to grow crops like mung beans and fodder. This is reflected in the stark statistic that only 3 % of Bihar's *kharif* (monsoon season) agricultural land is cultivated during the summer months (5). Transforming Bihar's agricultural sector through a green revolution hinge critically on making irrigation more affordable for farmers. Recent studies have highlighted the transformative potential of electric tubewells in agricultural irrigation. Research indicates that farmers with access to electric pumps increased their cropping intensity by 40 % compared to those using diesel pumps (6). Similarly, research indicates that electric tubewell adoption in Gujarat led to a 35 % reduction in irrigation costs and a 25 %

increase in farm income (7). The shift from diesel to electric pumps has shown particular promise in Bihar. Research also indicates that electric tubewell user achieved 30-45 % lower irrigation costs compared to diesel pump users (8). However, they also cautioned about the need for proper groundwater management practices to ensure sustainability. Groundwater sustainability has become increasingly important in the context of electric tubewell adoption. Research indicates that a comprehensive analysis of groundwater depletion patterns in areas with high electric tubewell density highlights the need for balanced extraction policies (9). This concern was further emphasized in an integrated framework for sustainable groundwater management in regions transitioning to electric irrigation systems.

A critical issue emerges from the low electricity costs in the agricultural sector (₹ 0.75 per unit), which may lead to unsustainable groundwater extraction. The research aims to address the intersection of sustainable aquifer management and agricultural profitability by assessing water productivity in electrically irrigated crops, comparing irrigation costs between electrical and diesel-operated systems and analysing crop profitability in specific regions (e.g., Gorai village, Samastipur District). The research aims to address the intersection of sustainable aquifer management and agricultural profitability, particularly important given Bihar's heavy reliance on groundwater resources for agricultural development and poverty alleviation.

Materials and Methods

This chapter deals with the materials and methods used during the experimental projects. It includes data collection, analytical tools and experimental methodology.

Study area description

The study was conducted in Gorai village (25.96 °N, 85.69 °E) of Kalyanpur block, Samastipur district, Bihar, India. The village, situated on the bank of the Burhi Gandak River, has a total agricultural area of 210 ha and a population of 3473, the study area shown in Fig. 1. The soil is predominantly sandy loam, with groundwater serving as the main irrigation source. The prevalent cropping patterns include rice-wheat, rice-*rabi* maize, maize-wheat, maize-*rabi* maize and rice-potato sequences. The agricultural calendar for major crops in the study area is shown in Table 1.

Data collection

The study utilized both primary and secondary data sources. Primary data was collected through a structured questionnaire administered to 20 randomly selected farmers in Gorai village during the agricultural year 2021-22. The questionnaire captured comprehensive information about agricultural input usage, irrigation water consumption patterns and crop output data for major crops in the region. Secondary data was obtained from multiple institutional sources. Climate-related parameters were sourced from the Centre for Advanced Studies on Climate

Table 1. Sowing and harvesting months for major crops of the study area

S.No.	Name of crop	Transplanting/sowing month	Harvesting month
1.	Wheat	November	April
2.	Paddy	June-July	November
3.	*Rabi*-Maize	November	May
4.	*Kharif*-Maize	June-July	October
5.	*Spring*-Maize	February	June

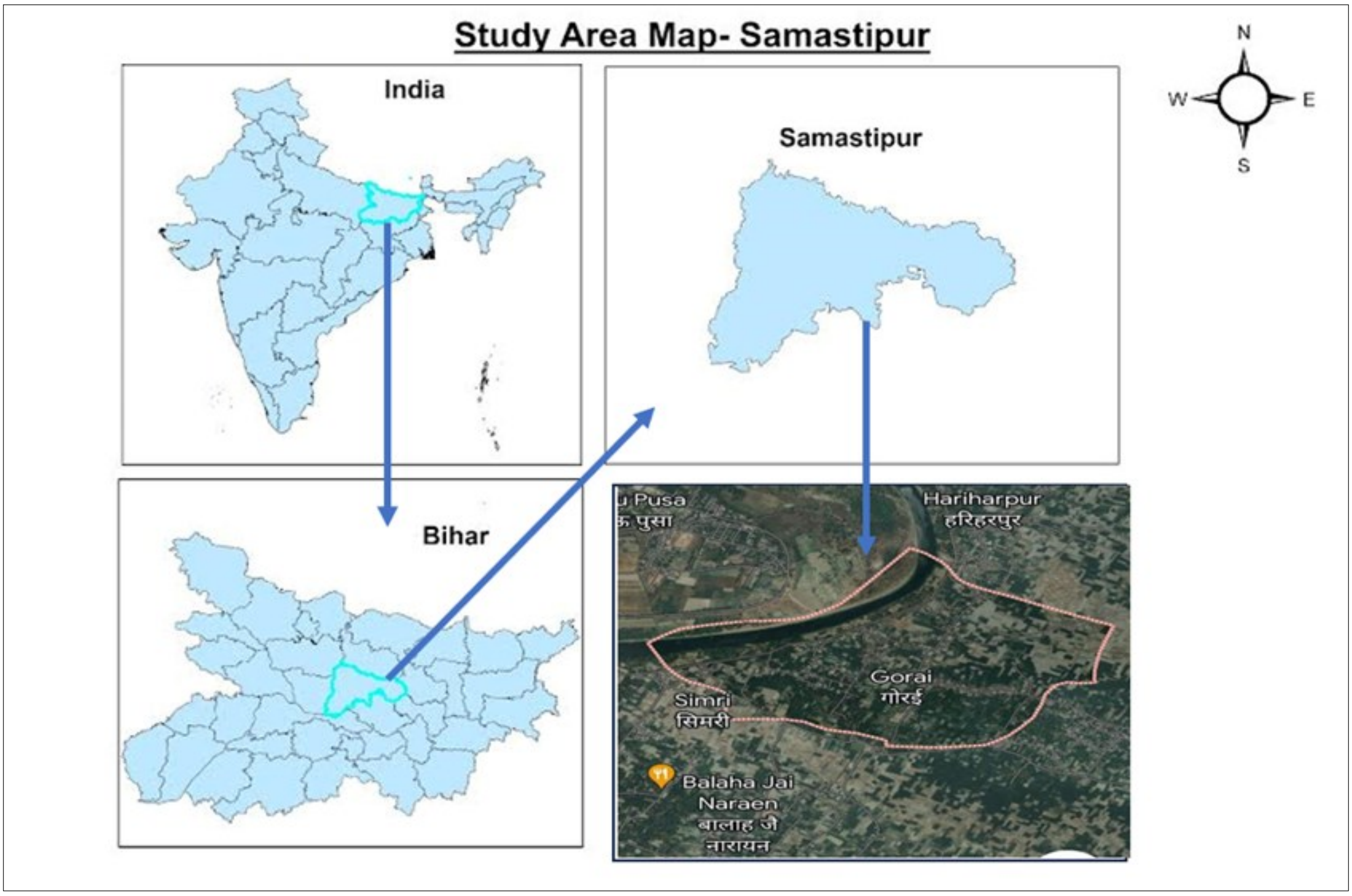

Fig. 1. Map of study area.

Change, RPCAU, Pusa. Crop pricing data was based on the minimum support prices (MSP) announced for 2022-23. Additionally, technical specifications of irrigation equipment and associated costs were collected from local agricultural extension offices and equipment suppliers.

Pump discharge estimation

The Coordinate Method was employed to calculate pump discharge (10, 11).

$$PD = \frac{CaX\sqrt{g}}{\sqrt{2Y}} \quad \text{(Eqn. 1)}$$

Where: PD is pump discharge rate (m^3/sec); C is coefficient of contraction, dimensionless; a is cross-sectional area of pipe (m^2); X is x-coordinate (m); Y is y-coordinate (m); g is acceleration due to gravity (m/sec^2).

Estimation of irrigation water volume

The following equation is used to estimate the total volume of irrigation water (θ) required for a particular crop throughout its entire growth period (12, 13).

$$\theta_{crop} = Irri_n \times H_{PI} \times PD \quad \text{(Eqn. 2)}$$

Where, θ_{crop} is the total irrigation water used for crop production (m^3), $Irri_n$ is the total number of irrigations given to a particular crop during the crop period, H_{PI} is the hours of irrigation water used per irrigation, PD is the pump discharge rate (m^3/hour).

Estimation of irrigation water productivity

The irrigation water productivity for a given crop (kg/m^3) was estimated using the data on crop yield and the estimated volume of water applied for all sample farmers growing that crop. The irrigation water productivity (kg/m^3) of water for different crops was estimated as (12, 14).

$$WP_{irri} = \frac{Y_{crop}}{\theta_{crop}} \quad \text{(Eqn. 3)}$$

Where, WP_{irri} is the irrigation water productivity (kg/m^3), Y_{crop} is the average yield of the crops measured in kilogram, θ_{crop} is the total irrigation water used for crop production (m^3).

Estimation of gross water productivity

Gross water productivity (kg/m^3) for a given crop was calculated using crop yield data and the total volume of water applied, including rainfall, during the crop production period. The gross water productivity for various crops was estimated following the methodology using the formula (14):

$$WP_{gross} = \frac{Y_{crop}}{\text{gross inflow}} \quad \text{(Eqn. 4)}$$

Where: WP_{gross} is the gross water productivity (kg/m^3), Y_{crop} is the average yield of the crops measured in kilogram; gross inflow is the total irrigation water used plus rainfall during the period of crop production (m^3).

Estimation of irrigation costs

Electrically operated pumping sets

The cost of irrigation for a particular crop during the crop period using electrically operated pumping sets was calculated using the formula:

$$C_{irri(e)} = hp \times 7.5 \times Irri_n \times H_{PI} \times 0.75 \quad \text{(Eqn. 5)}$$

Where: $C_{irri(e)}$ is the cost of irrigation for a particular crop during the entire crop period (₹), hp is the horsepower of the electric pump, $Irri_n$ is the total number of irrigations given to the particular crop during the crop period; H_{PI} is the hours of irrigation water used per irrigation. The electricity cost per unit was considered ₹ 0.75.

Diesel-operated pumping sets

The cost of irrigation using diesel-operated pumping sets was estimated as:

$$C_{irri(d)} = V \times Irri_n \times H_{PI} \times 94 \quad \text{(Eqn. 6)}$$

Where, $C_{irri(d)}$ is the cost of irrigation for a particular crop during the entire crop period (₹), V is the volume of diesel consumed by diesel pump per hour (litres), $Irri_n$ is the total number of irrigations given to the particular crop during the crop period, H_{PI} is the hours of irrigation water used per irrigation. The cost of diesel was taken as ₹ 94/L.

Estimation of profit/net income

The net income from the crop was estimated by using data on crop production multiplied by the MSP of the crop minus the cost of cultivation of a particular crop (15).

$$NI_{crop} = Y_{crop} \times MSP - IC \quad \text{(Eqn. 7)}$$

Where: NI_{crop} is the profit/net income from crop production (₹/ha), Y_{crop} is the quantity of crop production (kg/ha), MSP is the minimum support price for 2022-23 (₹/kg) and IC is the total input cost per (₹/ha) used for the crop production.

Results and Discussion

This section presents the findings of the study, highlighting the water productivity, irrigation costs and comparative performance of electric and diesel-operated tube wells for major crops in the study area. The data provide insights into the resource efficiency of groundwater irrigation and its economic implications. Tables and figures summarize critical metrics, such as water productivity, irrigation costs and crop yields, to facilitate analysis and interpretation. The discussion focuses on evaluating water use efficiency across different crops, considering the variations in irrigation methods and energy sources. Additionally, implications for groundwater sustainability and recommendations for improved irrigation practices are presented. The discharge of tube wells was measured using the coordinate method (10). Water productivity (WP) was calculated based on irrigation and gross inflow and expressed in terms of kg/m^3 of water. The cost of irrigation for electric pumps was determined based on an electricity rate of ₹ 0.75 per unit, while for diesel pumps, it was calculated using a diesel rate of 94 ₹/L. Total income was computed using the minimum support price (MSP) of crops for the year 2022-23. The total input cost included the expenses for seed, field preparation, sowing, fertilizers, irrigation, herbicides, pesticides, labour and harvesting.

Water productivity of major crops irrigated through electrical tube wells

The major crops grown in the study area include paddy, *kharif* maize, *rabi* maize, *spring* maize and wheat, irrigated using groundwater through electric tube wells. Data on irrigation

Table 2. Irrigation water use and water productivity for wheat crop

S. No.	Name of farmer	Crop yield (kg/ha)	Irrigation water used (m^3/ha)	Irrigation water used (mm)	Irrigation water productivity (kg/m^3)	Gross water productivity (kg/m^3)
1	Ram Sudhar Thakur	4349.95	2163.42	216	2.01	1.74
2	Nagendra Thakur	4429.04	2224.58	223	1.99	1.72
3	Pintu Kumar	4112.68	1997.02	200	2.06	1.75
4	Chitranjan Thakur	4270.86	2080.90	208	2.05	1.76
5	Om Prakash Thakur	4033.59	2245.51	225	1.79	1.56
6	Suresh Thakur	3954.50	2094.61	210	1.89	1.62
7	Manish Kumar	4191.77	2221.67	222	1.88	1.64
	Average	4191.77	2146.81	215	1.95	1.69

Table 3. Irrigation water use and water productivity for *kharif* maize crop

S. No.	Name of farmer	Crop yield (kg/ha)	Irrigation water used (m^3/ha)	Irrigation water used(mm)	Irrigation water productivity (kg/m^3)	Gross water productivity (kg/m^3)
1	Ram Sudhar Thakur	5536.30	665.92	67	8.31	0.75
2	Pintu Kumar	5615.39	665.67	67	8.43	0.76
3	Ballu Rai	5694.48	677.09	68	8.41	0.77
4	Chitranjan Thakur	5378.12	693.63	69	7.75	0.72
5	Suresh	5299.03	698.20	70	7.59	0.71
6	Rajeshwar Shah	5773.57	789.88	79	7.31	0.77
7	Amish Kumar	5457.21	740.55	74	7.37	0.73
8	Ranjit Kumar	5615.39	685.25	69	8.19	0.76
9	Jago Sahni	5536.30	767.92	77	7.21	0.74
10	Sanjay Thakur	5536.30	777.76	78	7.12	0.73
	Average	5544.21	716.19	72	7.77	0.74

Table 4. Irrigation water use and water productivity for *rabi* maize crop

S. No.	Name of farmer	Crop yield (kg/ha)	Irrigation water used (m^3/ha)	Irrigation water used (mm)	Irrigation water productivity (kg/m^3)	Gross water productivity (kg/m^3)
1	Sanjay Mahto	5140.85	5266.95	527	0.98	0.92
2	Ranjit Kumar	5536.30	5482.06	548	1.01	0.95
3	Jago Sahni	6327.20	6143.41	614	1.03	0.98
	Average	5668.12	5630.81	563	1.01	0.95

Table 5. Irrigation water use and water productivity for *spring* maize crop

S. No.	Name of farmer	Crop yield (kg/ha)	Irrigation water used (m^3/ha)	Irrigation water used(mm)	Irrigation water productivity (kg/m^3)	Gross water productivity (kg/m^3)
1	Sushil Thakur	5536.30	3420.99	342	1.62	0.97
2	Purushottam Thakur	5140.85	3838.93	384	1.34	0.84
3	Sanjay Thakur	5378.12	3888.84	389	1.38	0.87
	Average	5351.75	3716.25	372	1.45	0.89

Table 6. Irrigation water use and water productivity for paddy crop

S. No.	Name of farmer	Crop yield (kg/ha)	Irrigation water used (m^3/ha)	Irrigation water used (mm)	Irrigation water productivity (kg/m^3)	Gross water productivity (kg/m^3)
1	Rajesh Thakur	5536.30	7112.04	711	0.78	0.42
2	Nagendra Thakur	5694.48	7415.27	742	0.77	0.43
3	Om Prakash Thakur	5378.12	7485.03	749	0.72	0.40
4	Dr. Manish Kumar	5457.21	7405.57	741	0.74	0.41
5	Sonu Mahto	5694.48	6782.43	678	0.84	0.45
6	Sushil Thakur	5773.57	6841.99	684	0.84	0.45
7	Anmol Kumar	6327.20	7192.23	719	0.88	0.48
8	Purushottam Thakur	5931.75	7677.86	768	0.77	0.44
9	Ashok Thakur	6722.65	8529.98	853	0.78	0.46
	Average	5835.08	7382.49	738	0.79	0.44

water use, crop yield, irrigation water productivity and gross water productivity for these crops are summarized in Table 2-6. The highest yield of wheat was recorded at 4429.04 kg/ha (Nagendra Thakur), while the lowest was 3954.50 kg/ha (Suresh Thakur). Irrigation water productivity ranged from 1.79 to 2.06 kg/m^3, averaging 1.95 kg/m^3. Gross water productivity ranged from 1.56 to 1.76 kg/m^3, with an average of 1.69 kg/m^3. The highest yield of the *kharif* maize crop was recorded at 5773.57 kg/ha for Rajeshwar Shah, while the lowest yield was 5299.03 kg/ha for Suresh. The irrigation water productivity for *kharif* maize ranged from 7.12 kg/m^3 to 8.43 kg/m^3, with an average of 7.77 kg/m^3, indicating efficient water use in crop production. The gross water productivity varied between 0.71 kg/m^3 and 0.77 kg/m^3, with an average of 0.74 kg/m^3. The relatively lower gross water productivity values can be attributed to the significant rainfall received during the cropping season, which reduced the reliance on irrigation water. The highest yield of the *rabi* maize crop was 6327.20 kg/ha, recorded by Jago Sahni, while the lowest yield was 5140.85 kg/ha for Sanjay Mahto. Irrigation water productivity ranged from 0.98 kg/m^3 to 1.03 kg/m^3, with an average of 1.01 kg/m^3. Gross water productivity varied between 0.92 kg/m^3 and 0.98 kg/m^3, averaging 0.95 kg/m^3. The highest yield of the *spring* maize crop was 5536.30 kg/ha, achieved by Sushil Thakur, while the lowest yield was 5140.85 kg/ha for Purushottam Thakur. Irrigation water productivity ranged from 1.34 kg/m^3 to 1.62 kg/m^3, with an average of 1.45 kg/m^3. Gross water productivity varied from 0.84 kg/m^3 to 0.97 kg/m^3, averaging 0.89 kg/m^3. The highest yield of the paddy crop was 6722.65 kg/ha, recorded by Ashok Thakur, while the lowest yield was 5378.12 kg/ha for Om Prakash Thakur. Irrigation water productivity for paddy ranged from 0.72 kg/m^3 to

0.88 kg/m^3, with an average of 0.79 kg/m^3. Gross water productivity ranged from 0.40 kg/m^3 to 0.48 kg/m^3, averaging 0.44 kg/m^3.

Crop-wise comparison of irrigation costs: Electrical vs. diesel-operated tubewell

The study area is predominantly served by electric pumps, though diesel pumps are still in use. The subsidized electricity rate for agricultural purposes in Bihar is ₹ 0.75/unit, significantly lower than rates for other sectors. Diesel pump irrigation costs were calculated based on farmer interviews, where 3 HP diesel pumps were commonly used. These pumps consume approximately 0.5 L diesel/hr. Table 7-11 present the irrigation costs for different crops under electric and diesel pumping systems. Electric pump irrigation costs for wheat ranged from ₹ 93 to ₹ 140, with an average cost of ₹ 120. In comparison, diesel pump irrigation was significantly more expensive, with costs ranging from ₹ 3678 to ₹ 4458 and averaging ₹ 3961 - approximately 33 times higher than electric pumps. Electric pump irrigation costs for *kharif* maize ranged from ₹ 35 to ₹ 46, with an average cost of ₹ 43. In contrast, diesel pump irrigation was substantially more expensive, with costs ranging from ₹ 1226 to ₹ 1486 and averaging ₹ 1306 - approximately 30.4 times higher than electric pumps. For *rabi* maize, electric pump irrigation costs ranged from ₹ 284 to ₹ 363, with an average cost of ₹ 319, while diesel pump irrigation was considerably more expensive at ₹ 10113 to ₹ 13003, averaging ₹ 11669 - making it 36.6 times higher than electric pumps. For *spring* maize, electric pump irrigation costs ranged from ₹ 177 to ₹ 225, averaging ₹ 208, while diesel pump costs varied from ₹ 6192 to ₹ 7430, with an average of ₹ 6632 - approximately 32 times higher than electric pumps. Electric pump irrigation costs for paddy ranged from ₹ 311 to ₹ 450, with an average cost of ₹ 370. In comparison, diesel pump irrigation was dramatically more expensive, with costs ranging from ₹ 12075 to ₹ 14861 and averaging ₹ 13420 - approximately 36 times higher than electric pumps. The irrigation costs for diesel pumps are significantly higher than those for electric pumps across all crops studied, with diesel pump costs ranging from 30 to 37 times more expensive. The subsidized electricity rates incentivize farmers to use electric pumps, but excessive groundwater extraction could lead to aquifer depletion. To ensure sustainable groundwater management, comprehensive village irrigation plans and incentives for efficient water management practices are necessary.

Table 7. Cost of Irrigation for wheat crop

S. No.	Name of farmer	Electric pump cost (₹/ha)	Diesel pump cost (₹/ha)
1	Ram Sudhar Thakur	140	3901
2	Nagendra Thakur	93	3901
3	Pintu Kumar	136	3792
4	Chitranjan Thakur	106	4458
5	Om Prakash Thakur	101	4235
6	Suresh Thakur	132	3678
7	Manish Kumar	135	3761
	Average	120	3961

Table 8. Cost of Irrigation for *kharif* maize crop

S. No.	Name of farmer	Electric pump cost (₹/ha)	Diesel pump cost (₹/ha)
1	Ram Sudhar Thakur	46	1300
2	Pintu Kumar	45	1264
3	Ballu Rai	44	1226
4	Chitranjan Thakur	35	1486
5	Suresh Thakur	44	1226
6	Rajeshwar Shah	46	1300
7	Anish Kumar	45	1253
8	Ranjit Kumar	35	1486
9	Jago Sahni	45	1264
10	Sanjay Thakur	45	1254
	Average	43	1306

Table 9. Cost of irrigation for *rabi* maize crop

S. No.	Name of farmer	Electric pump cost (₹/ha)	Diesel pump cost (₹/ha)
1	Sanjay Mahto	311	13003
2	Ranjit Kumar	284	11889
3	Jago Sahni	363	10113
	Average	319	11669

Table 10. Cost of irrigation for *spring* maize crop

S. No.	Name of farmer	Electric pump cost (₹/ha)	Diesel pump cost (₹/ha)
1	Sushil Thakur	177	7430
2	Purushottam Thakur	222	6192
3	Sanjay Thakur	225	6272
	Average	208	6632

Table 11. Cost of irrigation for paddy crop

S. No.	Name of farmer	Electric pump cost (₹/ha)	Diesel pump cost (₹/ha)
1	Rajesh Thakur	355	14861
2	Nagendra Thakur	311	13003
3	Om Prakash Thakur	337	14118
4	Dr. Manish Kumar	450	12539
5	Sonu Mahto	333	13932
6	Sushil Thakur	355	14861
7	Anmol Kumar	433	12075
8	Purushottam Thakur	444	12384
9	Ashok Thakur	311	13003
	Average	370	13420

Profitability of electrically and diesel-operated pumping systems

The analysis of profitability for farmers using electric and diesel-operated pumping systems was conducted based on data for five crops: wheat, *kharif* maize, *rabi* maize, *spring* maize and paddy. The total income per hectare was calculated using the Minimum Support Price (MSP) for the 2022-23 cropping season. Total input costs included seed, field preparation, sowing, fertilizers, irrigation, herbicides, pesticides, labour and harvesting. The profitability comparison across crops is summarized in Table 12-16. For wheat crops, with an average total income of ₹ 84464/ha, electric pump users earned an average profit of ₹ 51567/ha compared to ₹ 47541/ha for diesel pump users - an 8.5 % higher profit margin with electric pumps. For *kharif* maize, with an average total income of ₹ 108777/ha, electric pump users earned ₹ 83856/ha in profits versus ₹ 82147/ha for diesel users - a modest 2 % advantage for electric pumps. For *rabi* maize, with an average total income of ₹ 111208/ha, electric pump users earned significantly more with ₹ 86310/ha in profits compared to ₹ 74961/ha for diesel users - a 15 % higher profit with electric pumps. For *spring* maize, with an average total income of ₹ 105001/ha, electric pump users earned ₹ 79349/ha in profits versus ₹ 72926/ha for diesel users - about 9 % more profit with electric pumps. For paddy, with an average total income of ₹ 119035/ha, electric pump users showed the largest advantage, earning ₹ 59289/ha in profits compared to ₹ 46259/ha for diesel users - a substantial 28 % higher profit margin with electric pumps. The key trend across all crops is that electric pumps

Table 12. Profitability for wheat crop under different irrigation pumping systems

S.No.	Name of farmer	Total income per ha (₹)	Electric pump		Disel pump	
			Total input cost per ha (₹)	Profit/Net income per ha (₹)	Total input cost per ha (₹)	Profit/Net income per ha (₹)
1	Ram Sudhar Thakur	87651	32077	55574	36375	51276
2	Nagendra Thakur	89245	33110	56134	37462	51782
3	Pintu Kumar	82870	31504	51365	35161	47709
4	Chitranjan Thakur	86057	32320	53737	36671	49385
5	Om Prakash Thakur	81276	30343	50932	34695	46581
6	Suresh	79683	38274	41408	41820	37862
7	Manish Kumar	84464	32644	51819	36271	48192
	Average	84464	32896	51567	36922	47541

Table 13. Profitability for *kharif* maize crop under different irrigation pumping systems

S. No.	Name of farmer	Total income per ha (₹)	Electric pump		Diesel pump	
			Total input cost per ha (₹)	Profit per ha (₹)	Total input cost per ha (₹)	Profit per ha (₹)
1	Ram Sudhar Thakur	108622	21990	86632	23422	85199
2	Pintu Kumar	110174	23384	86789	24602	85571
3	Ballu Rai	111725	23759	87966	24941	86784
4	Chitranjan Thakur	105518	30470	75048	31920	73597
5	Suresh	103967	21387	82579	22569	81397
6	Rajeshwar Shah	113277	23366	89910	24620	88656
7	Amish Kumar	107070	27713	79357	28921	78148
8	Ranjit Kumar	110174	27110	83063	28561	81612
9	Jago Sahni	108622	24966	83655	28921	78148
10	Sanjay Thakur	108622	25057	83564	26266	82355
	Average	108777	24920	83856	26475	82147

Table 14. Profitability for *rabi* maize crop under different irrigation pumping systems

S.No.	Name of farmer	Total income per ha (₹)	Electric pump		Diesel pump	
			Total input cost per ha (₹)	Profit per ha (₹)	Total input cost per ha (₹)	Profit per ha (₹)
1	Sanjay Mahto	100863	22050	78813	34743	66120
2	Ranjit Kumar	108622	27359	81262	38964	69657
3	Jago Sahni	124139	25284	98855	35034	89104
	Average	111208	24898	86310	36247	74961

Table 15. Profitability for *spring* maize crop under different irrigation pumping systems

S.No.	Name of farmer	Total income per ha (₹)	Electric pump		Diesel pump	
			Total input cost per ha (₹)	Profit per ha (₹)	Total input cost per ha (₹)	Profit per ha (₹)
1	Sushil Thakur	108622	26462	82159	33715	74906
2	Purushottam Thakur	100863	25255	75608	31225	69638
3	Sanjay Thakur	105518	25237	80281	31285	74233
	Average	105001	25651	79349	32075	72926

Table 16. Profitability for paddy crop under different irrigation pumping systems

S.No.	Name of farmer	Total income per ha (₹)	Electric pump		Diesel pump	
			Total input cost per ha (₹)	Profit per ha (₹)	Total input cost per ha (₹)	Profit per ha (₹)
1	Rajesh Thakur	112940	61620	51319	76126	36814
2	Nagendra Thakur	116167	58063	58104	72569	43598
3	Omprakash Thakur	109713	50158	59555	64664	45049
4	Dr. Manish Kumar	111327	58355	52971	70444	40882
5	Sonu Mahto	116167	62608	53558	77114	39052
6	Sushil Thakur	117780	63858	53922	72924	44855
7	Anmol Kumar	129074	62884	66190	74525	54549
8	Purushottam Thakur	121007	59733	61274	71673	49334
9	Ashok Thakur	137142	60434	76707	74940	62201
	Average	119035	59746	59289	72775	46259

consistently delivered higher profits, with advantages ranging from 2 % to 28 %, primarily due to their significantly lower irrigation costs. The profit advantage was most pronounced for paddy cultivation (28 %) and *rabi* maize (15 %).

Conclusion

The study highlights the superior economic and agronomic performance of electrically operated tubewells compared to diesel-based systems in Gorai village, Samastipur district. Electrification significantly reduced irrigation costs by 30 to 37 times, leading to higher profitability, especially for paddy (22 % gain) and *rabi* maize (13 %). Water productivity varied widely among crops, with *kharif* maize achieving the highest efficiency (7.77 kg/m^3), underscoring the role of crop choice in sustainable water use. Despite these economic gains, the extremely low electricity tariffs (₹ 0.75/unit) raise concerns over potential groundwater overextraction. Therefore, policies encouraging pump electrification must be paired with robust groundwater governance and rational pricing strategies to ensure long-term sustainability.

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Authors' contributions

RC conceptualized the research project, supervised field execution, conducted data analysis and led the manuscript preparation and formulation. AK conducted field investigations, collected primary data through farmer surveys and contributed to report writing and literature review. PP participated in field investigations, assisted in data collection and analysis and contributed to manuscript writing and technical content development. NK conducted field investigations, collected and validated data and contributed to manuscript writing with a focus on final article formatting and presentation.

Compliance with ethical standards

Conflict of interest: The authors declare no conflict of interest.

Ethical issues: None

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