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Economic access to groundwater irrigation under alternate energy regimes in Bihar

S K Srivastava[1]*, Avinash Kishore[2], and Jaspal Singh[3]

[1]ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi 110 012
[2]International Food Policy Research Institute (IFPRI), South Asia Office, New Delhi 110 012
[3]NITI Aayog, New Delhi 110 001
*Corresponding author: shivendraiari@gmail.com

Abstract With abundant groundwater resources, Bihar has the potential to harness the positive groundwater and agricultural development linkages by improving the economic access to groundwater irrigation. Using the representative data from Central Groundwater Board and the 5th Minor Irrigation Census, this study has examined the spatio-temporal changes in groundwater level, and compared the groundwater extraction cost under different energy policy regimes. The analysis shows a stable groundwater level in large parts of the state. The majority of the groundwater pumps are dependent on diesel energy, which is more than four times costlier than electric energy. Electric pumps are economical than diesel pumps even without the power subsidy. As the power supply in the state has been improving, farmers can significantly reduce irrigation costs by shifting to electric pumps. Among the electric pump owners, farmers with metered pricing (pro-rata) incur less energy cost as compared to flat-rate pricing. Bihar presently has both flat and pro-rata based pricing policies for electric pumps, leading to a trade-off between economic and equity aspects of groundwater use which needs to be optimized.

Keywords Groundwater, Energy, Pricing policy, Bihar

JEL Codes Q25, Q28, Q41, Q42

Over the years, groundwater has emerged as a predominant irrigation source in India due to its reliable supply compared to canal water. This is reflected from an increase in its share in net irrigated area, from 30.36% in 1964-65 to 64.10% in 2015-16. As agriculture is heavily dependent on groundwater, efficient management of groundwater resources is crucial to sustaining food security. There exists a wide spatial heterogeneity in groundwater use. While groundwater is over-exploited in the north-western and parts of the southern region of India, it remains under-utilized in the eastern region on account of several economic and non-economic reasons (Srivastava et al. 2012). Even in the water surplus eastern India, where groundwater is largely under-utilized at the aggregate level, a few areas have started witnessing groundwater depletion (Srivastava et al. 2018). Under-development of groundwater resources in eastern states leads to the loss of opportunity to harness the positive groundwater and agricultural development linkages (Srivastava et al. 2014). At the same time, groundwater depletion poses a threat to the ecological balance and leads to inequality in its distribution with adverse financial implications for the farmers (Sarkar 2011). Therefore, promoting 'sustainable' utilization of groundwater resources in the eastern region remains a critical agenda for balancing the trade-off between economy and ecology.

Given the widespread poverty in eastern states (Alkire et al. 2021), economic access to groundwater is a major challenge in promoting groundwater use for irrigation. As the majority of groundwater pumps in eastern states are operated using costlier diesel energy (Foster et al. 2021), there exists a potential to reduce the groundwater extraction cost and improve economic access to groundwater by providing a reliable and cheaper alternate source (e.g. electricity and solar) to energize groundwater pumps. This study has evaluated such prospects in the state of Bihar, where the overall stage of groundwater utilization is 46% (CGWB 2019) and 89% of the wells are energized using diesel energy (GoI 2017). Kishore (2020) has found that irrigation in Bihar is expensive which forces farmers to over-economise on water application with negative consequences on agricultural outcomes such as low crop yields, high vulnerability to draughts and heatwaves, and low cropping intensity. As the power supply situation in Bihar has been improving (Kishore 2020), it is imperative to empirically assess the economic aspects of groundwater irrigation under alternate energy policy regimes. The study has two objectives: (1) examine spatial variation and temporal changes in groundwater level, and (2) estimate and compare groundwater extraction cost under different energy policy regimes. The findings provide an empirical basis for promoting economic access to groundwater and its sustainable use in agriculture in Bihar.

Data and methodology

Spatial variation and temporal changes in groundwater level in Bihar have been examined using the groundwater level data at the monitoring wells of the Central Groundwater Board (CGWB). In the year 2019, CGWB monitored groundwater levels at 620 monitoring wells in the state in both pre-monsoon and post-monsoon seasons. To understand spatial variation, these wells were geo-located and groundwater levels were spatially interpolated using the Inverse Distance Weighting (IDW) method in ArcGIS software. IDW is a deterministic method for multivariate interpolation approach to estimate an unknown value at a location with a weighted average of the values available at the known points.

Further, changes in groundwater level were examined during the period 2008 to 2019. For this, only those wells were considered for which at least nine years of consistent data are available. Following Srivastava et al. (2018), Mann-Kendall (MK) test was applied to test significant monotonic increase/decrease in groundwater level during 2008 to 2019 at each monitoring well. Thereafter, Sen's slope was estimated to measure the magnitude of the trend (change per unit of time) in groundwater level.

MK test is a non-parametric method to assess the monotone increase or decrease in a given time series and can be suitably used for the series with missing data and skewed values. In this method, Kendall's S-statistics is computed by comparing the later measured values with the earlier measured values for n(n-1)/2 possible pairs of data for n observations. Kendall's S-statistics is computed as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(y_j - y_i) \quad \ldots(1)$$

Where,

$$sign\left(y_j - y_i\right) = \begin{cases} = +1 \; if \; \left(y_j - y_i\right) > 0 \\ = 0 \; if \; \left(y_j - y_i\right) = 0 \\ = -1 \; if \; \left(y_j - y_i\right) < 0 \end{cases} \quad \ldots(2)$$

Large positive values of S indicate an increasing trend and large negative values indicate a decreasing trend with time. For a time series of more than equal to 10 years ($n \geq 10$), the MK test statistics is near normally distributed.

Sen's slope measures the magnitude of the trend (change per unit time) in groundwater level. To derive an estimate of the slope β, the slopes of all data pairs are calculated as:

$$\beta_i = \left(\frac{y_j - y_k}{t_j - t_k}\right) \quad \ldots(3)$$

Where, i=1,2,…, N, J>k, y_j and y_k are measurements at times t_j and t_k, respectively. If there are n values y_j in the time series, we get as many as N= n(n-1)/2 slope estimates β_i. The Sen's slope estimator is the median of these N values of β_i. The N values of β_i are ranked from the smallest to the largest and the Sen's slope is given by

$$\beta = \begin{cases} \beta_{\frac{N+1}{2}} \; if \; N \; is \; odd \\ \frac{1}{2}\left(\beta_{\frac{N}{2}} + \beta_{\frac{N+2}{2}}\right) \; if \; N \; is \; even \end{cases} \quad \ldots(4)$$

Economic access to groundwater irrigation under alternate energy regimes was examined by estimating groundwater extraction costs. The total cost of groundwater extraction comprises the amortized fixed cost of constructing wells and installing pump sets, and the variable cost of energy (diesel/electricity) use. As shallow tubewells are predominant groundwater structures in Bihar, the cost calculations were made for these types of wells.

The fixed cost (including the cost of construction of wells and installation of the machine) of the functional wells constructed in the year 2013-14 was taken from the 5th MI census. This cost was inflated for 2019-20 using the wholesale price index of irrigation machines which increased at the rate of 2.34% per annum during 2013-14 to 2019-20. For amortization of fixed cost, the rate of interest is assumed 6% and the expected life of 10 years for diesel pumps and 15 years for electric pumps). The formula for amortizing the fixed cost is:

$$AC = \frac{CB \times (1+i)^n \times i}{(1+i)^n - 1} \quad \ldots(5)$$

Where, AC = annual amortized cost (Rs), CB = initial cost of constructing wells and installing pumps (Rs), i = interest rate , and n = life of groundwater structures.

Amortized fixed cost of wells is expressed in terms of per unit volume of groundwater extraction (Rs/m^3). For this, the volume of groundwater extracted for irrigating crops was estimated as follows:

$$\text{Groundwater Draft (lit./sec.)} = \frac{\text{hp} \times 75 \times \text{pump efficiency}}{\text{Total Head (m)}} \quad \ldots(6)$$

$$\text{Total Head (m)} = \text{Water table (m)} + \text{draw down (m)} + \text{friction losses} \quad \ldots(7)$$

$$\text{Groundwater Draft (m}^3\text{/well/ha)} = \frac{\text{Groundwater Draft (lit./sec.)}}{1000} \times 3600 \times \text{Operating hours (hours/ha)} \quad \ldots(8)$$

The information on horsepower (hp) of the pump and operating hours were taken from the 5th MI census. The values of draw-down for dug wells, shallow tubewells and deep tubewells was assumed as 1, 2 and 4 m, respectively. Friction losses were assumed as 10% of the water table and drawdown. The information on the water table was taken from CGWB.

Energy cost was calculated by multiplying prevailing energy prices (for diesel and electricity) with the estimated energy used (1 hp = 0.746 Kilowatt) per unit volume (m^3) of groundwater. The energy cost was estimated separately for diesel and electric operated pumps. Further, Bihar has both subsidized flat-rate and subsidized pro-rata tariff systems for supplying electricity to groundwater pumps. Energy costs were calculated under these energy regimes and compared with each other.

Results and discussion

Status of groundwater resources and use

Bihar is endowed with rich water resources due to the high precipitation, extensive river basin network, and alluvial aquifer with significant storage space for groundwater. On average, the state receives annual precipitation of 120 centimetres. Rainfall is a major source of groundwater replenishment, contributing 74% to the total groundwater recharge. The net annual groundwater availability for different uses is 29 billion cubic meters (BCM). But, only 46% of the available groundwater is extracted, implying an under-utilization of available groundwater resources at the aggregate level (CGWB 2019). As groundwater is largely under-utilized, there exists a huge scope to accelerate sustainable use of groundwater for harnessing a positive groundwater-agricultural development linkage. Although evidence at the aggregate level indicates the under-utilization of groundwater resources in Bihar, there are few areas with depleting groundwater levels as well. This is indicated by the categorization of 13% (72 numbers), 3% (18 numbers) and 2% (12 numbers) of total administrative blocks (534) in the state as semi-critical, critical, and over-exploited, respectively (CGWB 2019). Irrigation being the predominant consumer of groundwater bears the prime responsibility of using this resource sustainably. Presently, groundwater irrigates 63% of the net irrigated area and its share has been rising.

Spatial variations and temporal change in groundwater level

According to the data from CGWB, the average groundwater level in Bihar was 6.37 meters below ground level (mbgl), varying from 0.74 mbgl to 16.11 mbgl in the pre-monsoon season (May) of 2019 (Table 1). About 92% of the wells have a shallow water level of fewer than 10 mbgl and 8% have a water level of more than 10 mbgl. It is to be noted that at groundwater level higher than 8-10 mbgl, centrifugal pumps become inefficient and need to be replaced with submersible pumps for groundwater extraction (Sekhri 2013). The

Table 1 Groundwater levels in Bihar in 2019

Season	Groundwater level (m bgl)	Distribution of monitoring wells across groundwater level (%)						Total wells (no)
		0-2	2-5	5-10	10-20	20-40	>40	
Pre-monsoon (May)	6.37 (0.74-16.11)	2	35	55	8	0	0	621
Post-monsoon (November)	3.28 (0.02-14)	29	54	16	1	0	0	627

Note Figures within parentheses are minimum and maximum values of observed groundwater levels at monitoring wells
Source Authors' calculations based on data of CGWB. http://cgwb.gov.in/GW-data-access.html

prevalence of shallow groundwater depth in most parts of the state offers scope to sustainably and economically utilize groundwater resources and harness productive groundwater-agricultural development linkages in the eastern region (Srivastava et al. 2014). Further, in the post-monsoon season, groundwater level goes up by about 3 mbgl from the pre-monsoon level improving the prospects of physical and economic access to groundwater. The rising groundwater level in the post-monsoon season is evident from the shifting distribution of monitoring wells towards lower groundwater level categories.

The evidence shows that groundwater level in 29% of wells in Bihar rises upto 2 mbgl which is a water-logging situation. A persistent water-logging in the root zone (0-3 mbgl) is not conducive for optimum crop growth and requires effective drainage of the excess water. Among various technologies for excess water conditions, the installation of low horse-power solar pumps can be promoted to withdraw the surplus water and provide assured irrigation to the crops. On the other hand, it is essential to keep monitoring the groundwater level in the wells located in the areas with deeper groundwater levels.

Figure 1 shows the spatial heterogeneity and temporal changes in groundwater level in pre- and post-monsoon seasons. The groundwater in north Bihar is at a shallower level as compared to that in South Bihar. During the pre-monsoon season, the groundwater level in most of the north Bihar remains below 5 mbgl, whereas in south Bihar it goes up to 10 mbgl. A substantial recharge takes place from rainfall during the monsoon season and the volume of groundwater extraction remains lower than the recharge. Subsequently, the groundwater level rises in most of the areas of the state in the post-monsoon season. This is visible from the shifting area from the category of 3-5 mbgl groundwater level in the pre-monsoon season to the category of <3 mbgl groundwater level in the post-monsoon season in north Bihar. Similarly, rising groundwater levels can also be seen in South Bihar after the monsoon season. Such inter-seasonal changes in groundwater levels reveal ample scope to accelerate groundwater use for productive purposes.

For the sustainable management of groundwater resources, groundwater levels should be stable over the long run in both pre-monsoon and post-monsoon seasons. A comparison of maps of groundwater level (pre-monsoon) from 1997 to 2019 provides some signs of groundwater depletion in a few pockets in the last ten years (2008 and 2019). Therefore, a detailed examination of the long-run trend in groundwater level at monitoring wells of CGWB was undertaken by applying the Mann Kendall test and estimating Sen's slope.

The MK test was applied at each of the 228 monitoring wells separately during the pre-monsoon and post-monsoon season for the period 2008-2019. The results reveal no significant change in groundwater in more than 70% of the wells in pre- as well as post-monsoon seasons (Table 2). This implies that the groundwater level is largely stable in the state. Further, 12% of the wells witnessed a rising trend in groundwater level in the pre-monsoon season at an average rate of 16 centimetres/annum from 2008 to 2019. Interestingly, the number of the wells witnessing a significant rising trend doubled in the post-monsoon season. On the other hand, 14% of the wells witnessed a significant declining trend at an average annual rate of 23 centimetres in the pre-monsoon season. But, the number of wells witnessing a declining trend reduced to half (7%) in the post-monsoon season during the period under

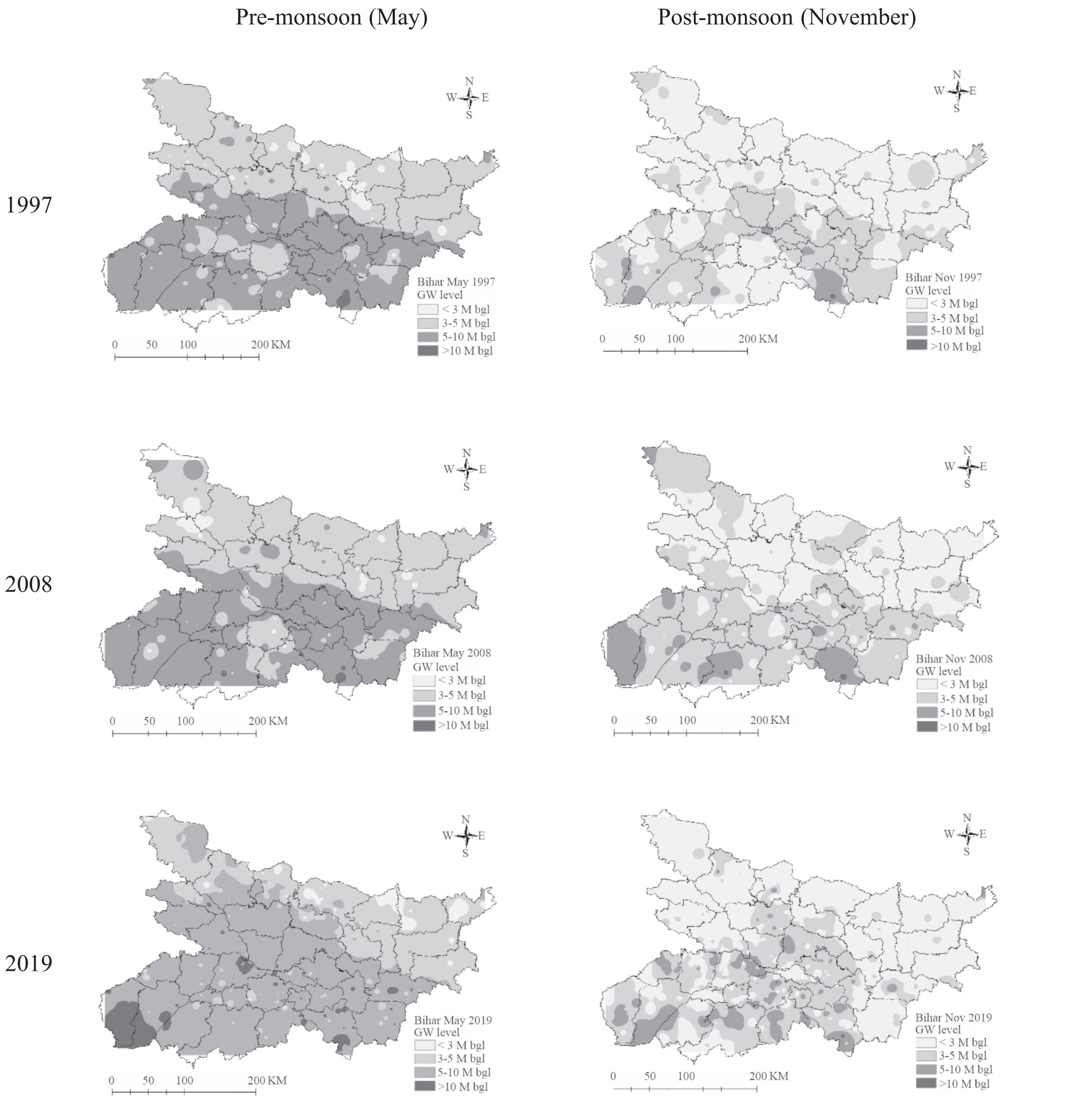

Figure 1 Spatial variation and temporal changes in groundwater level
Source Authors' analysis based on data of CGWB. http://cgwb.gov.in/GW-data-access.html

Table 2 Trends in groundwater level during 2008 to 2019 in Bihar (Mann-Kendall test and Sen's slope estimator)

Season	Particulars	No significant trend	Significantly rising trend	Significantly declining trends	Total wells (no.)
Pre-monsoon	Wells (%)	73	12	14	228
(May)	Sen's Slope (cm/year)	1	-16	23	
Post-monsoon	Wells (%)	70	23	7	228
(November)	Sen's Slope (cm/year)	-3	-14	25	

Source Authors' estimates

consideration. This implies that the water level in about half of the wells witnessing a declining trend in the pre-monsoon season recovered (with either no trend or rising trend) in the post-monsoon season. Overall, stability in groundwater level or rising groundwater level shows scope to sustainably promote groundwater use. At the same time, careful groundwater monitoring and control are required in the areas witnessing declining groundwater levels in both pre- and post-monsoon season (7% of the wells).

Structure of groundwater irrigation

According to the 5th Minor Irrigation (MI) Census, there were 6.44 lakhs groundwater structures for withdrawal of water for irrigation in Bihar up to the year 2013-14 (Table 3). Between 1986-87 and 1993-94, groundwater structures increased by about two lakhs. In 2000-01, Jharkhand was separated from Bihar, and the number of groundwater structures in Bihar reduced to 7.9 lakhs. Subsequently, total groundwater structures registered a declining trend. It is to be noted that the number of shallow wells increased by 35962 between the last two MI censuses (2006-07 and 2013-14). But, the increase in the number of shallow wells could not outpace the decrease in the number of dugwells and deep tubewells in the state, leading to a net reduction (by 7745) in the total number of groundwater structures. Interestingly, during this period the number of functional wells increased by 32329. The increase in the of functional wells and shallow tubewells in recent years implies a rising trend in the construction of new groundwater structures in Bihar, whereas traditional groundwater structures, like dugwells, are going out of use.

The analysis reveals that the dugwells are being substituted by shallow tubewells. At present, shallow tubwells are the predominant groundwater structure in the state. Surprisingly, the number of deep tubewells have declined in recent years.

Energy use pattern for groundwater irrigation

Successive MI censuses reveal that most of the groundwater structures in Bihar are energized by diesel (Table 4). According to the latest (5th) MI Census (2013-14), about 89% of wells relied on diesel for extracting groundwater for irrigation. The predominance of diesel as the energy source was primarily due to the low levels of electrification and unreliable supply of electricity (Hoda et al. 2021). Further, shallow water levels and

Table 3 Changing composition of groundwater structures

Year	Total number of wells (no.)				Composition of wells (%)		
	Dugwells	Shallow Tubewells	Deep Tubewells	Total	Dugwells	Shallow Tubewells	Deep Tubewells
1986-87	337624	429046	14957	781627	43.2	54.9	1.9
1993-94	391198	589519	6440	987157	39.6	59.7	0.7
2000-01	135177	651383	6190	792750	17.1	82.2	0.8
2006-07	56112	571871	23259	651242	8.6	87.8	3.6
2013-14	22877	607833	12787	643497	3.6	94.5	2.0

Source Authors' calculations based on successive minor irrigation census data

Table 4 Distribution of groundwater wells according to energy sources (wells with one energy source)

(%)

Year	Electricity	Diesel	Others	Total wells (no)
1993-94	5.4	70.9	23.7	980717
2000-01	5.2	86.0	8.8	786560
2006-07	0.0	0.0	100.0	651242
2013-14	6.7	88.9	4.3	482826

Source Authors' calculations based on successive minor irrigation census data fragmented land holdings prompt farmers to use low-power diesel-operated centrifugal pumps as these pumps can be easily transported and used with different borings.

With the rising diesel prices, extracting groundwater for irrigation has become costlier. Simultaneously, infrastructure for electricity supply is improving. Thus, farmers are gradually shifting from diesel to electricity for energizing pumps. The evidence from MI Censuses shows a rising share of electric-operated pumps in the state. The share of groundwater structures energized using electricity in total structures (with a single energy source) increased from 5.4% in 1993-94 to 6.7% in 2013-14. Although farmers are gradually shifting towards electricity, a majority of the groundwater pumps are dependent on diesel.

Cost of groundwater extraction under different energy regimes

Among several direct and indirect factors, access to reliable and cheaper source of energy is a critical factor indirectly affecting the extent of groundwater use for irrigation. It is essential to assess the financial implications of using alternative energy sources for groundwater irrigation. As diesel and electricity are two major sources to energize groundwater structures, the cost to extract a unit volume of groundwater for irrigation has been estimated and compared between diesel and electric operated pumps for the reference year 2020-21.

Table 5 presents the cost incurred in groundwater extraction by the predominant shallow tubewells. The results show that a shallow tubewell operated using diesel incurs Rs 2.40 to extract one cubic meter (m^3) of groundwater. On the other hand, an electric shallow tubewell incurs Rs 0.60/m^3, which is four times less as compared to diesel pumps. Such a large difference in the cost between diesel and electric pumps is primarily accounted for by differences in the energy costs and the utilization levels of the pumps. Note, the fuel cost accounts for half of the total cost of operation of a diesel pump. Further, the data from the 5th MI Census show that electric pump owners operate their pumps for a longer time. Therefore, a higher utilization level of electric pumps also results in lower groundwater extraction costs. There is ample scope to diversify energy sources towards electricity by improving the power supply infrastructure. The electricity supply for irrigation in Bihar has improved in recent years and the farmers are gradually switching from diesel to electric pumps.

Bihar has pro-rata and flat-rate tariff systems for metered and unmetered connections, respectively. For the metered connections, farmers were charged a highly subsidized electricity tariff of Rs 0.70/unit in 2020-21 and the government provided a subsidy of Rs 4.75/unit (plus fixed charges of 30/Hp). The farmers with unmetered connections were charged a monthly flat rate of Rs 84/Hp with the subsidy grant of Rs 716/hp/month. The average diesel price in Bihar in 2020-21 was Rs.90.95/l. A comparison of energy costs under different price policy regimes shows that farmers incur the lowest energy cost in the pro-rata based tariff system (Table 6).

With the same utilization level of pumps, energy cost per unit volume of groundwater extraction under a flat-rate tariff system would be 6.75 times higher than in the pro-rata based tariff system. Lower energy cost under the pro-rata tariff system provides an economic rationale to install meters on the electric-operated pumps. This will further reduce the inefficient use of groundwater as the positive marginal cost will incentivize farmers to reduce inefficient use of groundwater. However, a flat-rate tariff has the potential to promote more equitable groundwater markets as pump-owners who pay a flat tariff can sell

Table 5 Cost of groundwater extraction by shallow tubewells in Bihar in 2020-21

Total cost (Rs/m^3)			Share of energy in total cost (%)	
Diesel	Electricity	Ratio of total cost with diesel and electricity	Diesel	Electricity
2.40	0.60	4.02	48	7

Source Authors' calculations

Table 6 Energy cost and the total cost incurred by shallow tubewells under different energy sources and regimes in 2020-21

Energy cost (Rs/m^3)			Total cost (Rs/m^3)		
Electricity (Metered)	Electricity (Flat rate)	Diesel	Electricity (Metered)	Electricity (Flat rate)	Diesel
With electricity subsidy					
0.04	0.27	1.01	0.60	0.81	2.40
Without electricity subsidy					
0.28	2.58	1.01	0.85	3.11	2.40

Notes Electricity tariff in Bihar: Rs 0.70/unit for metered connections and Rs 85/hp/month for unmetered connections in 2020-21. The government paid a subsidy of Rs 4.85/unit (plus fixed charges of 30/hp) for metered connections and Rs 716/hp/month.
Diesel prices: Rs 90.94/litre in Bihar in 2020-21
Source Authors' calculations

groundwater without incurring marginal costs on energy. Further, energy cost under subsidized pro-rata as well as flat-rate systems was found to be significantly cheaper than the energy cost with diesel. Thus, under the prevailing energy pricing scenario, it would be economical for the farmers to shift from diesel to electricity as the source of energy for irrigation. Even if the subsidy on the electricity is removed, the energy cost of pumping groundwater at the full cost of electricity supply (Rs 5.55/unit) would be 2.60 times cheaper than the cost of diesel. Thus, large-scale electrification of wells in the state would significantly reduce the groundwater irrigation cost and improve economic access to groundwater.

Conclusions

At an aggregate level, groundwater resources in Bihar are under-utilized. In most of the areas, groundwater is at a shallow level and even rises in the post-monsoon season from the pre-monsoon level. A majority of the observation wells in the state have seen no significant change in the groundwater level during the past ten years in pre- as well as post-monsoon season. Also about half of the wells witnessing a declining trend in pre-monsoon get recovered in the post-monsoon season. Such evidence unravels the scope to sustainably and economically utilize groundwater resources and unleashes the positive groundwater and agricultural development linkages. Spatially, groundwater in north Bihar is at a shallower level as compared to South Bihar. Further, a few areas in the state are witnessing a depletion in groundwater level and a rise in the level up to the water-logging situation. This underlines a need for constant monitoring and location-specific technological and policy interventions for sustainable management of groundwater resources.

Most of the traditional groundwater structures (e.g. dugwells) in the state are getting obsolete over time and shallow tubewells have emerged as the predominant groundwater structure. With the improving power infrastructure, the number of electric pumps is rising in Bihar. However, a majority of the groundwater pumps are still dependent on diesel energy. There is a huge potential to diversify towards alternative energy sources such as electricity, solar, etc for energizing groundwater pumps. Economically, electric pumps are four times less costly than diesel pumps in the state due to the different energy costs and utilization levels of the two types of pumps. As the power supply in Bihar is improving, it would be economical for the farmers to shift from diesel to electric operated pumps. Even if subsidy on the electricity (under pro-rata tariff system) is removed, it will still be cheaper than diesel. Large-scale electrification of wells in the state would significantly reduce the groundwater irrigation cost and improve economic access to groundwater.

The government of Bihar is implementing both flat and pro-rata electricity pricing systems. With the same level of utilization, farmers in Bihar incur lower energy costs under a pro-rata based subsidized electricity tariff system as compared to the flat rate regime. This provides an economic rationale for the universal meterization of electric pumps in the state. A policy shift from a flat rate to a pro-rata electricity pricing regime would incentivize farmers to reduce inefficient use of groundwater. However, a flat-rate tariff system has the potential to support more competitive groundwater markets as well-owners paying a flat tariff can sell groundwater without incurring marginal costs on energy. Thus, there exists a trade-off between economic and equity aspects of groundwater use which needs to be optimized.

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