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Estimation of the economic value of irrigation water in canal and tube well command areas

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ABSTRACT

In recent years, inequality in the distribution of tube wells and non-availability or non-accessibility of canal water during the *rabi* season leads to a lack of economic value fixation of irrigation water to crops. The main objective of this paper is to calculate the economic value of irrigation water for major crops in the Paliganj distributary of the Sone canal system and the Nalanda corridor site of tube well irrigation, Bihar, India using the Residual Value Method (RVM). Results revealed that the average irrigation water economic value on the basis of applied irrigation through the canal and tube well in the Paliganj distributary for rice, *kharif* maize, wheat, lentil, khesari, gram, *rabi* maize, potato, onion, and green gram crops was assessed as 3.73, 22.60, 11.67, 21.50, 27.42, 23.27, 14.75, 98.06, 84.92, and 27.17 Rs./m^3, respectively. In the Nalanda corridor, the average irrigation water economic value of rice, *kharif* maize, wheat, lentil, gram, pea, mustard, potato, *rabi* maize, and green gram crops was assessed as 12.54, 24.61, 18.71, 44.15, 39.53, 37.85, 32.35, 96.93, 15.44, and 30.25 Rs./m^3, respectively.

Key words: canal command, economic value, irrigation water, Nalanda corridor, Paliganj distributary, tube well command

HIGHLIGHTS

- The residual value approach was applied to estimate water economic values in the canal- and tube well-irrigated areas.
- Water value for vegetable crops is generally higher as compared to field crops.
- Economic value of irrigation water serves as the tool for decision-makers for uniform allocation of water to crops.

INTRODUCTION

In developing countries, water is increasingly becoming scarce because diversion or allocation of fresh water for agricultural purposes is reducing owing to increasing population, urbanization, and industrialization (Kiprop *et al.* 2015). Due to rising population, urbanization, climate change, competition & conflicts for water uses and users, and water scarcity increases mostly at global, national, and regional levels (Menezes *et al.* 2022; Yasin *et al.* 2022). Hence, the allocation of water among the major sector uses, such as agricultural, industrial, and domestic is a critical issue for most of the countries in the world (World Bank 2022). Water allocation is in reality a challenging task as decisions about meeting all types of water demands are considered keeping in view social objectives, such as efficiency, sustainability, equity and economics (Gallego-Ayala *et al.* 2011; Adeoti & Fati 2022). The lack of an efficient and equitable water pricing system is an additional handicap in the process of managing water allocation (Latinopoulos 2005; Upadhyaya *et al.* 2022). The participation in the water market has been found to decline with an increase in the size of landholdings (Singh *et al.* 2007).

To grow more food to feed the ever-increasing population with limited or reduced availability of natural resources such as water is a great challenge. This challenge can be met if water is utilized efficiently and judiciously in agricultural production systems (Singh 2007). In irrigated areas, mainly through canals and groundwater, water is efficiently utilized if those crops are selected which consume less water and give relatively better yields. Groundwater irrigation through tube wells is the most appropriate alternative source of irrigation that can harness the potential benefits of available resources at a reasonable cost and within a short period of time (Singh *et al.* 2007).

Studies on irrigation water pricing are scanty, but experts always desire, discuss, and show their dedication in determining the economic value of irrigation water. When water suppliers and water users know the actual value of irrigation water, they will realize its importance and it will be easy to convince and encourage the water users to utilize water more efficiently in agriculture (Chebil *et al.* 2022). However, there is an urgent need to lay greater emphasis on the cost of producing a unit quantity of water at the water source (surface and groundwater) and charging economic water rates (Berbel *et al.* 2019). Any financial scrutiny should also examine the percentage of net income per crop which can support the cost of purchasing water for its maturity (Sangal 1991). Many different crops are cultivated in the region. The allocated lands for crops are shown in Table 1. According to Table 1, rice and wheat have a bigger production area in the region.

To identify the issues of irrigation water, it is necessary to assess the irrigation water economic value under different situations as is proposed in this study. So, it is necessary to determine the real value of irrigation water applied and optimally allocate this important input among the products in such a way that the highest value of production is attained. In estimating agricultural water demand, the market economic value cannot be considered as there is no market for it or the market is incomplete. Because of this, it is hard to determine the economic value for it directly. For this reason, several models have been used by researchers to determine the economic value of agricultural water and the willingness to pay, including net-back analysis, hedonic models (Esmaeili & Vazirzadeh 2009) and optimization models such as the Residual Value Method (RVM) (Ashfaq *et al.* 2005; Muchara *et al.* 2016; Qamar *et al.* 2018; Qureshi *et al.* 2018; Upadhyaya & Roy 2020); while capital budgeting techniques, namely net present value (NPV), benefit–cost ratio (B:C ratio) and internal rate of return (IRR) have been used for evaluating the investment in tube wells (Singh *et al.* 2007). In valuing irrigation water, very few studies have employed the RVM technique. Berbel *et al.* (2011) applied residual value techniques for the economic analysis of irrigation water for the Guadalquivir river basin, in Southern Spain. They found that the RVM technique is simple, and the results obtained are robust and consistent with alternative method findings. Aparnathi & Bhatt (2014) applied the linear programming (LP) model to maximize net benefit from optimal cropping patterns with different extents of allocation of water from canal and tube wells for the Nadiad branch canal command of Mahi command, Gujarat, India. Kiprop *et al.* (2015) applied the residual value technique to determine the economic value of irrigation water used across the Kerio valley basin in Kenya. Very few studies have been conducted in Indian conditions for the estimation of the economic value of irrigation water in canals as well as tube well-irrigated command areas using the residual valuation method.

Low irrigation water pricing results in indiscriminate and unscrupulous use of irrigation water in the upper, middle, and tail reaches of a canal, leading to either over-saturation or under-saturation conditions. For the last two decades, irrigation water charges have not been revised in many states of the country and as a result revenue from irrigation water is not increasing (Upadhyaya *et al.* 2022). In the future, agriculture is going to face a new challenge of producing more from less water available, because more water is being diverted toward industries, urban and domestic sectors. Due to the poor maintenance of the canal irrigation system, an increasing number of tube well water markets have developed, particularly in Bihar.

In recent years, due to inequality in the distribution of tube well and non-availability or non-accessibility of canal water during the *rabi* season, most of the non-tube well owners are forced to purchase water from tube

Table 1 | Crop production, area, and yield in the study region (2019–2020)

Crop	Production (million tonnes)	Area (million hectares)	Yield (kg/hectare)
Rice	6.05	2.89	2,096
Wheat	5.90	2.25	2,626
Maize	2.01	0.65	3,083
Lentil	0.12	0.15	793
Potato	7.71	0.258	29,885
Onion	1.31	0.058	22,825
Rapeseed and mustard	0.10	0.08	1,187
Gram	–	–	769

Source: Ministry of Agriculture and Farmers' Welfare (2020).

well owners. It is important to mention here that south Bihar is considered an agriculturally well-developed region endowed with an assured irrigation system through private diesel-operated tube wells. Keeping in view the importance of groundwater in increasing agricultural production, the objective of the present study is to determine the economic value of irrigation water for major crops in the Paliganj distributary of the Sone canal system and Nalanda corridor, Bihar, India, based on the economic value of tube well water and canal water obtained from state departments, agricultural input data collected from farmers and thereafter application of the RVM.

MATERIALS AND METHODS

This section introduces the study area along with its location, basic characteristics like rainfall, canal water availability, groundwater availability, information about soil, crop, climate, evapotranspiration of crops computed using meteorological data, other data related to input cost, labor cost, fixed cost used to calculate the total cost of cultivation, monetary returns from (main product and by-product) rice and wheat crops, and total irrigation water applied collected from farmers in a prescribed format through a developed questionnaire for the Paliganj distributary and Nalanda corridor.

Study area

Paliganj distributary command

The study was undertaken in the Paliganj distributary of the Sone canal system, Bihar, India which arises at 75 km from the Patna main canal, on the right side. The total length of the Paliganj distributary is 27.4 km and its design discharge is 5.1 cumecs. It is divided into three reaches such as the head (I), middle (II), and tail (III) reaches. The lengths of I, II, and III reaches are 10.45, 6.65, and 10.3 km, respectively. The gross command areas (GCA) of these reaches are 2,767, 2,513, and 2,794 ha, respectively, and culturable command areas (CCA) are 2,479, 2,102, and 2,400 ha, respectively (Figure 1).

Nalanda corridor command

The study was undertaken in 15 villages of Noorsarai, Chandi and Nagar Nausa blocks of the Nalanda district of Bihar, India (Figure 1). The average annual rainfall of the district is 1,002.2 mm. About 92.55% of the rainfall is received during June to October by the south-west monsoon. Agriculture is the foremost source of livelihood. The farmers mainly grow paddy, as well as potato and onion. The cultivated area in the district is 1,948.43 km^2. This corridor site is characterized by four types of soil, namely clay loam, fine loam, loam, and course loam, which is mainly derived from an alluvial deposit of the Gangetic plain. The net annual groundwater availability in Noorsarai, Chandi, and Nagar Nausa blocks is 3,721, 3,762, and 2,689 ha m, respectively (Central Groundwater Water Board 2013). In Nalanda district, the gross irrigated area is 179,263 ha, out of which the area irrigated through tube wells/bore wells is 118,000 ha (which is approximately 65.82% of gross irrigated area) (District Survey Report 2021).

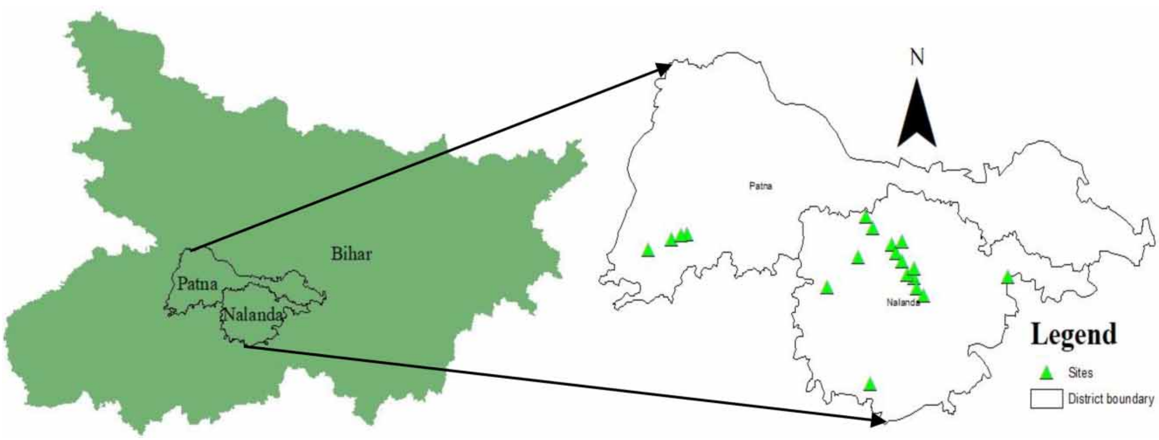

Figure 1 | Selected sites in the Paliganj distributary and Nalanda corridor.

Data collection

In order to collect required data/information about agricultural inputs used and their costs, labor cost involved in agricultural operations, the value of land, implements, infrastructure, output (main as well as by-product) produced along with their economic value, a structured questionnaire was developed. Thirty farmers from each site, representing I, II, and III reaches of the Paliganj distributary command and Nalanda corridor command, were interviewed and questionnaires were filled in. Irrigation water economic value was assessed by considering water actually used by crops as well as water applied by farmers depending on availability.

Data analysis

In analyzing data, descriptive statistics of the variables used in the analysis of production functions were used to describe the socio-economic characteristics of farmers. The residual value technique was used to determine the average economic value of irrigation water used in production across major crops grown in the Paliganj distributary command and Nalanda corridor command.

Estimating financial and economic returns

Farm costs have three components, i.e. fixed costs (includes rent of land, and farm machinery), variable costs (includes labor, seed, fertilizer, farm yard manure, pesticides, draught power, and irrigation service) and total costs. The total costs are obtained by adding both fixed costs and variable costs. All costs are estimated on a per-hectare basis. The average cost (i.e. land, labor, seed, fertilizer, farmyard manure, pesticides, and farm machinery) and returns (i.e. yield, economic values and other earnings) are defined for the average farm (Berbel *et al.* 2011). The financial returns (FR) or sale economic values are predicted by averaging yield from each crop by multiplying the farm gate economic values (FGP), and summing up the by-product by multiplying the economic values received by farmers from the market. The financial net returns (FNR) or gross margins are obtained by subtracting the total cost of cultivation from the gross FR (Kiprop *et al.* 2015; Yasin *et al.* 2022). The economic returns (ER) are obtained by evaluating the main product of the crop at economic values (EP). By-product economic values are the same as those used for estimating gross FR (Ashfaq *et al.* 2005). The cost of crop production was deducted from the gross FR of each individual crop. These FR were further divided by the amount of water applied (m^3).

Residual value method

RVM is a technique used to compute irrigation water economic value of crops or the value water productivity where water is used as an intermediate input into crop production (Kiprop *et al.* 2015; Roy 2019; Upadhyaya & Roy 2020). According to Euler's theorem, for an agricultural production function involving constant returns to scale, the summation of the marginal products will actually yield the total product. The relationship between inputs and output of crop production can be expressed mathematically through what is called a production function. The model conceptualizes around the fact that agricultural production is the function of input variables. For a homogeneous agricultural production function, $f\,(x_1, x_2, \ldots, x_n)$ of degree 1, if the economic value of each input i is its 'marginal product' $f_i'\,(x_1, x_2, \ldots, x_n)$ then the total cost, i.e. $\sum_{i=1}^{n} x_i\, f_i'\,(x_1, x_2, \ldots, x_n)$ is equal to the total output, i.e. $f\,(x_1, x_2, \ldots, x_n)$. Agricultural production function 'Y' is assumed to be influenced by four factors, i.e. money invested (M), labor force used (L), available natural resources such as land area (A) and water (W) utilized. It may be expressed as:

$$Y = f(M, L, A, W) \tag{1}$$

Assuming agricultural production and economic values are known and technology is constant, P_o is the economic value of output, and P_i is the economic value of input under perfect information. Assuming that the objective of farmers is to maximize production, the production function may be written as:

$$PF = \sum_{j=1}^{n} P_o.Y_j - \sum_{i=1}^{n} P_i\, X_i - P_w\, Q_w \tag{2}$$

The optimal profits can be determined if the first derivative of 'PF' with respect to x is equal to zero.

$$\frac{d\,PF}{dx} = P_o \cdot \frac{d\,f(x)}{dx} - \; P_i = 0 \tag{3}$$

Therefore, $P_o\;(dy/dx) = P_i$.

If all inputs, including water, are exchanged in a competitive market and employed in a production process. The value of water is estimated by ($P_w \cdot Q_w$) in Equation (4):

$$P_w \cdot Q_w = P_o \cdot Y - \sum_{i=1}^{n} P_i \cdot X_i \quad (4)$$

The RVM basically calculates the incremental contribution of each input in the production process, if all the inputs except water are assigned appropriate economic values. Therefore, the residual value of water can be calculated as the difference between the total value of output ($Y \cdot PF$) and the costs of all non-water inputs to production. The economic value of irrigation water is calculated by P_w in the Equation (5):

$$P_w = \frac{\sum_{j=1}^{n} P_o . Y_j - \sum_{i=1}^{n} P_i \, X_i}{\sum Q_w} \quad (5)$$

In both cases (i.e. Paliganj distributary command and Nalanda corridor command), farmers generally applied irrigation water to crops at the maximum production water supply (i.e. water consumption $\geq$ evapotranspiration). In such conditions, assumed marginal water productivity is zero (Berbel *et al.* 2011).

The study undertook a valuation of the residual value of water for 10 major crops grown in the Paliganj distributary command and 10 major crops grown in the Nalanda corridor command.

Econometric characterization of each crop

Several socio-economic and technological factors affect the sale and purchase of irrigation water. Some of these variables have been identified as measurable. However, some factors are plot-specific and others are socio-psychological, which may not be quantified easily. For the application of the RVM, secondary data were made available by farmers for all case studies (Paliganj distributary and Nalanda corridor) under assessment, which results from a consultation with farmers in each community. Standard crop budgets have been created for each crop, which results from field surveys. For each crop, the average input costs and yield returns were defined, assuming that each farm adopted standard production techniques. In addition, for each crop, a mean amount of water applied was considered, based on the average amounts accounted at each farmer's field (Rodrigues *et al.* 2021). A multiple linear regression model (RVM) is used to determine the economic value of irrigation water for each crop as shown in Equations (1)–(4).

RESULTS AND DISCUSSION

The empirical information is drawn from the agricultural service agencies and field surveys from farmers' respondents. Data sets included the quantity of output, economic values, and costs of selected crops and water. The most important management implication of this study is the reallocation of irrigation water according to the economic value of water in various crops. In order to assess the irrigation water economic value of different crops in the Paliganj distributary command (irrigated with canal and groundwater) and Nalanda corridor site (irrigated by groundwater only), required data were collected from 30 farmers of the Paliganj distributary command and 15 villages of Nalanda corridor through the developed questionnaire.

Residual return to water of the Paliganj distributary

Farm budgets for 10 crops, namely rice, maize *kharif*, wheat, lentil, khesari, gram, maize *rabi*, potato, onion and green gram, were developed. Farm costs which include rent of land, labor (involved in ploughing/tilling/harrowing/sowing/dibbling/planting/transplanting/weeding/harvesting/threshing), seed, organic matter, fertilizer, insecticide, and pesticide were all summed up to arrive at the total cost of cultivation for each crop. The cost of the main product such as cereal crops on minimum support price (MSP), and khesari and vegetable (potato and onion) crops on local market rate was considered. The gross margins or FNR are calculated for each crop in order to analyze the value of the water of these crops. Table 2 provides a summary of the crop budgets of the 10 crops obtained from the sampled 30 representative farmers of the Paliganj distributary command. These crops together make up around 90% of the total irrigated land area in both command areas.

Table 2 | Summary statistics of crop budgets of the Paliganj distributary command

Crop	Total cost (Rs.)	Total sales (Rs.)	Gross margin (Rs.)
Rice	67,939	93,120	25,181
Wheat	62,606	88,875	26,269
Lentil	44,524	71,400	26,876
Gram	52,518	81,600	29,082
Khesari	42,225	76,500	34,275
Green gram	31,448	72,750	41,303
Maize Kharif	38,899	89,760	50,861
Maize Rabi	49,409	104,720	55,311
Potato	91,876	312,500	220,624
Onion	67,857	450,000	382,143

The result shows the gross margins for the different crop enterprises. From the results, onion had the highest gross margin (Rs. 3,82,143) compared to other crops followed by potato (Rs. 2,20,624), maize *rabi* (Rs. 55,311), maize *kharif* (Rs. 50,861), green gram (Rs. 41,303), khesari (Rs. 34,275), gram (Rs. 29,082), lentil (Rs. 26,876), wheat (Rs. 26,269), and rice (Rs. 25,181), respectively, in decreasing order. This result was consistent with another study by Kiprop *et al.* (2015), who calculated it as Ksh 91,288 (Rs. 61,218.05) and Ksh 84,944 (Rs. 56,963.74) for the green gram and maize crops, respectively. These crop budgets were utilized to determine the economic value of irrigation water (Rs./m^3) through the RVM. The cost of production was subtracted from the gross returns of each individual crop. These returns were further divided by the amount of water applied (m^3) to achieve the economic value of irrigation water at zero cost of irrigation. Table 3 provides a summary of the data at the farm crop level, which was used to evaluate the economic value of irrigation water for different crops (Rs./m^3). The economic value of irrigation water was derived from the crop output with irrigation over the entire production period of the year.

It may be observed from Table 3 that the economic value of irrigation water after considering irrigation water applied through canals and tube well in the Paliganj distributary command for field crops; rice, wheat, maize *rabi*, lentil, maize *kharif*, gram, green gram, and khesari are 3.73, 11.67, 14.75, 21.50, 22.60, 23.27, 27.17, and 27.42 Rs./m^3, respectively. Similarly, for the vegetable crops, onion and potato are 84.92 and 98.06 Rs./m^3, respectively. Maximum irrigation water economic value of 98.06 Rs./m^3 for potatoes and minimum 3.73 Rs./m^3 for rice is observed, also quoted by Berbel *et al.* (2011). This clearly shows that the consumption of water by rice is quite high as compared to potato but the profit earned from potato is maximum as compared to all other crops. This result was consistent with other studies by Ashfaq *et al.* (2005) and Kiprop *et al.* (2015), who

Table 3 | Economic value of irrigation water for different crops (Rs./m^3)

	Economic result per ha			Apparent productivity	
Crop	Total sales (Rs.)	Gross margin (Rs.)	Water average doses (m^3)	Sales/water (Rs./m^3)	Irrigation water economic value (Rs./m^3)
Rice	93,120	25,181	6,750	13.79	3.73
Wheat	88,875	26,269	2,250	39.50	11.67
Maize *Rabi*	104,720	55,311	3,750	27.92	14.75
Lentil	71,400	26,876	1,250	57.12	21.50
Maize *Kharif*	89,760	50,861	2,250	39.89	22.60
Gram	81,600	29,082	1,250	65.28	23.27
Green gram	72,750	41,303	1,520	47.86	27.17
Khesari	76,500	34,275	1,250	61.20	27.42
Onion	450,000	382,143	4,500	100.00	84.92
Potato	312,500	220,624	2,250	138.89	98.06

calculated the economic value of irrigation water for field crops; rice, wheat, maize and green gram were 0.63, 1.13, 9.97 Rs./m^3 (Ksh 14.87) and 13.98 Rs./m^3 (Ksh 20.85), respectively, and for vegetable crops; potato and onion were 6.60 and 13.10 Rs./m^3, respectively. Muchara *et al.* (2016) estimated water economic value for potatoes was ranging from −US$1.67/m^3 (–Rs. 138.24/m^3) to US$1.13/m^3 (Rs. 93.54/m^3). The results of Ren *et al.* (2018) also supported the economic value of canal irrigated areas as being 3.39–5.64 Rs./m^3 and 1.20–2.12 Rs./m^3 and for tube well-irrigated areas 3.76–6.01 Rs./m^3 and 1.55–2.49 Rs./m^3 for maize and rice crops, respectively. Finally, it is concluded that at the crop level water values estimated for vegetable crops are generally higher compared to field crops. This indicates that there is greater potential in vegetable crops than in cereal crops.

Residual return to water of Nalanda corridor command

Farm budgets for the 10 crops, namely rice, maize *kharif*, wheat, lentil, gram, pea, mustard, potato, maize *rabi* and green gram were developed. Farm costs which include rent of land, labor (involved in ploughing/tilling/harrowing/sowing/dibbling/planting/transplanting/weeding/harvesting/threshing), seed, organic matter, fertilizer, insecticide, and pesticide were all summed up to arrive at the total cost of cultivation for each crop. The cost of main products such as cereal crops on MSP, and pea and vegetable crops (potato) on the local market rate was considered. The gross margins or FNR are calculated for each crop in order to analyse the value of the water of these crops. Table 4 provides a summary of the crop budgets of the 10 crops obtained from 15 villages of this command (irrigated through tube well only).

The result shows the gross margins for the different crop enterprises. From the results potato had the highest gross margin (Rs. 2,17,418) compared to other crops followed by maize *rabi* (Rs. 57,915), maize *kharif* (Rs. 55,373), pea (Rs. 51,098), green gram (Rs. 45,371), lentil (Rs. 33,109), wheat (Rs. 32,739), mustard (Rs. 32,348), gram (Rs. 29,646), and rice (Rs. 28,219), respectively, in decreasing order. This result was consistent with the study by Kiprop *et al.* (2015), who calculated it as Ksh 91,288 (Rs. 61,218.05) and Ksh 84,944 (Rs. 56,963.74) for the green gram and maize crops, respectively. These crop budgets were utilized to determine the economic value of irrigation water (Rs./m^3) through the RVM. The cost of production was subtracted from the gross returns of each crop. These returns were further divided by the amount of water applied (m^3) to achieve the economic value of irrigation water at the zero cost of irrigation. Table 5 provides a summary of the data at the farm crop level, which was used to evaluate the economic value of irrigation water for different crops (Rs./m^3). The economic value of irrigation water was derived from the crop output with irrigation over the entire production period of one year.

Results reported in Table 5 reveal that at Nalanda corridor command, irrigation water economic values for field crops rice, maize *rabi*, wheat, maize *kharif*, green gram, mustard, pea, gram, and lentil are 12.54, 15.44, 18.71, 24.61, 30.25, 32.35, 37.85, 39.53, and 44.15 Rs./m^3, respectively. Similarly, for the potato crop the value is 96.93 Rs./m^3. A maximum irrigation water economic value of 96.93 Rs./m^3 for potato crop and a minimum of 12.54 Rs./m^3 for rice is observed. The presented results are compared with other countries' studies analyzing the economic value of water for irrigation at the regional level. Ziolkowska (2015) estimated the economic

Table 4 | Summary statistics of crop budgets of Nalanda corridor

Crop	Total cost (Rs.)	Total sales (Rs.)	Gross margin (Rs.)
Rice	64,901	93,120	28,219
Gram	46,854	76,500	29,646
Mustard	37,403	69,750	32,348
Wheat	56,136	88,875	32,739
Lentil	43,391	76,500	33,109
Green gram	49,204	94,575	45,371
Pea	48,903	100,000	51,098
Maize *Kharif*	38,128	93,500	55,373
Maize *Rabi*	56,155	114,070	57,915
Potato	95,082	312,500	217,418

Table 5 | Economic value of irrigation water for different crops (Rs./m^3)

Crop	Economic result per ha		Water average doses (m^3)	Apparent productivity	
	Total sales (Rs.)	Gross margin (Rs.)		Sales/water (Rs./m^3)	Irrigation water economic value (Rs./m^3)
Rice	93,120	28,219	2,250	41.39	12.54
Maize *Rabi*	114,070	57,915	3,750	30.42	15.44
Wheat	88,875	32,739	1,750	50.79	18.71
Maize *Kharif*	93,500	55,373	2,250	41.56	24.61
Green gram	94,575	45,371	1,500	63.05	30.25
Mustard	69,750	32,348	1,000	69.75	32.35
Pea	100,000	51,098	1,350	74.07	37.85
Gram	76,500	29,646	750	102.00	39.53
Lentil	76,500	33,109	750	102.00	44.15
Potato	312,500	217,418	2,250	138.89	96.63

value of irrigation water for maize as 5.80 Rs./m^3 (US\$0.07/m^3) and for wheat they are lowest. Rodrigues *et al.* (2021) also reported field crops such as wheat and maize to have a lower economic value of irrigation water. The result shows that vegetable crop such as potato has great potential to be cropped in the Nalanda corridor.

Policy recommendation

In light of the above results, the economic value of irrigation water indicates vegetable crops such as potato and onion give high FR while utilizing less water. Farmers should be encouraged to grow more vegetable crops such as potato and onion in the Paliganj distributary command and Nalanda corridor command. It is also recommended that these command areas are also highly suitable for high-value horticultural crops which provide maximum gross return while utilizing less water for farmers, increasing water use efficiency and improving the livelihoods of area inhabitants.

CONCLUSION

Two case studies have been reported here. At the Paliganj distributary site, canal water as well as groundwater has been applied for irrigation, whereas, at the Nalanda corridor site, only groundwater has been used for applying irrigation. A comparison of irrigation water pricing at the Paliganj distributary site as well as the Nalanda corridor site showed that the irrigation water economic value at the Nalanda corridor site is higher than the Paliganj distributary site because farmers realize the importance of water at Nalanda and they apply it efficiently and judiciously when it is essentially required by crops, whereas at Paliganj canal water charges are much lower compared to groundwater and farmers applying it unconsciously. The results of this study may serve as a tool for decision-makers on how irrigation water should be economically valued in order for some crops to be suitable. Also, it provides standard economic value for the most representative crops in both regions, thereby offering support for new farmers on which crops should be farmed in those irrigation communities.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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