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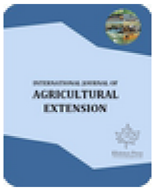

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EXPLORING WATER RESOURCE ECONOMICS: A STUDY ON GROUNDWATER EFFICIENCY AND YIELD OPTIMIZATION IN COTTON FARMING ACROSS SINDH, PAKISTAN

[a]Akbar K. Khajjak*, [b]Tehmina Mangan, [c]Anosha Nangraj
[a] Sindh Agriculture University Tandojam, Pakistan.
[b] Begum Nusrat Bhutto Women University, Sukkur, Pakistan.
[c] Habib University Karachi, Pakistan.

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ABSTRACT

Groundwater exploitation depletes the water table, endangering the region's delicate natural systems. However, the groundwater level in Sindh will fluctuate in order to satisfy irrigation water requirements, which has not been well examined to assess agricultural sustainability. The increased water demand due to the expanding population has caused the agriculture community to consume groundwater, hence the groundwater table is fast diminishing. The present study expounds the cotton growers' technical, allocative, economic, and water usage efficiencies. In addition, the research looked into the factors that influence cotton producers' allocative efficiency and offered policy implications based on the findings. Primary data was obtained from 390 cotton producers, 195 from each of the Chihu and Malwa minor canals in Naushero Feroze and Benazirabad districts, respectively. Data Envelope Analyses (DEA) were used to assess technical, allocative, economic, and ground water efficiencies, while a two-limit tobit regression model was used to investigate factors impacting allocative efficiency. The study's findings reveal that cotton producers exhibit commendable technical efficiency, with scores surpassing 70%. However, deficiencies emerge in resource allocation, input-output effectiveness, and groundwater utilization, where a majority of scores fall below 50%. Growers' experience and tube well depth significantly influence allocative efficiency. Notably, the head section of canals has greater access to surface water, leading middle and tail users to rely more on groundwater, elevating their production costs. This underscores the importance of a multidisciplinary approach by stakeholders in addressing these challenges. Authorities, particularly the irrigation department, should address disparities among head, middle, and tail users. Furthermore, imparting comprehensive knowledge to growers regarding resource management and efficient farming practices is essential for sustainable solutions.

Corresponding Author: Akbar K. Khajjak
Email: akbareconomist70@gmail.com

INTRODUCTION

Groundwater irrigation is important in agricultural productivity in arid locations because it provides a more consistent water supply than surface water and is reliable throughout protracted droughts (Singh et al., 2024). Arid and semi-arid regions, where irrigation water is the most important natural resource, account for about half of all agricultural land in emerging countries today (Hamlat et al., 2024). Logically, scholars have given the subject of water shortage a lot of thought (Xue et al., 2018; Yihun, 2015). Pakistan is one of the world's major groundwater extractors. With 5.2 million hectares of groundwater-irrigated land, Pakistan irrigates 4.6 percent of the world's groundwater-fed cropland (Qureshi, 2020; Watto and Mugera, 2015). However, over drafting to satisfy growing agricultural water needs has put enormous strain on groundwater supplies over the last few decades (Watto & Mugera, 2015). The percentage of land irrigated by groundwater has progressively grown in 2010 up to 47 percent from 8% in 1960 (FAO, 2016; Mukherji and Facon, 2009). The accessibility of groundwater played a pivotal role in fostering enhanced economic growth by ensuring reliable and improved crop yields, concurrently mitigating the vulnerability of crops to external factors such as droughts (Asghar et al., 2018; Lal, 2018). Conversely, the over-exploitation of aquifers in freshwater zones has led to a decline in water levels, rendering groundwater largely unavailable in many regions of Pakistan (Daud et al., 2017; Lal, 2018; Watto et al., 2018).

Pakistan is the world's fourth-largest yarn producer, the second-largest exporter, and the seventh-largest fabric manufacturer. Cotton commodities contribute for over 60% of Pakistan's foreign earnings (Malik et al., 2017; Memon, 2016). However, cotton and its derivatives account for at least 2% of Pakistan's gross domestic product, while agriculture accounts for roughly 10% of the country's value added (Rehman et al., 2015; Rizwan et al., 2017; Shuli et al., 2018). Surface and groundwater irrigation are responsible for a major portion of overall cotton output (Asghar et al., 2018; Steenbergen and Oliemans, 1997). Access to ground water has enhanced the production of crops and farmers' revenue limits, thus improving rural livelihoods and the agricultural economy of Pakistan (Aslam, 2016; Street, 1994). Pumping expenses have increased as the depth of the groundwater table has increased (Qureshi et al., 2010; Salam et al., 2020). Pumping costs are rising, increasing the cost of output and reducing farmers' profit margins (Asghar et al., 2018; Hassan et al., 2020; Sharif, 2011). Groundwater irrigation for mostly cultivated crops may become economically unviable as a result of this trend (Watto and Mugera, 2016, 2015). By lowering the cost of inputs, the cost of production may be reduced (Shafiq and Rehman, 2000; Yousafzai et al., 2019), through changing management methods, i.e., by increasing the efficiency of technical and resource usage (Khaliq et al., 2011; Zhang et al., 2017) or by changing inputs in a cost-minimizing percentage, by attaining allocative efficiency (Kaneva, 2016; Khan and Burki, 2000). Prices of gas, electricity, and other agricultural inputs have been increased upwards several times in recent years, with these increases in input costs far exceeding the growth in the price of agricultural products (Afzal and Ahmad, 2009; Imran et al., 2018). As a result, economic, enhancing technical, ground water usage, and allocative efficiency is a more active tool for decreasing cost of production (Mokgalabone, 2015; Watto and Mugera, 2013). In earlier studies, farmers were shown to be inefficient in their use of groundwater (GELA, 2019; Tarjuelo et al., 2015). The factors that influence technical and groundwater efficiency have also been investigated (Lansink and Reinhard, 2004; Watto and Mugera, 2019), and The findings show that, in addition to farmers' socioeconomic factors, owning tube wells enhances technical and irrigation efficiency substantially (Akram et al., 2020). In Pakistan, the degree of efficiency across the head, middle, and tail of smaller canals branching out from the main river and their causes has not been well investigated (Mutema et al., 2023). However, we believe that rising irrigation costs would have a negative impact on cotton producers' allocative efficiency (Asghar et al., 2018; Dinar and Letey, 1991).

An additional issue pertains to the emergence of shortages at the basin level, where the allocation of existing supplies to all consumers and purposes becomes a complex task (Barker et al., 1999). Referred to as basin scarcity, this scenario is outlined by Molden (2020). Increasingly, water scarcity in various global locations has evolved into a significant impediment to socioeconomic development and poses a threat to livelihoods (Liu et al., 2017; Mapholi et al., 2014). Pakistan's per capita surface water availability fell from 5,260 cubic meters per year in 1951 to around 1,000 cubic meters in 2016. This amount is expected to fall to around 860 cubic meters by 2025, demonstrating our shift from a "water strained" to a "water shortage" country (Government of Pakistan, 2018). In terms of surface water resources, the Indus Basin is considered the world's most degraded river basin (Arif and William, 2016). Pakistan's agricultural industry is facing significant problems as a result of changing climate, population expansion, and rising living standards (Abid et al., 2016; Ali Amin, Javed Iqbal, 2018; Ali et al., 2017; Rehman et al., 2020). Pakistan can only store 30 days' worth of water in the Indus Basin. If no new storage is built in the foreseeable future, canal diversions will stay unchanged, and the shortfall will increase by 12% over the next decade (Qureshi, 2011). Another issue is an insufficient pricing mechanism, which encourages water users to construct additional tube wells. A reasonable price would not only prevent excessive usage, but also result in near-optimal production and conserve this natural resource for future generations (Sahibzada, 2002). Farmers' capacity to distribute resources is harmed as a result of such barriers, which leads to inefficiencies in the production process (Bashir and Khan, 2005).

Allocative and economic efficiency estimates are necessary in order to thoroughly investigate production efficiency because, while technical efficiency estimates are clearly important for understanding farm management practices, they do not provide comprehensive information about the allocation of all resources and the minimization of their costs (Tang et al., 2015). Policymakers may create plans for encouraging rural development and boosting farm income with the use of this extensive data on allocative and economic efficiency and the variables affecting it (Thabethe & Labuschagne, 2014). This study focuses on cotton producers' technical, allocative, economic, and water consumption efficiency since it is crucial for lowering production costs and increasing profit margins. The primary goals of the study were to quantify the technical, allocative, economic, and ground water consumption efficiency of the farmers cultivating cotton along the minor tributaries of the Indus River. Furthermore, to determine the primary determinants of allocative efficiency. Lastly, provide recommendations for policy based on the findings.

METHODOLOGY

Conceptual Framework

Agronomists and irrigation engineers frequently use computationally simple and intuitively attractive approaches to study efficiency differentials, Examples is agricultural yield per acre of land or water consumed (Sharma et al., 2024). Due to the exclusion of potential changes and differences in other production parameters as manpower, equipment utilization, or chemical inputs, such metrics may not fully explain the causes of variations in crop output at different farms (Coelli et al., 1998). Technical efficiency assessment, which considers all production and input factors simultaneously to evaluate productivity and efficiency, is a more comprehensive and accurate evaluation technique (Ji et al., 2012). When a farmer produces a certain output with the fewest possible inputs, that farmer has reached the pinnacle of technical efficiency (Watto and Mugera, 2015). The amount of groundwater that may be utilized without affecting the other inputs and outputs is determined by groundwater utilization efficiency (Korattukudy Varghese et al., 2011). Only the physical factors of production are considered by labor productivity; input prices and finished goods values are not considered. When a farmer allocates inputs to lower the cost of generating a specific amount of output, they are achieving allocative efficiency (Farrell, 1957).

Efficiency Estimation, Data Envelopment Analysis

Data Envelopment Analysis represents a non-parametric approach, while the Stochastic Frontier Approach within Data Envelopment Analysis is a parametric method, both utilized for assessing the relative efficiency of decision-making units with diverse inputs and outputs. This study employs a non-parametric frontier approach for data-envelopment analysis to evaluate the relative efficiency of homogeneous decision-making units with varying inputs and outputs (Zhang et al., 2014). The research focuses on measuring water consumption, allocative efficiency, economic efficiency, and technical efficiency for cotton fields using data-envelopment analysis, which is a nonparametric approach grounded in mathematical programming techniques. Charnes et al. (1978) pioneered the application of the DEA approach, drawing inspiration from Farrell's work in 1957 (Asghar et al., 2018; Farrell, 1957), to establish an input-oriented measure of efficiency based on consistent returns to scale technology. The study introduces a data-envelopment-analysis model with a variable return to scale assumption, relaxing the CRS requirement. The author conducts a comprehensive review of data-envelopment-analysis methodologies, integrating components explored in the development of the present research's data-envelopment-analysis model with a single output and multiple inputs. The analytical technique utilizes varied returns to scale technology within a data-envelopment-analysis framework. Assuming (n) farms produce a single commodity with

(K) inputs, the linear programming problem (θ λ) aims to determine the input-oriented technical efficiency of farm (j).

Technical Efficiency Estimation

The following linear programming issue was resolved by concentrating on input resources in order to assess the technical efficacy of a particular firm. Return to scale for variables that are input oriented. Technical efficiency was assessed using the DEA approach, then (Coelli et al., 1998). Indicated as:

$\min \theta$

$\theta, \{\lambda_i\}_{i=1}^{n}$ ………. ……. ………..(1)

Subject to:

$\sum_{i=1}^{n} y_i \lambda_i \geq y_j$ ….. …. ……. …. (2)

$\sum_{i=1}^{n} x_{ki} \lambda_i \leq \theta x_{kj}, \text{for} k = 1, 2, \dots, K$ ….. …….. ….. (3)

$\sum_{i=1}^{n} \lambda_i = 1$ ………. …….. …………… (4)

$\lambda_i \geq 0$ ………. …….. ………………….. (5)

Let y_i represent the production of i-th firm, where i = 1, 2,….,j,…., n, and n is the total number of firms. The input quantities x_{ki} denote K-th input applied by the i-th firm k = 1, 2 ,…, K, where K signifies the total number of inputs utilized by the firms. The weights $\{\lambda_i\}_{i=1}^{n}$ are to be estimated, While θ represent the input-oriented estimates of the technical efficinecy for firm j. It is important to highlight that Equation comprises K equations (3), Equations (1), (4) are solved for each of the j firms to determine the optimal level of the specified function. whereas θ^*, serving an estimate of the input-oriented technical efficiency of *j* firm (*TEj*):

$TE = \theta^*$ …….. ……… …….. (6)

Economic Efficiency Estimation

The economic efficiency DEA model serves as a strategic tool for evaluating the overall effectiveness of resource utilization in agricultural systems. By quantifying the relationship between input and output variables, it enables researchers to gauge the economic efficiency of farming operations, aiding in the identification of optimal production practices and resource allocation strategies.

The following linear programming problem is described to assess the efficiency of cost-oriented input of firm j:

min

$\{x_{kj}\}_{k=1}^{K}, \{\lambda_i\}_{i=1}^{n} \sum_{k=1}^{K} w_{kj} \, x_{kj}$ …… …… ….. (7)

Subject to:

$\sum_{i=1}^{n} y_i \lambda_i \geq y_j$ ……. ……. ………. (8)

$\sum_{i=1}^{n} x_{ki} \lambda_i \leq \theta x_{kj}, \text{for} k = 1, 2, \dots, K$ …. …… ….. (9)

$\sum_{i=1}^{n} \lambda_i = 1$ …….. …….. ……… (10)

$\lambda_i \geq 0$ …….. ……. ……….. (11)

Where, w_{kj} is the input price k that j^{th} firm uses. The model is presented in equation (7) and (11) and is computed for *j* firms to achieve the best solution: $\{x_{kj}^*\}_{k=1}^{K}$ and $\{\lambda_i^*\}_{i=1}^{n}$.Cost efficiency of j (EEj) firm is estimated as follows:

$EE_j = \sum_{k=1}^{K} w_{kj} x_{kj}^* / \sum_{k=1}^{K} w_{kj} x_{kj}$ ……. ….. ……. (12)

Equation (12) indicates that EE_j is the proportion of the minimum cost of manufacturing to the actual cost of production observed.

Allocative Efficiency Estimation

The allocative efficiency DEA model is instrumental in assessing the optimal allocation of resources within agricultural operations. By scrutinizing the distribution of inputs to maximize output, this model facilitates a nuanced evaluation of how efficiently resources are allocated, providing valuable insights for improving resource management in agricultural settings.

We calculated the allocative efficiency of company j (AEj) using Equations (6) and (12):

$AE_j = \frac{EE_j}{TE_j}$ …….. ……. ………. (13)

Water Use Efficiency Estimation

The water use efficiency DEA model is a valuable tool for evaluating the effectiveness of water utilization in agricultural practices. By quantifying the relationship between water inputs and crop outputs, it aids in identifying and optimizing water-efficient farming techniques, crucial for sustainable water resource management.

Two techniques are used in non-parametric research to find the efficiency of each individual input: the slack-based DEA methodology and the DEA sub-vector efficiency Model (Watto and Mugera, 2019). An input-oriented variable return to scale model was employed in the current study to evaluate the effect of water on agricultural productivity. The model that was chosen below therefore matches the data the best. Conversely, water usage efficiency, while all other inputs remain constant, is equivalent to agricultural productivity in terms of water consumption.

$Min_{\theta,\lambda} \theta$ ….. ….. ………. (14)

Subject to:

$-y_i + Y\lambda \geq 0,$ .... (15)
$x_i - X\lambda \geq 0,$ .... (16)
$\frac{N1}{\lambda} = 1,$ .... (17)
$\lambda \geq 0,$ .... (18)

The ith farm's input vector is xi, and its output vector is yi, according to equations 14 through 18. When choosing the optimal weights, we kept this in mind (Coelli et al., 1998). The equation is run *n* times to provide farm efficiency ratings, and weights are selected to optimize efficiency scores. Farms with efficiency ratings of 1 are effective at using the available water resources to generate the most agricultural output possible. Unproductive farming is indicated by a point below one (Fatima et al., 2020).

Factors Affecting Allocative Efficiency, Two-Limit Tobit Regression Model

An econometric model was constructed for the factors affecting efficiencies of the farmers. Allocative inefficiency scores range between zero and one. This type of variables falls in the category of two-sided censored variables. For such dependent variables, the most commonly used econometric model is the Two-Limit Tobit Regression Model (Watto and Mugera, 2019). As the dependent variables are in proportionate manner, it demands of a censoring that should be in between zero and one. Thus, this model satisfies the condition of the data by censoring the dependent variable equation below.

The two-limit tobit regression model is given by
Equation (6):

$$\theta_*^k = a_{j0} + \sum_{j=1}^{mn} \beta_j t_{jk} + \varepsilon_{jk,}$$

$$\theta_k = \begin{Bmatrix} \theta_*^k, & if\ 0 < \theta_*^k < 1 \\ & 0, if\ \theta_*^k < 0 \quad , \\ & 1, if\ \theta_*^k \geq 1 \end{Bmatrix}$$

The efficiency score is *k*, and the explanatory factors are *tjk*, and e_{jk} is the error term. Maximum likelihood approach was used for the estimation of the parameters in tobit regression.

Study Area and Sampling

The study was carried out in the Sindh Province of Pakistan in the districts of Shaheed Benazirabad and Naushero Feroz. Chihu and Malwa small canals, which are part of the Sukkur barrage left command of the Indus River, are diverted from the districts included in the research. According to the Indus River system, these two districts are situated in the center of Sindh province, leaving the head (Sukkur and Khairpur districts) and tail (Thatta, Badin, and Sajawal districts) behind. Shaheed Benazirabad and Naushehro Feroze districts are being studied for the planned research for two reasons: Farmers in the agricultural region may grow a wide range of crops, such as cereals, sugarcane, wheat, fodders, and horticulture harvests, thanks to the alluvial soils in the area. The most prevalent agricultural patterns are wheat-cotton and wheat-sugarcane systems. Second, because these areas are situated beneath the province's main river system, they will offer an organized and unambiguous picture of the distribution patterns and availability of water.

Multi-stage stratified random sampling was used to interview 390 farmers who made up the study's sample. There were 195 respondents in each of the two strata of the sample, Chihu minor and Malwa minor. Additionally, according on the percentage of cotton producers, each stratum was split into three divisions: the head, middle, and tail of the minors. Each division had a sample of 65 respondents.

Data and Variable Definition

Producers gathered information on various factors including cotton output, seed rate, irrigation amount, fertilizer rate, machine usage, labor input, chemical use, and the relative prices of these inputs. The data collected were utilized to compute efficiency in technical, allocative, economic, and groundwater utilization. Additionally, information on household socioeconomics, demographics, cotton grower and farm characteristics, as well as groundwater data, was collected to further evaluate their impact on efficiency. The DEA model was employed to assess performance across different farm sizes by inputting cotton input costs and quantities in per-acre units. All expenses were calculated in Pakistani rupees, as detailed in Table 1.

Cotton farmers provided details on the frequency of irrigations, the duration of each irrigation, and the associated costs, using a pre-tested questionnaire. This information was gathered to estimate the utilization of groundwater for irrigating cotton crops and to assess the related expenses. To estimate the volume of groundwater used for irrigation, a modified version of the estimation model from Watto and Mugera (2015) was employed.

$$Q = \left[\frac{t\ \times 129574.1\ \times BHP}{\left[d + \left(\frac{255.5998\ \times BHP^2}{d^2} \times D^4\right)\right]}\right]/1000,$$

Here, Q stands for the total volume of ground water in cubic meters, t for the amount of time spent irrigation in hours, BHP for engine power in horsepower, d for digging depth in meters, and D for suction pipe diameter in inches. The entire irrigation period will be multiplied by the irrigation cost to get the overall cost of ground water irrigation.

Table-1. Description of variables.

Variables	Unit	Description
Cotton Yield	Kg per-acre	The number of bolls of cotton harvested per acre
Cropped Areas	Acres	The cotton-growing area
Seeds Rates	Kg per-acre	The amount of cotton seed planted per-acre.
Labor	Person per-acre	Per acre, the number of laborers used
Fertilizer Use	Kilograms per acre	The quantity of fertilizer (N+P+K) used per acre
Chemical Use	Kilograms per acre	The quantity of chemical used per acre
Ground Water Irrigation	Cubic meters per acre	The amount of groundwater that has been applied per acre
Machineries	Machinery per-acre	Per acre, the number of machine hours needed for land preparation
Demographic and Farm Characteristics		
Age	Years	Age of the respondent
Education	Number of years of formal schooling	Education of the sample
Family-Size	Household size	Number of people who rely on the farm household's income
Farming Experience	Years in farming	Number of years spent in farming
Depth of Tube Well	meters	The deepness of the tube well's borehole
Discharge of Tube Well	Cubic meters per-hour	The tube well's ability to release groundwater
Electric	Binary (1,0)	If the farmer utilizes groundwater from an electric Tube well, the answer is 1; otherwise, the answer is 0.
Tractor-functioned	Binary (1,0)	1 if the farmer utilizes tractor-functioned groundwater, 0 otherwise
Diesel motor	Binary (1,0)	1 if the farmer uses groundwater from diesel motor, 0 otherwise

RESULTS AND DISCUSSION

The descriptive statistics, frequencies, and ratings of cotton farms technical, allocative, economic, and ground water use efficiencies for the selected variables are shown in this section, followed by the estimated values.

Economic analysis of cotton farms

Table 2 shows variations in cotton input consumption and cost, as well as cotton output discrepancies, among farmers residing at the head, middle, and tail of the minors. Such differences are the leading source for the identification of changes in technical, allocative, water use, and economic efficiency across the minors. It was observed that there was a significant difference on average in the groundwater use across head, middle, and tail of both Chihu and Malwa minor. The use of water was found to be excessive in head part of minors then in middle or tail of minors. Fertilizer application and pesticides usage was found to be greater in the both the tails of minors with respect to head and middle. Whereas no significance difference was found in the use of seed, labor, and machinery across the minors. Cotton outputs were witnessed to be higher towards head side of the minors with an average yield of 974.5 kilograms in Chihu in comparison to 919.4 and 920.6 kilograms in middle and tail of Chihu minor. However, Chihu minor was witnessed to have greater yields than Malwa in overall comparison. The cost of ground water irrigation per acre borne by the tail farmers was observed to be higher than head and middle farmers. This is because of the excess availability of water in the head of minors. This one higher cost factor leads towards all higher costs borne by the tail users eventually cumulated in total production cost which was higher for tail users of both Chihu and Malwa minors.

Table 2. Descriptive and inferential statistics of quantity and costs of inputs to cotton production between head, middle, and tail of Chihu and Malwa Minors.

Variables	Unit	Naushero Feroz Minor			Benazirabad Minor		
		Head N=65	Middle N=65	Tail N=65	Head N=65	Middle N=65	Tail N=65
Quantities of Inputs and Outputs							
Cotton Cultivated Area	Acre	7	6.7	6.3	15	14.3	14
Groundwater Irrigation	m^3/ac	3213	3404	3336.9	4115	3502.4	3835.2
Seed Rate	kg/ac	7.2	7.4	7.3	7.2	7.3	7.4
Labor	No./ac	4	5.0	4	6	4	5
Machinery	Hours/ac	2.12	2.0	2.1	2.7	2.7	2.8
Fertilizers (N+P+K)	kg/ac	253.5	274.8	287.4	210.1	214.7	224
Chemical (Pesticides, Weedicides)	No./ac	1.5	2.0	2.1	1.7	1.9	2.3
Cotton Output	kg/ac	974.5	919.4	920.6	881.1	848.5	832.7
Costs of Inputs							
Groundwater Irrigation Cost	PKR/ac	10,732	11,495	12,061	11,790	11,774	11,981
Seed Cost	PKR/ac	1,744	1,855	1,984	1,646	1,656	1,654
Labor Cost	PKR/ac	877	990	1,001	823	867	877
Machinery Cost	PKR/ac	4,236	4,440	4,773	3,986	4,129	4,651
Fertilizer (N+P+K) Cost	PKR/ac	10,796	11,440	12,094	9,909	9,956	10,201
Chemicals Cost	PKR/ac	1,879	2,102	2,227	2,025	2,157	2,135
Total Cost	PKR/ac	47,297	48,675	48,279	48,696	48,987	51,321

Note: m^3/ac stands for million cubic per acre, kg/ac indicates kilograms per acre, No./ac stands for number of units per acre, PKR stands for Pakistani Rupees.

Characteristics of Cotton Farmers by Location Across the Minor

For the three types of groundwater users, Table 3 shows personal characteristics of producers, household characteristics, and agricultural properties. According to average age, the Chihu head growers were the oldest, while the Malwa head growers were the youngest. The education level revealed that the Malwa middle growers' group were more educated than rest of the groups. Whereas Chihu tail growers and Malwa middle growers' group were of almost same educational level. According to the average farm size, it was witnessed that the Malwa head growers' group had the largest landholding with 9.8 acres, followed by the Chichu head growers' group with 9.5 acres of land and Malwa head growers' group (8.7 acres). Average Family size of Chihu tail growers' group was witnessed to be the largest whereas the Malwa middle growers' group was the smallest between the groups. Chihu tail growers' group had the largest number regarding tube well depth with 144.2 feet whereas Malwa middle growers' group had lowest depth with 49.1 feet. Regarding salinity perception of the farmers, 29 % of the Malwa head growers group notified that their water is saline while 18% of the Malwa tail growers group witnessed salinity in water. Salinity perceptions of the farmers were their personal observation and were not based upon water testing for irrigating purpose.

Technical and Allocative Efficiency by farm Location across the Minor

The findings of the input-oriented DEA model estimate for technical and allocative efficiencies are presented in Tables 4 and 5. It was seen that as we progressed from head to tail in both minors, the average technical efficiency ratings were decreasing. Chihu head growers' group was found to be 77% technically efficient on average, followed by 73% in middle and 76% in the tail, while Malwa head growers' group was 81% technically efficient on average followed by 80% in the middle and 78% in the tail. Almost all the groups were found to be technically efficient above 50% level.

The allocative efficiency scores were not that good in comparison with technical efficiency scores as majority of the growers fall below 50% allocative efficiency level. However, differences in the scores across the minors follows the same pattern as of technical efficiency. Chihu head growers' group was found to be 48% allocatively efficient on average, followed by 43% in middle and 35% in the tail, while Malwa head growers' group was 63% allocatively efficient on average followed by 54% in the middle and 55% in the tail. The results of technical efficiency estimates indicated that cotton growers were doing well at operating with high level of efficiency. The studies conducted by (Asghar et al., 2018; Gul et al., 2009) on wheat and cotton crops in Punjab also found higher technical efficiency level in their respective sample.

Table 3. Descriptive statistics of socio-economic characteristics and groundwater irrigation characteristics of the head, middle, and tail of Chihu and Malwa minors (used in the two-limit tobit regression).

Characteristics	Chihu Minor						Malwa Minor					
	Head		Middle		Tail		Head		Middle		Tail	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age	42.9	10.9	38.5	9.8	39.7	10.2	37.5	6.6	38.8	7.4	41.6	9.7
Education	7.2	6.6	5.3	4.8	7.6	6.9	5.6	3.2	7.7	2.6	5.4	2.8
Total area	9.5	5.9	7.2	3.6	6.5	2.3	9.8	5.3	8.7	4.4	8.4	3.9
Family size	9.4	5.0	8.7	4.2	9.8	5.4	8.7	4.1	8.2	3.6	9.6	4.7
Tw depth Feet	100.4	10.4	121.6	14	144.2	14.3	36.5	9.6	49.1	11.1	77.8	13.0
Tube well capacity liters/hrs	5024 116.6	4484 835.7	3446 559.1	1882 409.9	3059 319.7	1609 613.7	5024 116.6	4484 835.7	3298 529.8	2495 435.5	4059 766.9	351 704 1.2
Other Characteristics												
Using diesel%	52		51		48		62		43		69	
Using electric%	20		25		31		27		45		12	
Tractor operated%	28		24		21		11		12		19	
Off-farm income%	34		43		48		44		56		53	
Salinity in water (Yes %)	23		27		24		29		22		18	

Table 4. Distribution of technical efficiency of the head, middle, and tail grower groups of Chihu and Malwa minor.

Technical Efficiency						
Efficiency Scores	Chihu Minor			Malwa Minor		
	Head	Middle	Tail	Head	Middle	Tail
<0.50	0.0	0.0	6.9	0.0	0.0	1.4
0.51-0.60	21.9	34.4	16.7	3.1	15.6	8.3
0.61-0.70	15.6	9.4	16.7	25.0	10.9	26.4
0.71-0.80	21.9	23.4	19.4	23.4	28.1	22.2
0.81-0.90	10.9	9.4	5.6	12.5	12.5	13.9
0.91-1	29.7	23.4	34.7	35.9	32.8	27.8
Mean	0.77	0.73	0.76	0.81	0.80	0.78
Standard Deviation	0.20	0.20	0.20	0.10	0.20	0.20
Minimum	0.50	0.50	0.40	0.60	0.50	0.40
Maximum	1.0	1.0	1.0	1.0	1.0	1.0

Table 5. Distribution of allocative efficiency of the head, middle, and tail farms at Chihu and Malwa minors.

Allocative Efficiency						
Efficiency Scores	Chihu Minor			Malwa Minor		
	Head	Middle	Tail	Head	Middle	Tail
<0.50	50.0	73.4	91.7	18.8	26.6	33.3
0.51-0.60	25.0	17.2	2.8	14.1	48.4	31.9
0.61-0.70	18.8	0.0	2.8	14.1	20.3	23.6
0.71-0.80	1.6	1.6	1.4	45.3	3.1	9.7
0.81-0.90	1.6	1.6	0.0	4.7	0.0	1.4
0.91-1	3.1	6.3	1.4	3.1	1.6	0.0
Mean	0.48	0.43	0.35	0.63	0.54	0.55
Standard Deviation	0.20	0.20	0.10	0.20	0.10	0.10
Minimum	0.20	0.20	0.10	0.20	0.30	0.30
Maximum	1.0	1.0	1.0	1.0	1.0	1.0

Economic and Water Use Efficiency by Location across the Minor

Table 6 and 7 indicates the results of the output-oriented DEA model estimation for economic and input-oriented DEA model for water use efficiencies. The scores for both economic and water use efficiencies were witnessed to be alarming as a few of the growers were found to be above 50% level of efficiency. Chihu head growers' group was observed to be 38% economically efficient on average, followed by 32% in middle and 27% in the tail, whereas Malwa scores were comparatively better than Chihu. Head growers' group in Malwa was 52% economically efficient on average followed by 43% efficient in each middle tail. The water use efficiency scores for Chihu minor were witnessed to be better than Malwa minor however scoring pattern for water use efficiency across the minor was found to be opposite to all the efficiency score patterns. As scores across head, middle, and tail found to be improved as moving towards tail. Higher percentage of cotton growers fall below 50% efficiency level with highest 97.2% in the Chihu tail group. On average, Chihu head growers were using water on 49% efficiency level, improving to 52% efficiency in the tail. Malwa minor showing the same improved efficiency pattern across the minor with 32% efficiency in the head to 41% efficiency in the tail.

Factors Affecting Allocative Efficiency

After the estimation of efficiencies, the focus of the research was on factors that influence the allocative efficiencies of cotton growers. For the purpose, allocative inefficiencies (subtracting efficiency score from 1) were taken and regressed using two-limit tobit regression model. Table 8 presents the results of two-limit tobit regression. Results show that age of the farmer, experience, and depth of tube well were among the significant variables. The negative coefficient signs of age and experience variables indicate that inefficiencies decrease with increase in age and experience of the growers. Whereas positive coefficient sign for depth of tube well variable indicates that inefficiencies increase with increase in depth of tube well. The similarity is most probably due the factors that influence the efficiency were almost identical such as higher level of education (Seyoum et al., 1998). Enough research evidence shows significance in efficiency scores and education level (Watto and Mugera, 2019) as well in farm size (Sarker and De, 2004). Our results showed significant difference between the technical efficiency across head, middle, and tail of the minors. This decreasing efficiency pattern across the minors was due to less availability of water resource as moving from head to tail of minors. Despite technical efficiency scores, all other efficiency scores (allocative, economic, and water use efficiency) were found to be poor as on average, majority of the sample groups fell below 50% of efficiency level. However, tendency in efficiency scores moving from head to tail was common in all efficiency scores despite water use efficiency where the declining score pattern was opposite as water use efficiency scores were found to be better as we moved towards middle to tail. Lower allocative efficiency scores indicates that there is enough room for efficient allocation of resources mainly ground water resource, for which the growers are bearing higher costs (See Table 2).

The overall lower economic efficiency scores indicate that the production cost of cotton in Chihu and Malwa minor is higher in relation to the output they receive. Which specifically mean that the growers can reduce their production cost including seed, labor, machinery fertilizer, chemical use (see Table no: 2) by 50% with respect to their outputs. Two-limit tobit regression results indicated that the allocative inefficiency of cotton growers decreased with increase in age and experience of the growers. Such relationship of efficiency scores and education of farmer was also witnessed by (Watto & Mugera, 2019) working on wheat crop in Punjab. Depth of tube well also showed significancy with allocative inefficiency with a positive coefficient sign indicating increase in allocative inefficiency with increase in tube well depth (Asghar et al., 2018). Such relation of tube well depth and allocative efficiency was also discovered by (Qureshi et al., 2003).

Table 6. Distribution of economic efficiency of the head, middle, and tail farms at Chihu and Malwa minor.

Economic Efficiency						
Efficiency Scores	Chihu Minor			Malwa Minor		
	Head	Middle	Tail	Head	Middle	Tail
<0.50	75.0	87.5	97.2	45.3	73.4	70.8
0.51-0.60	14.1	4.7	0.0	31.3	17.2	19.4
0.61-0.70	6.3	1.6	0.0	6.3	6.3	5.6
0.71-0.80	0.0	0.0	1.4	12.5	1.6	4.2
0.81-0.90	1.6	3.1	0.0	1.6	0.0	0.0
0.91-1	3.1	3.1	1.4	3.1	1.6	0.0
Mean	0.38	0.32	0.27	0.52	0.43	0.43
Standard Deviation	0.20	0.20	0.10	0.20	0.10	0.10
Minimum	0.20	0.10	0.10	0.20	0.20	0.20
Maximum	1.0	1.0	1.0	1.0	1.0	1.0

Table 7. Distribution of water use efficiency of the head, middle, and tail farms at Chihu and Malwa minor.

Water Use Efficiency						
Efficiency Scores	Chihu Minor			Malwa Minor		
	Head	Middle	Tail	Head	Middle	Tail
<0.50	62.5	73.4	56.9	79.7	75.0	70.8
0.51-0.60	10.9	6.3	9.7	1.6	3.1	5.6
0.61-0.70	10.9	1.6	4.2	3.1	1.6	4.2
0.71-0.80	0.0	3.1	4.2	6.3	4.7	1.4
0.81-0.90	1.6	3.1	5.6	0.0	1.6	2.8
0.91-1	14.1	12.5	19.4	9.4	14.1	15.3
Mean	0.49	0.44	0.52	0.32	0.39	0.41
Standard Deviation	0.20	0.30	0.30	0.30	0.30	0.30
Minimum	0.10	0.10	0.10	0.00	0.10	0.10
Maximum	1.0	1.0	1.0	1.0	1.0	1.0

Table 8. Tobit Regression Results for Factors Affecting Allocative Efficiency of Cotton Growers.

Variables	**Coefficient**	**P value**
Age	-0.0012** (0.0312)	0.023
Education	-0.0034 (0.0012)	0.190

Farm Area	-0.0008	0.422
	(0.0221)	
Family Size	0.0007	0.652
	(0.0331)	
Experience	-0.0004*	0.069
	(0.0012)	
Depth of Tube Well	0.1417***	0.000
	(0.0110)	
Discharge Capacity	0.0089	0.562
	(0.0724)	
Diesel Operated	0.0177	0.442
	(0.0391)	
Tractor Operated	0.0754	0.302
	(0.0004)	
Constant	-0.2760	-
Log Likelihood	143.2	-

Note: This result was analyzed using Stata software. The parentheses values indicate standard error. * Indicate significance at 10%, ** indicate significance at 5%, *** indicates significance at 1%.

CONCLUSION

This paper analyzed the grower's technical, allocative, economic, and ground water use efficiency for cotton farmers. Moreover, the paper also analyzed the factor affecting the efficiency. The data was gathered based on location of farm with respect to minor canals. The results revealed that growers despite technically being efficient, were remarkably not efficient in allocation of resources, economically, and in practice of ground water. Such results prove to be an indication that technical efficiency estimates alone does not provide sufficient knowledge about grower's efficient allocation of resources, therefore, a thorough research on all the efficiency estimates is necessary. One of the main findings of the research was that there is a significant difference in the decreasing efficiency scores of the growers having farms towards middle or tail of minor canal. The findings of the study suggest that stake holders should initiate an approach which benefits the growers in increasing their allocative, economic, and water use efficiency.

The main reason for the differentiation of efficiencies across the minor canals is that the head users of the canal enjoy excessive water and the low pricing mechanism of canal water allow them to reduce their production costs. Whereas In comparison, middle or tail users utilize the left over or lower water than the head users. This low canal water availability force them to extract ground water which increases their cost of production. Thus, being yields remaining low or almost identical to head users, middle and tail users suffer with comparatively lower efficiencies. This issue of discrepancy among head, middle, and tail users should be overviewed by the authorities concerned specifically irrigation department, accompanied with comprehensive knowledge to the growers about adequate resource management and efficient farm practices.

Lower efficiency scores for allocative, economic, and water use efficiency indicate that there is a dire need of re-examining the policy measures regarding the prices, specifically water prices. These inefficiencies highlight that despite of higher input costs, growers are unaware or having lack of knowledge about input minimization and output maximization. Extension services should educate the cotton growers about adequate utilization of resources, specifically water resource. Current study analysis suggests that there is need for a multi-disciplinary problem-solving approach in which all the stake holders including irrigation department and agriculture extension service should take part with direct linkage with local growers, as such authorities have a reach to the local growers. The focus of this approach should be on the on the technical support and consultancy of the cotton growers.

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