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EXPLORING THE INEFFICIENT GROUNDWATER USE BY WHEAT FARMERS: AN EVIDENCE FROM SINDH, PAKISTAN

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ABSTRACT

Pakistan's agricultural production is lower than that of many other developing countries. The agricultural community is nearly illiterate and uses old and conservative farming methods. These constraints impede the adoption and spread of new technologies at the agricultural level. The objective of this study was to calculate economic, allocative, technical, and water-use efficiency. In addition, the drivers of inefficiency for wheat fields in Benazirabad and Naushahro Feroz districts were measured. For the analysis, 390 farmers' data were used, 195 from each of the Chihu and Malwa minor canals. Data-envelopment-analysis, a non-parametric method, was utilized to determine the ratings of efficiency. The findings revealed that the mean economic, allocative, and technical efficiency scores of farms in the study region were 52%, 62%, and 83%. The average water-use efficiency score was found to be 52%. For the improvement in the present farming system, quantified results suggested the need for potential increase in wheat production by 17% with keeping the same level of inputs. Results further revealed that the production cost can be reduced by 48% by producing the same level of output leading to optimal allocation of resources. There is also a potential gap of improvement for water-use efficiency. Improvement in agriculture extension services, timely and proper supply of inputs and the creation of local level marketplaces at lower administrative entities can improve the efficiency scores of wheat farmers.

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INTRODUCTION

In arid and semi-arid regions, lack of water became a significant problem for the long-term growth of irrigated agriculture (Bouwer, 2000). The scale of agricultural production and cropping technology are the critical factors that influence the production yields in such areas. (Daghighi et al., 2017). Irrigation water demand is a key indicator of efficiency estimation in the areas which are suitable for agricultural production (Li et al., 2020). High unpredictability in water supply, water management and governance policies, and ambiguity about climate change effects compound this challenge (Steinfeld et al., 2020). On a global perspective, efficient use of agricultural water is essential for food security and water relief (Cao et al., 2020). Inefficiency in use of water can cause serious impacts on survival of future generations relying upon this resource (Hai et al., 2020).

In many regions of the earth, groundwater irrigation is critical for increasing agricultural productivity and improving the livelihoods of rural populations. In South Asia, for example, the area irrigated has quadrupled since 1950 (Pahl-Wostl and Knieper, 2014; Qureshi, 2020). India Bangladesh, and Pakistan are the largest groundwater users in South Asia, with an estimated annual extraction of 320 billion m^3, where Bangladesh = 30 bm^3; Pakistan = 60 bm^3; India = 230 bm^3 (Qureshi, 2015; Shah, 2007). More than 85% of the land is utilized for agriculture, compared to only 40% in the rest of the world (Ahmad et al., 2020; Chindarkar and Grafton, 2019). These three nations irrigate 48 million hectares (mha) of groundwater-fed farmland, accounting for around 42% of worldwide groundwater-fed cropland (Mukherjee et al., 2015; Watto and Mugera, 2015). The major causes of this significant groundwater use are declining surface water supplies and the desire to expand the irrigated area in order to feed a growing population (Mukherjee, 2018; Shah, 2007).

Wheat is Pakistan's principal grain crop, and for its rich nutritious value, it is an important intake for general public (Abid et al., 2016; Pena, 2007). When compared to other crops grown in Pakistan, wheat has the biggest area under cultivation (Sheikh et al., 2003). In past few years the area under cultivation decreased by 1.9 percent, while the output and yield of wheat decreased by 6 percent and 4.1 percent, respectively (Chandio et al., 2016). Aside from the shrinking area under wheat cultivation, the major cause of massive reductions in wheat output and yield was witnessed to be a severe shortage of water to irrigate the crop (Aslam, 2016; Mahmood et al., 2020).

It is clear that technical efficiency estimate provides crucial information about practices of managing a farm, but it does not provide thorough information about the allocation of all the resources used and the minimization rate to such costs used in production process, therefore allocative, water-use and economic efficiency estimates are required in order to investigate production efficiency comprehensively (Brázdik, 2006; Tang et al., 2015). This reliable information on allocative and economic efficiency, as well as the factors that influence it, aids policymakers in developing strategies for promoting rural development and increasing farm revenue (Thabethe and Labuschagne, 2014; Wadud, 2003). Policymakers may use this dependable data on efficiency estimations to initiate a pragmatic approach toward research-dragged and targeted loopholes in agricultural production. The study's major goals were to determine the degree of technical, allocative, economic, and groundwater usage efficiency of farmers producing wheat crops along the Indus River's minor tributaries. Moreover, to examine the key determinants of allocative efficiency. And, finally, to make policy recommendations based on the findings.

METHODOLOGY

Conceptual Framework

Production firms and farms both use different approaches to study efficiency differentials. In case of agriculture farm, yield per acre and water consumption level of crop are considered to be the main variables. But these variables are not sufficient enough. Such measures may not provide full knowledge about the reasons for variations in crop yield at diverse farms. This is due to the omission of probable differences and variability in other production factors such as labor, equipment utilization, or chemical inputs (Coelli et al., 1998). Technical efficiency measurement, is a more thorough and accurate evaluation method that considers all variables of production and inputs at the same time to estimate productivity and efficiency (Ji et al., 2012). A farmer's technical efficiency is attained when he or she generates a particular output with the fewest feasible inputs (Watto and Mugera, 2015). Groundwater usage efficiency calculates how much groundwater may be used without altering the remaining inputs and output (Varghese et al., 2011). Labor productivity considers just the physical aspects of manufacturing, not the market pricing of inputs or the value of finished goods. Allocative efficiency is achieved when a farmer distributes inputs to reduce the cost of producing a given amount of output (Farrell, 1957).

Data Envelopment Analysis, Efficiency Estimation

Data Envelopment Analysis is a non-parametric method, and Data Envelopment Analysis Stochastic Frontier Approach is a parametric method and are used to evaluate relative efficiency. The non-parametric frontier technique of data-envelopment-analysis. The relative efficiency of a collection of homogeneous decision making units with multiple inputs and outputs is assessed using data-envelopment-analysis (Zhang et al., 2014). Water use, allocative, economic, and technical efficiency for the wheat testing farms in this study were assessed using data-envelopment analysis, a non-parametric approach based on mathematical programming techniques. The DEA technique was originally used in the research by (Charnes et al., 1978), which drew inspiration from the work of (Asghar et al., 2018; Farrell, 1957). With the premise of constant returns to scale technology, an input-oriented measure of efficiency was established. A data-envelopment-analysis model with a variable return to scale assumption that loosens the CRS assumption. The author offers a thorough overview of data-envelopment-analysis approaches, components of which were investigated in the creation of the current research's data-envelopment-analysis model for a single output and many inputs, as the data-envelopment-analysis model is supplied in the study. With varying returns to scale technology, we'll employ the data-envelopment-analysis approach. Assume that a single product is produced by n farms utilizing K inputs. The linear programming problem is addressed: $\theta\,\lambda$ to determine the input-oriented technical efficiency of a farm j.

Technical Efficiency Estimation

By focusing on input resources, the following linear programming problem was solved to evaluate the technological efficiency of a specific business j. For input-oriented variables, go back to scale. The DEA method was employed to evaluate technical efficiency, followed by (Coelli et al., 1998). Indicated as:

$$\min \theta$$
$$\theta\,,\{\lambda_i\}_{i=1}^{n} \quad (1)$$
Subject to:
$$\sum_{i=1}^{n} y_i\lambda_i \geq y_j \quad (2)$$
$$\sum_{i=1}^{n} x_{ki}\lambda_i \leq \theta x_{kj}, \text{for} k = 1, 2, \dots, K \quad (3)$$
$$\sum_{i=1}^{n} \lambda_i = 1 \quad (4)$$
$$\lambda_i \geq 0 \quad (5)$$

Where y_i is the production of i firm produced by, where *i = 1, 2,….,j,…., n*, and n is the number of firms, x_{ki} is the k input quantity applied by i firm (for *I = 1,2,….,j,…, n)* for *k = 1, 2 ,…., K,*, where K is the number of inputs used by the firms, and $\{\lambda_i\}_{i=1}^{n}$ are the weights to be estimated. While θ is the input-oriented estimates of firm j technical efficiency. It is worth noting that Equation contains K equations (3). Equations (1) to (4) are solved for j businesses to get the optimal level of the specified function, θ^*, which is an estimate of the input-oriented technical efficiency of j firm (*TEj*):

$$TE = \theta^* \quad (6)$$

Economic Efficiency Estimation

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

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

Subject to:
$$\sum_{i=1}^{n} y_i\lambda_i \geq y_j \quad (8)$$
$$\sum_{i=1}^{n} x_{ki}\lambda_i \leq \theta x_{kj}, \text{for} k = 1, 2, \dots, K \quad (9)$$
$$\sum_{i=1}^{n} \lambda_i = 1 \quad (10)$$

$$\lambda_i \geq 0 \quad (11)$$

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: $\{x^*_{kj}\}^K_{k=1}$ and $\{\lambda^*_i\}^n_{i=1}$.Cost efficiency of j (EEj) firm is estimated as follows:

$$EE_j = \sum_{k=1}^{K} w_{kj}x^*_{kj} / \sum_{k=1}^{K} w_{kj}x_{kj} \quad (12)$$

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

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

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

Water Use Efficiency Estimation

In non-parametric research, the efficiency of individual input is determined using two methods: the DEA Sub Vector Efficiency method and the Slack Based DEA technique (Watto and Mugera, 2019). The current study used an input-oriented variable return to scale model to assess the impact of water on agricultural production. As a result, the model selected below best fits the data. Water usage efficiency, on the other hand, equals agricultural production in terms of water consumption while maintaining all other inputs constant.

$$Min_{\theta,\lambda}\theta \quad (14)$$

Subject to:

$$-y_i + Y\lambda \geq 0, \quad (15)$$

$$x_i - X\lambda \geq 0, \quad (16)$$

$$\frac{N1}{\lambda} = 1, \quad (17)$$

$$\lambda \geq 0, \quad (18)$$

Equation (14 to 18) indicates the i^{th} farm, whereas vector input is x_i and output vector is denoted by y_i. We took this into account while deciding on the best weights (Coelli et al., 1998). To achieve farm efficiency ratings, the equation is iterated n times, and some weights are chosen to maximize efficiency scores. Those farms with efficiency ratings of 1 are efficient and successful in producing the maximum amount of agricultural produce with the resources of water available. A point below the one indicates unproductive farming (Fatima et al., 2020).

Sampling and Area of Study

The research was conducted in the Pakistani districts of Naushahro Feroze and Shaheed Benazirabad in Sindh Province. From Sukkur barrage left bank command system, two minors were selected from Rohri canal (Chihu and Malwa minors, respectively) are driven from these districts which were taken in the study. These two districts lie under the middle part of Sindh province with respect to the Indus River system leaving behind the head (Sukkur, Khairpur districts) and the tail (Thatta, Badin, Sajawal districts). There are two basic reasons for undertaking Naushahro Feroze and Shaheed Benazirabad districts for the proposed study firstly: Alluvial soils in the agricultural area enable farmers to cultivate a variety of crops, including wheat, cereals, sugarcane, fodders, and other horticultural crops. Wheat–cotton and wheat–sugarcane cropping systems are the most common cropping patterns. Secondly: as these districts lie under the middle part of the major river system of the province, it will provide a clear and neat picture of the water-use efficiency at farm level and also will provide allocative and economic efficiencies of the farms located in this region.

For the study, a sample of 390 respondents (farmers) was interviewed using a multi-stage stratified random sampling approach. The sample was distributed into two strata, namely Chihu minor and Malwa minor, 195 respondents for each stratum. Furthermore, each stratum was divided into three divisions: head, middle, and tail of the minors, each consisting of a sample of 65 respondents respectively.

Data and Variable Definition

Each of the wheat-growers was interviewed were conducted using a standardized questionnaire together wheat yield, seed rate, irrigation quantity, fertilizer rate, machine use, labor input, and chemical use, as well as relative costs of these inputs. This data was used to calculate the efficiency of technical, allocative, economic, and groundwater usage. To further evaluate their influence on efficiency, data on household socioeconomics, demographics, wheat producer and farm characteristics, and ground water data were collected. To compare performance across different farm sizes, Wheat input quantities and prices were entered into the DEA model in per-acre units. All of the costs were calculated in Pakistani rupees as shown in Table 1.

The estimation process of ground water application to irrigate wheat crop and the costs indulged in the process undergoes an equation for which wheat producers provided information on the number of irrigations applied to the crop, the duration of irrigations, and the cost of irrigation.

An approximate estimation model was adapted from (Watto and Mugera, 2015) for obtaining volume of ground water irrigation.

$$Q = \left[\frac{t \times 129574.1 \times BHP}{\left[d + \left(\frac{255.5998 \times BHP^2}{d^2} \times D^4\right)\right]}\right] / 1000 \quad (19)$$

Here, Q represents the total volume in cubic meters of ground water, t is the time spent on irrigation in hours, BHP represent the power of engine in horsepower, d is boring depth in meters, D represents diameter of suction pipe in inches. For the calculation of the total cost of ground water irrigation, total irrigation time will be multiplied by the cost of irrigation.

Table 1. Variables and description.

Variables	Unit	Description
Wheat Yield	Kg per-acre	The number of bushels of wheat harvested per acre
Cropped Areas	Acres	The wheat-growing area
Seeds Rates	Kg per-acre	The amount of wheat 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
Machinery	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 estimated frequencies and scores of wheat farmers' technical, allocative, economic, and ground water usage efficiency are shown in this section, followed by descriptive statistics for the selected variables.

Economic Analysis of Wheat Cultivation in the Study Area

Table 2 shows the different inputs used per unit area in wheat cultivation and the costs of those inputs. Along with the wheat output differences among the farmers living at head, middle, and tail of the minors. These discrepancies are the most common way to spot variations in technical, allocative, economic, and water usage efficiency across minors. The average groundwater usage across the head, middle, and tail of both Chihu and Malwa minor was found to be with a significant difference. The use of groundwater was found to be excessive in tail part of minors and then in middle or head of minors. In comparison to the head and middle parts of the minors, fertilizer application and pesticide use were shown to be higher in the tails. Although there has been no discernible change in seed usage, labor, or machinery between the minors, there was a substantial difference in the use of seed, labor, and machinery. Wheat yields were greater on the minors' head side, with an average yield of 1621.3 kilograms in Chihu, compared to 1598.4 and 1576.2 kilograms in the middle and tail of the Chihu minor, respectively. Chihu minor, on the other hand, was found to have higher yields than Malwa in general. The cost of groundwater irrigation per acre incurred by tail farmers was found to be greater than the cost borne by the head and middle farmers. This is due to the fact that minors have an abundance of water in their heads. This higher cost component resulted in greater expenses being borne by tail farmers, resulting in a total production cost that was greater for tail farmers of both Chihu and Malwa minors.

Table 2. Descriptive statistics of variables used to assess wheat farms.

Variables	Unit	Chihu Minor			Malwa Minor		
		Head N=65	Middle N=65	Tail N=65	Head N=65	Middle N=65	Tail N=65
Quantities of Inputs and Outputs							
Wheat Cultivated Area	Acre	7.2	6.8	6.3	14.3	13.8	10.4
Groundwater Irrigation	m^3/ac	2454	3034	3436.9	3215	3522.2	3742.5
Seed Rate	kg/ac	50.2	55.4	55.7	51.4	50.3	52.4
Labor	No./ac	3	5	5	5	4	4
Machinery	Hours/ac	3.2	3.5	3.1	3.7	3.5	3.8
Fertilizers (N+P+K)	kg/ac	262.2	278.8	294.3	253.3	258.3	262.5
Chemical (Pesticides, Weedicides)	No./ac	1.2	1.5	1.4	1.6	1.8	1.4
Wheat Output	kg/ac	1621.3	1598.4	1576.2	1532.4	1522.3	1513.9
Costs of Inputs							
Groundwater Irrigation Cost	PKR/ac	6,645	9,642	11,278	8,652	10,547	12,782
Seed Cost	PKR/ac	3,100	3,110	3,000	3,225	3,220	3,220
Labor Cost	PKR/ac	977	1,090	1,110	1,023	1,147	1,166
Machinery Cost	PKR/ac	5,335	5,560	5,662	4,976	5,227	5,471
Fertilizer (N+P+K) Cost	PKR/ac	11,254	11,440	12,072	10,423	10,458	10,434
Chemicals Cost	PKR/ac	1,432	1,532	1,534	1,625	1,547	1,454
Total Cost	PKR/ac	32,165	3,564	38,465	40,463	43,654	44,533

Characteristics of Wheat Farms by Location across the Minor

Table 3 depicts the correlation among the selected variables in the form of inputs used in cultivation of wheat crop. The use of groundwater, seed and machinery is found to be significant in accordance with wheat yield. The relationship of labor was found to be significant with fertilizer applied, chemical used, and machinery used in wheat production. Whereas Table 4 shows farmers' socioeconomic features and groundwater irrigation characteristics of Canals of two districts, Chihu and Malwa. Further, the canal is divided into three categories which consist of head, middle, and tail. The mean age of farmers varies in both districts. However, The Chihu minor's head and Malwa minor's tail were found to be the elderly, while the Chihu minor's middle and Malwa minor's head were the youngest of the three classes in terms of average age. The Chihu minor's tail and Malwa minor's middle had a higher education average than the other selected minors', while the Chihu's middle and Malwa's tail had the lowest level of education. Farmers were found to live in large family size. Which is due to the traditional practice of having a shared family in rural communities. Farmers' households are typically large, with an average household size of 8 to 9 people. In terms of average tube well depth feet, Chihu's tail had the deepest tube well than all categories with 144.2 feet depth. However, Malwa's Head had 36.5 feet depth which was found to be the smallest depth than others. At the same time, those tube wells which are the deepest have the highest discharge potential. For installing these tube wells, the cost is high.

Tube wells were either diesel, electrical, or tractor-operated by both Chihu and Malwa minors. Although, the head, middle, and tail had more percentage used diesel for the purchase of water in both Chihu and Malwa, in that sequence, electric and tractor-operated tube wells were installed. However, there was not any statistically significant change in all three categories of both districts. However, Malwa minor's second group has had the most off-farm sources of revenue. Despite the fact that none of the farmers had checked the consistency of the groundwater to see if it was suitable for irrigation, while a significant population of farmers indicated that their groundwater was saline.

Table 3. Pearson correlation results of inputs used in wheat production.

Inputs	Yield of Wheat	Groundwater Irrigation	Seed	Labor	N+P+K	Chemicals Used	Machinery Used
Yield of Wheat	1						
Groundwater Irrigation	0.154* (0.005)	1					
Seed	0.212** (0.004)	-0.054 (0.642)	1				
Labor	-0.002 (0.643)	-0.034 (0.865)	0.123* (0.043)	1			
N+P+K	0.288 (0.006)	0.056 (0.578)	0.432 (0.788)	0.032* (0.025)	1		
Chemicals Used	0.078 (0.875)	0.155 (0.877)	0.296* (0.042)	0.087* (0.045)	0.211 (0.097)	1	
Machinery Used	0.231** (0.003)	0.004** (0.002)	0.244** (0.001)	0.023* (0.032)	0.984 (0.143)	-0.087 (0.324)	1

The parenthesis values show the level of correlation significance (P-value). **indicates level of significance at 0.01, * indicates level of significance at 0.05.

Table 4. Descriptive statistics of socio-economic variables.

Characteristics	Chihu Minor						Malwa Minor					
	Head		Middle		Tail		Head		Middle		Tail	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age	42.8	10.9	38.7	9.8	39.6	10.3	37.3	6.6	38.9	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	11	5.6	8.5	3.3	7.8	2.7	10.8	5.4	8.5	4.8	6.4	3.3
Family size	9.3	5.0	8.9	4.5	9.7	5.4	8.8	4.1	8.2	3.6	9.6	4.7
Tube well 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	5024116.6	4484835.7	3446559.1	1882409.9	3059319.7	1609613.7	5024116.6	4484835.7	3298529.8	2495435.5	4059766.9	3517041.2
Other Characteristics (%)												
Using diesel	54		50		49		60		43		70	
Using electric	16		26		32		27		45		12	
Tractor operated	30		24		21		13		12		18	
Off-farm income	34		44		48		44		56		54	
Salinity in water (Yes)	23		27		24		29		22		18	

Technical Efficiency by Farm Location across the Minor

Table 5 illustrates the frequency distribution of technical efficiency of the head, middle, and tail grower groups of Chihu and Malwa minor. For all groups of tube well, technical efficiency varies. The average technical efficiency score for Chihu Minor was 82%, 81%, and 83% of head, middle, and tail, respectively. However, the technical efficiency for Malwa minor was 84%, 83%, and 83% of head, middle, and tail, respectively. However, efficiency score of all groups of both minors increases as frequency distribution moves from 0.50 to 1 in ascending order. While the average degree of technical efficiency was reasonably low, with the highest level of efficiency scores are at 0.91 to 1 frequency distribution which is 38% of tail in Chihu minor. On the other hand, 41% of head in malwa minor.

Allocative Efficiency by farm Location across the Minor

Table 6 indicates the frequency distribution of allocative efficiency of the head, middle, and tail farms of Chihu and Malwa minors. The mean frequency distribution of head, middle, and tail farms of Chihu minor were calculated to be 69%, 52%, and 45% respectively allocatively efficient. In case of Malwa minor the mean frequency distribution for head, middle, and tail was 70%, 67%, and 65% respectively. In Chihu minor Just 15% at Head, 4% at middle, and 3% at Tail, while in Malwa minor just 7% at head, 9% at middle, and 3% at tail had 100 percent allocative performance. Further, the result shows that tail of Chihu minor was found to be more efficient at frequency <0.50 with 83% efficiency. Contrary to it, the head of Malwa minor was found to be more efficient at frequency 0.71-0.80 with 36% efficiency.

Economic Efficiency by farm Location across the Minor

Table 7 illustrates the frequency distribution of economic efficiency of the head, middle, and tail farms of Chihu and Malwa minors. In this table the mean economic efficiency estimated for Chihu minor was 56%, 42%, and 37% of head, middle, and tail, respectively. For Malwa minor the mean economic efficiency score for head, middle, and tail was 58%, 52%, and 51%, respectively.

Table 5. Distribution of technical efficiency of the head, middle, and tail farm of Chihu and Malwa minor.

Efficiency Scores %	Naushero Feroz Minor				Benazirabad Minor				Grand Total
	Head	Middle	Tail	Total	Head	Middle	Tail	Total	
0.01-0.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.21-30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.31-40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.41-50	1.5	0.0	3.1	1.5	0.0	0.0	1.5	0.5	1.0
0.51-0.60	10.8	0.0	4.6	5.1	3.1	9.2	1.5	4.6	4.9
0.61-0.70	10.8	32.3	18.5	20.5	15.4	9.2	20.0	14.9	17.7
0.71-0.80	20.0	15.4	15.4	17.4	23.1	27.7	26.2	25.6	21.5
0.81-0.90	20.0	21.5	20.0	20.5	16.9	13.8	12.3	15.4	17.9
0.91-1	36.9	30.8	38.5	34.9	41.5	40.0	38.5	39.0	36.9
Mean	0.82	0.81	0.83	0.82	0.84	0.83	0.83	0.84	0.83
St.Dev	0.16	0.14	0.16	0.15	0.14	0.14	0.14	0.14	0.15
Min	0.41	0.61	0.46	0.41	0.56	0.54	0.43	0.43	0.41
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 6. Distribution of allocative efficiency of the head, middle, and tail farms of Chihu and Malwa minors.

Efficiency Scores %	Naushero Feroz Minor				Benazirabad Minor				Grand Total
	Head	Middle	Tail	Total	Head	Middle	Tail	Total	
0.01-0.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.21-30	0.0	4.6	4.6	3.1	0.0	0.0	0.0	0.0	1.5
0.31-40	6.2	26.2	27.7	20.0	1.5	4.5	3.1	2.6	11.5
0.41-50	7.7	15.4	50.8	24.6	6.2	10.6	6.2	7.7	15.9
0.51-0.60	16.9	24.6	9.2	16.9	10.8	18.2	27.7	19.0	18.2
0.61-0.70	23.1	18.5	1.5	15.4	21.5	25.8	29.2	25.6	20.3
0.71-0.80	18.5	1.5	1.5	7.7	36.9	13.6	20.0	23.6	15.6
0.81-0.90	12.3	4.6	1.5	5.6	15.4	18.2	10.8	14.9	10.5
0.91-1	15.4	4.6	3.1	6.7	7.7	9.1	3.1	6.7	6.4
Mean	0.69	0.52	0.45	0.55	0.70	0.67	0.65	0.68	0.62
St.Dev	0.19	0.16	0.12	0.19	0.13	0.16	0.13	0.14	0.18
Min	0.32	0.25	0.24	0.24	0.40	0.30	0.38	0.30	0.24
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

While average degree of technical efficiency was reasonably low, and distribution for Chihu minor just 6% at head, 3% at middle, and 3% at tail, while in Malwa minor just 4% at head, 1% at middle, and 0% at tail had 100 percent allocative performance. However, efficiency score of all groups of both minors increases as frequency distribution moves from 1 to <0.50 in descending order, with the highest level of efficiency scores are at <0.50 frequency distribution which is 89% of tail in Chihu minor. On other hand, 44% of head in Malwa minor.

Water Use Efficiency by farm Location across the Minor

Table 8 indicates the frequency distribution of water use efficiency of the head, middle, and tail farms of Chihu and Malwa minors. In Chihu minor, water usage efficiency scores for the head range from 13% to 100%, with a mean of 58 percent. In the middle, water usage efficiency ratings range from 15 percent to 100 percent, with a mean value of 52 percent. The water use efficiency figures for tail range from a low of 25% to a high of 100%, with an average value of 60%. However, in Malwa, water usage efficiency scores for the head range from 4% to 100%, with a mean of 48 percent. In the middle, water usage efficiency ratings range from 8 percent to 100 percent, with a mean value of 47 percent. The water-use efficiency figures for tail range from a low of 8% to a high of 100%, with an average value of 47%. The frequency distribution for Chihu minor Just 15% at head, 16% at middle, and 24% at tail, while in Malwa Minor just 21% at Head, 18% at Middle, and 18% at Tail had 100 percent allocative performance.

Discussion

The study's goals were to assess farmers' technical, allocative, and groundwater usage efficiency in Districts Benazirabad and Naushahro Feroze. We discovered evidence of significant technical inefficiency among farmers, and the results show that technical efficiency varies from 41 to 100%, with an average score of 82%, 81 percent, and 83 percent for Chihu minor, and given current technology and input utilization, production can be improved by 17 to 19 percent on average, according to the tail.

Table 7. Distribution of economic efficiency of the head, middle, and tail grower groups of Chihu and Malwa minors.

Efficiency Scores %	Naushero Feroz Minor				Benazirabad Minor				Grand Total
	Head	Middle	Tail	Total	Head	Middle	Tail	Total	
0.01-0.20	4.6	0.0	0.0	1.5	0.0	0.0	3.1	1.0	1.3
0.21-30	3.1	30.8	35.4	23.1	4.6	3.1	1.5	3.1	13.1
0.31-40	9.2	27.7	29.2	22.1	6.2	13.8	21.5	13.8	17.9
0.41-50	24.6	18.5	24.6	23.1	13.8	26.2	18.5	19.5	21.3
0.51-0.60	20.0	10.8	6.2	12.3	32.3	29.2	32.3	31.3	21.8
0.61-0.70	15.4	6.2	0.0	7.2	21.5	18.5	12.3	17.4	12.3
0.71-0.80	10.8	0.0	0.0	4.1	12.3	7.7	4.6	8.2	6.2
0.81-0.90	6.2	3.1	1.5	3.6	4.6	0.0	6.2	3.6	3.6
0.91-1	6.2	3.1	3.1	3.1	4.6	1.5	0.0	2.1	2.6
Mean	0.58	0.52	0.60	0.58	0.48	0.47	0.47	0.48	0.52
St.Dev	0.24	0.23	0.26	0.24	0.32	0.30	0.31	0.31	0.28
Min	0.13	0.15	0.25	0.13	0.04	0.08	0.08	0.04	0.04
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 8. Distribution of allocative efficiency of the head, middle, and tail farms of Chihu and Malwa minors.

Water Use Efficiency									
Efficiency Scores %	Naushero Feroz Minor				Benazirabad Minor				Grand Total
	Head	Middle	Tail	Total	Head	Middle	Tail	Total	
0.01-0.20	1.5	0.0	0.0	1.0	16.9	24.6	24.6	22.1	11.5
0.21-30	6.2	7.7	6.2	6.7	18.5	15.4	18.5	18.5	12.6
0.31-40	18.5	26.2	23.1	24.1	13.8	16.9	9.2	13.3	18.7
0.41-50	15.4	58.5	41.5	15.9	9.2	4.6	7.7	7.2	11.5
0.51-0.60	18.5	16.9	16.9	17.4	3.1	7.7	6.2	6.2	11.8
0.61-0.70	12.3	4.6	7.7	8.7	6.2	3.1	7.7	5.1	6.9
0.71-0.80	9.2	1.5	4.6	5.1	7.7	7.7	4.6	5.6	5.4
0.81-0.90	3.1	1.5	4.6	3.1	4.6	3.1	3.1	3.6	3.3
0.91-1	15.4	16.9	24.6	17.9	20.0	16.9	18.5	18.5	18.2
Mean	0.58	0.52	0.60	0.58	0.48	0.47	0.47	0.48	0.52
St.Dev	0.24	0.23	0.26	0.24	0.32	0.30	0.31	0.31	0.28
Min	0.13	0.15	0.25	0.13	0.04	0.08	0.08	0.04	0.04
Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

A study conducted by Rizwan et al. (2020) found that rice farmers were not technically efficient to their optimal level and suggested short and long term policy initiatives to ensure improved rice production. The study results are also in-line with the study conducted by Asghar et al. (2018) who also worked on the efficiency estimation on wheat crop, their results indicate similar trends of technical efficiency levels among wheat growers in Pakistan's Punjab province. Another study was conducted by Zhang et al. (2020), who mentioned the importance of scale efficiency where their results suggested that small scale farmers proved to be more efficient than medium and large scale farmers. On the other hand, allocative efficiency ranges from 24 to 100 percent, and the mean scores for the head, middle, and tail of Chihu minor were calculated to be 69 percent, 52 percent, and 45 percent, respectively, implying that output can be increased by 31 to 55 percent on average given current technology and input usage. The economic efficiency of Chihu minor, on the other hand, varies from 19 to 100%, an average of 56%, 42 percent, and 37 percent for the head, middle, and tail, individually. For Malwa minor, the average economic efficiency score for the head, middle, and tail was 58 percent, 52 percent, and 51 percent, respectively, indicating that output may be improved by 42 to 63 percent on average given current technology and input consumption. While groundwater usage efficiency ranges from 4% to 100%, the average score for Chihu minor was 58 percent, 52 percent, and 60 percent for the head, middle, and tail, respectively. For Malwa minor, the average economic efficiency score for the head, middle, and tail was 48 percent, 47 percent, and 47 percent, respectively, indicating that output may be improved by 40 to 53 percent on average given current technology and input consumption. Watto and Mugera (2016) also indicated such low efficiencies regarding groundwater use in Pakistan, however, the discrepancies across the minor canals remained beyond their scope of study.

Furthermore, Gul et al. (2019) and Janjua et al. (2010) has indicated that natural calamities such as floods, droughts, and unseasonably wet weather have a negative influence on efficiency. Furthermore, Ali et al. (2011) and Imran et al. (2018) indicated that resource quality has an impact on efficiency, with higher-quality soil lowering technical efficiency, and land size has an impact as well, with bigger land sizes lowering technical efficiency. However, one of the primary causes for farmers' poor performance is changing weather, and better-quality land helps mitigate the impact of this effect. Similarly, wealthier farmers would be better able to respond to these shocks by increasing their investment or adopting equipment that is less susceptible to environmental shocks like drought (Challinor et al., 2010; Tadesse et al., 2018).

CONCLUSIONS AND RECOMMENDATIONS

The most apparent conclusion drawn from the study's findings is that effective policies are required to encourage formal education in rural families as a means of increasing efficiency over time. Farmers will be able to make better technical judgments and allocate inputs more efficiently and effectively as a result of this. The government should guarantee that timely and quality extension services are provided. The extension department has to be strengthened, and more funds should be allocated to extension activities in rural regions. Farmers who have better access to financing are more productive than those who do not. As a result, it is suggested that farmers be given soft loans to help them cope with rising production costs and more effective use of input resources. Government-supported initiatives should lower the transaction cost of loans, which has a beneficial influence on agricultural efficiency. Growers who have been located close to the market are more effective and more efficient than those who are located further away. As a result, market and road infrastructure development should be prioritized. The farm entrance should be closer to the supply outlets. Younger farmers are more technically efficient than older farmers. Incentives should be created to recruit and encourage younger individuals to work in agriculture. The introduction of new blood into farmland would result in increased agricultural production and efficiency. To increase the farms' overall technological efficiency, they must expand their scale of operation. As a result, it appears that corporate and supportive farming are the maximum viable choices in this respect.

These findings point to the need for focused interventions that educate farmers on enhancing and maintaining soil health through improved management techniques and less intensive cropping systems. Simultaneously, efforts must be made to educate farmers on how to protect themselves from the negative effects of weather shocks by using more robust cultivars or moving to different crops.

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REFERENCES

Abid, M., Schneider, U.A., Scheffran, J., 2016. Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan. J. Rural Stud. 47, 254–266.

Ahmad, F., Uddin, M., Goparaju, L., Rizvi, J., Biradar, C., 2020. Quantification of the land potential for scaling agroforestry in South Asia. KN-Journal Cartogr. Geogr. Inf. 70, 71–89.

Asghar, S., Sasaki, N., Jourdain, D., Tsusaka, T.W., 2018. Levels of technical, allocative, and groundwater use efficiency and the factors affecting the allocative efficiency of wheat farmers in Pakistan. Sustainability 10. doi.org/10.3390/su10051619.

Aslam, M., 2016. Agricultural Productivity Current Scenario, Constraints and Future Prospects in Pakistan. Sarhad J. Agric. 32, 289–303.

Bouwer, H., 2000. Integrated water management: emerging issues and challenges. Agric. water Manag. 45, 217–228.

Brázdik, F., 2006. Non-parametric analysis of technical efficiency: Factors affecting efficiency of West Java rice farms. CERGE-EI Work. Pap. Ser. 286. ISSN 1211-3298.

Cao, X., Zeng, W., Wu, M., Guo, X., Wang, W., 2020. Hybrid analytical framework for regional agricultural water resource utilization and efficiency evaluation. Agric. Water Manag. 231, 106027. doi.org/10.1016/j.agwat.2020.106027.

Challinor, A.J., Simelton, E.S., Fraser, E.D.G., Hemming, D., Collins, M., 2010. Increased crop failure due to climate change: assessing adaptation options using models and socio-economic data for wheat in China. Environ. Res. Lett. 5, 34012. doi.org/10.1088/1748-9326/5/3/034012.

Chandio, A.A., Jiang, Y., Joyo, M.A., Rehman, A., 2016. Impact of area under cultivation, water availability, credit disbursement, and fertilizer off-take on wheat production in Pakistan. J. Appl. Environ. Biol. Sci. 6, 10–18.

Charnes, A., Cooper, W.W., Rhodes, E., 1978. Measuring the efficiency of decision making units. Eur. J. Oper. Res. 2, 429–444.

Chindarkar, N., Grafton, R.Q., 2019. India's depleting groundwater: When science meets policy. Asia Pacific Policy Stud. 6, 108–124. doi.org/10.1002/app5.269.

Coelli, T., Rao, D.S.P., Battese, G.E., 1998. An Introduction to efficiency and productivity analysis Kluwer Academic Publishers. Boston/Dordrecht. doi.org/10.1007/978-1-4615-5493-6.

Daghighi, A., Nahvi, A., Kim, U., 2017. Optimal cultivation pattern to increase revenue and reduce water use: application of linear programming to arjan plain in fars province. Agriculture 7, 73. doi.org/10.3390/agriculture7090073.

Farrell, M.J., 1957. The measurement of productive efficiency. J. R. Stat. Soc. Ser. A 120, 253–290.

Fatima, H., Almas, L.K., Haroon, S., 2020. Comparative water efficiency analysis of sole and multiple cropping systems under tunnel farming in Punjab-Pakistan. J. Water Resour. Prot. 12, 455-471.

Gul, F., Jan, D., Ashfaq, M., 2019. Assessing the socio-economic impact of climate change on wheat production in Khyber Pakhtunkhwa, Pakistan. Environ. Sci. Pollut. Res. 26, 6576–6585.

Hai, Y., Long, A., Zhang, P., Deng, X., Li, J., Deng, M., 2020. Evaluating agricultural water-use efficiency based on water footprint of crop values: a case study in Xinjiang of China. J. Arid Land 12, 580–593.

Imran, M.A., Ali, A., Ashfaq, M., Hassan, S., Culas, R., Ma, C., 2018. Impact of Climate Smart Agriculture (CSA) practices on cotton production and livelihood of farmers in Punjab, Pakistan. Sustainability 10. doi.org/10.3390/su10062101.

Janjua, P.Z., Samad, G., Khan, N.U., Nasir, M., 2010. Impact of climate change on wheat production: A case study of Pakistan [with comments]. Pak. Dev. Rev. 799–822.

Ji, R., Qi, L., Huo, Z., 2012. Design of fuzzy control algorithm for precious irrigation system in greenhouse, in: International Conference on Computer and Computing Technologies in Agriculture. Springer, pp. 278–283.

li, A., Rehman, F., Nasir, M., Ranjha, M.Z., 2011. Agricultural policy and wheat production: a case study of Pakistan. Sarhad J. Agric. 27, 201–211.

Li, J., Fei, L., Li, S., Xue, C., Shi, Z., Hinkelmann, R., 2020. Development of "water-suitable" agriculture based on a statistical analysis of factors affecting irrigation water demand. Sci. Total Environ. 744. doi.org/10.1016/j.scitotenv.2020.140986.

Mahmood, N., Arshad, M., Kächele, H., Ullah, A., Müller, K., 2020. Economic efficiency of rainfed wheat farmers under changing climate: Evidence from Pakistan. Environ. Sci. Pollut. Res. 27, 34453–34467. doi.org/10.1007/s11356-020-09673-5.

Mukherjee, A., 2018. Overview of the groundwater of South Asia, in: Groundwater of South Asia. Springer, pp. 3–20.

Mukherjee, A., Saha, D., Harvey, C.F., Taylor, R.G., Ahmed, K.M., Bhanja, S.N., 2015. Groundwater systems of the Indian sub-continent. J. Hydrol. Reg. Stud. 4, 1–14.

Pahl-Wostl, C., Knieper, C., 2014. The capacity of water governance to deal with the climate change adaptation challenge: Using fuzzy set Qualitative Comparative Analysis to distinguish between polycentric, fragmented and centralized regimes. Glob. Environ. Chang. 29, 139-154.

Pena, R.J., 2007. Current and future trends of wheat quality needs, in: Wheat Production in Stressed Environments. Springer, pp. 411–424.

Qureshi, A.S., 2015. Improving food security and livelihood resilience through groundwater management in Pakistan. Glob. Adv. Res. J. Agric. Sci. 4, 687–710.

Qureshi, A.S., 2020. Groundwater governance in Pakistan: From colossal development to neglected management. Water 12, 1-20. doi.org/10.3390/w12113017

Rizwan, M., Qing, P., Saboor, A., Iqbal, M.A., Nazir, A., 2020. Production risk and competency among categorized rice peasants: Cross-sectional evidence from an emerging country. Sustainability 12, 1-15. doi.org/10.3390/su12093770.

Shah, T., 2007. The groundwater economy of South Asia: an assessment of size, significance and socio-ecological impacts. Agric. Groundw. Revolut. Oppor. Threat. to Dev. 7–36. DOI:10.1079/9781845931728.0007.

Sheikh, A.D., Rehman, T., Yates, C.M., 2003. Logit models for identifying the factors that influence the uptake of new 'no-tillage'technologies by farmers in the rice–wheat and the cotton–wheat farming systems of Pakistan's Punjab. Agric. Syst. 75, 79–95.

Steinfeld, C.M.M., Sharma, A., Mehrotra, R., Kingsford, R.T., 2020. The human dimension of water availability: Influence of management rules on water supply for irrigated agriculture and the environment. J. Hydrol. 588. doi.org/10.1016/j.jhydrol.2020.125009.

Tadesse, W., Bishaw, Z., Assefa, S., 2018. Wheat production and breeding in Sub-Saharan Africa: Challenges and opportunities in the face of climate change. Int. J. Clim. Chang. Strateg. Manag. 11, 696-715.

Tang, J., Folmer, H., Xue, J., 2015. Technical and allocative efficiency of irrigation water use in the Guanzhong Plain, China. Food Policy 50, 43–52.

Thabethe, L.E.M., Marlene Labuschagne, 2014. Estimation of Technical, Economic and Allocative Efficiencies in Sugarcane Production in South Africa: A Case of Mpumalanga Growers. J. Econ. Sustain. Dev. 5, 86–95.

Varghese, S.K., Veettil, P.C., Buysse, J., Speelman, S., Frija, A., Van Huylenbroeck, G., 2011. Effect of water scarcity on groundwater use efficiency in the rice sector of Karnataka: a case study. WIT Trans. Ecol. Environ. 145, 783–791.

Wadud, M.A., 2003. Technical, allocative, and economic efficiency of farms in Bangladesh: A stochastic frontier and DEA approach. J. Dev. Areas. 37, 109–126.

Watto, M., Mugera, A., 2019. Wheat farming system performance and irrigation efficiency in Pakistan: A bootstrapped metafrontier approach. Int. Trans. Oper. Res. 26, 686–706.

Watto, M.A., Mugera, A.W., 2015. Econometric estimation of groundwater irrigation efficiency of cotton cultivation farms in Pakistan. J. Hydrol. Reg. Stud. 4, 193–211.

Watto, M.A., Mugera, A.W., 2016. Groundwater depletion in the Indus Plains of Pakistan: imperatives, repercussions and management issues. Int. J. River Basin Manag. 14, 447–458.

Zhang, D., Saboor, A., Chen, W., Rizwan, M., 2020. Measuring returns to scale among vegetable producers under technological change: an evidence from china. J. Anim. Plant Sci. 30, 475–484.

Zhang, Z., Chen, X., Heck, P., 2014. Emergy-based regional socio-economic metabolism analysis: An application of data envelopment analysis and decomposition analysis. Sustainability 6, 8618–8638.