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Using Non Parametric Approach to Explore Groundwater use Efficiency of Spring Maize in Bari Doab, Punjab Pakistan

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ABSTRACT

In this contemporary world, researcher and policy makers are trying hard to nourish the expanding population in long term. One school of thought is trying to cope with the scenario of diversifying individual's diet and other is emphasizing on increasing supply of food. With the passage of time extra food is the prime need keeping in view limited resources. In agriculture water is a significant player but alarming situation of water scarcity is adversely affecting the fate of Pakistan's agriculture. Without improving production efficiencies, we could not meet the need of future generation. Present research is conducted with the intention to quantify the irrigation water used by spring maize and to investigate the various factors affecting the water use efficiency of spring maize in Bari doab. Primary data of 312 respondents from head middle and tail (104 from each location) of Depalpur distributary (District Okara) were surveyed by employing Multistage sampling technique. Results indicated that, on an average, 2915 m3 per acre of water was used to produce spring maize in the study area. Farmer residing in the middle location of the irrigation system achieved 83 percent of groundwater use efficiency. Farming experience, schooling years, tube well ownership, watercourse lining, and quality of subsoil water had a positive and statistical significant impact on groundwater use efficiency, while farm size had a negative influence on efficiency. Policy recommendation includes Government may invest in lining of watercourses to improve groundwater use efficiency of the farmers.

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1. Introduction

In many developed and developing countries, irrigation water is mainly used by agriculture sector and is considered the primary factor in enhancing agricultural productivity (Arancibia et al., 2020; Kirby et al., 2015; Petit et al., 2021; Tomar et al., 2020). Globally, 70 percent of conjunctive water i.e., groundwater and surface water is used for irrigation purposes (Dieter et al., 2018; Siebert et al., 2010) and in Asia, this share rises to 90 percent or more (Meier, Zabel, & Mauser, 2018). Pakistan is blessed with three hydrological units (Indus Basin, Makran Coast, & Kharan Desert) and Indus basin is at top which provides approximately 218 billion cubic meter surface as well as groundwater resources to the country (Nasreen & Ashraf, 2020). Out of total area of 79.6 million hectare, 24-million-hectare area is under crop production in Pakistan (GOP, 2024). Being agricultural country, Pakistan is utilizing approximately 94 percent of available groundwater and surface water resources to produce 90 percent of food grain (Zaveri et al., 2016). Nearly 50 percent of crop water requirements are fulfilled by groundwater (Qureshi, McCornick, Sarwar, & Sharma, 2010), while 10 percent of agricultural produce is obtain by rain fed areas of Pakistan (Kahlown & Majeed, 2004).

Although groundwater used for irrigation has significantly impacted agricultural production, its overuse has caused depletion of groundwater table and threatens future water availability (Dalin, Wada, Kastner, & Puma, 2017; Döll, Müller Schmied, Schuh, Portmann, & Eicker, 2014; Feng et al., 2013; Ouyang et al., 2019; Salem, Kazama, Shahid, & Dey, 2017; Taylor et al., 2013). Ouyang et al. (2021) found that over extraction of groundwater for excessive irrigation through flooding and irregular crop irrigation causes severe groundwater depletion. Konikow (2015) forecasted that irrigation sector puts huge stress on groundwater reserves and is depleting at a rate of 545 km^2 annually. In addition, climatic variation effects groundwater (Taylor et al., 2013) and may receive less rainfall in future (Kumar, 2012) and increased drought interval (Mojid, Shibly, & Acharjee, 2020) failing in recharge to groundwater levels. Sivakumar et al. (2011) forecasted that irrigation water demand in Asia will increase by 10 percent with a 1^0 C rise in temperature and global irrigation demand will increase by 19 percent during 2050. In South Asia, Pakistan is the second largest groundwater harvesting nation, with an estimated withdrawal of 60 billion m^3, after India with an extraction of 230 billion m^3 annually (Qureshi, 2015; Subhadra, 2015; Suhag, 2016), contributing approximately 9 percent to the extraction of groundwater globally (Bhutta & Smedema, 2007; World, 2008).

Maize is an important food crop worldwide and has been consumed by humans and livestock since ancient times. The increasing demand for maize production in different industries has strengthen its prominent position in the agricultural economy (Anderson, Cronholm, & Biscaye, 2017). It is evident that global maize trade touched to 16 million tons in 1950. At present, maize is cultivated across 130 million hectares in only seventy countries, yielding five hundred million tons of production (Dowswell, Paliwal, & Cantrell, 2019). In Pakistan, maize ranks 4^{th} among cereal crops in term of cultivated area and production of its various products (GOP, 2024). Estimating crop-water requirement is important for predicting irrigation needs and managing irrigation water (Hossain, Yesmin, Maniruzzaman, & Biswas, 2017), as effective demand management is considered prerequisite in addressing water scarcity.

Pakistan is still facing an imminent and severe groundwater crisis (Lytton, Ali, Garthwaite, Punthakey, & Saeed, 2021). The available quantity of water is not adequate to meet the desirable demand (Wada et al., 2010). Groundwater is depleting at an exponential rate due to unrestricted extraction of groundwater combined with insufficient recharge from unpredictable rainfall. With the passage of time, this country's resource base is diminishing rapidly and adversely affecting the rural economy. Additionally, competition of water uses among various sectors (household, industries, environment etc) is increasing day by day. Decreasing available irrigation water, make it essential to rapidly adopt modern measures for efficient water management. In the country, managing and allocating water resources has been a persistent challenge for both decision makers and researches. Therefore, it is the need of hour to develop understanding in efficient management of groundwater for judicious use of this resource, and to boost agricultural productivity. The work could be a milestone for the policy makers to develop site specific strategies for efficient consumption of available resources.

1.1. Research Objectives

- To quantify groundwater, use for spring maize cultivation across different farm categories in Bari doab.
- To investigate the various factors affecting groundwater use efficiency in spring maize.

2. Literature Review

Keeping in view of food security, a lot of work on technical efficiency of maize crop is carried out. Many developing and developed countries have used crop efficiency to reveal various factors responsible for the crop production. Empirical research on technical efficiency mainly revolves around socioeconomic characteristics. Among socioeconomic characteristics, age is considered as imperative influential feature. Chaovanapoonphol and Somyana (2020) found direct and significant relationship between age, and the technical efficiency of maize crops in contract farming. However, Ebukiba, Anthony, and Adamu (2020) identified a negative relationship between age of the farmer and technical efficiency of maize grower.

Farming experience, another important socioeconomic feature, is a vital factor in assessing technical efficiency of crop production. Abdulai, Nkegbe, and Donkoh (2013) supported the argument with his findings that experience of the farmer is directly and significantly impacted the technical efficiency of maize production. Likewise, Okuyama, Maruyama, Takagaki, and Kikuchi (2017) concluded that technical efficiency of crop can be positively influenced by experience of cultivating crop, nitrogenous fertilizer application and famer participation in agricultural cooperatives.

Likewise, Tumuri, Geleta, and Sime (2024) showed that farmers having higher schooling education were more technical efficient in receiving, interpreting, and adopting modern crop production innovations compared to less educated farmers. Ng'ombe and Kalinda (2015) used stochastic production frontier and technical inefficiency model to investigate the relationship of different categories of formal and non-formal education. The outcome revealed that all the education categories exhibited negative relation with technical inefficiency of maize production.

Other than socio-economic perspective, farm size is another factor considered empirically in literature. Mango et al. (2015) analyzed positive and significant association between farm size and technically efficiency of maize crop. Agricultural Extension services, which represent institutional factors, have been reflected in many studies. For instance, Abdulai, Nkegbe, and Donkoh (2018) found a positive and significant relationship between extension services and technical efficiency of maize crop. The researcher recommended that strengthening the agriculture extension department could lead to more effective extension services and higher efficiency for maize growers.

Martey, Wiredu, Etwire, and Kuwornu (2019) analyzed the relationship between agricultural loan and the technical efficiency of the maize growers. The results revealed a positive association between credit and technical efficiency of maize growers. The study suggested that significant benefits are only attainable when resource-poor small farmers are targeted. This link could be stronger when the interaction between farmer and financial institutions is smooth. Abdallah (2016) also supported the argument and found credit access plays pivotal role in achieving technical efficiency in maize crop. The research concluded that easy loan increased technical efficiency of maize farmer up to 3.8 percent.

Chaity and Rahman (2017) determined that female farmers participating in NGOs training programs increased their knowledge of adopting modern techniques and sustained their production. Ahmed and Melesse (2018) revealed that member farmers of agricultural cooperatives were actively participating in off-farm activities, achieving higher levels of technical efficiency compared with non-participant. Similarly, Olagunju, Ogunniyi, Oyetunde-

Usman, Omotayo, and Awotide (2021) argued that participation in agricultural cooperatives could result in higher technical efficiency scores. However, Hailu, Weersink, and Minten (2015) contradicted these findings, nothing that cooperative membership had no significant influence on technical efficiency.

Dlamini, Masuku, and Rugambisa (2012) used stochastic frontier analysis to explain the association between socio-economic characteristics, seed rate, pesticides, fertilizer and labour used with technical efficiency of maize and found that all the inputs used were directly related with crop production. Wu, Hua, Luo, and Tanaka (2022) concluded that temperature and humidity in arid and semi-arid areas are directly linked with non-efficiency of maize growers. Memon, Noonari, Wagan, Lakhio, and Wakeel (2016) found that nitrogenous application, phosphate fertilizer, maize seed rate and seed quantity were the significant influencer in attaining positive levels of maize technical efficiencies. Linh, Nanseki, and Chomei (2015) highlighted electricity source, milling machines, market distance, availability of extension services, access to credit, age of farmer and family size are the main factors affecting allocative and technical efficiency of maize and rice growers.

After reviewing the literature, it is evident that there are very few studies examining the impact of groundwater use efficiency on spring maize. Most studies have analyzed the maize crop through the lens of technical efficiency. This study contributes to the literature by analyzing groundwater use efficiency in Bari doab. Additionally, location-based estimation of groundwater use efficiency is discussed. Policy makers and researcher can develop site specific strategies taking into account limited water resources.

3. Materials and Methods

3.1. Study area and sampling

A Primary data of 312 respondents was collected from Depalpur distributary of Okara district from Punjab province. The district lies between Ravi River and Sutlaj River in Bari doab are depicted in figure 1. Adequate quantity of canal water was not available in the study area during rabi season. Farmers were heavily relying on groundwater and extracting it continuously. Gradual decrease in groundwater table was observed in the area where tubewell/ turbines were installed in field at a bore depth of 250 to 450 meter.

Multistage sampling technique was employed to collect the primary data. During first stage Depalpur distributary from Bari doab was selected randomly with the help of Punjab Irrigation Department Punjab, Lahore (Figure 1). In second stage nine watercourses from head (11510-L, 17230-R & 10350-R), middle (21030-R, 69710-L & 69910-L) and tail (112350-R, 112030-R & 133280-L) of the distributary were selected randomly. From three locations of the Depalpur distributary, 104 respondents from each location were interviewed. Out of 312 respondents, 224 were growing spring maize. Predominant cropping pattern in the vicinity were wheat-seasonal maize, wheat-rice, Potato-Spring Maize-Seasonal maize, and Potato-Spring maize-rice. Cross- sectional data were collected through a well-structured questionnaire using Open data Kit (ODK) an application for data collection.

3.2. Variable used for Groundwater efficiency

For estimation of groundwater efficiency, information of various inputs (land preparation, seed rate, fertilizer, chemical application, mechanical weeding, crop area, and groundwater quantity) and output (spring maize yield) was used as shown in Table 1. Efficiency Measurement System (EMS) software was used to calculate efficiency scores of various farms in the study area. The quantity of groundwater extracted used in the estimation calculated by Srivastava, Kumar, and Singh (2009); Watto (2015).

$$Q = \frac{t*129574.1*BHP}{[d+(255.5998*BHP^{2})/d^{2}*D^{4}]} \quad (1)$$

Where Q: Volume of water in litres
t: Total irrigation time (hours)
BHP: Engine power
d: Bore Depth
D: Diameter of suction Pipe

Table 1
Variables Used for Calculation of Groundwater Efficiency of Spring Maize

Variable	Unit	Definition
Crop area	Acres	Spring maize acres sown
Seed Rate	Kilogram per acre	The spring maize seed quantity used per acre
Land preparation (Rotavator, plough, disc plough)	Numbers per acre	For land preparation number of implement used per acre
Phosphorus fertilizer	Bags per acre	The quantity of phosphorus fertilizer used per acre
Nitrogen fertilizer	Bags per acre	The quantity of nitrogen fertilizer used per acre
Mechanical weeding	Numbers per acre	The number of mechanical weeding per acre
Chemical Application	Numbers per acre	The numbers of chemical applied per acre
Irrigation water	Cubic meter per acre	Quantity of water applied per acre
Yield	Monds per acre	Output of spring maize per acre.

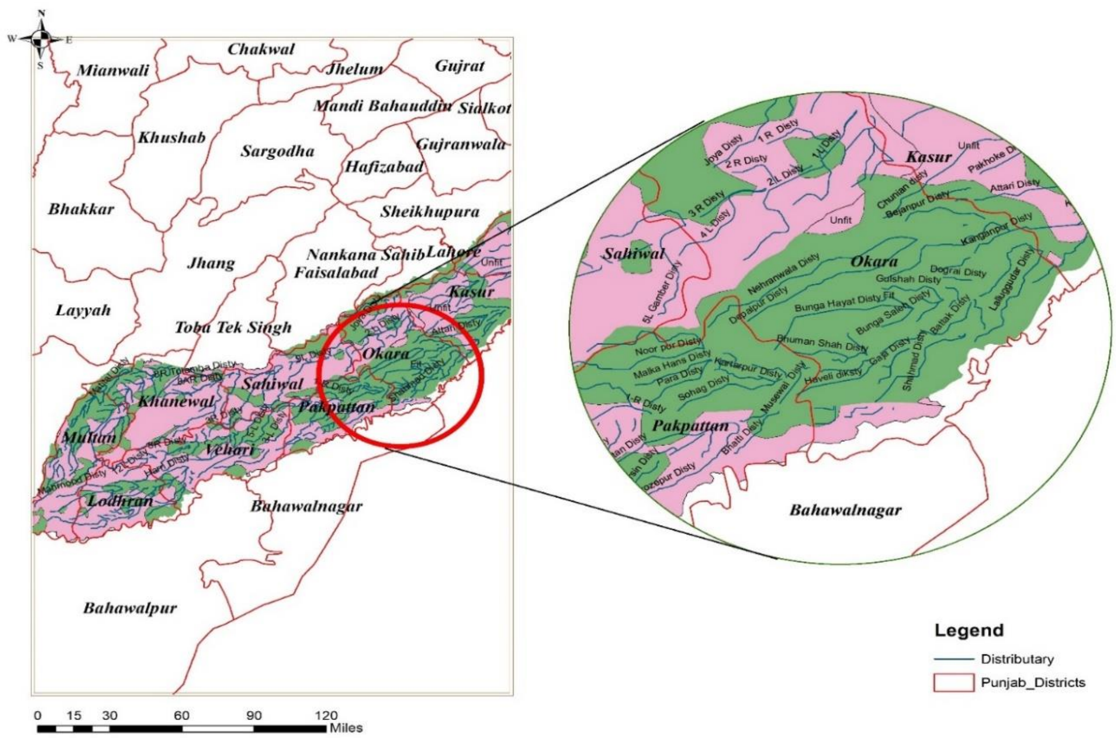

Figure 1: Distributary Selection from Bari Doab using GIS software

For efficiency analysis mainly two approaches are used; Parametric (Stochastic Frontier Analysis) and non-parametric (Data Envelopment Analysis DEA). DEA can estimate relative efficiency of a group of homogeneous decision-making units by using multiple inputs and output (Zhang, Chen, & Heck, 2014). Optimization of each farm's individual efficiency score can be done through mono objective linear programming by incorporating different inputs and output (Carlucci, Cirà, & Coccorese, 2018). An input oriented variable return to scale, Data Envelopment Analysis (DEA) is given as following.

$Min(\lambda_{jo}\theta)\theta_{jo}$ (2)
Subject to
$\sum_{i=1}^{n} \lambda_i Y_i - Y_{io} \geq 0$ (3)
$-\sum_{i=1}^{n} \lambda_i X_{k-jo.i} + X_{io} \geq 0$ (4)
$-\sum_{i=1}^{n} \lambda_i X_{jo.i} + \theta_{jo} X_{io} \geq 0$ (5)
$\sum_{i=1}^{n} \lambda_i = 1$ (6)
$\lambda_i \geq 0$
Y_{io} is output quantity of all the spring maize growers
X_{io} is input quantity of all the spring maize growers.

$\sum_{i=1}^{n} \lambda_i$ is equation used to compute efficiency in Variable Return to Scale. N1/ λ = 1 represents convexity constraint which shows that smaller firm is benchmarked by an inefficient firm.

Groundwater use efficiency was calculated by Watto and Mugera (2014).

$$GW_E = {}^{V_a}/_{V_i} * 100 \quad (7)$$

Where GW_E is groundwater efficiency, V_a is the actual amount of input (groundwater) and V_i is irrigation water applied.

3.3. Tobit Analysis (Bootstrap Truncated Analysis)

For efficiency analysis Tobit analysis was employed which is a commonly used technique. Various researchers Akter et al. (2021); Alhassan, Loomis, Frasier, Davies, and Andales (2013); Chebil, Frija, and Thabet (2015); Dibaba and Goshu (2018); Dinku and Beyene (2019); Hassan (2021); Issahaku and Maharjan (2014); Mirza, Najam, Mehdi, and Ahmad (2015); Mohammadpour et al. (2020); Sarker and Alam (2016); Wassihun, Feleke, Abate, and Bayeh (2022); Wei et al. (2020); Yirga et al. (2013); Zulfiqar, Datta, and Thapa (2017) incorporated this technique in different agricultural crop productivity. Efficiency scores are considered as censored variable having values in between zero and one. Inconsistent to this argument McDonald (2009) claimed these values as fractional values not censored. Moreover, Banker and Natarajan (2008) suggested that second stage Ordinary Least Square (OLS) is more reliable than Tobit regression. Although, second stage OLS performs in peculiar condition and provides rare assumptions of data producing sequences as suggested by the Simar and Wilson (2011). Furthermore, he concluded that second stage bootstrap truncated model gives more consistent results. Following is the model use for the Tobit regression analysis.

$$Y_{Ei} = \alpha_i + \sum_{i=1}^{n} \beta_i Z_i + \varepsilon_i \; for \; i = 1, \ldots.., N \quad (8)$$

Y_{Ei} = Groundwater use efficiency of ith farm.
Z_i = Set of explanatory variables (Figure 2)
ε_i = Error term

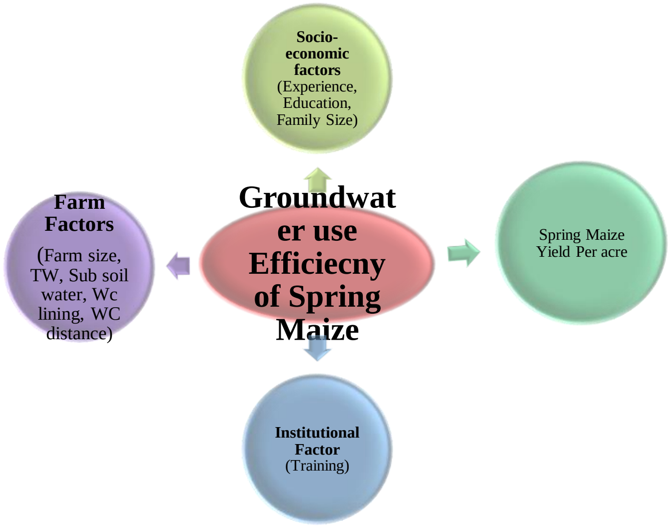

Figure 2: Factors Affecting Groundwater Use Efficiency using Tobit Analysis

4. Results and Discussion

4.1. Farm and Farmer's Characteristics

Table 2 explains the socio-economic characteristics of the respondents. The average age of the respondents in the study area was 44.9 years. Farmers situated at the end of the watercourses were generally older than those in other locations. The education of the respondents in the study area was relatively low and on an average farmers had 21.39 years of regular schooling. Farming experience of the household head located at head were more experience with an age of 23 years than other sampled farmers. The results showed that 79 percent of the respondents were cultivating their own lands, 12 percent were cultivating their own land with rented land and only 8 percent or the respondents were tenants in the study area. On an average, the respondents had 9 family members residing under one roof and sharing their meal.

Farmers located at tail end were having on an average, 1.56 tube wells and extracting more groundwater compared to other farm locations. Overall, on an average, 1 tube well was used by farmers to irrigate spring maize. The majority of the farmers at tail end were extracting more groundwater than other farmers. On an average, 2775 m^3 groundwater was utilized by middle farmer followed by head and tail located farmers who extracted more groundwater i.e., 2956 m^3 and 3060 m^3 respectively.

Table 2

Socio-economics Characteristics of the Sparing Maize Growers

Characteristics	Head	Middle	Tail	Overall
Age (years)	43.0	46.3	45.6	44.9
Education (schooling years)	7.6	7.2	8.9	7.75
Farmer experience (years)	23	20.8	22.3	21.39
Tenancy Status (percentage)				
Owner	83.3	80.2	73.5	79.9
Owner cum Tenant	10.0	11.1	16.9	12.0
Tenant	6.7	8.6	9.4	8.0
Family Size (Numbers)	8.9	9.2	9.15	9.08
Tube well possession (numbers)	1.4	1.3	1.56	1.45
Bore depth (meter)	100.1	98.2	99.5	99.3
Irrigation quantity (cubic meter)	2956.9	2775.3	3060.3	2915.7

4.2. Spring Maize Acreage at Field

The percentage of land utilized for spring maize at head, middle and tail was 73, 82, and 74 percent respectively (Table 3). Approximately, maize crop is cultivating on 76 percent in the study area. On an average, 21.56 acres were allocated to the spring maize and middle located farmers were cultivating more maize than head and tail farmers. Present trend of cultivating more maize crop in the study rea may be due to more returns associated with the crop.

Table 3
Spring Maize Acreage in the Study Area

Category	Farm area	Total area	Percent area allocated to crop
Head	30.4	17.3	73.8
Middle	22.3	22.8	82.8
Tail	20.71	17.6	74.89
Total	25.21	21.56	76.7

4.3. Efficiency Scores according to Farm location

Table 4 presents the water use efficiency scores of seasonal maize growers in the study area. Compared with farmers located at the head and tail of the irrigation system, those in the middle were utilizing irrigation water more wisely. We found that irrigation efficiency of famers in middle location was 83 percent with the ranges from 0.58 to 1. It is obvious from the results that age of the middle-located farms respondents was high compared with rest of locations. Szabo, Apipoonanon, Pramanik, Leeson, and Singh (2021) argued that older farmers shows positive attitude towards on farm activities resulted in higher agricultural productivity. Results indicated that only 18 percent of farmers were found fully efficient at middle location. However, tail end farmer and head farmer were operating at 79.9 and 77.6 percent respectively. Farmers at the head location may have maximum access to surface water, leading to flooding of the fields and resulting in lower efficiency scores. While, the reduced irrigation efficiency of tail end farmer may reflect the practice of extracting a higher volume of groundwater without considering the actual needs of spring maize. Overall, irrigation efficiency in the study area was 80 percent revealed that there is considerable opportunity to increase irrigation efficiency by considering other inputs and remaining on same level of output.

Table 4
Distribution of Efficiency Scores Among Famer Categories According to Watercourse Location

Efficiency ranges	Head	Middle	Tail	Overall
<0.5	2	0	0	2
0.51-0.60	6	6	7	19
0.61-0.70	21	10	11	42
0.71-0.80	33	13	11	57
0.81-0.90	17	35	12	64
0.91-0.99	2	2	0	4
1	9	15	12	36
Average efficiency score	77.6	83.7	79.9	80.3
Min	0.46	0.58	0.53	0.46
Max	1	1	1	1

The parameters of groundwater irrigation efficiency by using Tobit model (Bootstrap truncated regression) is given in table 5. Among socioeconomic characteristics, experience of the respondent had direct and significant impact on the irrigation efficiency, supporting the concept that experienced farmer have better social interaction for learning (Mgale & Yunxian, 2020) and greater capability to negotiate in market (Pingali & Abraham, 2019; Shiimi, Taljaard, & Jordaan, 2012). Likewise, education of the respondent was positively associated with irrigation efficiency, representing that irrigation efficiency of farmer increased by 0.003 by one unit increase in schooling years. The results are consistent with the finding of Solís, Bravo-Ureta, and Quiroga (2009); Watto and Mugera (2015), who concluded that education significantly impacts farmer's irrigation efficiency. The results indicated a positive relationship between the farm's family size and irrigation efficiency, but this relationship was not statistically significant. However, Mwangi, Ndirangu, and Isaboke (2020) found positive and significant relationship of family size and efficiency of tomato farmer in Kenya.

The relationship between farm size of the spring maize growers and irrigation efficiency was negatively and statistically significant, indicating that large farmers were irrigating their farms less efficiently. This could be attributed to the practice of flood irrigation, which increases the likelihood of over irrigation with increase in farm size. In literature we found mixed results for farm size and efficiency relationship, e.g. Dhehibi and Telleria (2012) concluded that small farms are less efficient in terms of technical and groundwater use, while Balcombe, Fraser, Latruffe, Rahman, and Smith (2008) found direct relation between farm size and irrigation efficiency. Karagiannis, Tzouvelekas, and Xepapadeas (2003) revealed that farm size has no impact on technical and irrigation water efficiency. Pereira and Marques (2017) suggested that large farm size can contribute to the achievement of irrigation water efficiency.

Watercourse lining showed positive and significant impact on irrigation efficiency. Concerning watercourse distance, the results represent that the farmer located far from the watercourse did not impacting irrigation efficiency due to lined watercourses. Positive and statistically significant relationship of tube well ownership with irrigation efficiency implies that tube well owner had timely access and assurance of water availability in absence of surface water. Watto and Mugera (2014) analyzed negative relation of technical efficiency but positive relationship of irrigation efficiency with tube well owner of rice farmers. The impact of subsoil water on irrigation water use efficiency was positive and statistically significant explaining underground water was fit for irrigation to spring maize.

Furthermore, training of the respondent of spring maize grower showed direct and significant impact on the groundwater use efficiency indicating investing on human capital and skill by one unit will turn irrigation efficiency up to 0.005 units. Liu et al. (2021) and Liu et al. (2022) suggested that technical training is a valuable tool for boosting farm income and conserving limited resources. Likewise, Zulfiqar, Datta, Tsusaka, and Yaseen (2021) contextualized that lack of training for farmers on irrigation management is a significant issue in groundwater management.

Table 5
Factors Effecting Groundwater Use Efficiency of Spring Maize Growers

Variable	Coefficient	Std. Error	z-Statistic
C	0.654	0.036	18.34
Experience (years)	0.002*	0.001	2.89
Education (schooling years)	0.003**	0.002	2.10
Family size (numbers)	0.002	0.002	0.97
Tube well ownership (1=yes, 0=otherwise)	0.050*	0.018	2.82
Watercourse distance (meters)	0.0004	0.007	0.06
Farm size (acres)	-0.001*	0.000	-3.43
Watercourse lining (1=lined, 0=otherwise)	0.027***	0.018	1.49
Subsoil water (1=fit, 0=otherwise)	0.058*	0.021	2.81
Training (1=yes, 0=otherwise)	0.005	0.016	0.30
Log Likelihood	169.43		

*,**,*** Significance level at 1%, 5% and 10% respectively

5. Conclusion

This study was carried out to quantify groundwater used for cultivating spring maize and to highlight various factors affecting groundwater use efficiency in Bari doab. A non-parametric approach i.e., data envelopment analysis (DEA) was employed to evaluate groundwater use efficiency. Primary data from 312 respondent were collected from three locations (head, middle & tail) of Depalpur distributary in the district of Okara. The results indicated that spring maize farmer were operating at high irrigation efficiency in the Bari doab. On an average, groundwater use efficiency score was 80 percent in the study area. The average score of groundwater use efficiency of middle located farms was high (83%) compared with head and tail farmers (77% & 79%). Results indicated that only 36 spring maize farm were operating at full groundwater use efficiency level. On an average, farmer at middle location were using less groundwater at the rate of 2775 m^3 per acre than head (2956 m^3 per acre) and tail (3060 m^3 per acre) locations.

One of the imperative research objectives was to familiar water experts and policymakers with the research question of whether groundwater use efficiency can improve water resource management. The study's findings address this question by providing different policy implications in the result section. The results revealed that farmers with substantial farming experience and higher levels of schooling can improve groundwater use efficiency. Experience and education enhance a farmer's managerial skills and encourage efficient use of inputs. However, a large farm size can divert a farmer's attention to multiple tasks, leading to a reduction in groundwater use efficiency, as depicted by the negative relationship between farm size and groundwater use efficiency. Likewise, ownership of a tube well plays a significant role in improving groundwater use efficiency. Improved watercourses would help farmers in achieving higher levels of groundwater use efficiency. Government may initiate program for lining of watercourses to save huge volume of groundwater. Marginally fitted under groundwater would give better results for groundwater efficiency in spring maize.

Authors' Contribution

Tahir Mehmood: The novelty of idea, literature reviewing, methodology, data collection, data analysis, and wrote the manuscript.
Irfan Ahmad Baig: Supervised and gave technical support.
Abdul Saboor: Gave technical support.
Mukhtar Ahmad: Refine the draft & Editing.

Conflict of Interests/Disclosures

The authors declared no potential conflict of interest w.r.t the research, authorship and/or publication of this article.

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