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Water Use Efficiency Of Peach Cultivation In Khyber Pakhtunkhwa, Pakistan; Using Data Envelopment Analysis

Tariq[1*], Javed Iqbal[2] and Zahoor-ul-Haq[3]

[1]*PhD Scholar, Department of Economics, Abdul Wali Khan University, Mardan, KP Pakistan.*
[2]*Associate Professor, Department of Economics, Abdul Wali Khan University, Mardan, KP Pakistan.*
[3]*Professor, Department of Economics, Abdul Wali Khan University, Mardan, KP Pakistan.*
**Correspondence Author: Tariq*

Abstract

Agricultural water resources are dwindling, endangering the economic viability of irrigation systems in Pakistan. As in perspective of shrinking water supplies as well as declining agricultural water productivity, it is essential to enhance farm level effectiveness and make efficient use of existing groundwater sources. This research employed a non-parametric method to assess the extent of technical and irrigation water efficiency in Pakistani Peach cultivation. The average technical efficiency (TE) score for tube-well holders is 0.96, while it is 0.94 for water buyers. The average irrigation water efficiency (IWE) score for tube-well holders is 0.86, while it is 0.72 for water buyers. We discovered that across all farms, 59 percent of tube-well holders and 45 percent of total of water purchasers are TE, while just 36percent of the total of tube-well landlords and 30percent of total of water buyers are efficient in IW use. Peach growers have relatively high levels of technical efficiency, as shown by this research. However, irrigation water efficiency could be significantly improved. According to this study, broadening the importance of extension services in agriculture beyond purely modern agricultural basis to direct growers through costs and benefits evaluation of current production technology would aid in achieving greater levels of efficiency.

Keywords: Irrigation, Efficiency, Water use, Peach, Data Envelopment Analysis, Swat, Pakistan.

1. Introduction

The lack of water assets is a significant issue around the world. Either in developed or less-developed nations, water shortfall is progressively turning into an issue. Under the stress of this issue, another period of water resource management takes place in numerous pieces of the world. The prime target of this new period is characterized as the reasonable and effective use and the executives of water resources (Bithas, 2008). In developing world, irrigation assumes a crucial job in consistent growth of grain production. Water shortage in Pakistan, like in many other areas of the world, has become a growing economic as well as social problem for policymakers and competing water users (Karagiannis, Tzouvelekas, & Xepapadeas,2003; Hussain, & Hanjra, 2004). Water scarcity is endangering the viability of irrigated areas and posing major difficulties to the nation's economic situation of food security (Hussain, & Hanjra, 2004; Archer, Forsythe, Fowler, & Shah, 2010). Whereas the usage for irrigation water keeps going up, its amount of fresh water is decreasing, primarily due to climate change. As a consequence, increased competition for irrigation water is likely to boost dependency on groundwater resources.

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Pakistan is now the third-largest worldwide underground water user, accounting for approximately nine percent of global groundwater withdrawals (Giordano, 2009). With over a thousand tube-wells installed throughout the country, Pakistan meets more than half of its irrigation needs through groundwater abstraction (Rinaudo, Strosser, & Rieu,1997; Qureshi, McCornick, Sarwar, & Sharma, 2010). A tube-well seems to be a type of water hole that is drilled in earth to extract groundwater using a pump. In Pakistan, tube-wells with diameters ranging from five to seven inches are commonly used to extract groundwater. Depending on the depth of the water table, such tube wells were also equipped either by fifteen to twenty five horsepower (HP) diesel engines as well as fifteen to thirty HP electric motors.

For a long time, private tube-well development has played critical part in agricultural growth. Groundwater usage began to rise sharply in the early 1960s. At the time, government programmes which including electricity connection, power, fuel, and drilling service incentives, free pump sets, and low-interest long-term lending aided in the implementation of tube-well advanced technologies (Falcon, and Gotsch 2013; Johnson, 1989).

Afterward, higher yields as well as profitability from the farming of high-yielding different crops by dependable irrigation supplies from groundwater extractions, Meinzen Dick, and Rosegrant (1997); Byerlee, and Siddiq (1994), urged growers would use tube-well innovation even in the absence of government subsidies (Falcon, & Gotsch, 2013; Mohammad,1964; Nulty, 1972). As irrigated agriculture demands increased in subsequent years, a increasing number of freshwater resources have been obtained via ground-water inferences. (Shiva,1991; Rodell, Velicogna & Famiglietti, 2009). Groundwater contributed about 8% of total irrigation water supplies in 1960, but after twenty-five years later, this proportion had risen to round about forty- percent sharply (Byerlee, and Siddiq, 1994). Later, as surface water resources dwindled, the dependence on groundwater for irrigation purposes risen by even more of around Fifty percent. Surpassing its per year recharge of fifty-five cubic kilometer, subsequent emergent phenomenon rate increases of approximately to sixty cubic kilometer and have exceeded the annual replenishment limits (Giordano, 2009). In addition to making groundwater extraction more expensive, declining water tables are causing a slew of environmental issues with serious implications for the long-term viability of irrigated agriculture(Qureshi, McCornick, Sarwar, & Sharma, 2010; Kijne,1999; Khan, Rana, Gabriel, & Ullah, 2008). Throughout this perspective, the continued water shortages had already caused serious questions about the need to scrutinise the efficiency of agricultural water use so much attentively than in the past (Watto, & Mugera, 2014).

Furthermore, rising intersectoral water requirements had already provided additional momentum to enhance agricultural water effectiveness and yield. Moreover, researchers investigated irrigated agriculture water efficiency seem to be scarce as well as primarily concentrate on the agriculture production level, with only a few inquiry irrigated agriculture water usage only at agronomic scale. Among other studies, Karagiannis et al. (2003) assessed the "irrigation water efficiency of out-of-season vegetable farming in Greece". Frija, Chebil, Speelman, Buysse, and Van Huylenbroeck, (2009) calculated "irrigation water efficiency among South African small-scale irrigators and Tunisian small-scale greenhouse vegetable farmers", respectively. Manjunatha, Speelman, Chandrakanth, & Van Huylenbroeck (2011), investigated the "irrigation water efficiency of different agricultural crops in India". In the existing literature, however, there is no significant evidence of irrigation water efficiency estimation in peach production.

1.1. Research question

This study attempt to answer the question that; whether water resources are used efficiently for irrigation or not in selected region of Pakistan?

1.2. Significance of the study

Economic development is strongly associated with efficient use of scarce resources. Water which is one the very important natural resource is also going to scarce in the most region of the world and causes many difficulties in the form of agriculture, power, sanitation, ecosystem and so many other sectors. Every nation is trying to tackle down this issue through different methods. As therefore as a developing country, Pakistan should also have to give a special attention to this very problem. They require an effective policy for managing and preserving the country's water resources in the context of climate transition. Initiatives over the decades to update and reaffirm a water security policy had already failed due to a lack of need and agreement within and between federating elements. As a result, approval of the 2002 proposal national water arrangement has indeed been postponed for ten and a half years.

Pakistan needs to utilize more intelligent and less water-escalated practices. The nation has seen a considerable amount of supply-side estimates, for example, building reservoirs. The focal point of things to come changes anyway ought to be on improving water use efficiency particularly in the agriculture sector which keeps on being the biggest consumer of water while getting away tax assessment. The focus framework, particularly in the agriculture sector, can lessen water misfortune altogether 66% of water system water is lost because system leakage. While practices that are, crop zoning, use of modern technologies like direct seeding drip irrigation ought to be encourage and stressed which increment agriculture water-use efficiency.

1.3. Universe and scope of the study

The study will be conducted for selected provinces of Pakistan. The selection is made due to accessibility to data. The study will be looking for estimating water use inefficiency.

1.4. Objective of the study

The prime intention is to examine the efficient use of water resources in selected provinces of Pakistan. More specifically:

1. To estimate technical efficiency as well as irrigation water use efficiency of Peach plant in Khyber Pakhtunkhwa.
2. To examine the factors influencing farmers' efficiency in peach cultivation in Khyber Pakhtunkhwa.

Using a dataset of 252 Peach farms from Pakistan's Khyber Pakhtunkhwa province, to assess "technical efficiency and irrigation water efficiency", this research uses "non-parametric data envelopment analysis (DEA) and also the DEA sub-vector approach". Beside this a “second-stage truncated regression" was used to identify the factors influencing farmers' technical and irrigation water efficiency. The study's findings will help policymakers and extension service field staff in Pakistan to improve 'irrigation water efficiency' of peach cultivation.

The rest of the article is organized as; The first section describes methodology. The next part describes data and results estimation. The last section describes conclusion and policy recommendations.

2. Review of Literature

Following are some studies which have been reviewed to highlight the major finding observed by the researcher.

Dhehibi, B., Lachaal, L., Elloumi, M., and Messaoud,E. B. (2007) concentrated to measures irrigation water use efficiency utilizing stochastic production frontier: An application on citrus producing forms in Tunisia. They used stochastic production frontier approach. The outcomes demonstrated that the variables that is farmer's age, education , training for agriculture, forms size, portion of trees and water will in general control the level of technical and irrigation water use efficiency positively and recommending that the formers could build their productivity by utilizing inputs more effectively.

Phillips, M. A. (2013) analyzed the inefficiency in Japanese water utility firms utilizing a stochastic frontier approach. They used secondary panal data for the years 2004-2007. The discoveries recommend that the normal activity rate, client thickness and size factors are related with lower levels of inefficiency (or more elevated levels of efficiency), while water sanitization (a molding variable catching low starting water quality), appropriations and redistributing are related with more elevated levels of inefficiency. Since inefficiency exists, he proposed that to improve Japanese water utilities by taking a shot at copying "best practice" firms at whatever point conceivable and by giving an administrative system that can set proper motivating force plans to do as such.

Karagiannis, G., Tzouvelekas, V., and Xepapadeas, A. (2003) estimated irrigation water efficiency in Crete, Greece by utilizing stochastic creation frontier analysis . They used primary data from 50 arbitrarily chose working forms. Data on questioner were gathered during the 1998–99 harvesting period and to maintain a strategic distance from any issues related estimation, data were changed over to indexes. The experimental after effects of the investigation demonstrate that the water efficiency of irrigation is less than technical one, inferring that critical decreases ground water waste accomplished. Cultivators progressively productive in the use of irrigation water, given the current situation with innovation and information sources use. These discoveries of the investigation proposed that irrigation water estimating is a centre problem toward this path, and furthermore to execute a superior water management.

Zardari, N.H., Cordery, I., and Sharma, A. (2010) examined a target multi quality investigation approach for assignment of rare water system water assets. In this investigation, end client (rancher) and chief (water allocator) sentiments were studied and a conjoint examination (CA) based strategy was applied to the quantitative and subjective information to evaluate the utility related with each characteristic that assumes a job in framing the last thinking about the water clients. The utilities (part-worths) acquired from the conjoint investigation have a cardinal scale and were seen as practically identical inside and over the characteristics. A ranchers' overview on five water designation properties was finished from 62 ranchers and their assessments on the general significance of traits were inspired for a subarea of the Indus River Basin. The conjoint investigation technique was then applied to the review information and the utilities for each characteristic level were resolved. This permitted, for example, choices to be made, which assess the apparent estimation of the water and of the accessibility of neighborhood work to take a shot at the homestead. At long last, these interim scales were utilized inside the determination of the multi criteria investigation model ELECTRE multi attribute basic leadership technique to give a total and target positioning of nine water system regions with the goal that the best choices on water allotment could be made.

Shen, D., and Speed, R. (2009) broke down the water assets assignment in the People's Republic of China. Water assets allotment is a procedure for changing the characteristic or business as usual circulation of water assets to meet prerequisites for financial and social improvement. Utilizing illustrative technique the discovering uncovers that China has built up a lawful structure for the assignment of water assets that works at three levels that are' at the waterway bowl/territorial level, at the abstractor level, and inside open water supply frameworks. China has additionally manufactured related frameworks to deal with these distributions. Water assets portion arranging, and the execution of related administration frameworks, is happening crosswise over China. Notwithstanding, there are critical issues in regard of how issues of combination and consistency between these three degrees of portion are tended to. They suggested that Water assets allotment plans should be received as administrative instruments, as opposed to the optimistic targets they at present are, to give more noteworthy conviction to water clients. Turning around the disintegrating soundness of streams and freshwater biological systems will expect plans to put aside more water to meet environmental stream necessities. At an increasingly essential level, the allotment and arranging procedure would profit enormously from usage of water assets the board models and expanded partner contribution.

Watto, M. An., and Mugera, A. W. (2013) concentrated to quantify groundwater irrigation efficiency in Pakistan. They evaluated the efficient water use in Peach production in the Khyber Pakhtunkhwa region. They used primary data of 189 Peach producer involving 98 tube well proprietors and 91 water purchasers so as to get the differential effect of tube well possession on groundwater use efficiency. The Data Envelopment Analysis (DEA) sub-vector and slack-based models were used to figure out groundwater efficiency. The consequences of the investigation demonstrated low degrees of specialized wasteful aspects with water purchasers being progressively wasteful comparative with tube-well proprietors. Nonetheless, groundwater is inefficient than technical efficiency. Also the outcomes on return to scale show that most of Peach cultivators are working at expanding return to scale, proposing that efficiency can be improved by extending the size of activity. Likewise by utilizing second-stage regression, explore the variables that impact technical efficiency and groundwater use efficiency. The discovering demonstrated that the degree of training, seed quality and augmentation administrations have positive noteworthy effects on technical and groundwater use efficiency. So they proposed that information on crop water necessities and the use of improved harvest assortments can assume job in improving the efficiency of groundwater use.

Karagiannis et al. (2003) investigated irrigation water efficiency using a stochastic production frontier for a randomly selected sample of 50 out-of-season vegetable growing farms in Crete, Greece. The empirical results of the study, using the input-specific technical efficiency SFA model, show that irrigation water efficiency is on average much lower than technical efficiency, implying that significant reductions in groundwater waste could be achieved if Cretan out-of-season vegetable growers become more efficient in the use of irrigation water, given the current state of technology and inputs use. Similarly, modern greenhouse technologies, education, and extension are the primary factors positively associated with irrigation water efficiency. On the other hand, farming intensity, chemical use, and the percentage of rental land all have a negative impact on irrigation water efficiency. These findings offer some preliminary insights for developing short- and long-term water conservation policies based on the principle that "more (or at least the same) can be achieved with less water" through better management.

Hussain and Hanjra (2004) conducted a review of the empirical evidence for irrigation and poverty alleviation in Sri Lanka. The study's goal was to shed light on the connections between irrigation and poverty. The results of using primary data show that there are strong links between irrigation and poverty. There are both direct and indirect connections. Direct linkages operate through localised and household-level effects, while indirect linkages operate through regional, national, and economy-wide effects that benefit the poor in the long run. The benefits of irrigation to the poor can be amplified by launching both broad-scale and targeted interventions at the same time.

Giordano (2009) investigates the Global Groundwater Problems and Solutions. The study examines recent literature on the geographic and temporal dimensions of groundwater use, as well as the variety of technological and institutional approaches used in attempts to manage it. It comes to the conclusion that, in many cases, the most promising solutions may be found outside of the groundwater sector, within a broader approach to resource systems.

Rinaudo et al. (1997) investigated the relationship between Pakistan's water market functioning, access to water resources, and farm production strategies. The cluster analysis module of the statistical software SOLO is used to analyse farm-level data. The paper's findings describe the operation and organisation of these water markets, based on data collected in sample watercourses of the Fordwah Branch irrigation system in South Punjab, Pakistan. The variability in water market type and intensity is investigated in relation to access to water resources and farm production strategies and constraints. The importance of water markets in watercourse command areas is confirmed by this study. Groundwater sales and purchases account for the vast majority of irrigation water transactions. A water market appears to be an appropriate way to gain control over water resources and alleviate constraints associated with irrigation water supplies.

Qureshi et al. (2010) investigated the challenges and prospects for sustainable groundwater management in Pakistan's Indus Basin. 521 canal irrigators provided primary data for the study. The discovery demonstrates that groundwater has become critical in Pakistan's agricultural economy. Groundwater now accounts for nearly half of all irrigation needs. The findings show that groundwater is being overexploited, despite the fact that tens of thousands of new wells are being installed each year. It is concluded that for effective groundwater management, Pakistan must implement frameworks and instruments tailored to its needs in rain-fed areas.

Byerlee and Siddiq (1994) collaborated on this. Is the green revolution still going on? The quantitative impact of Pakistan's seed fertiliser revolution is being revisited. They used farm survey data and a methodology similar to CJD's in tracing changes in inputs and outputs over the last two decades for this study. They analysed trends in the yield of the dominant food grain, wheat, and the effects of biochemical technology on wheat yields to simplify the presentation and focus on key issues for the future. The study's findings show that the yield increases expected in the post-Green Revolution period from increased cropping intensity, a tripling of fertiliser dosage, and the release of newer higher yielding varieties have been cancelled by problems caused by increased cropping intensity, use of poor quality groundwater, low fertiliser efficiency, and increased weed and disease losses. This study recommended that new institutional policies, as well as research and extension strategies, be developed to improve wheat production efficiency and sustainability, and to keep Pakistan from becoming a major food grain importer in the coming decades.

Khan and Khan (2014) explored "the production and marketing costs of peaches in Swat, Khyber Pakhtunkhwa". They gathered primary data from 270 respondents growing peach in Swat district for the 2010-11 sessions. The study indicates that farmyard manure, numerous inorganic fertilizers, multiple herbicides, and the employing of workers for nutrient application were the most important production factors. Marketing costs include the purchase of empty cartons, picking, packing, shipping, lifting, and discharging, etc. Peach orchards averaged a profitability per acre of about 90% of total revenue. The major limitations were a shortage of money, elevated agri-input costs, perishable nature of product, infestations as well as environmental disasters, a dearth of market information, price fluctuations in national markets, and expensive shipping costs. The main recommendation of the study was to introduce ultimately benefited and strong immune peach sorts into the research region. To maximize returns to peach growers, agronomic losses may be minimized through productivity improvement, and trade opportunities must be discovered.

Ahmad et al. (2004) discussed "why Pakistan's Green Revolution was a short-term phenomenon; a lesson for the future". They discovered that the Green Revolution enhanced agricultural employment and productivity levels by using the percentage method to analyse secondary data. It also made an impact on income allocation as well as the political and socioeconomic atmosphere of the country. However, due to policy discrepancies, the Green Revolution's affect was limited to the short term. It is concluded that the green revolution has had a positive impact on agriculture and rural development in Pakistan. It also had an impact on our social and political structures, which had an impact on the economy later on. However, there were a few flaws in the revolutionary process that hampered long-term agricultural development and made it a short-term phenomenon. There is a need to overcome these weaknesses in order to develop our agriculture in the long run. Adopting an efficient, economical, and effective development model may lead to long-term development of the agriculture sector.

Kijne (1999) investigated the importance of management choices in improving the productivity of Pakistan's irrigation. This paper is heavily reliant on primary data. The accumulation of salts in the soil reduces productivity, according to a cost-benefit analysis. Similarly, the findings show that irrigated agriculture productivity is found to be dependent on political will to make changes and set up a regulatory system to enforce new rules, as well as a significant attitudinal change on the part of the farmers involved. According to this study, the only feasible solution in many areas is to gradually reduce the acreage of crops that require large amounts of water, such as sugarcane and rice.

Khan et al. (2008) probed the hydrogeologic assessment of increasing groundwater exploitation in Pakistan's Indus Basin. A surfaceground water quantity and quality model was developed using primary data to assess future groundwater trends in the Rechna Doab (RD), a sub-catchment of the Indus River Basin in Pakistan. The study's findings indicate that if dry conditions persist, there will be an overall decline in groundwater levels of around 10 metres for the entire RD over the next 25 years. Lower RD areas with limited surface water supplies will experience the greatest decline in groundwater levels (10 to 20 m), making groundwater pumping prohibitively expensive for farmers. This study also reveals a high risk of groundwater salinisation as a result of vertical upcoming and lateral movement of highly saline groundwater into fresh shallow aquifers. They proposed that if roundwater pumping continues at its current rate, there will be an overall decrease in groundwater salinity for the lower and middle RD due to increased river leakage.

Dhungana et al. (2004) examined the "economic inefficiency of Nepalese rice farms" using DEA analysis and a Tobit regression model. Significant differences in the level of inefficiency across sample farms, according to the study's findings, can be attributed to differences in the 'use intensities' of resources such as seed, labor, fertilizers, and mechanical power. Furthermore, the results of a Tobit regression stage-2 revealed that the variability is associated to agriculture characteristics including the farm owners' risk perception, the agricultural owner's sex, age, schooling, & household workforce funds. Policy measures based on the statistical results could include strategically targeting the dissemination of best farming practises to new farmers in order to minimize the population's mean inefficiency.

Solis et al. (2009) evaluated technical efficiency (TE) of Central American farmers contributing in natural resource management programs. Primary data from 639 farms in Salvador and Honduras' hillsides were used to estimate a household-level input-oriented stochastic distance frontier alongside a TE effects model. The study's key result was that improvements in TE benefit farm households financially while also enhancing environmental sustainability. The findings also revealed a link between productivity and output diversification, as well as a link between TE and off-farm income, human capital, and agricultural extension.

Memon et al. (2015) investigated the barriers to technology adoption through a case study of peach production in Pakistan's district Swat. They analysed primary data using frequency distribution, percentages, and mean values. An empirical probi-model was used to assess the impact of various factors on the adoption of new technologies. According to the study's findings, the main factors influencing the level of adoption of new technologies are a lack of information and a lack of credit services. The probit-model results revealed significant links between a lack of information, a lack of credit funds, the high cost of fertilisers, a lack of improved varieties, and the adoption of appropriate technologies. . They suggested that government intervention is critical to facilitating access to technology and inputs for the adoption of technology in agriculture in order to increase yield.

Zeb and Khan (2008) investigated peach marketing in the North West Frontier Province (NWFP) and peach growers' marketing channels in 2006. They used both primary data and the percentage method. Peach orchards occupied more than half (52.3%) of the orchard area, according to the study's findings. The vast majority (78%) of peach growers sold their crop to pre-harvest contractors. Vendors bought peaches from gardeners & auctioned them diferent cities of pakistan of total peach production in more than 50% in Lahore , Rawalpindi and Peshawar and some amount is sold to a local market Mingora about (32%)of total. According to the findings, about 80 % of consumer cost on peach purchasing the farmer and supplier received the most share. They suggested that in order to improve peach marketing, all agencies involved be trained and educated in modern packaging, grading, and product presentation techniques that meet international standards, allowing them to command higher prices. It is strongly advised that peach growers arrange adequate credit facilities at lower interest rates of return in order to reduce marketing losses and pre-harvest sales of their orchards.

Ullah et al. (2018) used time series data from 1997-1998 to 2014-15 to conduct a forecasting of peach area and production-wise econometric analysis in Pakistan. The area and production of peaches were projected from 2015-2016 to 2025-26. The Box-Jenkins (1976) method was used, and ARIMA (1,1,0) was found to be an appropriate forecasting model. They discovered that the forecasted value of peach area and production for 2025-26 was calculated to be 11.05 thousand hectares and 65.05 thousand tonnes, respectively. The minimum projection trend indicated a decline in peach area and production in Pakistan. During the course of study in Pakistan, it was concluded that peach production can be increased by using improved peach cultivars, an improved irrigation system, and adequate cultural practices.

3 Methodology for Approaches to Efficiency Measures

The efficiency and productivity of a decision making unit (DMU) are measured using either a methodological approach which including "stochastic frontier analysis or even a non-parametric way of measuring like data envelopment analysis (DEA)". Relying on Farrell's (1957) concept of assessing technical efficiency (TE) comparative toward a production possibility frontier, Charnes, Cooper, and Rhodes (1978) developed a multifactor (various input and output) profitability evaluation framework. A DEA model based on constant returns to scale was proposed by Charnes, Cooper, and Rhodes (1978). Later, Banker, Charnes, and Cooper (1984) proposed a DEA model with variable returns to scale (VRS). In several cases, the principle of a "constant return to scale" (CRS, hence forth) is not economically viable even though increasing input use of doesn't quite expand production proportionate. Moreover, researchers could indeed ascertain whether the input have used for various decision making units (DMUs, hence forth) can be lowered without jeopardizing the production level utilizing input-oriented efficiency estimates. As an outcome, we have choose an "input-oriented Data envelopment analysis" model for this study to evaluate technical as well as irrigation efficiency of water use.

1.1 Estimating technical and irrigation water use efficiency

In this section we will discuss the methodology for technical efficiency and irrigation water use efficiency.

1.1.1 Concept of Technical efficiency

The capacity of either a firm to generate the maximum possible output level considering the given assortment of inputs and indeed the existing state of technology is referred to as technical efficiency. Consider "n" DMUs that generate a production "Y" based on "X" input variables. The technical efficiency for a specified DMUj_o underneath the variable returns to scale (VRS, hence forth) specification could be calculated as follows by using the following standard linear programming problem:

$$Min_{(\lambda_{j_o},\theta_{j_o})}\theta_{j_o}, \quad (1)$$

Subject to:

$$-y_{j_o} + \sum_{j=1}^{n} Y_j\lambda_j \geq 0, \quad (i)$$

$$\theta_{X_{j_o}} - \sum_{j=1}^{n} X_j\lambda_j \geq 0, \quad (ii)$$

$$\sum_{j=1}^{n} I\lambda_j = 1 \quad (iii)$$

$$\lambda_j \geq 0, \quad (iv)$$

Where y_{j_o} is the production amount aimed at the DMU$_{jo}$; x_{jo} is the vector of input quantities; Y_j is 'n ×1' vector of all output quantities for all n DMUs; X_j is n × m matrix of input quantities for all n DMUs; I is n × 1 vector of ones; $_j$ is vector of weights; and $_{jo}$ is scalar. The equation $\sum_{j=1}^{n} I\lambda_j = 1$ is a convexity constraint to compute technical efficiency under the VRS specification.

1.1.2 Water Use Efficiency in Irrigation from an Economic Point of view

Irrigation water efficiency measures currently the case is either engineering or agricultural in nature. Irrigation water efficiency can be described in three ways that are (i) irrigational efficiency (water acquirement), (ii) efficiency in application of water there at farms; and the last one is (iii) farm reaction to agricultural application of water (the water certainly being used by cultivar, proportion to the total of water provided to a certain cultivar (McGuckin, Gollehon, & Ghosh 1992). Due to recent water scarcity, the economic power of irrigation water has been highlighted, and agricultural water efficiency has been described using fundamental models. In theory, economic effectiveness is attained once scarce resources are allocated and utilized in the most efficiently.

The phrase "more can be done with less water" refers to potential improvements, where it typically entails expanding factors of production and/or irrigated agriculture water - use efficiency. Allocative efficiency is intimately associated to appropriate irrigation water valuations, whilst irrigation efficiency is influenced by advanced technologies, land and environmental condition, as well as other factors. In this context, enhancing allocative efficiency constitutes the most essential (if not the sole) component of improving agricultural revenue and minimizing wastage of water.

The engineering literature's concept of irrigated agriculture water efficiency is tightly linked to its specific focus on allocated efficiency matters (Karagiannis, Tzouvelekas, & Xepapadeas 2003). Irrigated agriculture water efficiency is expressed as the ratio of the volume of water actually utilized by plant/crop to the volume of irrigated agriculture water applied:

$$E_i = \left(\frac{V_b}{V_f}\right) \times 100 \qquad (2)$$

Where E_i is the irrigation efficiency (%), V_b is the volume of water actually utilized (hectare-inch), and V_f is the volume of water applied to the field (acre-inch). Comparing flood irrigation system with sprinkler irrigation system, based on this concept, might minimize water usage enhance irrigation water - use efficiency, though at an increased cost. In contrast, a drip irrigation system might be more cost effective than a sprinkler system of irrigation (Karagiannis, Tzouvelekas, & Xepapadeas 2003).

Water efficiency in irrigation, as described in previous paragraph, is a physical indicator of a specified irrigation technique or method that implies a certain management level and isn't exactly comparable to technical efficiency, as identified by Farrell (1957), where it measures irrigators' managerial capability. Given human incapability, a sprinkler irrigation, comparable to any other output system/technology, might well be technically inefficient (McGuckin, Gollehon, & Ghosh 1992). The economic measure of irrigated agriculture efficient use of water is stated to be the proportion of least practical to identified utilisation irrigation water, implicit on situation in order of the preferable output and standard inputs. In broad sense, irrigation water efficiency is a measure of the technical efficiency of irrigation water use in agricultural output.

The basic Technical efficiency guideline implies a winding pressure among all input factors, whereas the irrigation water efficiency rule requires non-radial evaluation of irrigation water technical efficiency.

Figure 1. Technical and sub-vector irrigation water efficiency is represented graphically.

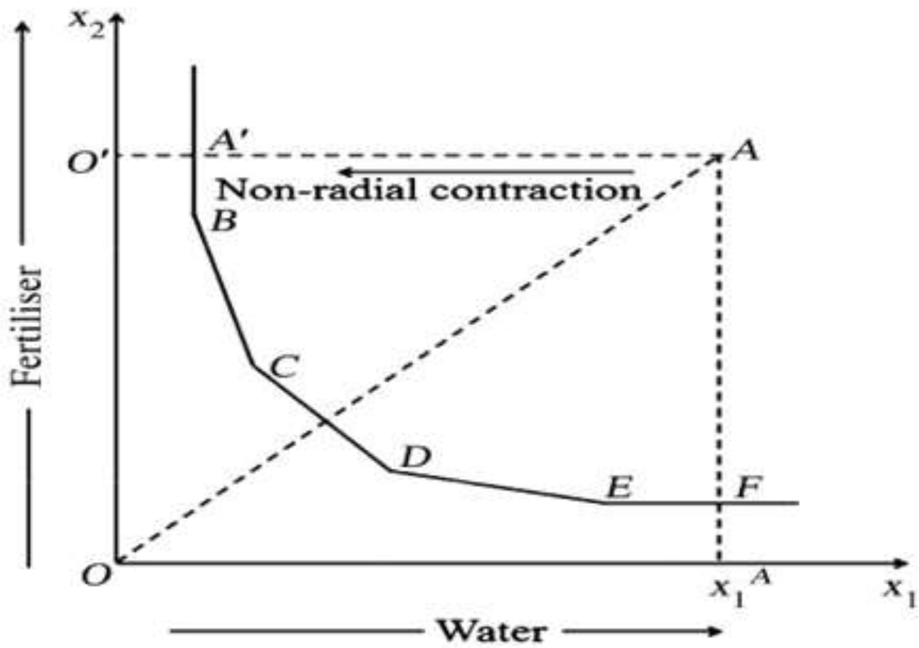


Figure 1 depicts technical efficacy (radial measure) and irrigation efficiency (non-outspread measure). Let's Consider six farms that produce a single output from two informational sources, namely water and fertilizer. Farms B, C, D, E, and F are actually productive given their location on the outskirts. Farm A, on the other hand, is wasteful due to its location away from the frontier. The radial contraction of inputs x_1 and x_2 results in a projected point A_0 on the frontier that is a linear combination of all detected data points. Farm A's technical efficiency in comparison to farms B, C, D, E, and F can be calculated as TE = OA0/OA. Irrigation water efficiency, on the other hand, entails non-radial reduction of a specific input while keeping other inputs and output constant. Farm A's non-radial efficiency (sub-vector efficiency) for input x_1 (irrigation water) could be calculated by reducing x_1 to a point A′ while holding x_2 and the output constant. The ratio can be used to calculate the sub-vector efficiency of input x (water) for farm A is as:

IE = O′A′/O′A.

1.2 The Sub Vector Efficiency Model

Regarding Speelman, S., D'Haese, Buysse, and D'Haese (2008), we address the associated linear programming problem to assess the irrigation water use efficiency for a specific DMU_{jo}.

$$\boldsymbol{Min_{(\lambda^w \theta)} \theta^w}, \quad \textbf{(3)}$$

Subject to:

$$-y_{j_o} + \sum_{j=1}^{n} Y_j \lambda_j \geq 0, \quad (i)$$

$$X_{j_o} - \sum_{j=1}^{n} X_{m-wj} \lambda_j \geq 0, \quad (ii)$$

$$\theta^w X_{j_o} - \sum_{j=1}^{n} X_{wj} \lambda_j \geq 0, \quad (iii)$$

$$\sum_{j=1}^{n} I\lambda_j = 1 \quad (iv)$$

$$\lambda_j \geq 0 \quad (v)$$

where θ^w denotes the DMU_{jo} input sub-vector efficiency w. The limitations (i), (iv) and (v) seem to be identical to those in Eqn (1). Limitation (ii) exempts the information w segment, whereas restriction (iii) contains the w input section. Irrigation water use efficiency (θ^w), like Technical-efficiency , can have a score between 0 and 1, with a score of 1 demonstrating that a DMU is the best possible performer and is situated just on frontier, with no possibility of decreasing irrigation water usage for a given agrarian production process. A DMU esteem less than one implies that irrigation water use inability occurs, implying that there is a valuable opportunity to save water.

Assessing efficiency in groundwater use by Watto, M.A., and Mugera, A.W. (2014) is calculated using following Equation (3.3),

$$\textit{Ground water use efficiency} = \textit{Technical efficiency} - \frac{V_{et}}{V_{ot}} \qquad (3.1)$$

Where V_{et} is the excessive amount of the input t, and V_{ot} is the actual quantity of the input t.

1.3 Truncated Regression Analysis

Most recent studies as mention bellow have used Tobit regression in the second stage to look into the factors of DEA efficiency measures, that are Speelman, D'Haese, Buysse, and D'Haese (2008); Frija, Chebil, Speelman, Buysse, and Van Huylenbroeck (2009); Dhungana, Nuthall, and Nartea (2004); and Wadud and White (2000). The assumption for Tobit regression is that efficiency scores are truncated numbers because they diverge from 0 to 1. According to McDonald (2009), efficiency scores really aren't truncated but instead converted into marginal values. In contexts of predicting confidence level, Simar and Wilson (2007) illustrated that single bootstrap truncated regression significantly improves the Tobit model. A single bootstrap truncated regression is applied to determine the factors of technical and irrigation water efficiency. The model appears as regards:

$$Y_j = \alpha_j + \sum_{j=1}^{n} \beta_j Z_j + \varepsilon_j \geq 0 \qquad (4)$$

$$j = 1, \dots. N$$

$$\varepsilon_j \rightarrow N(0, \sigma^2)$$

Where Y_j seems to be the irrigation water use efficiency, α_j is the intercept, β_j is the vector of variables to be measured, Z_j is the set of regressors for j = 1,..., 9, σ is the indicate variance, and j is the random error.

1.4 Study Area and Data Description

During the cropping season of 2020-21, this research taken place in the north farming area of Swat in Pakistan's province Khyber Pakhtunkhwa region (figure 1). The majority of households of the selected region mainly depend on groundwater as a significant agriculture irrigation source. Groundwater tables are gradually declining because of over-pumping. Downstream water tables have risen underground water drilling expenses numerous times over the last couple of decades. During this field survey, the drilled depth range was determined in the range of 35 as well as 60 metres. Farmers generally engage in informal groundwater trading due to the lower density of tube-well population.

Such casual groundwater trades have improved irrigated agriculture accessibility for landowners as well as local farmers having no tube wells. A multi stage survey approach was employed to gather data. At the initial phase, one tehsil from Swat valley had been selected randomly. A tehsil is indeed an administrative division and a district is usually composed of at least five tehsils. That after, 30 villages each with 210 - 240 household farms had been randomly picked from identified tehsil. Finally, 30 groundwater users were chosen at random from each village (fifteen tube-well owners and fifteen water buyers) to determine the differential impact of tube-well ownership and to reveal the difference in amount of water applied and production gains of tube-well owners and water buyers, for a total sample size of 300 respondents. However, only 120 water buyers and

132 tube-well owners out of a total of 300 farming households cultivated Peach crop during the cropping season of 2020-2021.

An interview schedule was used to collect the data. During the interview, we collected information on different output and input quantities. Total labour, including hired (casual and permanent) and family labour, is measured in hours per hectare; pesticide and farm operations are measured in number of applications per hectare; and groundwater use is measured in cubic meters per hectare.

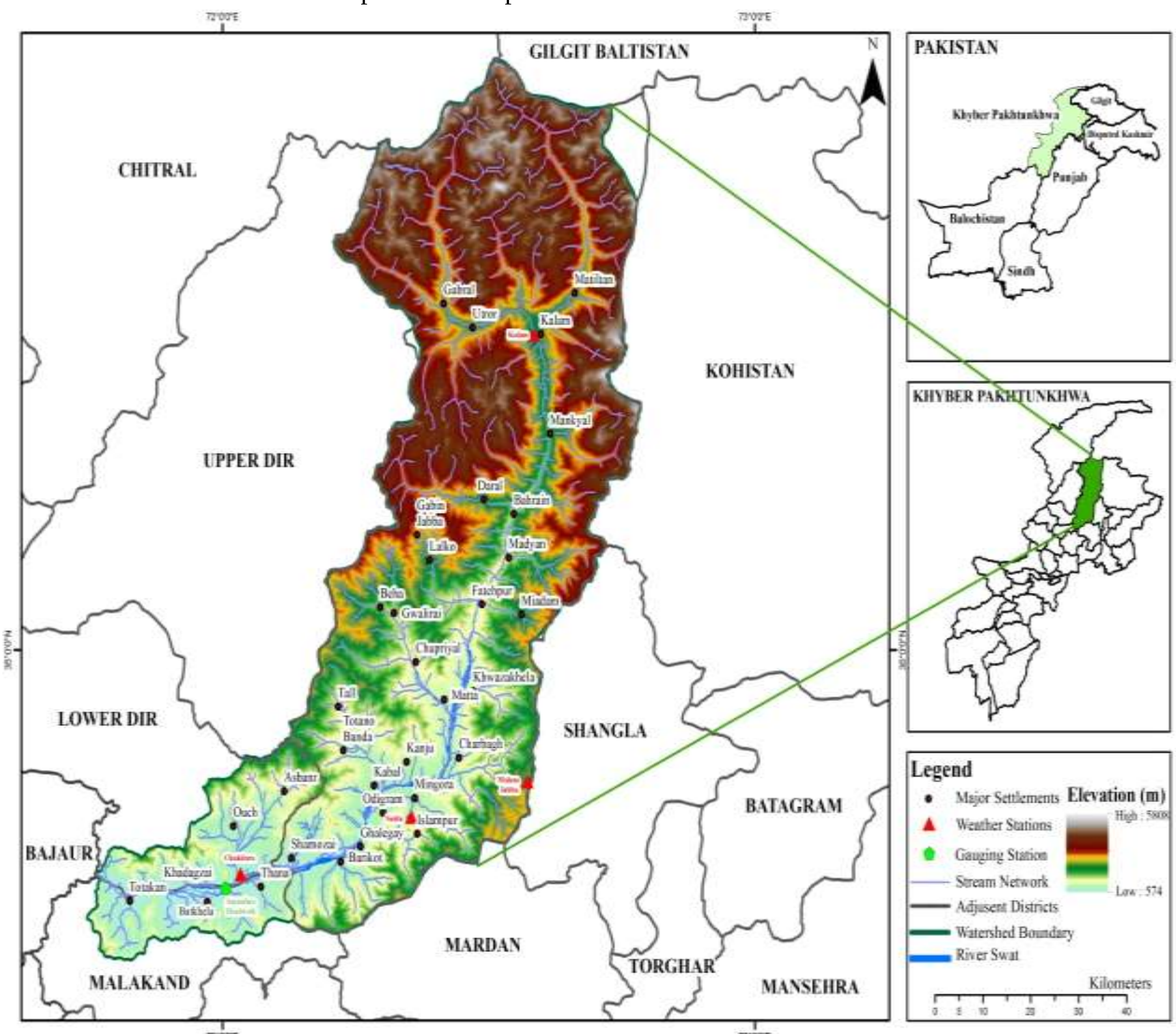


Figure 2. Map of district Swat in Khyber Pakhtunkhwa province, Pakistan.

We estimated irrigation volume of water utilising approximation measurements model similar to the ones employed by Eyhorn, Mäder, & Ramakrishnan (2005) and Srivastava, Kumar, and Singh (2009).

$$\mathbf{Q} = \frac{\mathbf{t} \times \mathbf{129574.1} \times \mathbf{BHP}}{\mathbf{d} + [(\mathbf{255.599} \times \mathbf{BHP^2})/(\mathbf{d^2} \times \mathbf{D^4})]} \qquad (\mathbf{5})$$

where Q denote the quantity of water (in litres), t is the total irrigation period (in hours) assigned to every farm in a cropping season, d is the wells depth (in metres), D is the pumping pipe diameter (in inches), and BHP is the engine power (in horsepower (KW)). The yield of peaches is determined in tonnes per hectare.

The descriptive statistics that has been used in analysis are shown in Table 1. The descriptive statistics reveal significant variation in the use of inputs and output produced by tube-well owners and water buyers.

Table 1 shows the descriptive statistics of variables used in data envelopment analysis.

Variable	Mean	S.D	Min	Max
Inputs				
Total labor (hr)	2184	955	1110	4578
Fertiliser (kg ha^{-1})	1953	950	741	3705
Number of chemical applications (No)	6.9	3.5	3	12
Number of farm operations (No)	18.3	7.5	12	27
Irrigation water m^3 ha^{-1}	47832	19585	24489	79575
Cropped area (ha)	4.29	5.50	1.50	12.15
Output				
Peach yield (t ha^{-1})	217.8	28.1	150.00	297.00

Source: estimated from data.

The average cultivated area for tube-well owners is 6.57 hectares, while water buyers have 1.75 hectares. All of the farms in the sample are classified as having a high proportion of family labor, and the number of hours worked at farms varies greatly. The average peach yield per hectare is 217.85 tonnes, with tube-well owners receiving 226.01 tonnes and water buyers receiving 207.48 tonnes. Fertilizer and chemical application vary significantly across farms. In terms of irrigation water, tube-well owners used 37.5% more groundwater than water buyers to irrigate one hectare of Peach crop over the course of the cropping season. The summary statistics for the explanatory variables are shown in Table 2.

Table 2. Summary statistics of variables included in the truncated regression

	Continuous variables				**Proportion of farmers with dummy variables**		
Variables	**Mean**	**S.D**	**Min**	**Max**	**0**	**1**	**2**
Age of Farmers (Year)	45.13	40.00	26	70	–	–	–
Status of Family (0 = single , 1 = Joint)	–	–	–	–	34.85	65.31	–
Education Level 0 = Illiterate, 1 = Matric, 2 = Higher Education	–	–	–	–	21.18	49.93	28.89
Off-farm income (0 = No, 1 = Yes)	–	–	–	–	50.20	49.80	–

Land status 0 = Tenants, 1 = Own land	–	–	–	–	18.58	81.47	–
Tube well ownership 0 = Water Buyer, 1= TW Owners)	–	–	–	–	58.67	41.33	–
Access to Credit (0 = No, 1 = Yes)	–	–	–	–	68.31	31.69	–
Extension services (0 = No, 1 = Yes)	–	–	–	–	58.15	41.85	–

Source: estimated from data.

On average the farmer is 45 years old, with a range of 26 to 70 years. The joint family system dominates the rural society of the study district. Approximately 65% of the farming families on the sampled farms are joint families. The education statistics clearly show a lack of education among the farming community. Only 28% of farmers have a level of education above matriculation, while 21% of household heads have no education at all. A sizable proportion of the farms surveyed cultivate their own land. Only 18.58% of farmers are renters. Because farming is a major source of income in rural communities, a large proportion (49.8%) of farmers had other sources of income. In our sample, 41.33% of Peach growers own tube-wells, while 58.76% buy groundwater from tube-well owners. Only 31.69% of farmers were able to obtain credit from private banks or government agencies. Finally, 41.85% of farmers took part in agricultural training programmes or sought advice from agricultural extension field staff about peach production technology. Only 28% of farmers have a level of education above matriculation, while 21% of household heads have no education at all. A sizable proportion of the farms surveyed cultivate their own land. Only 18.58% of farmers are renters. Because farming is a major source of income in rural communities, a large proportion (49.8%) of farmers had other sources of income. In our sample, 41.33% of Peach growers own tube-wells, while 58.76% buy groundwater from tube-well owners. Only 31.69% of farmers were able to obtain credit from private banks or government agencies. Finally, 41.85% of farmers took part in agricultural training programs or sought advice from agricultural extension field staff about peach production technology.

2. Results and Discussion

Table 3 shows the estimated results for technical and irrigation water efficiency under variable returns to scale. We found no significant technical inefficiencies between both types of Peach growers, i.e. tube-well owners and water buyers, on average. The mean TE score for tube-well owners is 0.93 and ranges from 0.71 to 1, whereas the mean TE score for water buyers is 0.95 and ranges from 0.72 to 1. According to the mean TE estimates, tube-well owners and water buyers are operating at relatively high levels of technical efficiency. However, only 42% of water buyers and 65% of tube-well owners were fully technically efficient (TE = 1) across all farms (TE = 1).

Table 3. Frequency distribution of technical and irrigation water efficiency (IWE)

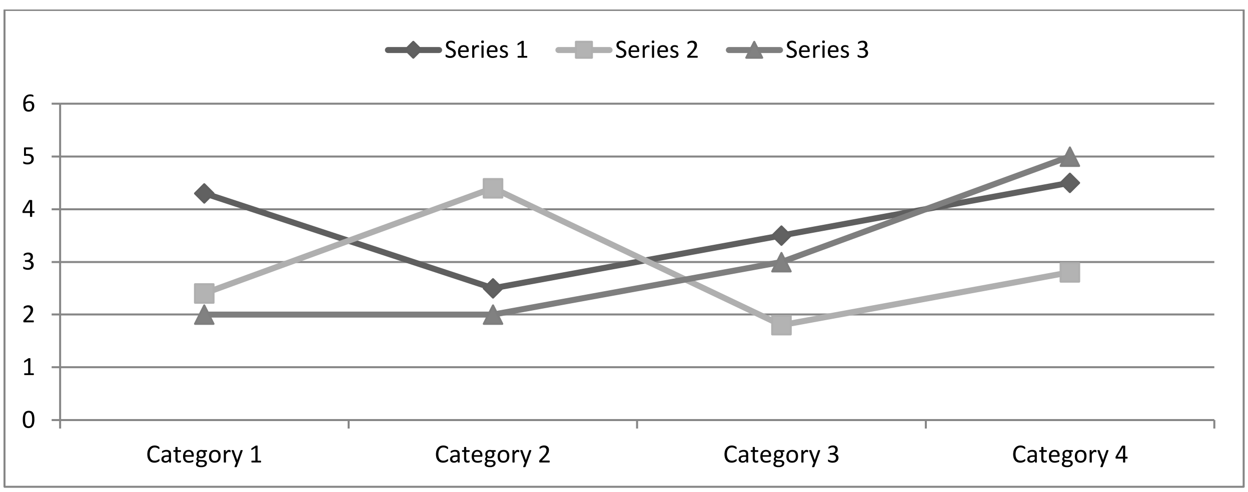
	Technical efficiency		Sub-vector IWE	
Efficiency Range	**Tube-well Owners**	**Water Buyers**	**Tube-well Owners**	**Water Buyers**

<30	0	0	0	0
30–40	0	0	4	0
40–50	2	2	14	5
50–60	1	4	28	10
60–70	3	6	23	7
70–80	6	4	5	14
80–90	26	10	10	20
90–99	38	15	8	14
100	56	79	40	50
Mean	0.93	0.95	0.74	0.88
SD	0.06	0.06	0.23	0.19
Minimum	0.71	0.72	0.40	0.50
Maximum	1	1	1	1

Source: estimated from data.

However, estimates of sub-vector irrigation water efficiency show large-scale inefficiencies in irrigation water application to Peach cultivation by both tube-well owners and water buyers. As shown in Fig. 3, irrigation water use inefficiencies are more distinct than technical inefficiencies.

Figure 3. Cumulative frequency distribution for technical and irrigation water efficiency. VRS, variable returns to scale; SV-IWE, sub-vector irrigation water efficiency.



According to the DEA sub-vector estimates, the mean IWE score for water buyers is 0.88 and ranges from 0.50 to 1, whereas the mean IWE score for tube-well owners is 0.74 and ranges from 0.40 to 1. Only 30% of tube-well owners and 41% of water buyers were found to use irrigation water efficiently (IWE = 1).

Table 4. Spearman's Rank Correlation between Technical Efficiency and Irrigation Water Efficiency (IWE)

Variable	Technical efficiency	Sub-vector IWE
Technical Efficiency	1.00	–
Sub-Vector IWE	0.75*	1.00

Source: Data estimation.

These estimates show that there is a significant opportunity to reduce groundwater use while maintaining the same output level by using the observed values of other inputs. This means that if irrigation water efficiency improves, farmers will be able to re-allocate some water to other uses, thereby helping to conserve groundwater resources. According to the correlation statistics (Table 4), any improvements in irrigation water efficiency may help improve overall technical efficiency in peach production. According to our IWE estimates, only 252 Peach farms can save a total volume of 1.47 million m3 groundwater during one cropping season by achieving 100% irrigation water efficiency, which translates into a potential savings of US$42354 (based on monetary exchange rates at the time of data collection, i.e. June 2021 (1$=155PKR)) by paying less groundwater extraction costs.

The average/mean TE and IWE estimates indicate that water buyers are less efficient than tube well owners. As Meinzen Dick, and Rosegrant (1997), discovered that tube-well owners outperformed water buyers in terms of farm productivity, owing to greater control over groundwater access and supplies. Nonetheless, water buyers are exposed to the risk of uncertain and delayed irrigation supplies. Because groundwater trading is informal, social ties between tube-well owners and water buyers have a strong influence. As a result, the lack of a formal contract can sometimes result in inequities in water allocation and distribution among buyers (Rinaudo, Strosser, & Rieu, 1997; Jacoby, Murgai, & Rehman, 2004).Furthermore, as a result of the ongoing energy crisis, water buyers face greater uncertainty and delays in obtaining water for irrigation, and it is highly likely that delayed water application will reduce the marginal product of other inputs such as fertilizer, labor, and chemical inputs. As a result, water buyers continue to be less efficient than tube-well owners. The majority of the estimated coefficients in the second-stage regression model confirm prior assumptions about their impact on efficiency levels. According to our estimates (Table 5), a farmer's age has significant impact on technical or irrigation water efficiency. Several other studies indicate that older farmers are more hesitant to adopt new farming techniques and technologies, causing agricultural production to lag (Speelman, D'Haese, Buysse, & D'Haese, 2008; Villano, & Fleming, 2006). Nonetheless, some studies have found that as a farmer's age increases causes positively affect on efficiency (Karagiannis, Tzouvelekas, & Xepapadeas 2003).

Table 5.Bootstrapped truncated estimates of determinants of irrigation water use efficiency

	Technical Efficiency		Irrigation Water Efficiency	
Explanatory variable	**coeff**	**SE**	**coeff**	**SE**

Age of Farmer (Year)	0.0267*	0.0174	0.0101	0.0205
Status of Family (Single=0, Joint=2)	−0.0100	0.0201	−0.0019	0.0407
Education (Illiterate=0, Metric=1, Higher=2)	0.0702**	0.0265	0.0805	0.0503
Education Up to Metric				
Higher Education	0.0982***	0.0318	−0.1967**	0.0808
Access to Credit (No=0, Yes=1)	0.0618*	0.0205	0.2078**	0.0834
Land tenure status dummy (0 = tenants, 1 = own land)	−0.0390	0.0393	−0.0145	0.0633
Off-farm income (Yes=1)	0.0493**	0.0272	0.0337	0.0560
Area of Crop (ha)	0.0097	0.0045	0.00102	0.0098
Tube-well ownership (water buyer=-0, tube-well owner=1)	0.0644*	0.0364	−0.1021	0.0894
Extension services (No=0, Yes=1)	0.0542*	0.0390	0.1101*	0.0842
Constant	0.8032**	0.5392	0.6721	0.6471
Log likelihood	253.11	–	68.91	–

1) **Significance level indicated by *(10%), **(5%), ***(1%).**
2) **'Coeff' means coefficient.**
3) **'SE' means Standard error.**

Source: own estimation.

The findings indicate that a farmer's family status (single or joint family) has no effect on technical or irrigation water efficiency. Education and extension services, as expected, have a positive impact on both technical and irrigation water efficiency, supporting the premise that increases in human capital enable farmers to better utilise resources and thus achieve higher efficiencies. In the literature, we find mixed results for the efficiency and education relationship; for example, Karagiannis, Tzouvelekas, & Xepapadeas (2003) and Solís, Bravo-Ureta, & Quiroga (2009), found education to have a significant impact, whereas Haji (2007), and Speelman, D'Haese, Buysse, & D'Haese (2008), found education to have no impact. These mixed results suggest that researchers should consider the relevance of a farmer's education to his farming business when interpreting the impact of education on efficiency levels. The impact of extension services on technical efficiency is consistent with the widely held belief that farmers who seek more extension advice and participate in training programmes are technically more efficient than those who have little or no contact with extension staff, (Frija, Chebil, Speelman, Buysse, & Van Huylenbroeck 2009; Parikh, & Shahn 1994). The negative (though non-significant) coefficient of land tenure status contradicts the widely held belief that, all else being equal, land owners typically invest more in new production technologies and, as a result, increase their expected returns, (Speelman, D'Haese, Buysse, & D'Haese 2008; Frija, Chebil, Speelman, Buysse, & Van Huylenbroeck 2009; Gebremedhin, & Swinton, 2003). However, some studies have found a negative impact of land ownership on farm efficiency, (Byiringiro, & Reardon, 1996). We discover that off-farm income is positively related to technical efficiency, implying that with alternative income resources, farmers may have a better chance of purchasing and using an optimal input mix, resulting in greater efficiency gains, (Karagiannis, Tzouvelekas, & Xepapadeas 2003). Off-farm income, on the other hand, was not found to be significantly related to irrigation water efficiency. Farmers who obtained credit, as opposed to those who did not, are more technically and irrigation water use efficient than those who did not. The effect of tube-well ownership on technical efficiency implies that tube-well owners have greater assurance and control over irrigation in terms of spatiotemporal crop requirements, and thus their expected returns (marginal product of other inputs) are higher than water buyers. Tube-well ownership is inversely related to irrigation water efficiency, implying that some tube-well owners may use more groundwater than the incremental value they generate.

3. Conclusion

The objectives of this research was to estimate technical efficiency (TE) and irrigation water efficiency (IWE), as well as the factors influencing a farmer's efficiency in peach cultivation. Using a dataset of 252 Peach farms from Pakistan's Khyber Pakhtunkhwa province, the study used a non-parametric approach, namely data envelopment analysis (DEA), to estimate TE and the DEA sub-vector model to estimate IWE. The results of a cross-sectional dataset of 252 Peach growers show that, on average, Peach growers have fairly high levels of technical efficiency. The average TE score for tube-well owners is 0.95, while the average TE score for water buyers is 0.93. Estimates of irrigation water efficiency, on the other hand, show significant inefficiencies in irrigation water applications to peach cultivation by both tube-well owners and water buyers. The average IWE score for tube-well owners is 0.88, while the average IWE score for water buyers is 0.74.

According to the average IWE estimates, tube-well owners and water buyers can reduce irrigation water application to peach plants by 21% and 28%, respectively. Both tube-well owners and water buyers can save 0.49 million m3 groundwater from one cropping season by reducing groundwater application by 21% and 28%, respectively.

While one of the study's key underlying research objectives was to estimate technical and irrigation water efficiency in peach production, the study suggests that educating farmers, creating better credit and off-farm income opportunities, and providing better extension services about production technology would help to achieve higher technical and irrigation water efficiency in peach production.

The study's key finding is that access to technology is not a major constraint in peach production; rather, farmers can improve production given the available technology. In this regard, we believe that shifting the role of agricultural extension advice from agronomic (e.g., production technology) to economic (e.g., cost benefit analysis of available production technology) would assist farmers in achieving higher levels of efficiency. Longer term, ongoing technical efficiency improvements in peach production within the efficient use of limited water resources are required for the required improvements in efficiency and productivity for Pakistan's highly competitive peach) industry.

REFERENCES

1. Ahmad, I., Shah, S. A. H., & Zahid, M. S. (2004). Why the Green Revolution was short run phenomena in the development process of Pakistan: a lesson for future.
2. Archer, D. R., Forsythe, N., Fowler, H. J., & Shah, S. M. (2010). Sustainability of water resources management in the Indus Basin under changing climatic and socio economic conditions. Hydrology and Earth System Sciences, 14(8), 1669-1680.
3. Banker RD, Charnes A and Cooper WW. (1984). Some models for the estimation of technical and scale inefficiencies in data envelopment analysis. Manage Sci, **30,** 1078 – 1092.
4. Byerlee, D., & Siddiq, A. (1994). Has the green revolution been sustained? The quantitative impact of the seed-fertilizer revolution in Pakistan revisited. World Development, 22(9), 1345-1361.
5. Byiringiro, F., & Reardon, T. (1996). Farm productivity in Rwanda: effects of farm size, erosion, and soil conservation investments. Agricultural economics, 15(2), 127-136.
6. Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. European journal of operational research, 2(6), 429-444.
7. Dhungana, B. R., Nuthall, P. L., & Nartea, G. V. (2004). Measuring the economic inefficiency of Nepalese rice farms using data envelopment analysis. Australian Journal of Agricultural and Resource Economics, 48(2), 347-369.
8. Eyhorn, F., Mäder, P., & Ramakrishnan, M. (2005). The Impact of Organic Cotton Farming on the Livelihoods of Smallholders. Evidence from the Maikaal bioRe poject in central India.
9. Falcon, W. P., & Gotsch, C. H. (2013). 9. Lessons in Agricultural Development—Pakistan. In Development Policy, I: Theory and Practice (pp. 269-316). Harvard University Press.
10. Faostat, F. A. O. (2012). Disponível em:< http://faostat. fao. org>. Acesso em, 14.
11. Farrell, M. J. (1957). The measurement of productive efficiency. Journal of the Royal Statistical Society: Series A (General), 120(3), 253-281.
12. Frija, A., Chebil, A., Speelman, S., Buysse, J., & Van Huylenbroeck, G. (2009). Water use and technical efficiencies in horticultural greenhouses in Tunisia. Agricultural Water Management, 96(11), 1509-1516.
13. Gebremedhin, B., & Swinton, S. M. (2003). Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs. Agricultural economics, 29(1), 69-84.
14. Giordano, M. (2009). Global groundwater? Issues and solutions. Annual review of Environment and Resources, 34(1), 153-178.
15. Haji, J. (2007). Production efficiency of smallholders' vegetable-dominated mixed farming system in eastern Ethiopia: A non-parametric approach. Journal of African Economies, 16(1), 1-27.
16. Hussain, I., & Hanjra, M. A. (2004). Irrigation and poverty alleviation: review of the empirical evidence. Irrigation and drainage, 53(1), 1-15.
17. Jacoby, H. G., Murgai, R., & Ur Rehman, S. (2004). Monopoly power and distribution in fragmented markets: The case of groundwater. The Review of Economic Studies, 71(3), 783-808.
18. Johnson, R. (1989). Private Tube-well Development in Pakistan’s Punjab: Review of Past Public Programmes/Policies and

Relevant Research. International Water Management Institute, Lahore.
19. Karagiannis, G., Tzouvelekas, V., & Xepapadeas, A. (2003). Measuring irrigation water efficiency with a stochastic production frontier. Environmental and resource economics, 26(1), 57-72.
20. Khan, S., Rana, T., Gabriel, H. F., & Ullah, M. K. (2008). Hydrogeologic assessment of escalating groundwater exploitation in the Indus Basin, Pakistan. Hydrogeology Journal, 16(8), 1635-1654.
21. Kijne, J. W. (1999). Improving the productivity of Pakistan's irrigation: The importance of management choices. Colombo, Sri Lanka: International Water Management Institute.
22. Manjunatha, A. V., Speelman, S., Chandrakanth, M. G., & Van Huylenbroeck, G. (2011). Impact of groundwater markets in India on water use efficiency: A data envelopment analysis approach. Journal of environmental management, 92(11), 2924-2929.
23. McDonald, J. (2009). Using least squares and tobit in second stage DEA efficiency analyses. European journal of operational research, 197(2), 792-798.
24. McGuckin, J. T., Gollehon, N., & Ghosh, S. (1992). Water conservation in irrigated agriculture: a stochastic production frontier model. Water Resources Research, 28(2), 305-312.
25. Meinzen-Dick, R. S., & Rosegrant, M. W. (1997). Managing water supply and demand in southern Africa. Achieving food security in southern Africa, 203-225.
26. Mohammad, G. (1964). Some strategic problems in agricultural development in Pakistan. The Pakistan Development Review, 4(2), 223-260.
27. Mohammad, G. (1965). Private tubewell development and cropping patterns in West Pakistan. The Pakistan Development Review, 5(1), 1-53
28. Nulty, L. (1972). The green revolution in West Pakistan. Implications of technological change. The green revolution in West Pakistan. Implications of technological change.
29. Parikh, A., & Shah, K. (1994). Measurement of technical efficiency in the north-west frontier Province of Pakistan. Journal of Agricultural Economics, 45(1), 132-138.
30. Qureshi, A. S., McCornick, P. G., Sarwar, A., & Sharma, B. R. (2010). Challenges and prospects of sustainable groundwater management in the Indus Basin, Pakistan. Water resources management, 24(8), 1551-1569.
31. Rinaudo, J. D., Strosser, P., & Rieu, T. (1997). Linking water market functioning, access to water resources and farm production strategies: example from Pakistan. Irrigation and Drainage Systems, 11(3), 261-280.
32. Rodell, M., Velicogna, I., & Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. Nature, 460(7258), 999-1002.
33. Shah T, David M, Sakthivadive R and David S, The Global Groundwater Situation: Overview of Opportunities and Challenges. International Water Management Institute, Colombo (2000).
34. Shiva V.(1991). The Green revolution in Punjab. Ecologist (21), 57 –60.
35. Simar, L., & Wilson, P. W. (2007). Estimation and inference in two-stage, semi-parametric models of production processes. Journal of econometrics, 136(1), 31-64.
36. Solís, D., Bravo-Ureta, B. E., & Quiroga, R. E. (2009). Technical efficiency among peasant farmers participating in natural resource management programmes in

Central America. Journal of Agricultural Economics, 60(1), 202-219.
37. Speelman, S., D'Haese, M., Buysse, J., & D'Haese, L. (2008). A measure for the efficiency of water use and its determinants, a case study of small-scale irrigation schemes in North-West Province, South Africa. Agricultural systems, 98(1), 31-39.
38. Srivastava, S. K., Kumar, R., & Singh, R. P. (2009). Extent of groundwater extraction and irrigation efficiency on farms under different water-market regimes in Central Uttar Pradesh. Agricultural Economics Research Review, 22(347-2016-16731), 87-98.
39. Van Steenbergen, F., & Oliemans, W. (2002). A review of policies in groundwater management in Pakistan 1950–2000. Water policy, 4(4), 323-344.
40. Villano, R., & Fleming, E. (2006). Technical inefficiency and production risk in rice farming: evidence from Central Luzon Philippines. Asian economic journal, 20(1), 29-46.
41. Wadud, A., & White, B. (2000). Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. Applied economics, 32(13), 1665-1673.
42. Watto, M. A., & Mugera, A. (2014). Measuring efficiency of cotton cultivation in Pakistan: a restricted production frontier study. Journal of the Science of Food and Agriculture, 94(14), 3038-3045.
43. Memon, M. H., Khan, K., Abbass, M. Y., Khan, G., & Kamal, M. A. (2015). Impediments to Technology Adoption: A Case Study of Peach Production in District Swat, Pakistan. Journal of Managerial Sciences, 9(2).