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Research Article

ANALYSIS OF GROUNDWATER USE EFFICIENCY AND PRODUCTIVITY OF CROPS IN PAKISTAN: EVIDENCE FROM BALOCHISTAN PROVINCE

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Abstract

Balochistan is the largest province of Pakistan in terms of area, and most of its population depends on agriculture. It has an arid/semi-arid climate with frequent drought and dry spells. Almost half of the cultivated area is irrigated, and the primary source of irrigation is groundwater. Indus water available in Balochistan remains underutilized. Drought and tube well subsidy and other factors have resulted in over-exploited groundwater and unsustainable groundwater table. This situation affects agriculture, hence the livelihood of the residents. The study focused on analyzing the impact of using groundwater for irrigation on agricultural productivity and farmer's livelihood in the Balochistan province of Pakistan. For this purpose, five villages were randomly selected from the district Quetta, where groundwater was the only source for irrigation. In each village, 20 farmers were interviewed through well-structured and pre-tested questionnaires. For each significant crop cultivated in the area, 'Water Productivity' was measured as Yield ⁄ Volume of water required in cubic meter/acre, 'Crop Profitability' was analyzed using 'Benefit-Cost Ratio' and 'Impact of Groundwater Use on Gross Value Product's was estimated using double log model. Results revealed that the net revenue generated from cropping was Rs. 32168 per month, whereas the monthly household expenditure of the farmers was Rs. 33960, on average. Cropping alone cannot sustain the households' livelihoods. With net income from livestock and non-farm income, farmers can meet their monthly household expenditure. Results of BCR show that all the crops are profitable, but this profitability is at the expense of over-fetching scarce groundwater. Wheat is the only crop with more than 1.19 kg/meter water productivity. Crops' water productivity may decline if the water table keeps reducing. GVP of wheat and maize is negatively affected by the cost of groundwater. Cost sensitivity can be decreased if cost-efficient methods of irrigation are available. The government should regularize groundwater use through proper legislation and provide infrastructure/incentives for using other sources of water for irrigation as well. Availability of good quality seed to farmers should be ensured to enhance crop yield.

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1. INTRODUCTION

The trend of groundwater extraction has increased over time to sustain ecosystems, for drinking, for overall socio-economic development, and particularly for practicing agriculture (Eissa et al., 2018, Rao 2018, and Batarseh, 2021). Water shortage is subject to the pattern that human beings follow for its usage rather than the absolute water shortage in some areas. Worldwide, fresh water is being mostly extracted in water stress areas (Britto et al., 2019; Huan, 2019; Ridoutt and Pfister, 2010b). Groundwater supplies more than half of the water used in agriculture (The World Bank, 2021). The sustainability of groundwater in terms of its extraction as well as quality is an issue of concern in developing countries (Morris et al., 2020). The proportion of groundwater utilized for irrigation purposes has increased progressively over the years from about 40 percent during the early 1980s to more than 80 percent in recent times (Morris et al., 2003; Ridoutt and Pfister, 2010; Rahman and Mondal, 2015 and Pointet, 2022).

Pakistan is the fourth country with the largest area under irrigation after China, India, and the USA; reliance on irrigation on groundwater is more than 70 percent (Pointet, 2022). Water scarcity would be intensified with the ever-increasing demand for food production of a population expanding rapidly, making Pakistan the fifth most populous country in the world. Per capita water availability in Pakistan has significantly reduced to 1,000 m3, and it is further expected to decline to 800 m3 by the end of 2025 (Ishaque et al., 2023). Pakistan ranks 14 out of the top 17 countries in the world facing water scarcity. Research indicates that the groundwater table is predicted to drop to a highly inappropriate level soon. Literature supports that in the near future, groundwater table is expected to reduce to dangerous levels (Kahlown and Majeed, 2003; WWF, 2007 & Lee, 2015). Increased burden on water resources, along with increasing water pollution and unpredictable climatic changes (Hassan et al., 2016), resulted in food insecurity (Hanjra & Qureshi, 2010). In order to ensure sustainability in using water for food, it is highly desirable to improve crop water productivity, particularly irrigation water productivity (IWP). Crop productivity measures the economic gain from the consumption of a unit of water in crop production (Molden et al., 2010). The concept of IWP is the ratio of a crop's yield to the amount of irrigation water applied to that crop. Water productivity for wheat in Pakistan is 0.5 kg/m3, which is quite low compared to 1.0 kg/m3 in India and 1.5 kg/m3 in California, USA. Similarly, the water productivity for maize is only 0.3 kg/m3, and it is not comparable with the highest value of 2.7 kg/m3 in Argentina (Qureshi et al., 2010). Although improved IWP is highly desirable. However, high IWP in areas where water is scarce may result in negative impacts on the environment when compared to crop production with low IWP in a water-sufficient area (Ridoutt and Pfister, 2010).

Balochistan is the largest province of Pakistan in terms of area. Most of its inhabitants depend upon agriculture for their livelihoods. Nonetheless, more than 58 percent of the area is unavailable for cultivation (Khalid, 2019). It has an arid and semi-arid climate with frequent drought and dry spells with an average annual precipitation of 250–350 mm, mostly during winter. Hence, the province is water-scarce, and agricultural practices highly depend on groundwater sources. Subsidy on the installation of tube wells for increasing productivity (Hossain, 2009) encouraged farmers of water stress zones like Balochistan to increase reliance on groundwater, which later resulted in unsustainable extraction of groundwater, leading to a decreased water table (Sheikh et al., 2016). Currently, the groundwater table is under stress, where sixty percent of the available groundwater has already been exploited. Every year, two to five meters of ground levels are declining (Bhatti et al., 2008 Ashraf, 2020). Because of this situation, crops, livestock, orchards, and the overall livelihood of people are affected. The situation affects crops, livestock, and orchards; hence, the livelihood of communities depends on groundwater resources. Although Indus water is available in Balochistan, it is underutilized and only about 40 percent of flood water resources are being utilized. Farmers have started abandoning the traditional farming systems of Sailaba (irrigation with floodwater) and Khushaba (irrigation with rainfall and runoff) and switched to groundwater irrigation for agricultural purposes. Quetta is the province's capital, where the groundwater abstraction rate is alarmingly high (Ashraf, 2020). With increasing water stress and food insecurity, access to agricultural productivity is highly required. The growth in population and reliance on agriculture are the main reasons for water shortage (TCI, 2004; Khan et al., 2013; & Khan et al., 2010). This study, therefore, analyzes the impact of using groundwater for irrigation on agricultural productivity and farmers' livelihood in the Balochistan province of Pakistan. Hence, the specific objectives of the study were as follows:

- To study the respondent's socio-economic characteristics of the respondents.
- To analyze agriculture's contribution in sustaining the respondents' livelihoods using annual net revenue of the crops grown in the study area and per month revenue of the farmers.
- To estimate the benefit-cost ratio of different crops, their productivity per acre, and water use efficiency per acre for capturing the impact of using groundwater for irrigation.
- To analyze the determinants of the Gross Value Product of various crops.

2. Methodology

Data was collected from Baluchistan's district 'Quetta'. Quetta is the province's capital, where the groundwater abstraction rate is alarmingly high (Ashraf, 2020). The reasons include a constant rise in population, influx of immigrants, over-reliance on ground water, and infrequent rainfalls (Zainuddin Kakar, 2018). Utilizing multistage random sampling, five villages, namely Chashma Acheozi, Aghbarg, Kechi Bag, Killi Khali, and Sardar Kharez, were selected, and from each village, 20 farmers were assigned randomly to be interviewed. All the farmers were male. A well-structured and pre-tested questionnaire was used for the collection of data.

In order to calculate the groundwater use efficiency of crops, the benefit-cost ratio was applied (as per Sinden and Thampapillai, 1995).

$$\mathrm{B.C.R} = \sum_{t=1}^{n} \frac{B}{(1+r)t} / \sum_{t=1}^{n} C/(1+r)t \quad 2.1$$

BCR is the benefit-cost ratio for different crops like wheat, maize, fodder, and tomato.

Where CP is Crop Productivity

CP= Yield (kg/acre) ∕ Volume of water required (cubic meter/acre) 2.2

The yield was first calculated in mounds and later converted to kilograms.

The volume of water required Water applied* No. of Irrigations.

Water applied = depth of water Required in inches* Area of an acre in ft.

WUE represents water use efficiency, and CWR represents each crop's water requirement. And Water applied= depth of water in inches* Area of an acre in ft.

WUE= CWR*100/Water applied 2.3

The following econometric model assessed the groundwater use efficiency on the gross value product of different crops being cultivated in Quetta.

$$\mathrm{LnGVP} = \beta_{\circ} + \beta 1\ln SC + \beta 2\ln FC + \beta 3\ln WUC + \beta 4\ln CC + \beta 5\ln MC + \beta 6\ln FExp + \beta 7\ln Edu \quad 2.4$$

whereas,

GVP= gross value product SC= seed cost in rupees, FC= fertilizer cost in rupees, WUC= Water Use Cost in rupees, CC= chemical cost in rupees, MC= mechanization cost in rupees, FExp= farming experience in years, and Edu= education of farmers in years

3. Results and Discussion

In the study area, the average family size of members was 14, and the average education was only four years of schooling. Farmers possessed experience of over 12 years, on average. The average land size owned by the respondents was 8.14 acres. Monthly income from cultivating different crops was above Rs. 32000, average monthly income from livestock was Rs. 7430, and average per month income from off-farm sources was Rs. 36527 (see table 2). Their total household expenditure was around Rs. 34000. Where expenses exceeded revenue by an amount of Rs.1791.85. Hence, cropping alone was unable to fulfill the needs of the respondents. Most of the area in Balochistan is rangeland, with only 5-7 % cultivable area, and more than three-fourths of its population depends upon livestock for their livelihoods (Mustafa *et al.*, 2019).

Table 2. Per Month Revenue of the Respondents (PKRs)

S.NO.	Variable	Average
1	Net revenue from crops	32168
2	Net revenue from livestock	7430
3	Total income from farming	39598
4	Off-farm income in PKRs	36527
5	Total income from farming and off-farm sources	76,125
6	Monthly household expenditure	33960.2
7	Net income [(farm+ off-farm)-HH expenditure]	42164.8

Livestock helps cover household expenditures by generating revenue, resulting in net income from farming that amounts to Rs. 7430 (Table 2). Income generated from off-farm sources further enhanced the household net income to Rs. 42164.8. Conclusively, livestock plays a vital role in sustaining households' livelihood in Quetta. The reason behind this finding seems quite comprehendible. The climate in Balochistan is predominantly semi-arid to arid. The province has large rangelands, which are suitable for grazing animals, and rainfall happens very rarely. This situation leads to the province's heavy reliance on livestock for livelihood (Mustafa et al., 2019).

The total revenue of wheat, maize, tomato, and fodder was PKRs. 60667.87, PKRs. 60095.67, PKRs. 145124.90 and PKRs. 96647.12, respectively, as given in Table 3.

Table 3. Net Revenue from the Crops Grown in Quetta (PKRs)

Crops	Total Revenue	Total cost	BCR=TR/TC
Wheat	60667.87	46207.24	1.31
Maize	60095.67	43823.13	1.37
Tomato	145124.90	75819.65	1.91
Fodder	96647.12	67586.88	1.43

Source: Author's own calculation

The total cost of wheat, maize, tomato, and fodder was PKRs. 46207.24, PKRs. 43823.13, PKRs. 75819.65 and PKRs. 67586.88, respectively. The benefit-cost ratios of different crops like wheat, maize, tomato, and fodder were 1.31, 1.37, 1.91, and 1.43, respectively. The benefit-cost ratio must be greater than 1 to accept growing any crop. The results of all crops showed that farmers can grow their respective crops.

The average yield of wheat, maize, and tomato in kilograms was 1512, 2469, and 6477 kilograms, respectively (see Table 4). The average number of irrigations applied for these crops was 4.56, 10.34, and 20 irrigations, respectively. The required water volume was calculated as 1268.09, 3255.06, and 7096.34 cubic meters, respectively. The calculated water productivity for wheat, maize, and tomatoes were 1.19, 0.75, and 0.91 kg per cubic meter, respectively. The water productivity in Quetta is almost similar to that in Khyber Pakhtunkhwa (KPK). For instance, maize is 0.75 kg/m^3 in Quetta and 0.76 kg/m^3 in KPK (Muhammad *et al.* 2014).

Table 5 shows the groundwater use efficiency for wheat, maize, and tomato crops. The crop water requirements were 4, 10, and 20 irrigations. Water applied for these crops was 4.56, 10.34, and 20.44 irrigations. Groundwater use efficiency calculated in meters for these crops was 0.87, 0.96, and 0.97, respectively.

There are different determinants of groundwater use efficiencies according to available literature, including quality of groundwater, farm size (Sarker and De, 2004), agricultural practices used by the farmers, type of tube well and tube well depth and tube well sharing (diesel/electricity/tractor) (Qureshi *et al.*, 2003 and Malik *et al.*, 2008), diameter of tube well discharge (inches), (Qureshi *et al.*, 2003), silt cleaning, condition of water channel (paved/unpaved), time of irrigation (day/night), availability of groundwater, education of the farmers (Watto and Mugera, 2016; Mekonnen, 2015; Fatima and Khan, 2015; Gill, 2015), irrigation

Table 4: Water Productivity per Acre of the Crops Grown in Quetta

Crop	Yield kg per acre	No. of Irrigations	Volume of water required cubic meters (m^3)	Water productivity (kg/cubic meter)
Wheat	1512	4.56	1268.09	1.19
Maize	2469	10.34	3255.06	0.75
Tomato	6477	20.44	7096.34	0.91

Source: Author's own calculation

Table 5: Groundwater Use Efficiency per Acre of Major Food Crops in Balochistan

Crops	Crop water required (m^3)	Water applied (m^3)	Groundwater use efficiency (m)
Wheat	4	4.56	0.87
Maize	10	10.34	0.96
Tomato	20	20.44	0.97

Source: Author's own calculation

Table 6: Factors Affecting Gross Value Product of Wheat in Quetta

Model	B	Sig.
(Constant)	10.25	.000
LnSC (Seed Cost)	0.038	.628
LnFC (Fertilizer Cost)	0.029	.328
LnWUC (Water Use Cost)	-0.162	.014
LnMC (Mechanization Cost)	0.066	.240
LnFExp (Farming Experience)	0.174	.028
LnEdu (Education)	0.036	.315
Dependent Variable: GVP (Gross Value Product)		

Source: Author's own calculation

method (flood/furrow/sprinkler), and time of irrigation (minutes), etc.

From the above Table, 6 of wheat regression shows that using recommended seed rate, fertilizer rate, rate of farm mechanization, having more farming experience, and more educated yield can be increased up to a certain level. The coefficient of SC, FC, MC, FExp, and Edu indicated that 1 percent increase in seed cost, fertilizer cost, mechanization cost, farm experience, and year of education brings 0.038, 0.029, 0.066, 0.174, and 0.036 percent increase in GVP, by keeping the effect of all other factors constant. The cost of irrigation significantly affects GVP, the negative sign of its coefficient indicates that overuse of water may decrease GVP, and a one percent increase in Water Use Cost brings a 0.162 percent decrease in GVP, keeping the effect of all other factors constant. Correct use of seed and other inputs helps in improving agricultural production, which in turn leads to increased revenue for wheat farmers (GOP, 2022 and Mala &Akbay, 2022)

Table 7: Factors Affecting Gross Value Product of Maize in Quetta

Model	B	Sig.
(Constant)	10.29	.000
LnSC (Seed Cost)	0.019	.368
LnFC (Fertilizer Cost)	0.064	.045
LnWUC (Water Use Cost)	-0.093	.009
LnMC (Mechanization Cost)	0.009	.826
LnFExp (Farming Experience)	0.143	.012
LnEdu	0.150	.038
Dependent Variable: GVP (Gross Value Product)		

Table 7 presents the factors affecting GVP in the case of maize, where independent variables include seed rate, fertilizer rate,

rate of farm mechanization, having more farming experience, and education of farmers. The coefficient of SC, FC, MC, FExp, and Edu indicated that a one percent increase in seed cost, fertilizer cost, mechanization cost, farm experience, and year of education brings 0.19, 0.064, 0.009, 0.143, and 0.150 percent increase in GVP, by keeping the effect of all other factors constant. The use of certified seed and balanced fertilizer is imperative for enhancing the productivity of corn (Siagian et al., 2021). Water use cost is another important factor in the production process. By using the recommended irrigation rate, yield can be increased up to a certain level, but if we are using tube well irrigation in exceeds, it negatively impacts the crop yield. The coefficient of FC indicated that a 1 percent increase in Water Use Cost brings a 0.093 percent decrease in GVP, and this change is statistically significant.

Table 8: Factors Affecting the Gross Value Product of Tomato in Quetta

Model	B	Sig.
(Constant)	7.115	.000
LnSC (Seed Cost)	0.160	.440
LnFC (Fertilizer Cost)	0.057	.667
LnWUC (Water Use Cost)	0.001	.995
LnCC (Chemical Cost)	-0.093	.268
LnMC (Mechanization Cost)	0.091	.406
LnFExp (Farming Experience)	0.137	.043
LnEdu (Education)	0.044	.675
Dependent Variable: GVP (Gross Value Product)		

Source: Author's own calculation

Table 8 of maize regression analysis shows that by using recommended seed rate, fertilizer rate, irrigation rate, and rate of farm mechanization, having more farming experience and more educated yield can be increased. The coefficient of SC, FC, IC, MC, FExp, and Edu indicated that one percent increase in seed cost, fertilizer cost, Water Use Cost, mechanization cost, farm experience, and year of education brings 0.160, 0.057, 0.001, 0.091, 0.137, and 0.044 percent increase in GVP, by keeping the effect of all other factors constant. The quality of the seed is essential for getting maximum benefit from the production of tomatoes (Noonari et al., 2015). Marketing management may be made available by the government. Chemical cost is also another critical factor in the production process. The coefficient of CC indicated that a 1 percent increase in chemical cost brings a 0.093 percent decrease in GVP by keeping the effect of all other factors constant.

4. Conclusion

The study focused on analyzing the impact of using groundwater for irrigation on agricultural productivity and farmer's livelihood in the Balochistan province of Pakistan. For this purpose, five villages were randomly selected from the district Quetta, where groundwater was the only source for irrigation. In each village, 20 farmers were interviewed using well-structured and pre-tested questionnaires. For wheat, maize, and tomato, 'water productivity' was measured as Yield ⁄ Volume of water required in cubic meter/acre, 'Crop Profitability' was analyzed using 'Benefit-Cost Ratio', and 'Impact of Groundwater Use on Gross Value Product was estimated using double log model. Results revealed that the net revenue generated from cropping was Rs. 32168 per month, whereas the monthly household expenditure of the farmer was Rs. 33960, on average. Cropping alone cannot sustain the households' livelihoods. With net income from livestock and non-farm income, farmers can meet their monthly household expenditure. Results of BCR show that all the crops are profitable, but this profitability is at the expense of over-fetching scarce groundwater. Wheat is the only crop with more than 1.19 kg/meter water productivity. Crops' water productivity may decline if the water table keeps reducing. GVP of wheat and maize is negatively affected by the cost of groundwater. Cost sensitivity can be decreased if cost-efficient methods of irrigation are available. The government should regularize groundwater use through proper legislation and provide infrastructure/incentives for using other water sources for irrigation. Governments must ensure the monitoring of groundwater extraction and encourage the engagement of the private sector for investment and co-financing of these initiatives. The government needs to rethink harmful subsidies in the energy and agricultural sectors, resulting in over-extraction of groundwater. The dam construction would greatly help reduce the burden on irrigation groundwater. Adequate use of fertilizer and availability of good quality seed to farmers were important factors in crop yield, so the availability of these inputs needs to be ensured for farmers. The government needs to provide groundwater testing facilities to all farmers.

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