Research Article

The Effect of On-Farm Water Management on Expansion of Irrigated Land in Bajaur, Pakistan

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Abstract | On-farm water management (OFWM) is one of the major components of FATA Water Resources Development Project (FWRDP) working in different areas of the erstwhile FATA. This study examines the transformative effect of on-farm water management on expansion of irrigated land in the newly merged district Bajaur. This study is based on household data collected through a pre-tested questionnaire from 120 farming households. Paired t-test was used to assess the role of OFWM in expansion of irrigated area. The results of the study showed that OFWM has a significant positive effect on irrigated land expansion in the research area. The results show that the average irrigated land area increased significantly for major crops, viz., wheat (16.7 kanal), maize (14.5 kanal), and rice (1.71 kanal). The results of the paired t-test revealed a significant increase in the mean differences of wheat, maize, and rice, after the implementation of OFWM practices as shown by $p<0.05$ for these crops. Based on the findings, it is concluded that the OFWM component of the FWRDP has a greater role in expansion of irrigated land in the study area. The findings of the study have important implications for the development of future water resources management projects in the study area and other water-scarce regions.

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Introduction

The FATA Water Resources Development Project (FWRDP), funded by the Asian Development Bank (ADB), is an integrated rural development project working in various parts of the newly merged districts since 2015. The major components of the project include community organization, development of irrigation infrastructure, on-farm water management, improved water-shed management, incentives and training etc. (FWRDP, 2022). The Project area consists of three erstwhile FATA districts, namely Bajaur, Mohmand and Khyber. The three districts have an estimated population of 2.65 million (GoP, 2017).

The main source of livelihood of the population living in these areas is agriculture, livestock and allied

activities. Being the major sector of the economy, agriculture faces a number of problems in Pakistan, inter alia, water scarcity problem being top of the list (Jan, 2020). This situation calls for improved water management practices in the water scarce areas in particular. It is essential to have effective planning and management to improve crop-water-productivity. The improper and mismanagement of water resources would result in serious consequences for agricultural development in such circumstances (Basharat *et al.*, 2014).

As such, the development of irrigation infrastructure is crucial for the economic development of rural areas, particularly in areas where agriculture is the main source of livelihood. Increase in irrigated land may have a number of advantages. Firstly, by meeting the crop-water-requirement, food production can be increased. Secondly, irrigation can reduce reliance on precipitation and act as a buffer against water scarcity, which can help in overcoming occurrences of droughts and climate change. Thirdly, irrigated agriculture can promote economic growth by creating jobs, improving farmers' income, and boosting the marketing channels. In Pakistan, the agriculture sector is the main consumer of water resources and irrigated land accounts for approximately 90 percent of the total agricultural output in the country (Jan, 2020; Bhatti and Rosa, 2009).

Literature suggests that sustainable water management in agriculture requires adopting various measures such as improved irrigation techniques, soil and plant practices, water pricing, wastewater reuse, and farmer participation (Chartzoulakis and Bertaki, 2015; WWF, 2023). Other studies reported that innovative irrigation practices enhance water efficiency, yet, farmers lack knowledge and incentives to achieve optimal water-use efficiency (Khatun and Roy, 2012; CORDIS, 2021).

Literature provides evidence of multiple benefits of improved water management in various contexts. For instance, Boretti and Rosa (2019) stated that the demand for food worldwide is predicted to increase by 60 percent by 2050. To fulfill this escalating demand, production must be increased, cropland must be expanded, and a climate resilient and integrated water management system must be strengthened (World Bank, 2022). In another study, Schultz *et al.* (2005) urged that water management plays a crucial role in addressing the challenges posed by population growth, food production, expansion in irrigated areas, and sustainable rural development. This expansion of irrigated areas played a crucial role in enhancing agricultural productivity and improving the socio-economic conditions of the rural communities. However, Steidl *et al.* (2015) concluded that a key priority should be given to monitoring water availability, especially when contemplating increased irrigation.

In rural areas of Pakistan, the majority of the population directly or indirectly depends on agriculture and related sectors for their livelihoods. However, water is one of the limiting factors to increased agricultural productivity in many areas of Pakistan, including Bajaur. Most of the land has been uncultivated because of no water for irrigation. The FWRDP is a comprehensive approach that connects all sectors of the economy to combat poverty effectively. As part of an integrated approach, FWRDP has given priority to irrigation infrastructure development in district Bajaur, Khyber Pakhtunkhwa Province of Pakistan. FWRDP has played a vital role in expanding the irrigated areas within the district. The project was purposefully designed to enhance water availability for irrigation. Through the implementation of various interventions, including the construction of irrigation canals, reservoirs, water storage infrastructure, and diversion weirs, FWRDP has made substantial contributions to the expansion of the irrigated area. The most effective approach for water conservation is through carefully managed deficit irrigation strategies, which are complemented by advanced irrigation systems and flexible, state of the art water delivery systems (Evan and Sadler, 2008). The main objective of this study is to investigate the role of on-farm water management components of the FWRDP in irrigated land expansion in the research area.

Materials and Methods

Sample design and sample size

This study adopted a multi-stage sampling procedure. FWRDP is working in the entire Bajaur district which had eight Tehsils. For the purpose of this study, two tehsils namely Khar and Utman Khel were selected randomly (Figure 1). The pilot study confirmed that FWRDP had constituted 81 community organizations (COs) in Bajaur district. Out of 81 COs, 57 COs were selected from two tehsils as a

sample (42 in Khar and 15 in Utman Khel).

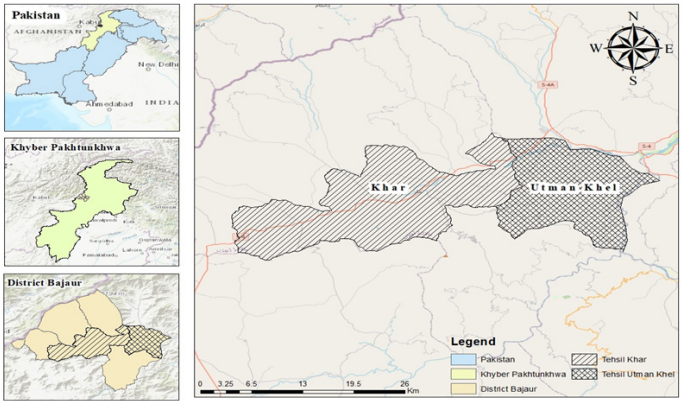

Figure 1: *Map of the research area.*

In the second stage of sampling, 20 COs were selected using proportionate random sampling technique. The formula of proportionate sampling technique is as follows:

$$ni = \frac{Ni}{N} * n \ldots (1)$$

Where;
n_i = required number of sampled COs in each tehsil; N_i = Total number of COs in each tehsil; i = Number of tehsils in the study area (i=1, 2); N = Total number of COs in the study area; n = Total sample size (COs).

Putting values in Equation 1, the following sample size was determined for each tehsil.

$$n_1 = 15/57 \times 20 = 5 \text{ (Utman Khel)}$$
$$n_2 = 42/57 \times 20 = 15 \text{ (Khar)}$$

As all households in the command area of a CO (a village) were beneficiaries of the project in terms of irrigation infrastructure development, therefore, in the third stage, a total of six beneficiaries were selected from each CO. Thus, the total number of households selected for the study was 120 households.

Data sources and data collection

For this study, primary data was collected from the beneficiary households through a questionnaire. A semi-structured questionnaire was specifically designed for this study which was pre-tested in the field before the final survey. The main focus of the questionnaire was on landholding, area under irrigation before and after FWRDP, cropping pattern, and total land allocated to various crops.

Data analysis

The aim of this study was to assess the role of on-farm water management in agricultural development and expansion of irrigated land in the research area. Therefore, before and after analysis was carried out. The following paired t-test was used to identify the differences in means of the irrigated land cultivated before and after the on-farm water management activities by the FWRDP.

$$t = \frac{\bar{d}}{sd/\sqrt{n}} \ldots (2)$$
$$\bar{d} = \bar{x}_1 - \bar{x}_2$$

Sd= Standard deviation; n = Number of observations.

Results and Discussion

This section provides an in-depth analysis of the findings that highlight the significant role of FWRDP in the expansion of irrigated areas. Through a comprehensive examination of the collected data and research outcomes, this section offers valuable insights into the extent to which FWRDP has effectively facilitated the expansion of irrigated areas.

Expansion in the irrigated land by FWRDP

The expansion of irrigated land can play a significant role in enhancing agriculture productivity by providing reliable access to water, allowing for larger land cultivation, and supporting the adoption of modern agricultural practices. However, it is important to implement sustainable irrigation practices that focus on water conservation, efficient water use, and environmental considerations to ensure long-term agricultural productivity and sustainability (Sirimewan and Naiduwa-Handi, 2018).

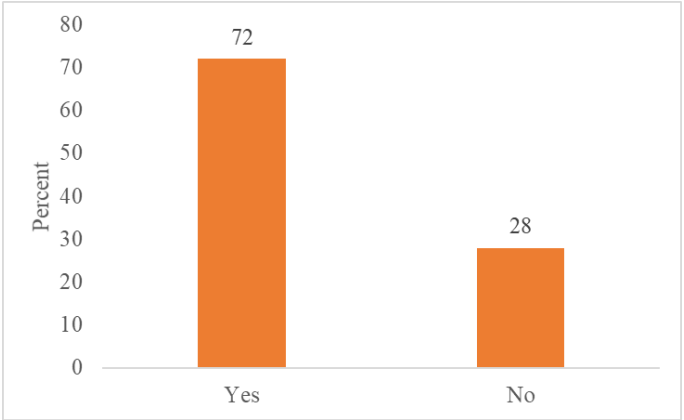

Figure 2: *Expansion in irrigated area.*
Source: *Field Survey, 2023.*

Figure 2 suggests that the FWRDP has played an important role in expanding the irrigated area. The table further shows that 72 percent respondents reported that their irrigated area had expanded due to the project, while 28 percent reported otherwise. This is a significant finding as expansion in irrigated areas can lead to increased crop yields and enhanced agricultural productivity, which in turn can contribute to food security and improved livelihoods. On-farm water management strategies could increase global crop production by 19 percent, comparable to current irrigation, but not enough for a larger population in the world (Rost *et al.*, 2009).

The role of FWRDP in expanding irrigated areas has helped farmers to access a reliable source of water for irrigation and enabled them to cultivate crops even during dry spells. The details of crop wise expanded irrigated land are given as under:

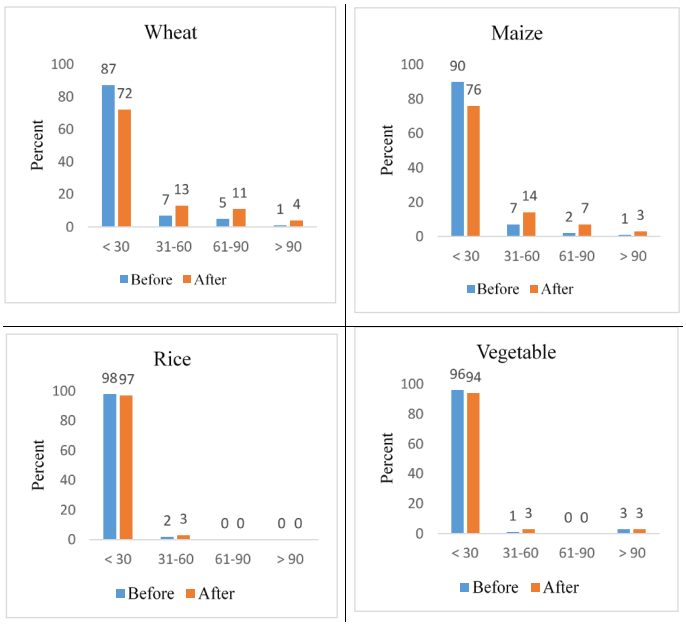

Figure 3: *Crop area before and after the FWRDP.*
Source: *Field Survey, 2023.*

Figure 3 provides information on the area cultivated for various crops like wheat, maize, rice and vegetable before and after the inception of the FWRDP categorized by different ranges of land size in kanal. Before the FWRDP, 87 percent farmers cultivated wheat in the range of <30 kanal of land. After the FWRDP intervention, the number of farmers who cultivated wheat in this range decreased to 72 percent. However, the number of farmers who cultivated wheat in the range of 31-60 kanal increased from 7 percent to 13 percent. Similarly, the number of farmers cultivating wheat in the range of 61-90 kanal increased from 5 percent to 11 percent, while those farmers who cultivated wheat in the range of >90 increased from 1 percent to 4 percent. Similar findings were reported by Zaveri and Lobell (2019) who reported that expansion in irrigation has played an important role in enhancing wheat production.

For maize, 74 percent of farmers cultivated it in the range of <30 kanal of land before FWRDP intervention, which decreased to 90 percent to 76 percent after intervention. However, the number of farmers cultivating maize in the range of 31-60 kanal increased from 7 percent to 14 percent and the number of farmers cultivating maize in the range of 61-90 increased from 2 to 7 percent. Cultivation of maize in the range of >90 also slightly increased from 1 percent to 3 percent. The results are in concurrence with those of Cassman and Grassini (2013) who found that expansion in irrigation is pivotal for increased productivity of maize and other crops in Sub-Saharan Africa.

Before the intervention, 98 percent of farmers cultivated rice in the range of <30 kanal, which decreased to 97 percent after intervention. The percentage of farmers who cultivated rice in the range of 31-60 kanal increased from 2 to 3 percent. For the remaining ranges, there were no significant changes. For vegetables, 96 percent of farmers cultivated them in the range of <30 kanal of land before FWRDP intervention, which decreased slightly to 94 percent after intervention. However, the number of farmers who cultivated vegetables in the range of 31-60 kanal increased from 1 percent to 3 percent. For the remaining ranges, there were no significant changes. Pakistan must increase food and fiber production despite limited agricultural land. Despite diverse climates, soil types, and irrigation resources, crop yields are low. Increasing food and fiber production is critical for self-sufficiency, meeting growing demand, and generating foreign exchange (Farooq *et al.*, 2007).

Expansion in the irrigated land by FWRDP: A comparison

The above mentioned results suggest that the FWRDP had a great effect on the cultivation of wheat and maize. The program may have encouraged more farmers to cultivate these crops in larger areas, potentially leading to increased yields and income. A comparison of the irrigated area under various crops before and after FWRDP intervention is provided in Table 1.

Table 1: *Crop wise expansion in the irrigated land by FWRDP.*

	Mean	Std. Dev.	t-value	Sig.
Difference in irrigated area under Wheat before and after FWRDP (in kanals)	16.700	22.064	8.291	0.000
Difference in irrigated area under Maize before and after FWRDP (in kanals)	14.550	19.263	8.274	0.000
Difference in irrigated area under Rice before and after FWRDP (in kanals)	1.717	7.226	2.602	0.010
Difference in irrigated area under Vegetables before and after FWRDP (in kanals)	.558	2.743	2.229	0.028

Table 1 shows the results of paired t-test, which shows that the implementation of OFWM practices through the FWRDP had a significant positive impact on the expansion of irrigated land in the study area as suggested by (Khadr *et al*., 2017) that the on-farm water resources management plays an essential role in the conservation and efficient utilization of water resources. The paired samples t-test revealed a significant increase in the mean differences of wheat, maize, rice, and vegetables after the implementation of OFWM practices. Specifically, the mean difference in wheat area before and after the FWRDP was 16.7 kanals with a standard deviation of 22.064 ($t=8.291$, $p<0.05$), while the mean difference in maize area before and after the FWRDP was 14.55 kanals with a standard deviation of 19.263 ($t=8.274$, $p<0.05$). The mean difference in rice area before and after the FWRDP was 1.717 kanals with a standard deviation of 7.226 ($t=2.602$, $p<0.05$), and the mean difference in vegetable area before and after the FWRDP was 0.558 kanals with a standard deviation of 2.743 ($t=2.229$, $p<0.05$). However, no significant difference was observed in barley area ($t=1.179$, $p>0.05$).

Overall, the findings suggest that the implementation of OFWM practices through the FWRDP caused significant expansion of irrigated land and increase crop yields, which can have important implications for food security and poverty alleviation in the study area. The results are in line with (Faramarzi *et al*., 2010) who conducted study in Iran and reported that improving water management in rainfed wheat cultivation, primarily in areas where yields are low, resulted a significant increase in the marginal return of water consumption and with implementation of better water management practices, such as optimizing irrigation scheduling, enhancing soil moisture retention, or adopting water-saving techniques, farmers potentially achieved higher yields with the same amount of water or maintain existing yields while reducing water usage.

Pakistan's irrigated agriculture plays a critical role in providing food and livelihood security for around 220 million people. However, this sector is facing numerous challenges. To tackle challenges, various investments such as expanding irrigation infrastructure, improving on-farm water management, and promoting resource conservation technologies can play their role. These investments can be achieved through public sector demonstration and research projects, cost-sharing/ subsidized schemes, and technology introduction, along with associated training and learning approaches. While these investments have resulted in positive outcomes, such as increased water availability, cropped areas and cropping intensity, as well as promoting resource conservation technologies and farm mechanization, most farmers are currently struggling to turn a profit, as the region's water productivity is the lowest in the area (Fatima and Mustafa, 2021).

Conclusions and Recommendations

The FWRDP has had a significant positive effect on agricultural productivity in the study area. The program has helped to expand the irrigated area, increase crop cultivation, and improve agricultural productivity. The expansion of irrigated land through OFWM has played an important role in enhancing agricultural productivity and improving the livelihoods of farmers. It has provided a consistent and sustainable water source for crops, enabling farmers to cultivate more land, introduce crop diversity, and adopt more effective irrigation techniques. These developments have made a substantial impact on agricultural productivity, contributing to increased crop yields, food security, and economic growth. The study found that the FWRDP had the greatest impact on the cultivation of wheat and maize, with a decrease in the proportion of respondents cultivating these crops in small areas. The study recommends continuation of command area development (on-farm water management) activities by FWRDP. The study further recommends to encourage farmers to diversify their crops and adopt modern agricultural practices, taking advantage of the expanded irrigated land, to further improve productivity and enhance

food security. This study has some limitations. This study has been conducted in just one newly merged district. In future, a more detailed study with greater geographical coverage and larger sample size needs to be conducted for results to be more representative.

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Novelty Statement

This study uses quantitative technique(s) to determine the effects of FWRDP interventions on beneficiary communities and provides evidence-based implications for re-formulating integrated rural development policies.

Author's Contribution

Ikramullah: Conceptualization, data curation, formal analysis, investigation, methodology, software, writing original draft.
Inayatullah Jan: Formal analysis, methodology, supervision, validation, writing review and editing

Conflict of interest
The authors have declared no conflict of interest.

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