

APPLICATION OF CLIMATE RESILIENT AND EFFICIENT IRRIGATION TECHNOLOGIES FOR ENHANCING WATER PRODUCTIVITY IN PAKISTAN

APPLICATION DE TECHNOLOGIES D'IRRIGATION EFFICIENTES ET RÉSILIENTES AU CLIMAT POUR AMÉLIORER LA PRODUCTIVITÉ DE L'EAU AU PAKISTAN

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ABSTRACT

Irrigation drives the agricultural and rural economy in Pakistan. Irrigation-driven cropping systems encompass over 22.5 million hectares, accounting for over 80 per cent of the country's total cultivated area. More than 90 per cent of total crop production is generated from irrigated lands, thus securing the food needs of over 240 million people. Notwithstanding its utmost significance, irrigated agriculture faces copious challenges, mainly shortages of canal water supplies, over-abstraction of groundwater due to lack of regulatory frameworks, and limited adoption of irrigation technologies leading to lower irrigation efficiency vis water productivity. Notably, climate change has aggravated the irrigation sector issues during the last two decades. Pakistan has been among the top ten most climate-vulnerable countries during the last two decades, exacerbating the irrigation sector challenges and urging the pressing need for transforming the conventional irrigation practices. This study has critically examined the climate-resilient and efficient irrigation technologies applied in the Punjab province of Pakistan from 2011 to 2025 under various development projects. The objective of this strategy revolves around the notion of enhancing water productivity (more crop per drop of water) with an investment of 500 million dollars. The analysis revealed that climate-resilient irrigation technologies, including precast concrete parabolic segment lining for the lining of water conveyance community watercourses; use of laser land levelling technology; installation of solar-powered drip irrigation; and on-farm water storage through constructing ponds, have transformed the farmers' existing inefficient irrigation practices to improve water conveyance, application, and water use efficiency and build on-farm climate resilience. The study found that during the last decade and a half, over 25,000 community watercourses were lined with precast concrete parabolic lining technology by organizing farmers into water users associations, solar-driven drip irrigation systems were installed on 20,500 hectares to promote high-value crops, almost 15,000 laser land levelling units were provided to farmers to act as service providers in rural areas, and about 4,000 on-farm water storages were developed to store and supplement demand-based irrigation water supplies. In total, these climate-resilient irrigation technologies have resulted in serving almost four (4) million hectares of irrigated area, falling mostly in climate-vulnerable and water-scarce regions of the Punjab province. These interventions have been executed through a community-driven development (CDD) framework and a cost-sharing framework whereby farmers contribute 30 per cent of the scheme cost, and the remaining 70 per cent is provided by the government as a grant. The evaluation studies revealed that on-farm water conveyance efficiency increased from 49 per cent to 68 per cent, and tail-end farmers have 40 per cent better irrigation supplies at their turnouts due to watercourse lining as compared to unimproved watercourses. These climate-resilient irrigation technologies have also resulted in enhancing the water productivity of wheat from Rs.0.91 kg/m³ to Rs.1.03 kg/m³ and 0.34 kg/ m³ to 0.41 kg/m³ for the rice crop. The analysis of the execution strategy unveiled that a farmer-driven and cost-sharing implementation model played a critical role in the adoption of climate resilience technologies by the most vulnerable farming community. The study concluded that climate-resilient irrigation technologies are fundamental to improving water use and productivity efficiency and building on-farm resilience in countries like Pakistan, vulnerable to water scarcity and climate change.\

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Keywords: Irrigation, climate change, drip irrigation, water efficiency, climate-resilient irrigation.

RÉSUMÉ

L'irrigation constitue le moteur de l'économie agricole et rurale au Pakistan. Les systèmes de culture irriguée couvrent plus de 22,5 millions d'hectares, soit plus de 80 % de la superficie cultivée totale du pays. Plus de 90 % de la production agricole totale provient des terres irriguées, garantissant ainsi les besoins alimentaires de plus de 240 millions de personnes. Malgré son importance capitale, l'agriculture irriguée est confrontée à de nombreux défis, principalement les pénuries d'approvisionnement en eau des canaux, la surexploitation des eaux souterraines due à l'absence de cadres réglementaires et l'adoption limitée des technologies d'irrigation, qui se traduit par une faible efficacité de l'irrigation et une faible productivité de l'eau. Le changement climatique a notamment aggravé les problèmes du secteur de l'irrigation au cours des deux dernières décennies. Durant cette période, le Pakistan a figuré parmi les dix pays les plus vulnérables au climat, ce qui a amplifié les défis du secteur de l'irrigation et rendu urgente la transformation des pratiques d'irrigation conventionnelles. Cette étude a examiné de manière critique les technologies d'irrigation efficaces et résilientes au climat appliquées dans la province pakistanaise du Pendjab de 2011 à 2025 dans le cadre de divers projets de développement. L'objectif de cette stratégie s'articule autour de l'amélioration de la productivité de l'eau — davantage de récolte pour chaque goutte d'eau — grâce à un investissement de 500 millions de dollars. L'analyse a révélé que les technologies d'irrigation résilientes au climat, notamment le revêtement des canaux communautaires d'acheminement de l'eau au moyen de segments paraboliques préfabriqués en béton, l'utilisation du nivellement des terres au laser, l'installation de systèmes d'irrigation goutte à goutte alimentés à l'énergie solaire et le stockage de l'eau à l'exploitation dans des bassins, ont transformé les pratiques d'irrigation inefficaces existantes des agriculteurs afin d'améliorer l'efficacité du transport, de l'application et de l'utilisation de l'eau et de renforcer la résilience climatique des exploitations. L'étude a constaté qu'au cours des quinze dernières années, plus de 25 000 canaux communautaires avaient été revêtus au moyen de la technologie des segments paraboliques préfabriqués en béton en organisant les agriculteurs en associations d'usagers de l'eau ; des systèmes d'irrigation goutte à goutte alimentés à l'énergie solaire avaient été installés sur 20 500 hectares afin de promouvoir les cultures à forte valeur ajoutée ; près de 15 000 unités de nivellement des terres au laser avaient été fournies aux agriculteurs pour leur permettre d'agir comme prestataires de services dans les zones rurales ; et environ 4 000 ouvrages de stockage de l'eau à l'exploitation avaient été aménagés afin d'emmagasiner l'eau d'irrigation et de compléter l'approvisionnement en fonction de la demande. Au total, ces technologies d'irrigation résilientes au climat ont permis de desservir près de quatre (4) millions d'hectares de terres irriguées, situées pour la plupart dans les régions du Pendjab vulnérables au climat et touchées par la pénurie d'eau. Ces interventions ont été mises en œuvre selon un cadre de développement piloté par les communautés (CDD) et un dispositif de partage des coûts, dans lequel les agriculteurs contribuent à hauteur de 30 % du coût du projet, les 70 % restants étant versés par le gouvernement sous forme de subvention. Les études d'évaluation ont révélé que l'efficacité du transport de l'eau à l'exploitation était passée de 49 % à 68 % et que, grâce au revêtement des canaux, les agriculteurs situés en aval bénéficiaient, à leurs prises d'eau, d'un approvisionnement en eau d'irrigation supérieur de 40 % à celui des canaux non améliorés. Ces technologies d'irrigation résilientes au climat ont également accru la productivité de l'eau du blé, qui est passée de Rs.0.91 kg/m³ à Rs.1.03 kg/m³, et celle du riz, passée de 0.34 kg/m³ à 0.41 kg/m³. L'analyse de la stratégie d'exécution a montré qu'un modèle de mise en œuvre piloté par les agriculteurs et fondé sur le partage des coûts avait joué un rôle crucial dans l'adoption des technologies de résilience climatique par les communautés agricoles les plus vulnérables. L'étude conclut que les technologies d'irrigation résilientes au climat sont indispensables pour améliorer l'efficacité de l'utilisation de l'eau et sa productivité, ainsi que pour renforcer la résilience des exploitations dans les pays comme le Pakistan, vulnérables à la pénurie d'eau et au changement climatique.

Mots clés : Irrigation; Changement climatique; Irrigation goutte à goutte; Efficacité de l'eau; Irrigation résiliente au climat.

INTRODUCTION

Pakistan is an agriculture-driven and irrigation-based economy. The agriculture sector occupies a major share in the country's economic growth. It generates over one-fourth of the total gross domestic product (GDP) and employs more than 38 per cent of the labour force (GOP 2025). The irrigated cropping system encompasses over 22.5 million hectares, which accounts for over 80 per cent of the country's total cultivated area (PDS, 2025). This proportion is even larger in the Punjab province, which is called the country's agriculture hub and food basket.

Punjab's irrigated lands produce over 75 per cent of total wheat produce in the country, 70 per cent of rice, 92 per cent of maize, 65 per cent of cotton, 76 per cent of sugarcane, 97 per cent of citrus, 78 per cent of mango, and 38 per cent of guava (BOS, 2024). This substantial production is attributed to the extensive network of the Indus Basin Irrigation System (IBIS) with a command area expanding over 8.5 million hectares (BOS, 2024). At large, the Punjab is playing a critical role in the agricultural development of Pakistan under multifaceted challenges linked with water shortages and climate change.

Despite the overarching significance of the agriculture sector, Punjab's irrigated agriculture has faced many challenges during the last two decades. The key issues pertain to the decline in canal water supplies, the widespread practice of flood irrigation by farmers leading to low water application efficiency, limited adoption of efficient irrigation technologies, and climate change (Yasin et al. 2021; Young et al. 2019). Resultantly, all these challenges lead to low water productivity, which is currently around 0.8 kg/m³ for wheat compared to India's 1.06 kg/m³ and Egypt's 1.22 kg/m³ (WB, 2025). The main reason for this low water productivity is inefficient use of available water, as about 40-50% is lost during its conveyance and application at the farm (OFWM, 2023).

Notably, the irrigation challenges have been aggravated by climate change. The abrupt rise and fall in temperature and unprecedented rains have resulted in lowering the crop yields and water productivity. Pakistan has consistently been ranked among the top ten most climate-vulnerable countries during the last two decades (Eckstein et al. 2021). Climate change impacts on agriculture and irrigation have serious socio-economic implications, contributing to water and food insecurity in the region (Dilawar et al. 2021). All these climate-water issues compelled the need for transforming the conventional irrigation practices to climate-resilient and efficient irrigation technologies.

In response to the above-mentioned multifaceted challenges, Punjab has introduced climate-resilient and efficient irrigation technologies during 15 years to help farmers enhance their crop yields and water productivity. This paper will critically examine the execution framework, scope and impact of climate-resilient and efficient irrigation technologies implemented in the Punjab province of Pakistan under various development projects to enhance water productivity.

ON FARM WATER MANAGEMENT (OFWM)

Institutionally, irrigation management in Pakistan is complex. It involves multiple stakeholders across different levels. At the provincial level, the canal outlet (*mogha*) is the dividing point of administrative mandate between the Provincial Irrigation Department (PID) and the Provincial Agriculture Department (PAD). The PID mainly operates above the outlet to allocate and regulate irrigation water diverted from the rivers through the network of canals, distributaries, and minors, which is generally called 'off-farm water management'. The on-farm water management territory starts at the outlet where irrigation water enters the watercourse. Farmers operate the watercourses according to the schedule (*warabandi*) determined by the PID at the time of construction of the irrigation scheme. The farmers, however, mutually exchange their turns on a need basis. The PAD, through its On Farm Water Management (OFWM) wing, supports farmers in water conservation and adoption of modern irrigation technologies and climate-resilient practices with the aim to improve water productivity.

Punjab's irrigation network is perhaps the largest contiguous irrigation system in the world. Irrigation water is delivered to fields through a widespread irrigation network comprising rivers, main canals, branch canals, distributaries, minors, and watercourses. Almost 60% of the irrigated area commanded by the IBIS is located in the Punjab province, served through a network of over 58,300 canal outlets irrigating over 8.4 million hectares of land (BOS, 2024).

Historically, farm water management has not been an essential part of the irrigation development programs in Pakistan. The construction of watercourses and land development was included in the new irrigation scheme during the early 1980s when the authorities realized that it takes much too long for the large number of small farmers to complete these works and hence delays the realization of the full benefits of the large investments done in constructing the bulk delivery system above the farm. Moreover, constructing new reservoirs was difficult due to political and financial implications, resulting in a farm-level water conservation strategy. As a result, watercourse lining (rehabilitation) was identified as one of the major interventions for farm-level water conservation. Soon this was followed by providing support for precision land levelling technology for saving water losses during water application. Based on positive results, the OFWM Department was created in 1976 within the administrative control of the PAD to operate below the outlet and help farmers in water conservation.

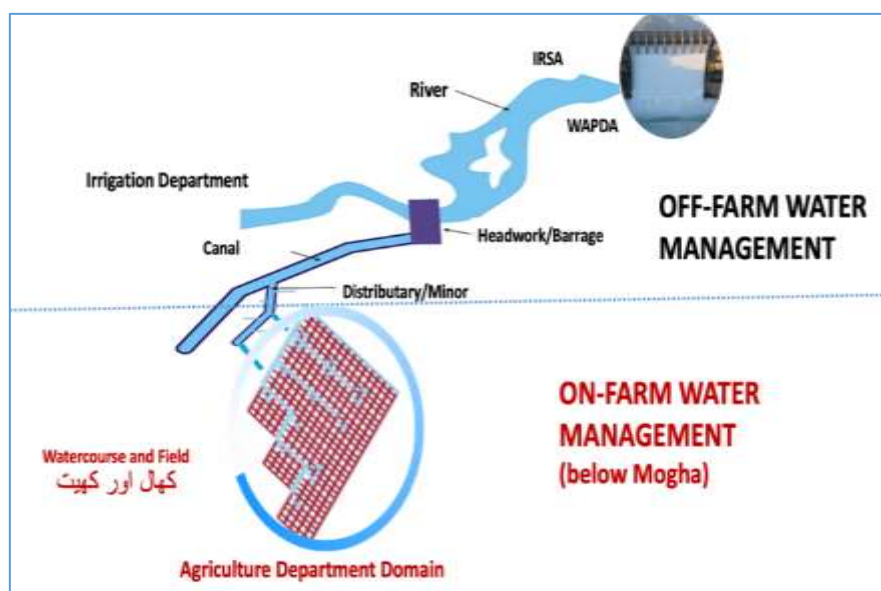


Figure 1. Operational jurisdiction of PID and PAD in Punjab, Pakistan

OFWM IMPLEMENTATION MODEL

The OFWM implementation model is based on an integrated Community-Driven Development (CDD) approach. This unique execution model acknowledges the active participation of farmers. The CDD model has four implementation partners, as illustrated in Figure 2. Under this approach, the farmers are organized by OFWM field staff into Water Users Associations (WUAs) under the legal instrument of WUA Act 1981. Farmers/WUAs procure the materials and equipment from the prequalified private sector supply and services companies (SSCs) under the technical supervision of OFWM field staff. The SSCs install the systems on farmers' fields. The consultants' role is to monitor construction and installation activities to ensure quality and verify the works as a third party. Farmers/WUAs provide execution support and also contribute financially about 30 percent of the entire scheme cost. The government provides around 70 percent cost of the scheme as financial support to farmers/WUAs for the adoption of water conservation and climate resilient technologies and practices (OFWM, 2023). This is a unique and well-accepted development model by the farmers and international development partners and financial institutions like the World Bank and Asian Development Bank.



Figure 2. Stakeholders and their key roles in the community-driven development model implemented by OFWM in Punjab, Pakistan.

The implementation of the CDD approach has resulted in many benefits, including (i) better implementation (ii) increased ownership; (iii) greater efficiency; (iv) more sustainability; (v) greater transparency and accountability; and, more importantly, (vi) empowerment through greater involvement of farming communities.

OFWM TECHNOLOGICAL INTERVENTIONS

Since its establishment in 1976, OFWM has played a key role in upgrading the farm-level water conveyance infrastructure and equipping farmers with modern irrigation technologies and climate resilient practices, together with creating an enabling environment for sustained technology transfer at the grassroots level for optimal and efficient management of available water resources. Major interventions are watercourse improvement, laser land levelling and solar-operated high efficiency irrigation systems.

Improving On-Farm Water Conveyance Channels

In Pakistan, irrigation water is supplied to fields through an irrigation channel called a watercourse, which receives water from a distributary or minor canal through a canal outlet and delivers it to farmer fields in the entire command of a watercourse in accordance with a fixed weekly water rotation schedule. One community watercourse irrigates about 120 ha (300 acres), serving around 40 farmers through an average length of 4.5 kilometres (OFWM, 2023). The average discharge in watercourses varies from 50 to 150 liters per second (OFWM, 2023).

In total, Punjab has over 58,300 watercourses with a total length of over 266,000 kilometres, irrigating over 8 million ha (21 million acres) of land in the entire province (OFWM, 2023). During water conveyance from outlet to farmers' fields, a significant portion of irrigation water (about 40-50%) is lost because of seepage, spillage, side leakage, ageing, irregular profile, zigzag alignment of banks, frequent bank cutting, and poor maintenance. The approximate current water conveyance loss from these water channels is 10 BCM (OFWM, 2023). This massive water loss can be saved through improvement and lining of critical reaches of these watercourses with modern and hydraulically efficient technologies.

Punjab has implemented various programs for the improvement and lining of watercourses from 2011 to 2025. Watercourse improvement and lining consist of completely demolishing the channel and rebuilding it according to the engineering design with clean compacted soil. Parts of the reconstructed

channel are lined, and necessary water control structures are installed to improve conveyance of the canal and tubewell water. Brick lining, being easy to install, had been used for almost three decades. However, a hydraulically more efficient, durable, climate resilient, quick in installation, and relatively more economical precast concrete parabolic segment (PCPS) technology was adapted for watercourse lining in Punjab. During the last 15 years, over 25,000 watercourses have been lined with PCPS technology through the CDD model explained above. OFWM (2023) reported that lining 50% of the length of a watercourse with PCPS results in a saving of 80% of water losses ranging from 0.2 to 0.3 cubic meter (164 to 229 acre-feet).



Figure 3. Glimpses of watercourses before and after lining/ improvement with PCPS technology in Punjab, Pakistan.

Rizwan et al. 2018 evaluated the impact of on-farm water management technologies, including watercourse lining in Punjab, and reported that watercourse lining and earthen improvements ensure about 30-45 percent water savings. This study determined the conveyance efficiency and losses of selected watercourses at each distributary were determined by measuring discharge at different points using a cutthroat flume before lining. After the lining, the conveyance efficiency enhanced to more than 95 percent and conveyance losses reduced to a minimum.

A recent study conducted by the Monitoring and Evaluation Consultants under the World Bank-funded Punjab Resilient and Inclusive Agriculture Transformation (PRIAT) Project reported a 19 percent increase in water conveyance efficiency and a 40 percent increase in water equity between head and tail-end due to watercourse lining (PRIAT, 2024). Watercourse improvement and lining have significantly enhanced the on-farm water conveyance efficiency and helped the farmers in better management of the available on-farm irrigation water supplies. OFWM (2023) reported that lining and improvement of watercourses results in a saving of about 6 BCM of water annually. Largely, the key to the success of the watercourse lining program is the WUA institution. Farmers through WUA have contributed over USD 250 million as their share in the program in addition to supervising the improvement activities.

Laser Land Levelling (LLL)

In gravity-fed surface irrigation systems, uneven and unlevelled soil surface greatly restrict the uniform application of irrigation water. It significantly affects the uniformity of water application, seed germination, plant growth and stand, and ultimately crop productivity. Traditional methods of land levelling such as animal-drawn wooden levelling and bucket-type scrapers had been highly laborious, expensive, time-consuming, and cumbersome, which involved soil movement with manually operated tractor mounted bucket-type soil scrapers and blades (Figure 4). The advent of automated Laser-controlled land levelling equipment brought innovation in levelling techniques by making the land levelling operation exceedingly accurate, cost-effective, simple, swift and easy. A Laser-guided land levelling unit consists of a transmitter, a tripod, a signal receiver, an electrical control panel, a solenoid hydraulic valve, and a bucket scraper.



Figure 4. Different land levelling technique/ technologies used over the decades in Punjab, Pakistan.

The introduction of Laser Land Levelling (LLL) has brought a revolution in Punjab's agriculture. It was initiated during 1984 by the Directorate of On Farm Water Management (OFWM). The intervention remained largely a government subsidized activity until 2006, when the government decided to upscale the LLL operation by involving private sector service providers and launched various projects. During the last two decades, OFWM has provided over 15,000 LLL units to farmers at subsidised rates. These farmers are acting as local service providers to provide rental services to the neighbouring farmers for laser land levelling of their fields. Currently, an annual capacity of laser land levelling of 5 million hectares exists in the private market.

Laser land levelling technology has transformed the land preparation operation in Punjab. It is a highly popular technology among the farmers. Laser levelled fields lead to uniform application of water and better distribution of fertilizers that improves nutrient application efficiency, leading to less usage of chemicals. Laser levelling indirectly controls contamination of groundwater also because of reduced deep percolation of water-soluble pesticides and chemicals. CGIAR (2015) commented that LLL technology is a climate-smart and sustainable farm water management intervention that enhances water application efficiency and reduces greenhouse gas emissions due to the reduction in the use of diesel and electricity and increases input efficiency.

Ashraf et al. 2017 conducted a study in the Sargodha district of Punjab to evaluate water use efficiency and economic feasibility of laser land levelling operating in the irrigated areas. This study found that about 51 percent water savings accrued from laser level fields as compared to unlevel fields in rice, wheat, and maize crops. Furthermore, crop yields from level fields were 6-10 percent more than from unlevel fields. The average water use efficiency of rice, wheat and maize in level fields was 33-38 percent higher than that in unlevel fields, whereas the net annual income obtained from level fields was 32 percent higher as compared to that from unlevel fields. Sheikh et al. 2022 revealed that laser land levelling technology reduced the groundwater abstraction and use by about 23 percent in irrigated fields in Punjab.

Solar Powered High Efficiency Irrigation Systems

Efficient water application is an important element of an integrated climate smart OFWM strategy. The application of too much water not only causes its wastage but also results in inefficient use of other inputs, e.g., nutrients, energy, labour etc. Furthermore, excess moisture in the root zone reduces soil aeration, retarding plant growth. Likewise, under-irrigation stresses the crop by constraining water availability at critical crop growth stages as well as non-water nutrients. Altogether, under or over application of water and its subsequent use led to reduced crop yields and poor quality of produce. The water application and use efficiencies may be improved through various technological interventions such as bed & furrow irrigation and high efficiency irrigation systems (HEIS).

Drip and sprinkler irrigation technologies, generally referred to as high efficiency irrigation systems (HEIS) in Punjab, are the most efficient methods of applying water to crops. These technologies are considered a paradigm shift in crop production in Punjab. solar powered drip and sprinkler irrigation systems have been promoted on over 20,500 hectares on farmer fields. Given the inflating cost of conventional fuels like diesel and considering the multiple benefits of solar systems, the government

has decided to promote solar energy for the promotion of high value agriculture. Solar coupled drip and sprinkler irrigation systems were introduced as a climate smart technology package for the promotion of high value agriculture in Punjab (Figure 5).



Figure 5. Conceptual layout of solar operated high efficiency irrigation systems

Raza et al. (2021) evaluated the solar operated high efficiency irrigation systems in Punjab and found that the installation of solar systems on 8,000 ha in Punjab has resulted in the increased adoption of high-efficiency irrigation systems, a reduction in the high operational costs incurred on account of old diesel-powered pumping systems (with an annual saving of 6.6 million liters of diesel), a 100 percent increase in farmer's income, a reduction of 17,622 tons of CO₂ emissions per annum, and 41 percent savings in water. The unit cost of PV-powered HEIS was found to be 0.1219 USD/kWh, which was 4 percent and 66 percent less than subsidized electricity and diesel costs, respectively.

IMPACT OF OFWM INTERVENTIONS

During the last 15 years (2011 to 2025), OFWM technologies have significantly contributed to transforming the Punjab's agriculture into a modern, resilient, and efficient sector. Many projects were implemented during the last 15 years to enhance the irrigation efficiency and improve water productivity. One of the major programs was the World Bank-funded Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP) implemented from 2012 to 2021, wherein improvement and lining of 13,000 watercourses were completed with PCPS technology, development of 4,500 small-scale lift irrigation outside canal commands were rehabilitated, over 5,000 laser land levelling units were provided to farmers/service providers, installation of high efficiency irrigation systems were completed on 37,000 ha, and construction of 575 on-farm water storage ponds were completed with an investment of USD 330 million on the CDD implementation model (OFWM, 2023).

The performance of the OFWM-PIPIP program was rated 'Highly Satisfactory (HS)' by the World Bank. The program had made a substantial impact in terms of water saving and enhancing farm gate water availability, improving water and crop productivity, reducing crop production input costs, increasing cropping intensity, crop diversification, and significant contribution to the rural economy. In total, the project has resulted in over 5 BCM of water savings per annum, direct benefit to 3 million ha of irrigated land and 750,000 farm families, and job creation for over 16,000 people in rural areas (OFWM, 2023). Moreover, the increase in water productivity is 192 percent, i.e. from Rs. 12/m³ (conventional system) to Rs. 35/m³ with drip irrigation (OFWM, 2023).

OFWM interventions such as watercourse lining, laser land levelling and solar-coupled high efficiency irrigation systems have modernized farm water management in Pakistan. Based on the success of these technologies, another USD 300 million project titled "Punjab Resilient and Inclusive Agriculture Transformation Project (PRIAT) is under implementation in Punjab with the objective to help farmers adopt modern climate resilient practices. During the last three years, over 4,036 watercourses have

been lined/ improved, installation of sprinkler systems has been completed on 1,666 sites, and 1,140 drip irrigation sites have been installed in the Punjab under the PRIAT project (Figure 6). These installations are resulting in modernizing the current irrigation practices and systems in the Punjab. Similarly, FAO is also implementing a project with USD 47 million in funding from the Green Climate Fund to improve irrigation systems and modernize farming practices. In total, over 51,000 watercourses have been lined/ improved, about 17,500 laser land levellers have been provided to farmers/ service providers, and installation of drip and sprinkler irrigation systems has been completed on about 40,000 ha in the Punjab.

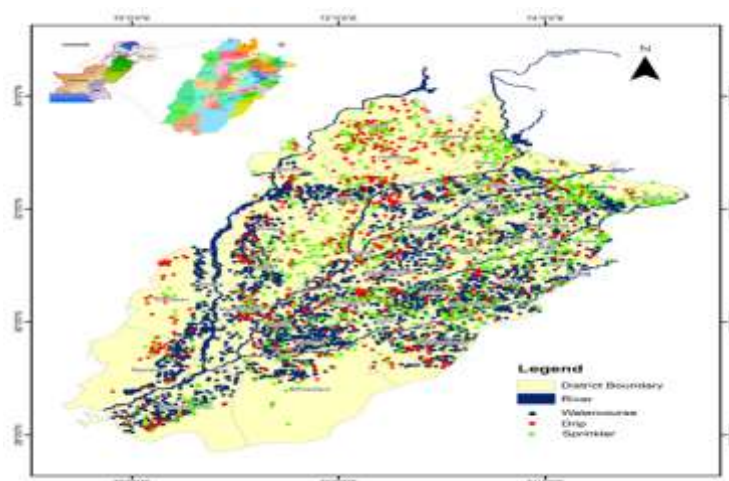


Figure 1. Footprints of OFWM interventions spread across the Punjab province

The climate-resilient irrigation technologies contributed to substantial improvements in water productivity under the PRIAT project. For wheat, water productivity increased from 0.91 kg/m³ to 1.03 kg/m³, while for rice it improved from 0.34 kg/m³ to 0.41 kg/m³. These gains demonstrate the effectiveness of the interventions in producing higher crop yields per unit of water consumed, thereby enhancing overall water-use efficiency and supporting more sustainable agricultural production under water-scarce conditions.

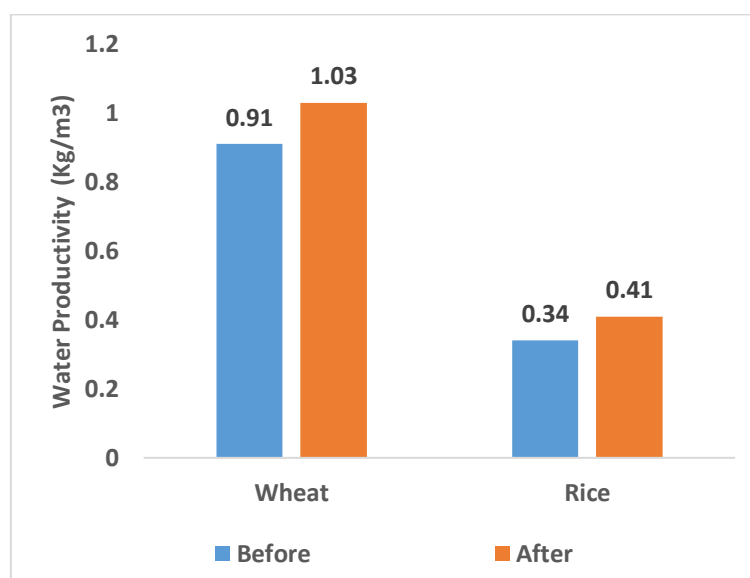


Figure 8. Water productivity

6. CONCLUSION

Water plays the most critical role in the growth of the agriculture sector in Punjab, Pakistan. The province is facing an acute water shortage and climate change challenges, significantly impacting the growth of the agriculture sector. Due to limited water storage, the strategy for increased water availability at the farm level has been through conservation measures such as improvement of watercourses, laser land levelling, and solar-powered drip and sprinkler irrigation technology. These OFWM technologies have significantly contributed to upgrading the farm-level water conveyance infrastructure, equipping farmers with climate smart irrigation technologies, and creating an enabling environment for sustained technology transfer at the grassroots level for optimal and efficient management of available water resources. The community driven development implementation model by organizing farmers into water users associations has been reasonably successful but needs more policy and technological backing. In general, the combined effect of OFWM interventions is leading to maximizing productivity and profitability of available water by minimizing water losses at various levels in order to ensure its adequacy, reliability, and sustainability at the farm level. In the wake of emerging challenges like climate change and water scarcity, the foreseen situation demands the continuity of ongoing efforts through an integrated approach based on promoting modern OFWM resource conservation technologies aimed at enhancing water productivity for a resilient and sustainable irrigation transformation in Punjab, Pakistan.

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