Promoting Water Conservation in Agricultural Practices

Immad Alam[1], Abdul Rehman[2], Muhammad Asif Khan[3], Nawab Zada[4], Aamir Shahid[5], Jehanzeb Khan Orakzai[6], Dr. Muqeem ul Islam[7]

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Abstract:

Pakistan's agricultural sector, which consumes 91.6% of the country's annual water resources, faces significant challenges in water efficiency. Despite its contributions to GDP, the sector's water productivity lags behind international standards due to traditional irrigation practices and low adoption of modern techniques. This research evaluates strategies for reducing water wastage over the next decade by adopting High-Efficiency Irrigation Systems (HEIS) and modern conservation technologies. A situational analysis highlights the inefficiencies of current irrigation methods, the financial and technological barriers faced by farmers, and the inadequacies of government support. Lessons from international best practices are analyzed, offering insights into effective policy frameworks and community-driven initiatives. Recommendations focus on enhancing governance, economic policies, and adaptive capacities, alongside shifting cropping patterns to optimize water use. The study underscores the urgency of aligning legislative priorities with sustainable agricultural water management to mitigate future resource constraints.

Key words:

Water efficiency, High-efficiency irrigation systems (HEIS), Sustainable agriculture, Water governance, Pakistan agriculture

[1] *Inland Revenue Service, Government of Pakistan, Email: immad.nust@gmail.com*
[2] *Pakistan Administrative Service, Government of Pakistan, Email: wazzie.rehman@gmail.com*
[3] *Provincial Planning Service, Khyber Pakhtunkhwa, Email: scpn1@yahoo.com*
[4] *Ministry of Finance, Government of Pakistan, Email: nawab92@yahoo.com*
[5] *Postal Group, Government of Pakistan, Email: amirshahid638@gmail.com*
[6] *Faculty Member, National Institute of Management, Email: Peshawarjanzeb@gmail.com*
[7] *Chief Instructor, National Institute of Public Administration (NIPA), Peshawar Email: muqeemci@nipapeshawar.gov.pk*

Executive summary

Water security is an important and growing challenge for Pakistan and one that extends far beyond the traditional water sector. It influences diverse aspects of economic and social development, as well as national and regional security.

Pakistan does not make the best use of its water endowment. Water use is heavily dominated by agriculture, which contributes around one-fifth of the national GDP, but less than half of this is from irrigated cropping. Irrigation contributes around US$22 billion to annual GDP. The four major crops (wheat, rice, sugarcane, and cotton) that represent nearly 80 percent of all water use generate less than 5 percent of GDP—around US$14 billion per year. Agriculture has an important, although declining role, in the Pakistan economy. It currently contributes a little under one-quarter of GDP. On an area basis, cropping is by far the dominant agricultural activity, but from an economic perspective, livestock production dominates. Livestock production uses very little water compared to irrigated cropping.

Improvements in water productivity in agriculture in recent decades have been achieved through increased fertilizer use, additional labor, and a huge increase in groundwater pumping. However, there has been little improvement in water use efficiency and very little intensification or transition toward higher-value crops. Agricultural water productivity lags well behind that of most other countries.

There are many methods of applying water to the field including traditional methods of surface irrigation such as Furrow irrigation, Basin irrigation, Border irrigation and modern High Efficiency Irrigation Systems (HEIS) such as Sprinkler irrigation and Drip irrigation. However, in Pakistan, due to low permeation of technology and financial constraints, irrigation is dominated by traditional methods leading to water losses in agricultural practices. It has therefore been proposed after critically analyzing the National Water Policy, 2018, the resource allocation towards water management, the implementation mechanisms in provinces and the cropping pattern of Pakistan that focus needs to be shifted towards adoption of High Efficiency Irrigation Systems (HEIS) and diversification of crops to conserve water in agricultural practices.

Introduction

Pakistan struggles to optimize its water resources, as evidenced by research (Young, et al., 2019). The country's water usage is predominantly agricultural, contributing approximately one-fifth of the national GDP, yet less than half of this stems from irrigated farming. Irrigation itself adds about US$22 billion annually to the GDP (Brioscoe & Qamar, 2005). However, the primary crops, namely wheat, rice, sugarcane, and cotton, which account for nearly 80 percent of water consumption, generate only around 5 percent of GDP, equivalent to roughly US$14 billion per year (Brioscoe & Qamar, 2005).

Figure 1 illustrates the proportions of water usage and the agricultural GDP dependent on water. The agricultural sector consumes approximately 91.6 percent of the total annual water usage in the country (UNDP & zuriarrain, 2016).

Pakistan has seen improvements in water productivity within agriculture, attributed to increased fertilizer application, additional labor, and a substantial rise in groundwater extraction. However, there has been little progress in enhancing water use efficiency or transitioning to higher-value crops. Pakistan's agricultural water productivity trails behind that of many other nations (Ahmad, Iftikhar, & Chaudry, 2007).

Various methods, both traditional (e.g., Furrow irrigation, Basin irrigation, Border irrigation) and modern (e.g., Sprinkler irrigation, Drip irrigation), exist for applying water to fields. However, in Pakistan, due to limited technology penetration and financial constraints, traditional methods dominate irrigation practices, leading to water losses.

Term of Reference

To evaluate how Pakistan can reduce water wastage in ten years by resorting to modern efficient technologies.

To undertake a situational analysis of current irrigation methods and their wastage, determine the extent to which certain conservation techniques are being currently used, highlight the issues faced by the farmers in accessing resources and support provided by government agencies

Analyze the existing government usage of these techniques, discuss relevant organizational structures and their technical and resource capacities, role play organizations associated with agriculture, their organizational challenges faced, provision of loans/credit on easy terms with awareness/education/training for farmers

Formulate a Plan to meet its objective. The Plan's special focus should be on implementation and sustainability.

Analyze at least two international best practices.

Discuss why the earlier steps, if any, in this direction failed and why the proposed plan can work.

Statement of Problem

The growing water demand, coupled with the impact of climate change has intensified the need for effective water conservation strategies. However, the prevalence of traditional irrigation systems in Pakistan is a threat to water conservation due to the inherent inefficient water utilization of these practices. Thus, there is a pressing need to research and identify innovative, context-specific approaches to conserve water in agriculture practices in Pakistan effectively.

Scope and Significance

i. The scope of the research is to assess the efficacy of water conservation policies in the realm of agriculture practices in Pakistan.
ii. To analyze the on-farm water management practices in vogue
iii. Suggest adoption of policies and efficient irrigation techniques based on international best practices.
iv. The study is significant because it undertakes a critical analysis of the current practices and policies of water conservation in agricultural practices and suggest improvements to the existing mechanisms and policies.

Methodology

i. A mix of Primary and Secondary Data
    a. Primary data includes interviews and a survey
    b. Secondary data includes research reports, publications, project reports and government-issued policy frameworks
ii. Situational Analysis of current water conservation policies, irrigation practices, institutional frameworks, irrigation infrastructure, water course improvement program
iii. Gap Analysis of current water conservation strategies and practices
iv. Gap Analysis of technological challenges related to the implementation of water conservation in agriculture practices
v. Cause and Effect Analysis—Adoption of HEIS
vi. SWOT Analysis of IRSA and On-farm Water Management Department, KP
vii. Stakeholder analysis of National Water Policy, 2018

Situational Analysis

Present Situation of water efficiency in agriculture

Currently, in Pakistan, we are facing close to 60% conveyance losses in the irrigation system (Young, et al., 2019). Irrigation services are not financially sustainable and financial performance is declining (Brioscoe & Qamar, 2005). Poor operational performance in irrigation continues to exacerbate waterlogging and salinization, especially in Sindh. Despite large-scale reclamation efforts, high water withdrawals and poor drainage mean salt continue to accumulate in soils and groundwater in the lower Indus Basin, affecting agricultural productivity (Young, et al., 2019).

We lose more than two-thirds of our available water resources due to poor management. For instance, there is around 25-40% water losses during irrigation application, which not only tends to exacerbate the waterlogging and salinity issues but has also significantly reduced the water productivity of major crops compared with the world average in general and neighboring countries in particular (Young, et al., 2019).

Excessive deep drainage losses inherent to conventional flooding or level basin irrigation systems are one of the main reasons for low water productivity. Adoption of border and furrow irrigation systems, relatively efficient irrigation methods, are low on Pakistani farms. Although furrow irrigation is practiced for a few row crops and vegetables in Pakistan their current management has caused irrigation efficiencies down to 50% on farms (Akbar, Ahmad, Ghafoor, & khan, 2016).

A study was conducted to evaluate the irrigation efficiencies of different surface irrigation systems on farms in Pakistan which showed excessive irrigation application of 49% to furrow bed, 63% to border, and 79% to furrow bed fields. The excess irrigation applications were lost as deep drainage because all fields were blocked at the tail ends and there was no tail drain runoff (WB, 2017).

Issues of Traditional Agricultural Practices in Pakistan

Reduced Efficiency due to Flood Irrigation

In traditional Pakistani irrigation systems, water flow to the field is controlled by temporary earthen dams that are removed to release water and then rebuilt. This constant destruction and reconstruction have weakened watercourse walls, decreased efficiency of water delivery, and required considerable time and labor.

Problem of uneven fields

When a field is uneven, farmers overwater to cover the high areas; this leads to waterlogging of the lower areas, possible increased soil salinity, and uneven crop growth.

Groundwater overdraft

The surface water scarcity has forced the farmers to abstract and even overdraw groundwater. According to a survey, 0.8 million water pumps are operating in Pakistan (Qureshi et al., 2008). The increasing number of water pumps and over extraction of groundwater has led to the salinization of almost 4.5 million ha of land, half of which lies in the irrigated lands of the Indus Basin. Due to inappropriate practices of irrigation and waterlogging from canal seepage, nearly 1 million ha of irrigated land is also affected (Qureshi et al., 2008). In the canal command areas of both Sindh and Punjab, there is a severe decline in the water table due to the overexploitation of groundwater (Bhutta & Smedema, 2007).

Small Farm Size

Farm size affects the productivity of the major crops in Pakistan (Ahmad et al. 2014a). It influences the extent to which practices are adopted and the system-scale effectiveness of these practices in terms of overall water use. Farm sizes in Pakistan are mostly less than 5 hectares. Farmers of smaller holdings tend to have less access to machinery, and being poorer, are typically less likely to be able to invest in water efficient irrigation technologies.

Present Policies for water conservation in agriculture

The major policy document in Pakistan that provides a framework for efficient utilization of water usage in Pakistan is the National Water Policy, 2018 issued by the Ministry of Water Resources. The key highlights of the policy framework are given below.

- The concept of "More Crop Per Drop" shall be pursued.
- Modernization of irrigation network
- The concept of participatory management of irrigation.
- Groundwater table shall be so managed that it does not impede crop growth or causes land salinity or underground saltwater intrusion.
- The Water Apportionment Accord of 1991. IRSA has to implement the Accord in letter and spirit as per provincial share stipulated in the Accord.
- Equity of water distribution between head and tail reaches shall be ensured.
- Use of treated sewage shall be promoted for non-edible crops
- Irrigation facilities shall be extended to new culturable command areas.
- Rain-fed areas where groundwater is available at relatively shallow level, will be given preference for solar pumping.
- Provincial governments would be encouraged to prepare large scale programs of rain water harvest ponds and mini dam construction in rain-fed areas

Legal Frameworks

i. The PCRWR Act (2007) outlines a clear national mandate for water research and analysis.
ii. Water Apportionment Accord (WAA) was signed amongst the Provinces on 16.03.1991 and IRSA was established for regulating and monitoring the distribution of water sources of Indus Rivers in accordance with the Accord

Institutional Framework

i. At the Primary Level in Pakistan, Ministry of Water Resources works on the development of water resources in the country and manages Indus Water Treaty, WAPDA, the Indus River System Authority (IRSA), and transboundary water organizations. WAPDA is responsible for construction of dams as well as the main canals from dams.
ii. At the Secondary Level in Provinces, the respective irrigation departments are responsible for management of secondary canals and construction of small dams
iii. At the tertiary level On Farm Water Management Departments in the Provinces are responsible for water course management and conveyance of water from canals to fields.

Critical Analysis and Evaluation of Existing Policies and Policy Documents

Involvement of Stakeholders

The NWP has little to say about the operational functions of WAPDA and IRSA, except to note the need to revitalize WAPDA and strengthen IRSA's role in real-time monitoring. The policy highlights the importance of financial sustainability for provincial irrigation operations and the role of technology to improve operational efficiency and effectiveness.

Design of Implementation Strategies

Pakistan's policies regarding water conservation in agriculture is facing the issue of implementation because the subject has been devolved to the provinces. Water resources are not included in the enumerated federal list of the 1973 Constitution of Pakistan; water management is largely, therefore, the purview of the provinces. Two areas fall within federal jurisdiction: interstate water disputes and policy setting for water and power development, as originally covered by the Water and Power Development Authority Act (1958). Article 155 of the Constitution includes a dedicated procedure in case of water allocation disputes. Disputes may be referred to the Council of Common Interests for decision, and it is the legal duty of federal and provincial governments to honor the council's decision. This provision was used for the approval of the 1991 Water Apportionment Accord. The Water Apportionment Accord was signed in 1991, and in 1992 the Indus River System Authority (IRSA) was established by federal legislation to implement the accord. Although the accord was a major step in interprovincial water sharing, little progress has been made since in resolving important ambiguities, particularly concerning the initial conditions.

Critical Analysis of Existing Implementation Strategies

Issues with Federal PSDP Allocation Towards Water Management

i. Comparison of the Federal PSDP allocations over two decades (Fig 2) indicate that allocation saw a 21% increase in the second decade. This 21% increase appears to be small and incompatible with the scale of interventions required for upgrading existing and constructing new irrigation water infrastructure for meeting targets of the National Water Policy, 2018. (FAO, 2018)
ii. No consistent pattern of yearly allocation is observed over two decades in the Federal PSDP (Fig 3). The observed increasing and decreasing trend in the federal PSDP allocations is inconsistent and based on short term planning, driven by urgent needs to revive projects of national importance such as raising and extension of major reservoirs (Mangla and Tarbela dams), construction of Diamer Bhasha, and Mohmand dams and construction, upgradation and remodeling of large canals.
iii. Weak institutional set up for implementation of national water policy and insufficient financing of the major infrastructure projects are two major barriers to implement targets of the national water policy.

This is evident by the fact that within the last three years only a single meeting of the National Water council is held. Furthermore, the nomination of five private (technical) members of the council are still pending

iv. After approval of the National Water policy in 2018, the funds allocation for large, medium and small dams have been increased substantially from 10.5 billion in 2017-18 to 84.14 billion in 2019-20. The statement is true that National Water Policy has been instrumental to a great extent towards increased allocation for new storages. Overall, at the national level, Canal extension and improvement is the highest National water priority and received PR 396 billion 43% of national agriculture water allocation, from the combined federal and provincial allocations

v. An allocation of PKR 282 billion to the agriculture on farm water management, is giant step to improve water efficiency at the National Scale. However, there is little evidence that benefits of the investment on lining of water courses outweigh the cost.

vi. The On-Farm Water Management Program is highly inclined towards lining of water courses. This is debatable whether the investment on lining of water courses can substantially result in water savings. Seepage losses are controlled but studies show that that in Pakistan almost 43.5% of the water losses still occur in lined watercourses and 66% in unlined water course. In addition to that research studies on economic productivity of water in various agroecological zones are needed, to harness full benefits of agriculture water.

Stakeholder Involvement, Impact and Engagement in Policy Design

The National Water Policy 2018 provides for the formation of two bodies incorporating the major stakeholders involved in conservation of water in agricultural practices.

National Water Council

A national body named as “National Water Council” (NWC) shall be established with the following composition:

1	Prime Minister of Pakistan	Chairman
2	Federal Minister for Water Resources	Member
3	Federal Minister for Power	Member
4	Federal Minister for Finance	Member
5	Federal Minister for Planning, Development & Reform	Member
6	Chief Ministers of Provinces	Members
7	5 Private sector members from water related disciplines	Members
8	Secretary, Ministry of Water Resources	Secretary

Steering Committee

A Steering Committee on water will assist the NWC by ensuring inter-provincial coordination and reviewing policy papers and monitoring reports before submission to NWC. The composition of the Steering Committee will be as follows:

Lack of Involvement of Farmers

1	Federal Minister for Water Resources	Secretary
2	Secretary Ministry of Water Resources	Member
3	Secretary, Ministry of Power Secretary	Member
4	Secretary Ministry of PD & Reform Secretary	Member
5	Secretary Ministry of Finance	Member
6	Chairman WAPDA	Member
7	Chief Engineering Advisor	Member/Secretary
8	Chairman NDMA	Member
9	Surveyor General of Pakistan	Member
10	Chairman Pakistan Engineering Council	Member
11	Provincial Irrigation Secretaries	Member
12	Secretary (Works), PWD, Govt. of Gilgit-Baltistan ACS Fata Secretariat	Member
13	ACS FATA Secretariat	Member
14	Secretary, (Irrigation & Small Dams), Govt. of AJ&K	Member

Lack of Involvement of Farmers

These two committees cover almost all the major stakeholders related to water conservation in agricultural practices. However, the absence of representation of farmers and land holders who ultimately execute the water conservation strategies at the farm level are absent from these committees. Therefore, even if policies are made for on ground execution to conserve water in agricultural practices, due to the absence of farmers and their input, such policies may not find adoptability at practical stage.

Performance of Institutional Frameworks for Implementation

To implement the policy of conservation of water in agricultural practices two major implementation strategies have been adopted by the Agricultural Departments of the Provinces

National Program from Improvement of Water Courses- Phase II

The Project aims to replicate the success achieved in National Program for the Improvement of Watercourses Phase-I and to enhance the agriculture growth in Pakistan. The broad objectives of the proposed project (NPIWC-II) are the social mobilization through capacity building of Water User Associations (WUAs), minimize the water conveyance and on farm water application losses, reduction in water logging and salinity, equity in water distribution, reduction in water distribution disputes, reduce the poverty through employment generation in agriculture sector and to increase the crops yield.

Project Components

1. Organization of Water Users Associations
2. Improvement of Watercourses
3. Construction of Water Storage Tanks
4. Provision of Laser Land Levelers

Project Outputs

1. Mobilization through capacity building of Water Users Associations.
2. Reconstruction/renovation and remodeling of 47,278 watercourses, involving complete earthen renovation, partial lining of critical reaches and installation of water control structures.
3. Construction of 14,932 water storage tanks with 60% subsidy,
4. Provision of 11,610 Laser Land Levelers at 50% cost sharing, with the expectation to save about 50% of irrigation water for wheat and about 68% of irrigation water for paddy.
5. The impacts of the project are given in Table 4,5 and 6

Critical Analysis

- Involvement of Water User Associations as stakeholders to encourage community participation
- Due to the 80:20 sharing model, the project encourages ownership of the infrastructure by the farmers
- Lack of interest of upstream farm owners
- Extra pressure from tail end users of water ways for improvement
- Major focus of improvement is at the tertiary level. However, it is more convenient and easier to focus on improvement at the secondary level to reduce conveyance losses
- Returns to investment on improvement on water ways vis-à-vis improvement in crop productivity is debatable
- Total Cost of the Project is 46.2 Billion whereas the total economic benefit from water saving was estimated at 2.3 Billion

Provision of High Efficiency Irrigation Systems (HEIS) on Cost Sharing (Subsidy)

Punjab

Under these arrangements, the government offers a subsidy of 60 percent of the installation cost for HEIS on up to 15 acres of land. The remaining costs are then covered by the beneficiary farmers. In addition to the system installation subsidy, the government also provides a subsidy of 60 percent of the scheme cost for constructing a water storage pond, if it is deemed necessary based on site-specific technical requirements. The decision to construct a water storage pond considers factors such as water availability, topography, and irrigation needs.

Khyber Pakhtunkhwa

The On Farm Water Management Department KP is providing subsidy to farmers for installation of HEIS with the help of World Bank Funding. The project supports installation of HEIS's such as drip, trickle, bubbler or sprinkler irrigation systems, primarily for high-value crops. These systems will be installed by a service provider on a shared-cost basis to crowd in private investment in these technologies. Farmers would provide 40 percent and the project 60 percent. Drip units would include a pumping unit, fertilizer tank, delivery fittings, filters, underground main pipeline, and delivery lines, etc. HEIS would be installed on at least 10,000 acres on a first-come-first served basis.

Sindh

The project that is being funded by the World Bank supports installation of HEIS drippers and bubblers for growing high value crops on irrigated and irrigable land; provide technical assistance packages to farmers on operations and maintenance of HEIS; and provide additional training and assistance to farmers in the use of HEIS by specialists and consultants. Approximately 2,600 HEISs will be installed on 14,300 ha (35,000 acres) of irrigated and irrigable land. HEIS' will be provided (on demand) to the farmers on a 40 percent cost sharing basis. They will be installed by Sales, Supply and Service companies (SSCs) who will also provide a technical assistance package for the farmers in operation and maintenance of the system. Additional training and assistance will also be provided by the HEIS specialist in the field teams assisted by the technical assistance and training (TAT) consultants. Directorate General Agriculture Engineering &Water Management will have the overall responsibility for implementing the project.

Balochistan

An incentives methodology implemented in which the construction of a storage tank will be provided (as a grant under the project) in return for the installation of HEIS over the maximum productive command area. Farmers will also be encouraged to allow installation of water meters to demonstrate water saving with no depletion in growth rates or yields.

The project will require beneficiaries to contribute to the capital costs and to the operation and maintenance (O&M) costs of all development works. Whilst beneficiaries would contribute 100 percent of all O&M costs, they would contribute 10 percent towards scheme costs, comprising cash equivalent to 2 percent of the capital cost, contribution in the form of labor at 8 percent of the capital cost. The FO Contract will be overall 25 percent (value) of the capital cost. Overal1, this will be equivalent to 25 percent of the scheme development costs.

Critical Analysis

- Despite provision of subsidy, the HEIS systems are still expensive for farmers to afford
- Due to lack of technological knowledge at the farmer level, the systems

are difficult to operate

- After installation services and O&M services of these systems make it unaffordable for the farmers at later stages
- Due to lack of technical knowledge of line departments involved, the O&M services are outsourced to private firms which inflates the cost for the farmer
- There is a need for capacity building of line department staff to offer services which can reduce the maintenance cost for the farmers

Monitoring Report of Promotion of High Value Agriculture Through Solarization of Drip & Sprinkler Irrigation Systems (Revised)

Project Objectives

i. Reduce the operational cost of high efficiency irrigation system
ii. Enhance crop and water productivity by through optimal use of water and non-water inputs by application of modern climate smart technologies
iii. Promote use of solar energy on in agriculture for promoting irrigated agriculture in remote areas
iv. Build farmers' capability at grassroots level for growing high value crops to get higher farm returns for alleviating poverty.
v. Create job opportunities in rural areas through introduction of climate smart technologies for high value irrigated agriculture

Observations

i. Promotion of High Value Agriculture Through Solarization Of Drip & Sprinkler Irrigation Systems (Revised) is a project that has been completed as far as the physical progress is concerned so its evaluation should be planned and department should submit its PC-IV.
ii. Agriculture Extension department may have played an important part in the sustainability of this project but there is a lack of coordination between Agriculture extension and Water Management Department
iii. Data Management of the Projects was not up to the mark and there were several anomalies found during analysis of Data which may not be according to the Farmer Criteria.
iv. Impact calculation of the project was not done neither a mechanism is devised for that process
v. Feedback from famers was not included in the project. A survey or the criteria may need to establish.
vi. Focus on Training & Development part was not included in this project which may lead to the sustainability challenges of the project.
vii. The quality control plans, quality check lists and methodologies were not available.

SWOT Analysis (on Farm Water Management Department, Punjab)

Strengths

Close proximity to Farmers and end users: The OFWM comes into close contact with farmers through WAUs which allows them to have feedback and propose solutions that are rooted in application

Government Support: The OFWM operates under the Agriculture Department of Punjab, benefiting from strong government backing and policy support. The Punjab government has allocated significant funds for water management projects in agriculture, such as the construction of watercourses and farm ponds. Out of total National Allocation for Agriculture Water Management, 31% share goes to on farm water management.

Technical Expertise: The wing has access to a pool of agricultural experts and engineers who provide valuable technical guidance and support to farmers. The Agriculture Department conducts regular training programs and workshops for farmers on modern irrigation techniques and water-saving practices.

Research and Development: The wing conducted research studies to explore innovative water management strategies and technologies suitable for local farming conditions.

Weaknesses

Data Unavailability: Insufficient data on water usage and agricultural practices may hinder evidence-based decision-making and program evaluation. There is a lack of comprehensive data on water usage patterns and crop water requirements, making it challenging to formulate targeted water management strategies.

Dependence on Foreign Funded Projects: Most of the HEIS projects are funded by World Bank and Asian Development Bank and hence there is a dependence on foreign loans which can become hindrances once these loans are not available.

Opportunities

High Percentage of conveyance losses in water courses: At present, Pakistan's tertiary level water courses suffer from a high-level of conveyance losses. This provides an opportunity to the organization to intervene and improve efficiency of water in agriculture

Low permeation of HEIS among farmers: At present, farmers in Pakistan are mostly deploying traditional irrigational methods. This is an opportunity for the organization to promote the use of HEIS among farmers to improve water conservation in agricultural services.

Government adopting the policy of More Crop Per Drop: The government through its NWP, 2018 puts emphasis on the policy of More Crop Per Drop which is an opportunity to improve water use efficiency in agriculture.

Decreasing Water Availability: Per Capita water availability in Pakistan is declining which makes it vital for the organization to intervene and allow the farmers to adopt efficient irrigation systems.

Threats

High Cost of HEIS: Adoption of HEIS is extremely important to improve water conservation in agriculture. However, the technology is expensive which is a threat to adoption

Low Technological understanding of farmer: Generally, farmers in Pakistan have a low technological know-how. This is a threat to the objectives of the organization to improve water conservation through adoption of HEIS.

Technological Challenges Related to Implementation

Electricity Availability

Study analysis showed high influence (31.51%) of this factor. Pakistan is facing severe electric power crises. Available and affordable power is basic need to operate this technology. During survey, adopters of this technology explained that they had installed the system but unfortunately, due to lack of electric power they were unable to operate it. They further pointed out that other power sources like diesel engine and tractors etc. cannot be used because of their high operational cost. If government offers proportional electricity price to farmers then adoption of high efficiency irrigation system can be enhanced (Kumar, 2005).

Technical Assistance

Training facilitates farmers to use technology more efficiently, training of water conserving Irrigation positively associated with adoption (Ribeiro Fabiana et,al, 2015). Field survey showed that respondents were disappointed due to lack of technical knowledge which is very important to operate a newly introduced technology. Technology users also claimed that right after the project installation government and supply & services companies should provide adequate training so that

Cost

Average land holding in Pakistan is 6.4 acres (Economic Survey of Pakistan). Average farmers have very small land size and limited financial resources. Farmers with larger land holdings do not have financial issues so they can easily adopt high efficiency irrigation system (Putler and Zilberman 1984). Due to high initial cost many small farmers are powerless to afford such kind of projects. During survey, farmers showed up this factor with 16.73% effect. The average cost per acre for installation of sprinkle irrigation is Rs. 200,000 compared to Rs. 30-40,000 for traditional irrigation methods.

Area/Farm Based Subsidy

Subsidy is financial support to any economic sector (department/institutions/individual) to promote policies (Myers, N.; Kent, J. (2001). During study data collection farmers communicated that government should provide area/farm size-based subsidy.

If one farmer had 25 acres of agriculture land, then he should give low subsidy as compared to a farmer owned 5-acre land because of small farmers' low financial resources.

Lack of Reliable Information

During the survey at district level, author came to know that many farmers don't know about this technology. Newly introduced technology adoption depends on farmer's specific time information towards this technology (Besley and Case 1993; Foster and Rosenzweig 1995; Conley and Udry 2010). No doubt, government of Pakistan is contributing in cost of project in form of subsidy but there is a huge need to market this project.

In Competencies of Supply & Services Companies

Farmers and other technology adopters also claimed that project execution team needs to improve their technology designing and installation expertise as farmers faced problems just after the installation of project. Not only is this but mostly project team members were unable to troubleshoot the problem. Timely irrigation to crops is very important for better production but due to late/delay in technology installation crop sowing time is greatly affected, ultimately leads to low production.

Non-Availability of Spare Parts

Farmers highlighted that advanced irrigation system consisted of many small parts. In case of a little fault/change of drippers they are unable to buy these parts because of their non-availability in local markets. This leads to delay in field irrigation.

Comparative Efficacy Analysis of Different Irrigation Techniques in Pakistan

Irrigation System	**Crop**	**Results**	**Reference**
Sprinkler vs. surface irrigation	Rice and wheat	Sprinkler was better (Rice produced 18% more yield)	Kahlown et al., (2007)
Rain gun sprinkler vs. surface irrigation	Corn fodder	Rain gun was better (34.52% of water saving)	Iqbal (1994)
Furrow vs. sprinkler vs. drip irrigation	Cotton	Cotton yields, Drip (4380 kg/ha) furrow (3630 kg/ha) sprinkler (3380 kg/ha) Drip irrigation produced 21% more seed cotton than the furrow method and 30% more than the sprinkler method.	Cetin (2002)
Furrow (conventional) vs. Drip.	Corn	Water used for irrigation Furrow irrigation (547- 629 mm/ year) Drip irrigation (371- 428 mm/ year)	Nazirbay et al., (2005)
Drip and furrow irrigation.	Tomato	Water savings Drip irrigation (56.4%) 22% more yield than furrow irrigation	Tagar et al., (2012)

Drip irrigation vs. furrow irrigation	Cotton	Increased seed cotton yield, yield components, water saving (53.3%) and water use efficiency (7.9 kg ha-1 mm-1) was obtained under drip irrigation system as compared to furrow irrigation system.	Muhammad et al., (2010)
Under plastic tunnel drip and furrow systems.	Tomato, cucumber and bell pepper	The average water use efficiency in drip irrigation was Tomato (250%) Cucumber (274%) Bell pepper (245%)	Musa et al., (2014)
Line planting under basin irrigation, Ridge planting and planting under furrow irrigation.	Maize	Ridge planting was superior to furrow irrigation and basin irrigation with regard to average water use efficiency	Kori et al., (2017)
Comparison between Trickle irrigation, Rain gun sprinkler, Border irrigation and Furrow irrigation were made.	Cotton	Water saved under furrow. Rain gun sprinkler (14.26%) and trickle irrigation (34%) compared with border irrigation method.	Waheed-uzZaman et al., (2000)
Basin, furrow and rain gun sprinkler systems.	Sunflower	Using rain gun sprinkler irrigation system, 30.8% and 28.3% higher water use efficiency and 21.1% and 9.0% more water application efficiency was achieved as compared to basin and furrow irrigation system, respectively	Rana et al., (2006)
• Precision land levelling • Bed planting • Drip irrigation	Wheat, rice and cotton	Crop sown on precisely levelled land resulted in saving of 2768.1 million m3 and 3699.3 million m3 of irrigation water Drip irrigation enhanced the yields by 30- 40%.	Rizwan et al., (2018)
Furrow irrigation system vs. flood irrigation system.	Kinnow mandarin	Furrow irrigation average water saving (46.14%) and water use efficiency (4.58 kg m3) flood irrigation WUE (2.34 kg m-3)	Raza et al., (2021)

Economic and Financial Analysis

Category-wise PSDP Allocation for Agriculture Water Management

The category wise analysis reveals that (Fig 7), overall, at the national level, Canal extension and improvement is the highest national water spending priority (43% of national agriculture water allocation), followed by on-Farm Water Management (31% of national water allocation) and lastly construction of dams (26% of national water allocation).

Economic Impact of Cropping Pattern in Water Conservation

Given the crop irrigation demands and areas typically grown, rice consumes around 32 percent of the water, wheat and cotton both consume around 25 percent and sugarcane 18 percent. Around half of the rice crop (and 5 percent to 10 percent of the sugarcane crop) is exported, thus presenting a very significant virtual water export. Growing low productivity paddy rice for export in an arid, water scarce country does not make good economic sense. Reforms and investment are required to move this water to higher-value crops (fruit and vegetables) for export and to meet the growing domestic demand.

While a diverse mix of crops is grown in Pakistan, around three-quarters of the area and two-thirds of the value comes from two food crops (wheat and rice) and two cash crops (sugarcane and cotton) (Ahmad, Iftikhar, & Chaudry, 2007).

Cotton

The blue water footprint of cotton in Pakistan is around double the global average; conversely its blue water productively (weight produced for given volume of irrigation water) is around half the global average. Around a quarter of the groundwater depletion in Pakistan is associated with agricultural exports, of which cotton represents a significant fraction.

Wheat and Sugarcane

Mekonnen and Hoekstra (2011) review agricultural water footprints by country. They show the blue water footprints for wheat and sugarcane (raw sugar equivalent) in Pakistan are around four times the world average, Pakistan ranks second highest in the world for the blue water footprints for wheat and sugarcane (raw sugar equivalent), and seventh highest for rice.

Rice

Mekonnen and Hoekstra (2011) show that blue water footprints for rice is more than six times the world average. Pakistan ranks seventh highest in the world for the blue water footprints for rice.

Ultimately, while both cotton and rice are major export earners for Pakistan, the water performance of these crops is very poor compared to that of other countries; combined, they account for well over half the total irrigation water use of Pakistan. For a water scarce country, directing over half of the water used to water-intensive crops that are not essential for domestic food security and that deliver comparatively poor economic return is not a good long-term option.

Comparison with International Best Practices

North China Plain Water Conservation Project (2008) (Bank, 2008)

Outcomes:

Increased water productivity and reduced consumptive use.

i. The value of agricultural production per unit of water consumed increased in the range of 60 to 80 percent throughout the project area;
ii. non-beneficial water consumption was reduced by a sixth.
iii. Agricultural production tripled and farmer per capita incomes increased between 10 to 554 percent.
iv. About 360,000 households were among the project's beneficiaries.
v. Annual water savings averaged 1,200 m3/ hectare.
vi. More sustainable groundwater use.
vii. Across most of the project area, groundwater depletion was reduced to negligible levels or eliminated.
viii. Adaptable institutional arrangements supported groundwater recovery, with priority given to providing farmers with incentive packages linked to reductions in water consumption. County-level groundwater management plans were piloted in four counties.
ix. Strengthened institutional arrangements for irrigation system operation and maintenance. The original project target was 100 water user associations (WUAs), but more than 500 were established, covering about two-thirds of the project area. Women's participation was estimated at 30 to 40 percent, and they were regularly elected to association committee posts. For the first time on this scale in China, WUAs assumed responsibility for both financing and operating irrigation systems.
x. Water charges. Volumetric water charges were initiated for about 62,000 hectares, 110 percent greater than the target area. Progressive increases in water charges typically rose from the relatively low pre-project baseline by a multiple of three to four times above appraisal targets.
xi. High benefits. The economic analysis suggested that the project achieved an overall rate of return of 24 percent, higher than the appraisal estimates of 21 percent.

Lessons Learned

The project successfully focused on new approaches to finding an appropriate mix of technical and institutional changes that reduced agricultural water consumption while at the same time benefiting the agricultural sector. Among the lessons are:

i. Development of WUAs. The success of the WUAs stemmed from two organizing principles: (a) democratic self-organized associations based on hydraulic boundaries, and (b) water measuring, with corresponding water charges on a volumetric basis.
ii. a flexible approach and adaptation to local conditions; the inclusion of farmers from the beginning in sub-project design; transference of control for water structures to WUAs; and the active support of both the Ministry of Water Resources and local governments.
iii. Importance of economic incentives. Approaches to water savings in agriculture are more likely to succeed if appropriate incentives are given to farmers to modify their practices.
iv. Monitoring and evaluation for technical innovations. Appropriate monitoring and evaluation system are necessary to verify the efficacy and efficiency of integrated water-saving measures in agriculture, and to share the information with water user associations.

Egypt Case

Different examples of water conservation campaigns in Egypt.

a. Volunteers clear the banks of the Nile River of plastic waste.
b. Conversation with public inhabitants about water conservation importance in Delta villages.
c. Spreading awareness among young students through artwork.
d. National Competition for Water Conservation for Primary Schools organized by the Ministry of Education and Technical Education and the Ministry of Housing, Utilities, and Urban Communities represented at the Holding Company for Water and Wastewater in cooperation with the European Union in Egypt.
e. Capacity building session for farmers to enhance their efficiency by utilizing the best practices in modern irrigation to ration water consumption, funded by the European Union in Egypt.
f. National Competition for Water Conservation for Farmers applying modern irrigation systems organized by the Ministry of Water Resources & Irrigation in cooperation with the European Union in Egypt.
g. Previous campaigns in lacked the concept of public participation in planning strategies and led to landscape degradation and detachment of inhabitants from the waterways' surrounding environment.
h. Therefore, creative planning of water conservation campaigns in Egypt, along with sustainable water management, urban planning, and landscape design supporting the implementation of different SDGs, is vital for decreasing the continuous degradation of waterways in Egypt. (Sara S. Fouad a b, 2023)

Israel Case

Innovating Drip Irrigation

Israel has developed several systems to save water. The drip irrigation system, invented in Israel, that has become known worldwide, is responsible for 90% of agricultural irrigation (Staff, 2024). Today, 80% of Israel`s wastewater is treated and reused for agricultural irrigation. The goal is to reach 90% in five years, representing 400 million cubic meters a year from wastewater alone. Another 150 million cubic meters of mainly salty water is pumped out from faulty aquifers. Rainwater is caught and stored in reservoirs in winter and used in the summer for irrigation (Staff, 2024). Desalination is yet another facet of Israel's water strategy. More than 360 million cubic meters of water a year are desalinated in Israel, representing about 50% of the municipal drinking water in use.

Gap Analysis

Sr.#	Current	Intervention	Desired
1	Low irrigation efficiency causes water logging and salinity problems that decreases cultivable area	Decrease conveyance and application losses through HEIST	Efficient irrigation system with minimum seepage.
2	Pakistan irrigation system is not self-sustainable due to irrational pricing system where only 20% of the operational and maintenance cost is recovered through abyana.	Rationalizing abyana	A sustainable irrigation system that is at least on break even stage. Pricing must be based on water usage on volumetric basis
3	Negligible number of water logging and salinity resistant variety development for water logged areas	Strong Liaison with agri research system	A range of variety development for different regions in various crops to use the water-logged area in agriculture production.
4	Equipment for water efficient technology are not locally assembled/produced	Training of On Farm Water Management Department regarding installation of equipment	All equipment to be assembled locally to increase its affordability.
5	Current conveyance and application losses accounts for 60 % losses	Improvements in water courses and water application techniques	Decreases all types of losses to minimal
6	No treatment plant employed for recycling of drainage water to be	Installation of drainage water treatment plants	Recycling of drainage water for re-use in irrigation

	reused in irrigation system		
7	Flood irrigation techniques	Provision of Agri-credit to farmers Public awareness Demonstration plots	High Efficiency Irrigation System
8	No regulatory frame work for underground water utilization which results in underground water depletion.	Government to draw legal framework	Ground water extraction to be regulated to ensure water table at respectable levels.
9	80% of water is used by four water intensive crops that contributes to 5% of GDP.	Increasing cropping intensity New cropping patterns	Efficiently utilization water resources to increase their contribution to GDP.
10	Limited availability of water reservoirs in rain-fed areas	Provision of Agri-credit facility to land owners of barani land	Construction of numerous small reservoirs/dams to ensure water conservation and availability for irrigation

Issues and Challenges in conservation of water in agricultural practices

1. Cropping pattern of Pakistan is dependent on high water consuming crops which are not essential for domestic food security and that deliver comparatively poor economic returns.
2. There is little attention given to development of drought resistant and salinity resistant crop varieties.
3. Almost 60% of Pakistan's agricultural water is lost in the canals and water ways during conveyance to the field
4. The current irrigation practices employed by the farmers have high water wastage and low yield.
5. HEIS are expensive to deploy which discourages the farmers from adopting them.
6. Farm sizes in Pakistan are small which also poses a challenge to adoption of HEIS.
7. The staff at On Farm Water Management Departments are not trained to provide operation and maintenance services for HEIS to the farmers.
8. Government is directing most of its budget to improvement of water ways and there is little focus on subsidizing HEIS.

9. The surface water scarcity has forced the farmers to abstract and even overdraw groundwater which is causing salinity issue.
10. The farmers in Pakistan do not have sufficient knowledge of technology utilization to adopt HEIS and promote water conservation.
11. Issue of electricity availability is a hindrance in adoption of water conserving technologies at the farm level
12. Less focus on impact analysis of projects of water conservation which reduces the efficacy of future planning.
13. There is no representation of farmers in the NWP, 2018 National Water Council
14. Federal PSDP allocation is not enough to meet the objectives on NWP, 2018.
15. The observed increasing and decreasing trend in the federal PSDP allocations is inconsistent and based on short term planning
16. There is little coordination among Primary, Secondary and Tertiary Level government agencies dealing with water conservation.

Conclusions

1. Although the National Water Policy, 2018 announced by the government is a step in the right direction, it faces a big challenge to its implementation due to the financial constraints as well as the misdirected priorities of the government which needs to focus on adoption of HEIS
2. While Pakistan's major agricultural export revenue is from cotton and rice, pursuing this policy of export is not necessarily water efficient and it delivers comparatively poor economic returns.
3. Involvement of Water User Associations and community participation model adopted by the government has led to positive outcomes in improvement of water ways. the same model can be adopted for improving HEIS usage among farmers.

Recommendations

Enhance the legislative foundation for water governance

a. Update the 2018 Water Policy to include HEIS in agri as a priority
b. Drafting a legal framework to enforce water conservation in agri practices

Strengthen national and basin water governance

a. Target setting for water conservation by provinces in liaison with
b. PCRWR
c. Achievement of targets to be ensured by a national water council.
c. Strengthen existing river basin commissions.

Improve and optimize economic policy instruments

d. a. Adequate allocation in PSD towards agriculture water management

d. b. Diversion of resources towards the adoption of HEIS

Strengthen adaptive capacity to climate and environmental change

a. Strengthen resilience to floods.
e. Development of drought-resistant crop varieties

Improve data collection and information sharing

a. Enhance the R&D capacity of PCRWR and OFWM
b. Create a National Water Information Sharing Platform.
c. Strengthen the role of public awareness and participation

Diversification of Pakistan's cropping pattern

a. Shift towards high revenue-yielding crop varieties
b. Focus on less water-intensive crops

Operational Plan

	Project Summary	Indicators	Verification	Risks
Goal	Achieving Significant Conservation of water in Agricultural Practices within 3 years	Degree of increase in installation of modern irrigation techniques	Local manufacturing of equipment for HEIS	Upfront investments
Outcome	1. Improved water table 2. Reduced water wastage	3. Reduced water scarcity for other sectors	PCRWR Reports	1. Climate Change 2. Population Explosion
Output	Increase in CCA	1. High yield per acre 2. Improved quality of yield	3. Increased Net Production 4. Increased GDP contribution	5. Drought spell 6. Soil degradation
Activities	1. Awareness among farmers about the efficient irrigation	3. Number of sessions conducted by	1. Feedback & demand from WUAs to OFWM 2. Feedback from SBP	1. Farmer`s resistance to Change 2. Complicated

	systems in 1st year 2. Arrangement of Farm Credit for adoption of HEIS	authorities 4. Volume of Credit disbursed	regarding credit facility	Procedures of Banks

Appendix

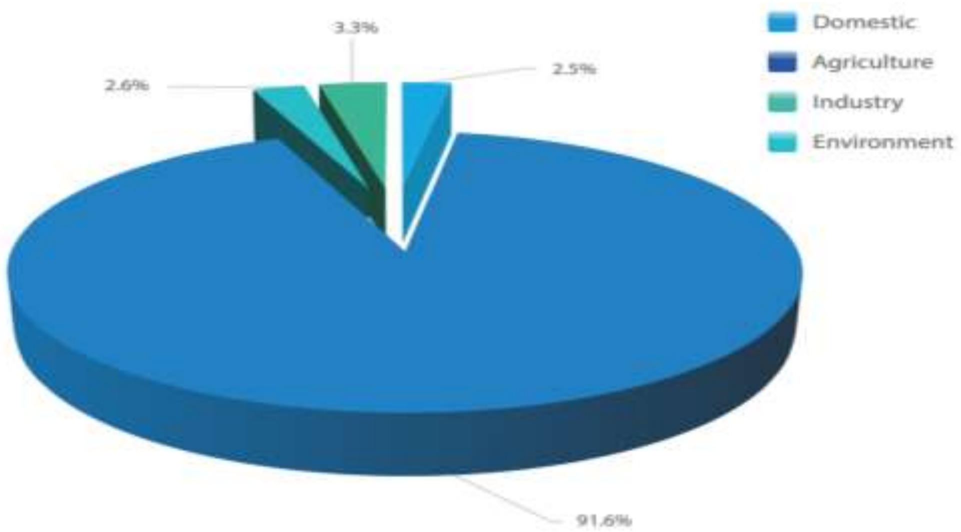
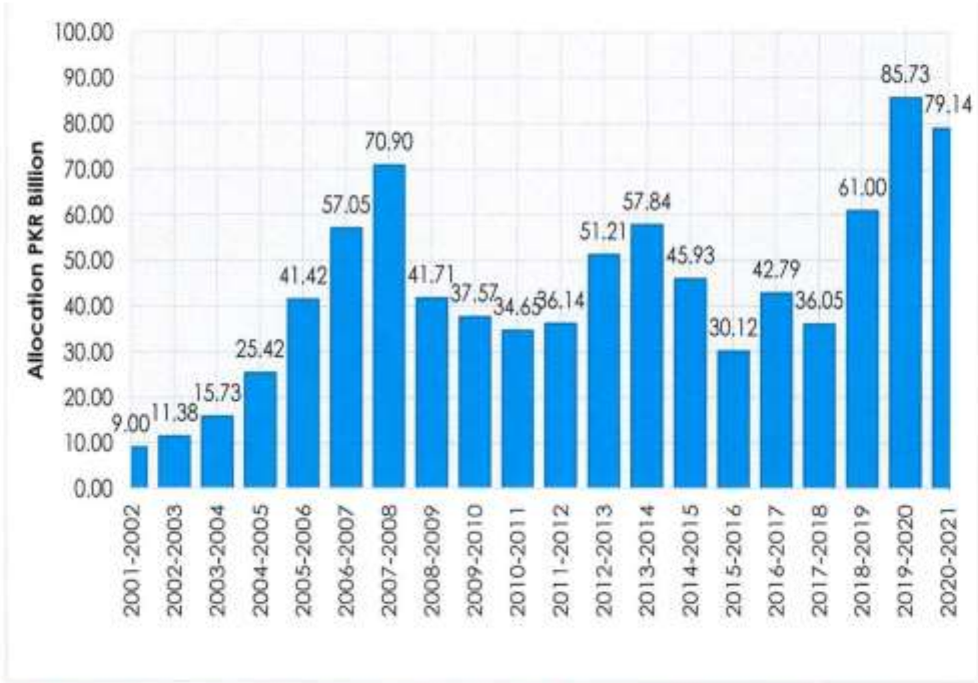


Figure 1: Water used by sub-sectors (2016). Source: UNDP



Data Source: Ministry of Water Resources, and Ministry of Planning Development and Special

Figure 2: Federal PSDP Allocation Towards Water Management

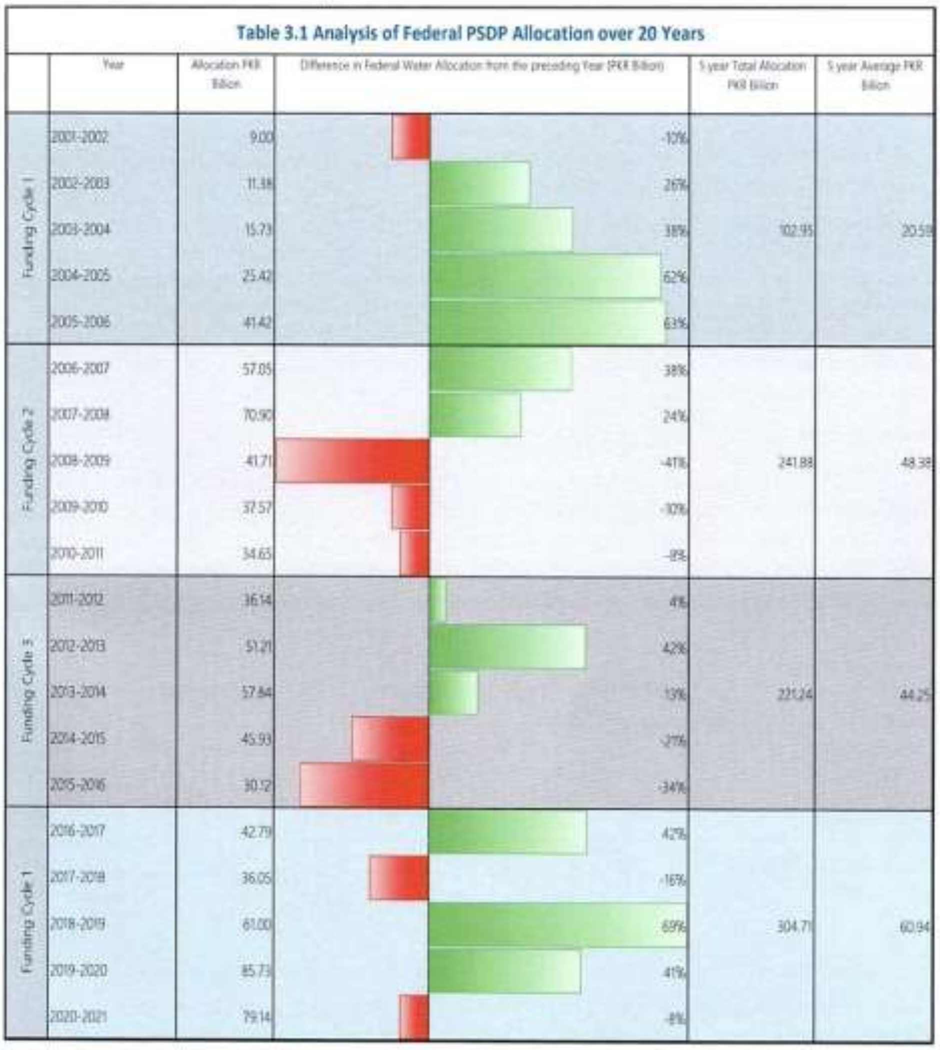


Table 3.1 Analysis of Federal PSDP Allocation over 20 Years

	Year	Allocation PKR Billion	Difference in Federal Water Allocation from the preceding Year (PKR Billion)	5 year Total Allocation PKR Billion	5 year Average PKR Billion
Funding Cycle 1	2001-2002	9.00	-10%	102.95	20.59
	2002-2003	11.38	26%		
	2003-2004	15.73	38%		
	2004-2005	25.42	62%		
	2005-2006	41.42	63%		
Funding Cycle 2	2006-2007	57.05	38%	241.88	48.38
	2007-2008	70.90	24%		
	2008-2009	41.71	-41%		
	2009-2010	37.57	-10%		
	2010-2011	34.65	-8%		
Funding Cycle 3	2011-2012	36.14	4%	221.24	44.25
	2012-2013	51.21	42%		
	2013-2014	57.84	13%		
	2014-2015	45.93	-21%		
	2015-2016	30.12	-34%		
Funding Cycle 1	2016-2017	42.79	42%	304.71	60.94
	2017-2018	36.05	-16%		
	2018-2019	61.00	69%		
	2019-2020	85.73	41%		
	2020-2021	79.14	-8%		

Data Source: Ministry of Water Resources, and Ministry of Planning Development and Special Initiatives[19]

Figure 3: Trend of Federal PSDP Allocation vis-à-vis previous year allocation towards water management

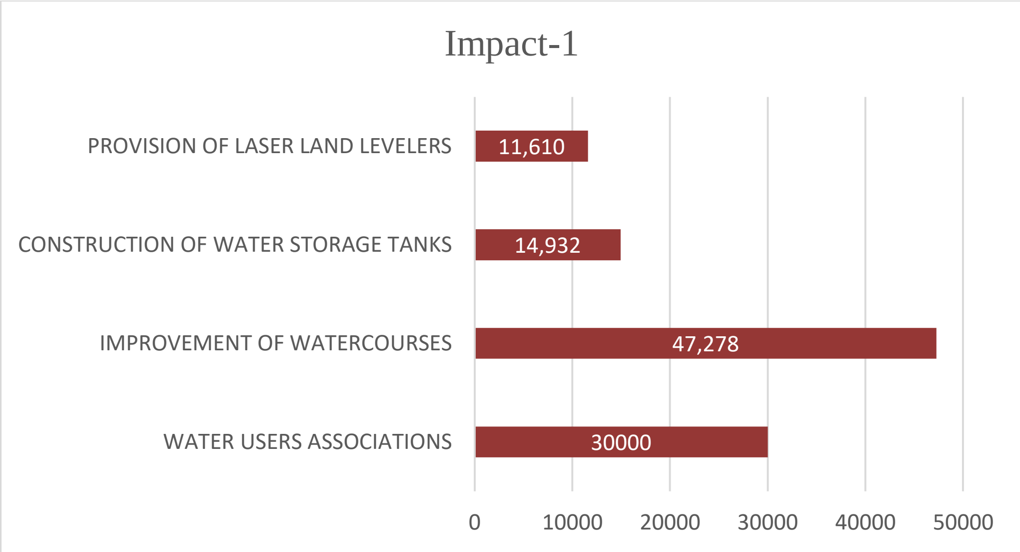


Figure-4: Impact of National Program from Improvement of Water Courses- Phase II (Achievements)

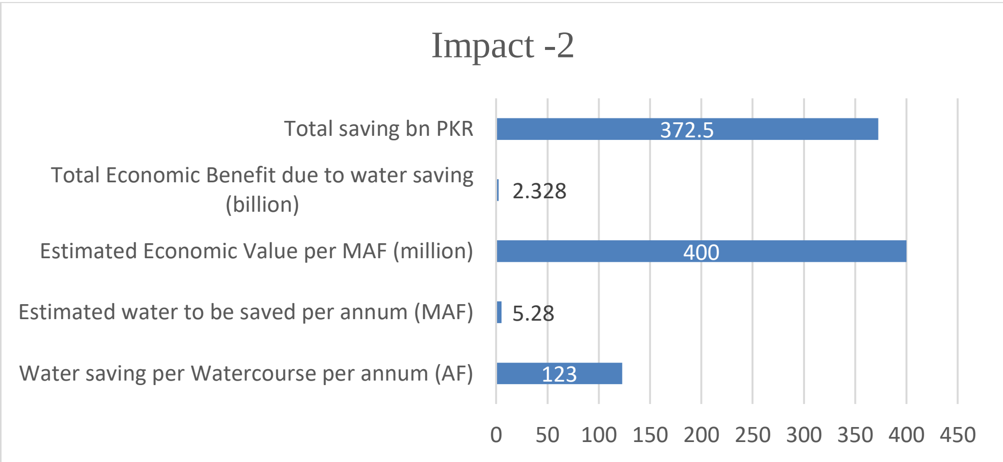


Figure-5: Impact of National Program from Improvement of Water Courses- Phase II (Economic Benefits)

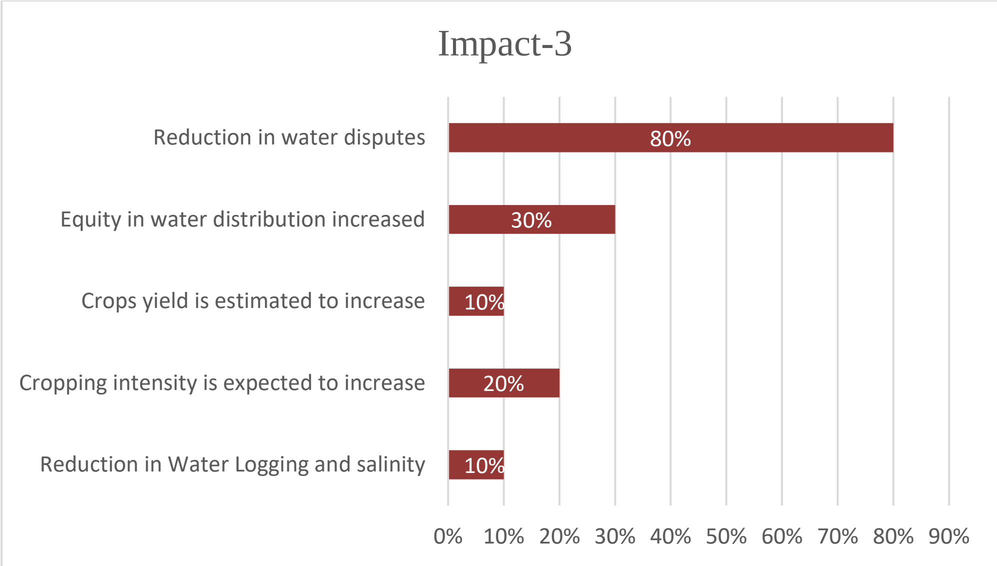


Figure 6: Impact of National Program from Improvement of Water Courses- Phase II (Improvement in water usage and crop productivity)

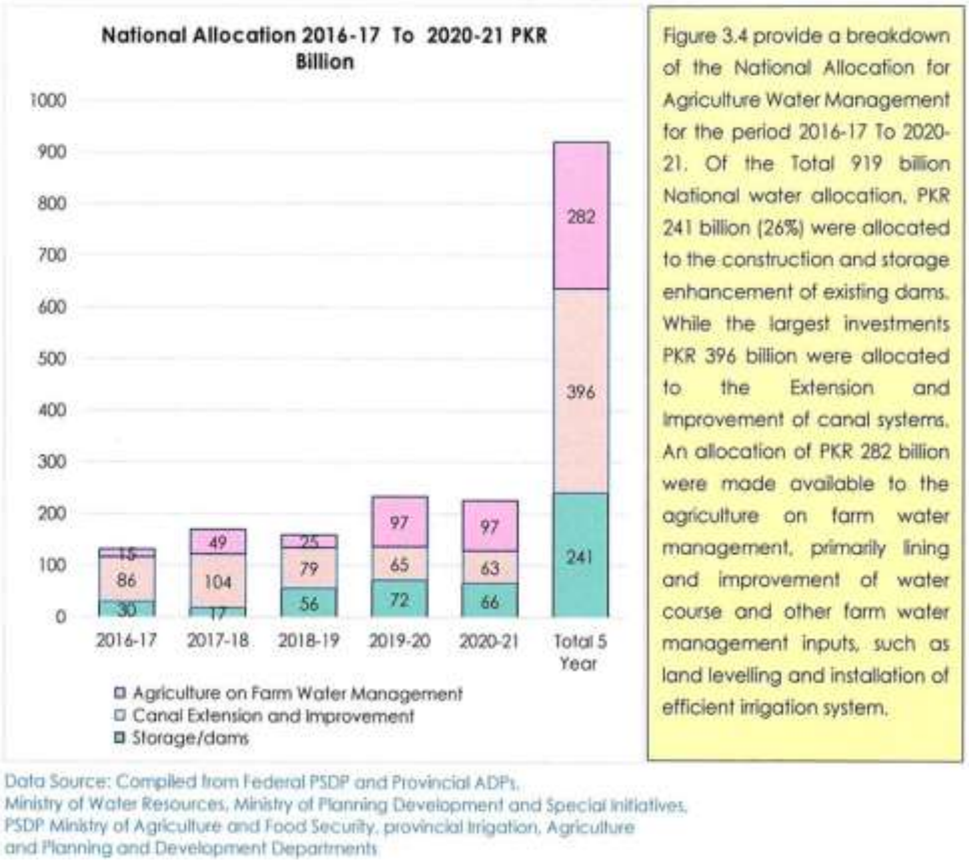


Figure 7: Breakdown of National Allocation for Agriculture Water Management

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