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Technology Prioritization for **Water Sector**



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1. INTRODUCTION

Pakistan's Nationally Determined Contributions (NDCs) 2021 emphasize the critical role of technology and infrastructure in reducing greenhouse gas emissions, enhancing resilience to climate change, and supporting sustainable development. Given the country's acute vulnerability to climate change, particularly in the water and waste sectors, it is essential to adopt sustainable management practices and modernize infrastructure. This is vital for managing the increasing impacts of climate change, such as floods and water scarcity, which are expected to intensify over the coming decades due to a rising population and warmer temperatures.

Pakistan, ranked 8th among nations most impacted by climate change from 2000 to 2019, currently faces the 10th position in vulnerability to natural hazards, notably floods, heatwaves, cyclones, and droughts.[1] Climate change's repercussions on the water sector profoundly affect the economy. The catastrophic 2022 flooding alone caused USD 1 billion in damages and persistent health risks due to contaminated water supplies.[2] The country's vision for 2025 emphasizes water availability through conservation, development, and governance, guided by instruments like the National Water Policy (NWP) 2018. Pakistan's Nationally Determined Contributions (NDCs) for the water sector focus on sustainable water resource management, flood and groundwater management, and irrigation efficiency. They aim to enhance water storage, improve irrigation systems, and promote climate-resilient agriculture. The NDCs also emphasize improving water quality, ensuring safe drinking water, and strengthening policies and governance. Capacity building and research are prioritized to understand climate impacts on water resources and support effective adaptation strategies. Despite these efforts, challenges persist, including disputes over water allocation, rising demand, environmental concerns, climate change impacts, and governance issues.[3] These persistent challenges are anticipated to intensify due to the adverse effects of climate change. Figure 1 below provides a glimpse, forecasting an increase in water demand attributable to projected warming in Pakistan, which may further exacerbate these challenges.

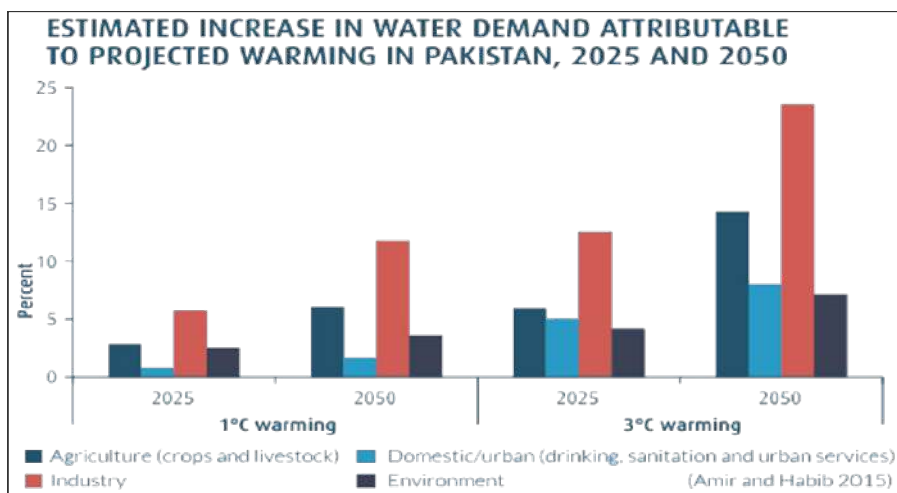


Figure 1: Increase in Water Demand from Climate Change

[1] D. Eckstein, V. Künzel, and L. Schäfer. 2021. Global Climate Risk Index 2021. Bonn: Germanwatch.

[2] Government of Pakistan, Ministry of Planning Development and Special Initiatives. 2022. Pakistan Floods 2022: Post-Disaster Needs Assessment. Islamabad.

[3] <https://www.undp.org/sites/g/files/zskgke326/files/migration/pk/553334d9b60c67a75df68de0f287e9349f5a73edf42e2c971fa8f708af5dd08b.pdf>



To address these challenges, the Ministry of Climate Change and Environmental Coordination (MoCC&EC), in collaboration with the Climate Technology Centre and Network (CTCN), is developing a **Technology Roadmap** for the **waste and water sectors**. This roadmap aims to strategically plan the deployment of technologies to meet Pakistan’s climate and development targets, aligning with the country's commitment to enhancing climate resilience and sustainable development.

The purpose of this report is to prioritize the technologies that will be included in the Technology Roadmap for the water sector. It critically examines the challenges mentioned above, aiming to contribute to the discourse on sustainable water management in Pakistan through technological interventions. By identifying existing and emerging technologies, the report focuses on those that have the potential to significantly impact water management, enhance climate resilience, and contribute to sustainable development in Pakistan. The report supports the objectives of Pakistan’s NDCs by identifying technologies that enhance both climate adaptation and mitigation capabilities. Prioritizing specific technologies ensures that the most effective and feasible solutions are integrated into national plans, thereby accelerating the implementation of Pakistan’s climate commitments.

2. Process for Technology Selection and Prioritization

Figure 2 below guides the steps on how the roadmap would ultimately be developed. For the continuous feedback and ownership from government, three committees were formulated to support the project namely: 1) Water Technical Committee, 2) Waste Technical Committee and 3) Technology Roadmap Committee as highlighted in **Annex-I**.

	 Planning and Preparation	 Sector Prioritization	 Roadmap Development Process
Activities	Kick off Workshop	Sector level assessment and Technology Prioritization	Committee Verification of Sector Level Technology Prioritization
	Stakeholder Sensitization	Gender and Social Assessment	
	Committees Established	Committee Meetings and Feedback	Roadmap Development
	Desk Review and Baseline		
Outcomes	Sub - Listing	Prioritization of 5 Technologies	Roadmap Developed

Figure 2: Steps for the Technology Roadmap Development



The activity initiated with a **desk review** where water sector sub-sectors were identified and mapped including Agricultural and Irrigation, Domestic/drinking water and Sanitation, Hydropower/Energy, Industrial, Livestock and Fisheries, Flooding and Water-Related Disasters and Non-Traditional Water Use. Following this development began a **kick-off workshop** in February (snapshot below), where stakeholders gathered to highlight priority water sub-sectors amongst these based on their contribution in terms of cost/benefit to the GDP, Potential for Green Growth/Sustainable development, ability to Address Climate Change Vulnerability, Potential for Environmental Sustainability, Feasibility for Development in the Sector, Existence of Effective Structures in place Locally to Plan and Manage the Sub-sector and if its Prioritization is in Government planning. Based on these parameters, **the agricultural, domestic and hydropower** received the highest votes and **were selected** amongst the identified subsectors. Secondly potential technology options within the water sector were also identified. This initial meeting set the stage for further detailed assessments by establishing the key focus areas.

In March 2024, the **1st stakeholder feedback waste & water technical committee meeting** took place, where a list of 29 technologies were identified through stakeholder sensitization and desk reviews. This included 11 technologies in the domestic, and 9 technologies in the agriculture and hydropower subsector, respectively. This meeting involved engaging stakeholders to gather on-ground insights and conducting comprehensive literature reviews, which helped in voting and subsequently narrowing down the list of potential technologies to three each in all the three subsectors, consisting of: Drip Irrigation, Leaky Dams and IoT Based Solar Pumps and Storage in the Agriculture sub-sector, Rainwater Harvesting, Chlorination and Groundwater Aquifer Recharge through wastewater in the Domestic and Micro and Small Hydropower Plants, Run-off River Plants and AI Integrated GIS and Remote Sensing for Water Management in the Hydropower subsector. A list of participants is attached as **Annex-II**.

Subsequently in April 2024, the **1st technology roadmap committee meeting** was held to finalize the scoring criteria for evaluating the shortlisted technologies. During this meeting, the committee developed and agreed on objective criteria to assess each technology, ensuring that they reflect the priorities and needs identified earlier. List of committee members is provided in **Annex-III**.

It was decided to gauge the **prioritization** of technologies based on three categories: **Legal, Regulatory, and Financial Landscape; Economic and Technical Feasibility;** and **Inclusive Development and Climate Impacts** for the technology. Each category further divided into specific metrics to gauge the points scored by the particular technology in that metric, which shall be explained in more detail in section 2.1 of this report. Participants from various provinces, involved in water sector, deliberated on the best options amongst the technologies and voted on existing and emerging technologies for agricultural, domestic and hydropower sub-sectors. The prioritization of technologies was guided by stakeholder voting, relevance to Pakistan's local context, potential impact, community resilience, and technological feasibility. Participants from various provinces also contemplated on the viability and voted on technologies based on their applicability to Pakistan's water sector challenges, with a focus on those that could significantly improve practices, enhance resource recovery, and promote sustainability. For example, technologies like drip irrigation and rainwater harvesting were prioritized for their impact and feasibility, reflecting their alignment with local needs and conditions. The technologies receiving the highest votes were identified as priorities. The process was facilitated through interactive platforms like Zoom and Mentimeter, ensuring a collaborative approach to decision-making.



The **Second Water Technical Committee** Meeting then focused on gathering feedback from stakeholders on the shortlisted technologies, discussing financial challenges and opportunities, and considering GESI (Gender Equality and Social Inclusion) aspects for each technology. This meeting aimed to ensure that the final selection of technologies is informed by detailed stakeholder input, financial viability, and inclusive development considerations. List of all the participants is attached in **Annex-III**.

Taking the lead from the kick-off workshop, followed by water committee meetings, and technology roadmap meetings to highlight the **Priority sub-sectors, Shortlist technologies, and scoring criteria for the water sector**, this document takes a step forward as it aims to assess the technologies identified through stakeholder consultations for the **water sector** and **prioritize 4 existing and 1 emerging technology** to develop a technology roadmap for Pakistan.

2.1 Technology Screening and Economic Analysis Methodology

As stated earlier in section 2, the decision finalized to assess the technologies on three major categories: **Legal, Regulatory, and Financial Landscape; Economic and Technical Feasibility; and Inclusive Development and Climate Impacts**. Each category has a specific metric, with individual scoring (on a scale of 1-5) and a weightage of 5% per metric. For instance, a technology scores 3 in any of the metric, its weightage would be 3% in that particular metric. The total weight would be 75% out of which each technology would be assessed for ranking. Here's a breakdown of how each category and its metrics assess the aspects of the technology as shown in Table 1:

Major Group	Group Score	Criteria	Scoring for each criterion	Criteria Weightage
Legal, Regulatory, and Financial Landscape	15	Are there any clear guidelines or regulations for this technology?	Individual score (scale of 1-5)	5%
		Do existing financial structures exist to invest in this technology in Pakistan? (i.e. Existing bankable projects? PPP? Targeted financing facilities?)	Individual score (scale of 1-5)	5%
		Is there an opportunity for private sector investment in this technology?	Individual score (scale of 1-5)	5%



Economic and Technical Feasibility	30	Does this technology efficiently minimize the use of energy and other resources?	Individual score (scale of 1-5)	5%
		Does this technology promote efficiency in the management and delivery of the waste sector?	Individual score (scale of 1-5)	5%
		Is this technology affordable?	Individual score (scale of 1-5)	5%
		Is this technology successfully in use in Pakistan? or there is a potential for a pilot?	Individual score (scale of 1-5)	5%
		Do the skills to implement and operate this technology exist in Pakistan?	Individual score (scale of 1-5)	5%
		Does Pakistan have the capacity to inculcate skills training for this technology through its research and technology institutions?	Individual score (scale of 1-5)	5%
Inclusive Development and Climate Impacts	30	Does this technology possess emission reduction potential?	Individual score (scale of 1-5)	5%
		Does this technology contribute to building resilience and adaptive capacity in Pakistan?	Individual score (scale of 1-5)	5%
		Does this technology enhance the quality of life in target communities?	Individual score (scale of 1-5)	5%
		Does this technology contribute to inclusive development and just transition?	Individual score (scale of 1-5)	5%
			Individual score (scale of 1-5)	5%
		Does this technology have any negative/positive impacts on women and/or minorities or youth and children?		
		Does this technology address gender specific needs and promote social equality?	Individual score (scale of 1-5)	5%
Total	75			

Table 1: Scoring Criteria for Technologies

1. Legal, Regulatory, and Financial Landscape

This category assesses the technology on three metrics. Out of the total 75 weightage, this category would gauge the technology for a total of 15 weightage points. The details of each metric are as below:



- **Are there any clear guidelines or regulations for this technology? (Metric 1 = 5%)**

Assesses whether there are established legal frameworks, policies, or guidelines that govern the use and implementation of the technology.

- **Do existing financial structures exist to invest in this technology in Pakistan? (e.g., Existing bankable projects? PPP? Targeted financing facilities?) (Metric 2 = 5%)**

Evaluates if there are financial mechanisms or investment structures in place to support the technology, such as public-private partnerships (PPP), specific financing programs, or bankable projects.

- **Is there an opportunity for private sector investment in this technology? (Metric 3 = 5%)**

Looks at the potential for private sector involvement and investment, which can indicate the technology's attractiveness and viability in the market.

2. Economic and Technical Feasibility

This category assesses the technology on six metrics. Out of the total 75 weightage, this category would gauge the technology for a total of 30 weightage points. The details of each metric are as below:

- **Does this technology efficiently minimize the use of energy and other resources? (Metric 1 = 5%)**

Assesses the technology's efficiency in resource utilization, focusing on energy and other critical inputs.

- **Does this technology promote efficiency in the management and delivery of the water/waste sectors? (Metric 2 = 5%)**

Evaluates how the technology improves efficiency in water or waste management, which is critical for sustainable operations.

- **Is this technology affordable? (Metric 3 = 5%)**

Looks at the cost-effectiveness and affordability of the technology, which is crucial for widespread adoption.

- **Is this technology successfully in use in Pakistan? Is there potential for a pilot? (Metric 4 = 5%)**

Determines whether the technology is already in use in Pakistan and its success rate. Also considers the potential for pilot projects to demonstrate feasibility.

- **Do the skills to implement and operate this technology exist in Pakistan? (metric 5 = 5%)**

Assesses the availability of local expertise and skills required for the implementation and operation of the technology.

- **Does Pakistan have the capacity to inculcate skills training for this technology through its research and technology institutions? (Metric 6 = 5%)**

Evaluates the country's capacity to develop and offer training programs related to the technology through educational and research institutions.



3. Inclusive Development and Climate Impacts

This category assesses the technology on six metrics. Out of the total 75 weightage, this category would gauge the technology for a total of 30 weightage points. The details of each metric are as below:

- **Does this technology possess emission reduction potential? (Metric 1 = 5%)**

Measures the technology's ability to reduce greenhouse gas emissions, contributing to climate change mitigation.

- **Does this technology contribute to building resilience and adaptive capacity in Pakistan? (Metric 2 = 5%)**

Assesses the technology's role in enhancing resilience to climate impacts and improving adaptive capacity, particularly in vulnerable sectors.

- **Does this technology enhance the quality of life in target communities? (Metric 3 = 5%)**

Evaluates the direct benefits of the technology on the quality of life, such as health improvements, economic opportunities, and social well-being.

- **Does this technology contribute to inclusive development and just transition? (Metric 4 = 5%)**

Looks at whether the technology supports equitable development and a fair transition for all stakeholders, particularly marginalized groups.

- **Does this technology have any harmful impacts on women and/or minorities or youth and children? (Metric 5 = 5%)**

Assesses potential negative impacts on vulnerable groups, ensuring that the technology does not exacerbate inequalities or cause harm.

- **Does this technology address gender-specific needs and promote social equality? (Metric 6 = 5%)**

Evaluates how the technology addresses the unique needs of different genders and promotes broader social equity.

Cost-Benefit Analysis

To consolidate the financial viability of the said technologies, a cost-benefit analysis (CBA) was conducted for the projects related to various waste and water technologies. A systematic methodology was adopted that leverages existing data from similar projects within the context of Pakistan. This data was then adjusted for inflation and included a contingency allowance to account for uncertainties.

The process begins with data collection, where we gather financial metrics from previously undertaken similar projects. These data points are adjusted to present value terms using an appropriate inflation index to reflect current market conditions. To further ensure accuracy, we add a contingency factor, typically a percentage of the estimated costs, to account for potential risks and uncertainties not captured in the base estimates.

The Net Present Value (NPV), Internal Rate of Return (IRR), and payback period for the project



was then calculated. NPV was determined by discounting future cash flows to their present value using a chosen discount rate that reflected the project's risk profile and the cost of capital. The IRR was computed as the discount rate that makes the NPV equal to zero, offering valuable insight into the project's profitability. The payback period was assessed to determine the time required for the project to recover its initial investment from its cash inflows. These financial metrics are supplemented with visual representations, including cumulative cash flow curves, to clearly illustrate the project's cash flow dynamics over time and to facilitate a deeper understanding of the timing and magnitude of financial returns.

Additionally, a sensitivity analysis was conducted by varying key variables such as discount rates, capital costs, and revenue projections to assess the project's feasibility under different scenarios. This approach provides a comprehensive view of the project's financial resilience and identifies potential risks under varying economic conditions. Despite the favorable outcomes shown in the sensitivity analysis, which indicates resilience to changes in key variables, we report these findings with caution due to the hypothetical nature of the underlying assumptions. Since current data analysis relies on data from previous projects, it inherently involves a significant degree of assumption, which may not fully capture the complexities of the future projects.

For some of the emerging technologies where similar projects within Pakistan were unable to be determined, the initiative was taken to address this gap by thoroughly researching analogous technologies in the context of other developing countries. The findings from these studies, were then incorporated to assess the feasibility of these projects within Pakistan. This approach ensured that the analysis remained robust, even in the absence of directly comparable local data, and allows us to make well-informed recommendations based on a broader spectrum of relevant case studies.

3. Sub-sector Baseline in Pakistan

3.1 Water Nexus Across Subsectors

The water sector in Pakistan exhibits distinct characteristics and challenges across three prioritized sub-sectors, i.e., agriculture, domestic use, and hydropower. The agriculture sector consumes around 91.6% of the total annual water use in the country^[4], engaging 60% of the population^[5] and contributing 22% to the national GDP^[6]. Water shortage in the agriculture sector could reduce the GDP by more than 4.6%^[7]. The domestic sector encapsulates residential and commercial sectors and accounts for 2.6% of water consumption in Pakistan.^[8] According to the PCRWR, the per capita availability of water in Pakistan has declined^[9] from 5,260 cubic meters per person in 1951 to 1,017 cubic meters per person in 2021, which is well below the recommended threshold of 1,700 cubic meters per person per year^[10]. Groundwater is a major source of domestic water supply and sources of recharge include rivers, tributaries, canal irrigation, and rain, contributing to an estimated 82 BCM^[11]. The water sector plays a pivotal role in power generation, especially hydropower. Pakistan's total installed capacity of

[4] <https://www.undp.org/sites/g/files/zskgke326/files/migration/pk/553334d9b60c67a75df68de0f287e9349f5a73edf42e2c971fa8f708af5dd08b.pdf>

[5] <https://water.muett.edu.pk/wp-content/uploads/2019/03/Recommendations-for-Pakistans-Water-Policy-Framework.pdf>

[6] https://www.finance.gov.pk/survey/chapters_23/02_Agriculture.pdf

[7] <https://documents1.worldbank.org/curated/en/099950111072234047/pdf/P17671804998b80030ac4f0233dc0b995ba.pdf>

[8] <https://www.undp.org/sites/g/files/zskgke326/files/migration/pk/553334d9b60c67a75df68de0f287e9349f5a73edf42e2c971fa8f708af5dd08b.pdf>

[9] <https://pcrwr.gov.pk/wp-content/uploads/2021/07/Water-Scarcity-in-Pakistan-Issues-and-Options-May-18.pdf>

[10] <https://www.sciencedirect.com/topics/engineering/water-stress-index#:~:text=A%20region%20is%20considered%20under,3%20per%20capita%20per%20year.>

[11] Majeed, Z., & Piracha, A. (2011). Water conservation of Pakistan's agricultural, municipal and industrial water. *International Journal of Water Resources and Arid Environments*, 1(3), 232-238.



hydropower generation is operational estimated to be 10,852.85 MW. Currently, about 25% of Pakistan's energy generation is sourced through hydropower[12].

3.2 Provincial Situation for Water Sector in Pakistan

In this section, a thorough review of government policies such as National Water Policy (NWP) 2018, Pakistan Vision 2025, National Climate Change Policy 2021 (NCCP), National Climate Resilience and Adaptation Plan 2023 (NCRAP), and Pakistan Water sector strategy has been conducted to understand the provincial status of top three prioritized sub-sectors. The policies highlight an ambition of reducing average cost per unit of electricity by over 25% by improving generation mix (15%) and reducing distribution losses (10%), increasing percentage of indigenous sources (hydropower included) of power generation to over 50%, increasing water storage capacity to 90 days, improve efficiency of usage in agriculture by 20%, ensuring access to clean drinking water to all Pakistani's and reducing food insecure population from 60% to 30% reflected in vision 2025[13]. Furthermore, a target of 60% from renewable energy was anticipated by 2030 in an attempt to decarbonizing the country's economy[14].

Along with national documents, provincial reports and documents on the water sector, such as **Sindh Water Policy 2023**, **Punjab Water Vision 2050**, **Balochistan agriculture policy and strategy**, **KPK Climate Change Policy 2022**, AJK policy briefs, and Gilgit sectoral documents have been thoroughly assessed to understand the existing situation of prioritized sub-sectors at provincial level in Pakistan. A comprehensive assessment of each province is given as follows:

3.2.1 Agriculture

Punjab:

Irrigation serves as the lifeblood of Punjab's economy, contributing a significant 26% to the province's GDP and employing over 54% of its workforce.[15] This vital sub-sector boasts one of the world's largest contiguous irrigation systems, serving a staggering 21 million acres (8.4 million hectares) of cultivable land and achieving cropping intensities exceeding 120%.[16] However, the system faces critical challenges. Water scarcity is a growing concern, exacerbated by climate change and recurring floods and droughts. Furthermore, aging infrastructure, chronic underfunding for maintenance, and inefficient water management practices have led to low water conveyance efficiencies and inequitable water distribution. Despite these challenges, over 90%[17] of Punjab's agricultural output relies on irrigated land, highlighting the crucial need for addressing water management issues through infrastructure modernization, improved water use practices, and sustainable resource management strategies.

[12] https://www.finance.gov.pk/survey/chapters_23/Economic_Survey_2022_23.pdf

[13] <https://www.pc.gov.pk/uploads/vision2025/Pakistan-Vision-2025.pdf>

[14] https://policy.asiapacificenergy.org/sites/default/files/Updated%20National%20Climate%20Change%20Policy%20%282021%29_0.pdf

[15] <https://nepra.org.pk/Policies/Hydel%20Potential%20in%20Pakistan.pdfsj>

[16] https://pnd.punjab.gov.pk/system/files/ADP%202017-18%20Irrigation_0.pdf

[17] <https://www.adb.org/sites/default/files/project-documents//37231-pak-rrp.pdf>



Sindh:

Sindh plays an important role in Pakistan's economy, with irrigated agriculture serving as the center of its rural economy. A substantial 77%^[18] of Sindh's agricultural land benefits from irrigation; however, the utilization of limited water resources is far from optimal. Approximately 60-75%^[19] of withdrawn water is lost, either through surface water evaporation or seepage into saline groundwater. The largest water use area in Sindh is agriculture, with crop consumption around 95%^[20] of total consumption, while the annual evapotranspiration losses are between 26.6 and 41.7 MAF.^[21] The region faces significant water scarcity issues, particularly in the summer months before the monsoon season.

Agricultural water demand is responsible for 90%^[22] of water withdrawals and is expected to surge if existing irrigation and cropping practices remain unchanged. The challenges in water efficiency are aggravated by the aftermath of the 2022 floods, which have inflicted severe damage on Sindh's agricultural sector. However, opportunities exist through the modernization of irrigation infrastructure, promoting water-saving crops and practices, and addressing salinity intrusion.

Gilgit Baltistan:

In Gilgit Baltistan, around 90% of the population is associated with economic activities related to agriculture.^[23] The total land area of GB is 72,971 km², and only 2% is cultivable out of the total area. Over 80% of the population relies on subsistence farming, cultivating cereal crops, fruits, vegetables, and fodder crucial for livestock. ^[24] Livestock contributes nearly 40%^[25] to household farm income, also providing essential fertilizer for traditional farming practices. The region is home to more than 1.6 million reared animals.^[26] Agriculture and livestock in GB heavily depend on natural water flows, which exhibit considerable variations seasonally and are susceptible to changes in climate, including shifts in temperature and precipitation. Indigenous management systems govern irrigation channels, making them vulnerable to even minor climate alterations.

AJ&K:

In AJ&K approximately 13% of the area is dedicated to agriculture, with a predominant 92% being rain-fed. ^[27] Agriculture in AJ&K primarily relies on rain, with maize, wheat, and rice being the major crops. The average farm area per family across AJ&K is 1.76 hectares, with the total cultivated area around 194,592 hectares, constituting about 14.6% of the total territory. ^[28] The agricultural landscape varies based on factors like soil conditions, climate, rainfall, and access to irrigation water. However, the hydrological cycle, influenced by global warming, requires the agriculture and livestock sectors, especially in rain-fed regions, to adapt to climate change. AJ&K faces seasonal water scarcity, particularly during dry seasons. Including agriculture within the water domain allows for integrated planning and management that considers both crop water requirements and water availability. This approach can promote sustainable water use practices in agriculture, such as irrigation efficiency improvements, to mitigate water scarcity impacts.

[18] <https://www.worldbank.org/en/news/factsheet/2022/12/19/factsheet-sindh-water-and-agriculture-transformation-project>

[19] <https://www.worldbank.org/en/news/factsheet/2022/12/19/factsheet-sindh-water-and-agriculture-transformation-project>

[20] <https://irrigation.sindh.gov.pk/Content/Departments/SindhWaterPolicy/SWP.pdf>

[21] <https://irrigation.sindh.gov.pk/Content/Departments/SindhWaterPolicy/SWP.pdf>

[22] <https://www.worldbank.org/en/news/factsheet/2022/12/19/factsheet-sindh-water-and-agriculture-transformation-project>

[23] <https://sjbipp.org/publications/PR/projectreport/PR-37-19.pdf>

[24] <https://www.cscoc.org.pk/attachments/news-bulletin/GB%20Water%20Dialogue.pdf>

[25] <https://www.cscoc.org.pk/attachments/news-bulletin/GB%20Water%20Dialogue.pdf>

[26] <https://www.cscoc.org.pk/attachments/news-bulletin/GB%20Water%20Dialogue.pdf>

[27] <https://pndajk.gov.pk/uploadfiles/downloads/CC%20AJK%20Policy%202017.pdf>

[28] <https://www.pndajk.gov.pk/uploadfiles/downloads/Statistical%20Year%20Book%202020.pdf>



Khyber-Pakhtunkhwa

In Khyber Pakhtunkhwa, the total reported land area of Khyber Pakhtunkhwa (KP), including tribal districts, is 8.352 million hectares, with 1.868 million hectares designated as cultivable and 6.484 million hectares as uncultivable.^[29] Among the cultivable land, only 0.957 million hectares receive irrigation, including 774,233 hectares from the government-managed canal system, while the remaining 0.911 million hectares rely on rainfed agriculture.^[30] and water scarcity requires efficient water use for expanded cultivation. The agriculture sector, encompassing both rabi and kharif cropping patterns, serves as a primary livelihood for most of the population and is the largest consumer of available water, accounting for around 90%.^[31] The region features 76,268 watercourses facilitating irrigation, with 26,080 being lined. Underground water extraction through 32,218 tube wells and dug wells is estimated at **3.4 MAF**.^[32]

Balochistan

The agriculture sector, including livestock, contributes significantly to the provincial GDP, constituting 1/3 of it. Moreover, it engages almost 2/3 of the labor force and sustains over half of the population.^[33] Within agriculture, livestock accounts for two-thirds of the value added, with crops (comprising fruit at 30%, field crops at 17%, and vegetables at 12%) and fisheries contributing the remaining three-fifths.^[34] Crop farming is particularly crucial for rural households, as nearly half of them are headed by crop farmers or agricultural laborers. This underscores the importance of crop production in enhancing rural incomes and alleviating poverty. The agriculture sector in Balochistan heavily relies on groundwater extracted through tube wells, facing significant challenges due to recurrent droughts and aquifer depletion. A substantial 70%^[35] of Balochistan's farmers lack access to a consistent water source like canals or minor irrigation schemes, leaving them dependent on rainfall or groundwater from tube wells.

Each province's agricultural sector is integral to the local economy, with unique challenges and adaptations needed in the face of climate change.

[29] https://www.irrigation.gkp.pk/images/IWRM%20Strategy_Main%20Document.pdf

[30] https://www.irrigation.gkp.pk/images/IWRM%20Strategy_Main%20Document.pdf

[31] https://www.irrigation.gkp.pk/images/IWRM%20Strategy_Main%20Document.pdf

[32] https://www.irrigation.gkp.pk/images/IWRM%20Strategy_Main%20Document.pdf

[33] https://pdf.usaid.gov/pdf_docs/PA00Z3HK.pdf

[34] https://pdf.usaid.gov/pdf_docs/PA00Z3HK.pdf

[35] https://pdf.usaid.gov/pdf_docs/PA00Z3HK.pdf



3.2.2 Domestic

Punjab:

In Punjab, access to improved drinking water sources is high at 98%, though rural areas slightly lag behind urban regions. [36] Groundwater extraction through hand pumps and motorized pumps remains substantial, emphasizing the necessity for diversified and sustainable water supply systems. Sanitation facilities, however, present disparities, with 80.1% having access but only 70.4% having non-shared facilities. [37] Open defecation, primarily in rural areas, affects 13% of the population, [38] underscoring the need for continued investment in expanding safe sanitation facilities.

Sindh:

In Sindh, around 65% [39] of households are equipped with flush toilets, comprising 98% in urban areas and 29% in rural areas. [40] Approximately 23% of households possess non-flush toilet facilities, while 12% reported having no toilet. [41] Notably, in rural areas, 24% of households lack toilet facilities, in contrast to only 1% in urban areas. [42] Most of the grey water is discharged untreated into water bodies, leading to **pollution and health risks**. It is necessary to make effective measures in this subsector for water conservation so that improved and adequate access to sanitation could be ensured.

AJK:

In AJK, the accessibility to improved water sources stands at 57%, which is notably lower than the national average of 89%. [43] Out of 1771 villages, 1032 have been provided with water supply facilities, with an overall average of 58.3%. Overall, 95% of the population has access to some form of a sanitation system. [44] Sanitation conditions in AJK are relatively better than the national average, with only 5% of the population lacking a sanitation system. [45] Approximately half of the population utilizes septic tanks or flush latrines, while other sanitation mechanisms include vent pits, open pits, pit latrines, and piped sewer systems. [46] However, 45% of school absences are attributed to waterborne diseases, indicating water quality challenges. [47] Cultural beliefs influence water treatment practices, emphasizing the need for targeted interventions and improved water access in the region.

Gilgit-Baltistan (GB):

There are subnational disparities in access to drinking water; 78% of the population in GB has access to safely managed and basic water sources. [48] 0.5% of population relies on limited

[36] <https://hudphed.punjab.gov.pk/system/files/3%20Punjab%20Water%2C%20Sanitation%20%26%20Hygiene%20%28Sector%20Status%20Report%202019%29.pdf>

[37] <https://hudphed.punjab.gov.pk/system/files/3%20Punjab%20Water%2C%20Sanitation%20%26%20Hygiene%20%28Sector%20Status%20Report%202019%29.pdf>

[38] <https://hudphed.punjab.gov.pk/system/files/3%20Punjab%20Water%2C%20Sanitation%20%26%20Hygiene%20%28Sector%20Status%20Report%202019%29.pdf>

[39] https://phenrd.sindh.gov.pk/elfinder/connector?_token=&cmd=file&target=fls2_ZGVwYXJ0bWVudHMvU2luZGggU3RyYXRIZ2JlFdBuOggU2VjdG9yIFBsYW4gZmluYWwgZHJhZnQgNi4wLnBkZg

[40] https://phenrd.sindh.gov.pk/elfinder/connector?_token=&cmd=file&target=fls2_ZGVwYXJ0bWVudHMvU2luZGggU3RyYXRIZ2JlFdBuOggU2VjdG9yIFBsYW4gZmluYWwgZHJhZnQgNi4wLnBkZg

[41] https://phenrd.sindh.gov.pk/elfinder/connector?_token=&cmd=file&target=fls2_ZGVwYXJ0bWVudHMvU2luZGggU3RyYXRIZ2JlFdBuOggU2VjdG9yIFBsYW4gZmluYWwgZHJhZnQgNi4wLnBkZg

[42] https://phenrd.sindh.gov.pk/elfinder/connector?_token=&cmd=file&target=fls2_ZGVwYXJ0bWVudHMvU2luZGggU3RyYXRIZ2JlFdBuOggU2VjdG9yIFBsYW4gZmluYWwgZHJhZnQgNi4wLnBkZg

[43] Water and Sanitation Sector Analysis of Azad Jammu and Kashmir Baseline Survey Report, 2016.

[44] <https://opendata.com.pk/dataset/3bd42404-2478-4c0f-9b7f-bd4d3def70ce/resource/5c5081a3-1d16-4122-834a-22bdd4980c28/download/water-sanitation-sector-analysis-of-ajk-2016.pdf>

[45] Water and Sanitation Sector Analysis of Azad Jammu and Kashmir Baseline Survey Report, 2016.

[46] https://www.sdgpakistan.pk/uploads/pub/Policy_Brief_AJK.pdf

[47] https://www.sdgpakistan.pk/uploads/pub/Policy_Brief_AJK.pdf

[48] <https://www.wateraid.org/pk/publications/infographic-on-wash-facts>



sources, 4.7% utilizes unimproved sources, and 16.7% depends on surface water.[49] In terms of sanitation, 0% have access to safely managed sanitation, 82.1% to basic sanitation, 0.8% to limited sanitation, 9.5% to unimproved sanitation, and 7.6% engage in open defecation practices. [50] Indigenous management systems governing irrigation channels in GB make them vulnerable to climate alterations, emphasizing the need for an integrated framework for improved water and sanitation access in the region.

Balochistan:

According to the Pakistan Social and Living Standards Measurement (PSLM) survey, 70% of Balochistan's population had access to water sources like tap water, hand pumps, motor pumps, and dug wells, while the remaining 30% relied on alternative sources. [51] Urban and rural disparities were evident, with 85% water availability in urban areas compared to 72% in rural areas.[52] Access to water was also more limited in rural regions, with 59% compared to 85% in urban areas.[53] Addressing water scarcity and sanitation challenges in Balochistan is crucial for achieving sustainable water management.

Khyber Pakhtunkhwa (KP):

Surface water (rivers, streams, springs) and groundwater (aquifers) are the primary sources for domestic water supply in KPK. The average depletion rate of groundwater is approximately 1.42 meters annually.[54] The water resource potential of the region is approximately 26.35 MAF, surpassing the total demand of about 2.96 MAF.[55] According to PSLM, around 83% of the KPK population has access to safely managed drinking water services. The proportion of the urban population with drinking water access is 97%, while for the rural population, it is 80%.[56] 86.7% of the population has adequate access to safe sanitation, and only 47% have flush toilets and handwashing services access in KPK.[57] Efficient domestic water management and strategies for water conservation are imperative for sustainable water practices in KP.

In each province, the challenges and opportunities in water and sanitation underscore the need for targeted interventions, technological advancements, and policy measures to ensure equitable access, mitigate health risks, and promote sustainable water management practices.

3.2.3 Hydropower

The figure 3 below shows the total installed capacity of hydropower projects in the country, which is about 10852.85 MW, out of which KP holds a major share of 53.34%, Punjab holds the second position with installed capacity of around 23.25%, AJK has 21.83% of total installed capacity while GB is at the last with 1.56% of the total installed capacity in the country

[49] <https://www.wateraid.org/pk/publications/infographic-on-wash-facts>

[50] <https://www.wateraid.org/pk/publications/infographic-on-wash-facts>

[51] https://www.pbs.gov.pk/sites/default/files/pslm/publications/PSLM_2019_20_District_Level.pdf

[52] https://www.pbs.gov.pk/sites/default/files/pslm/publications/PSLM_2019_20_District_Level.pdf

[53] https://www.pbs.gov.pk/sites/default/files/pslm/publications/PSLM_2019_20_District_Level.pdf

[54] https://www.irrigation.gkp.pk/images/IWRM%20Strategy_Main%20Document.pdf

[55] https://www.irrigation.gkp.pk/images/IWRM%20Strategy_Main%20Document.pdf

[56] https://www.pacadengg.org/pdf/Symposium_Presentations/27th%20-%20Sustainable%20Development%20Goals%20for%20Clean%20Water%20&%20Sanitation%20for%20Pakistan/4.%20KPK%20Status%20Of%20SDG-6%20.pdf

[57] https://www.pacadengg.org/pdf/Symposium_Presentations/27th%20-%20Sustainable%20Development%20Goals%20for%20Clean%20Water%20&%20Sanitation%20for%20Pakistan/4.%20KPK%20Status%20Of%20SDG-6%20.pdf

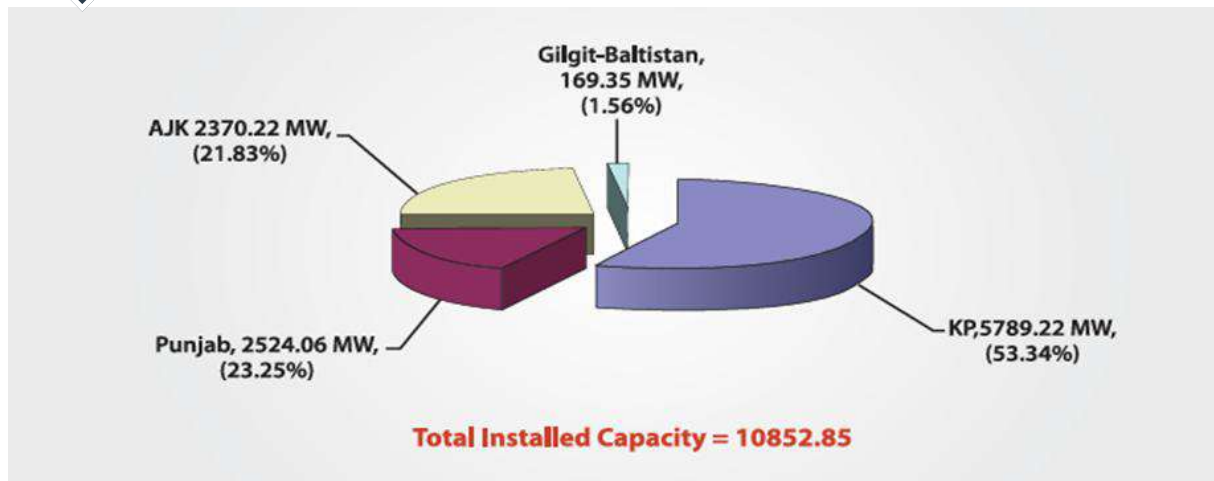


Figure 3: Province-wise existing installed generation capacity[58]

Punjab:

In Punjab, hydropower constitutes a substantial **26%**[59] of the province's electricity generation capacity, with an installed capacity of **9,861 MW**. [60] The existing infrastructure relies on run-of-the-river and canal-based power plants. Despite its significant contribution, challenges such as sedimentation, aging infrastructure, and water availability fluctuations due to climate change persist. An untapped potential of **5,895 MW**[61] on various canals offers opportunities for further development. Sustainable management practices, infrastructure modernization, and exploration of alternative hydropower sources are crucial for maintaining efficiency and overcoming challenges in this sector.

Hydropower plays a significant role in Punjab's water sector, accounting for **26%**[62] of the total electricity generation capacity in the province. Currently, Punjab has an installed hydropower capacity of **9,861 MW**. [63], mainly derived from run-of-the-river and canal-based power plants. However, there is an untapped potential of approximately **5,895 MW**[64] Identified on various canals, providing opportunities for further development.

Azad Jammu and Kashmir (AJK):

Azad Jammu and Kashmir have immense potential for hydropower generation, with various identified sites having the potential to generate 8295.75 MW. [65] About 60 potential hydropower sites with high, medium, and low heads have been identified. Out of these, 28 projects are operational as well. [66] Several projects with a collective capacity exceeding 8000 MW have been identified within the Jehlum, Neelum, and Poonch river catchments.[67] The socio-economic advancement of the state could benefit substantially from the development of these projects, providing a reliable and cost-effective energy source for the future.

[58] https://www.ppib.gov.pk/wp-content/uploads/2023/08/Hydropower_Resources-Book_2022.pdf

[59] <https://energy.punjab.gov.pk/hydel>

[60] <https://energy.punjab.gov.pk/hydel>

[61] <https://nepra.org.pk/Policies/Hydel%20Potential%20in%20Pakistan.pdf>

[62] <https://energy.punjab.gov.pk/hydel>

[63] <https://energy.punjab.gov.pk/hydel>

[64] <https://nepra.org.pk/Policies/Hydel%20Potential%20in%20Pakistan.pdf>

[65] https://www.ppib.gov.pk/wp-content/uploads/2023/08/Hydropower_Resources-Book_2022.pdf

[66] https://www.ppib.gov.pk/wp-content/uploads/2023/08/Hydropower_Resources-Book_2022.pdf

[67] <https://www.ajkpdo.gok.pk/home/>



Gilgit-Baltistan (GB):

The current energy demand in GB exceeds 500 MW. Despite having over 100 operational hydropower stations and various thermal stations, their combined output is only 150 MW. [68] There exists untapped hydropower potential exceeding 40000 MW[69] along the Indus River, its tributaries, sub-tributaries, and streams. However, the hydrology of GB, which is reliant on glaciers and snowmelt, is vulnerable to climate change impacts. Effective water resource management and conservation, along with harnessing untapped hydropower potential, are critical for addressing energy challenges in GB.

Khyber Pakhtunkhwa (KP):

KP plays a significant role in Pakistan's hydropower landscape, contributing **24,736 MW**, or **41%**, to the national hydropower resources of **60,000 MW**. [70] The province's identified sites for approximately **142** hydropower projects, with a combined capacity of about **24,000 MW**, [71] underscore its potential. The government of KP actively promotes a shift in the energy mix towards hydroelectricity, recognizing the challenges posed by the reliance on costly imported fuel. Hydropower projects necessitate proper management and utilization of water resources, presenting an opportunity for improved water resource management practices in the region.

In summary, hydropower potential varies across provinces, with each facing unique challenges and opportunities. Pakistan's total installed capacity of hydropower generation that is operational estimates to be **10,852.85 MW**. [72] Currently, only 25% of Pakistan's energy generation is sourced through hydropower. [73] There is dire need of sustainable management practices, infrastructure modernization, and exploration of untapped potential that is crucial for the continued contribution of hydropower to Pakistan's energy needs.

The summary of the above situation is as presented in the table 2 below:

Province/ Region	Agriculture	Domestic Water Access and Sanitation	Hydropower
Punjab	<ul style="list-style-type: none"> Contributes 26% to provincial GDP. Employs over 54% of workforce. World's largest contiguous irrigation system serving 21 million acres. Cropping intensities exceeding 120%. Challenges: Water scarcity, climate change, aging infrastructure, low water conveyance efficiency, inequitable water distribution. 90% of agricultural output relies on irrigation. 	<ul style="list-style-type: none"> 98% access to improved drinking water sources. Disparities in rural vs. urban areas. 80.1% have access to sanitation facilities, 13% practice open defecation. 	<ul style="list-style-type: none"> 26% of electricity generation capacity. Installed capacity: 9,861 MW. Untapped potential: 5,895 MW on various canals. Challenges: Sedimentation, aging infrastructure, climate change impacts.

[68] <https://www.csmcc.org.pk/attachments/news-bulletin/GB%20Water%20Dialogue.pdf>

[69] <https://www.csmcc.org.pk/attachments/news-bulletin/GB%20Water%20Dialogue.pdf>

[70] https://www.irrigation.gkp.pk/images/IWRM%20Strategy_Main%20Document.pdf

[71] https://www.irrigation.gkp.pk/images/IWRM%20Strategy_Main%20Document.pdf

[72] https://www.ppib.gov.pk/wp-content/uploads/2023/08/Hydropower_Resources-Book_2022.pdf

[73] https://www.finance.gov.pk/survey/chapters_23/Economic_Survey_2022_23.pdf



Province/ Region	Agriculture	Domestic Water Access and Sanitation	Hydropower
Sindh	<ul style="list-style-type: none"> • 77% of agricultural land is irrigated. • 60-75% of withdrawn water lost due to evaporation/seepage. • Agriculture consumes 95% of total water; 26.6-41.7 MAF lost annually due to evapotranspiration. • Challenges: Water scarcity, flood damage, salinity intrusion. • Opportunities: Modernization of irrigation, promotion of water-saving crops. 	<ul style="list-style-type: none"> • 65% of households have flush toilets (98% urban, 29% rural). • 12% lack toilets, especially in rural areas. • Grey water discharged untreated into water bodies, leading to pollution and health risks. 	-
Gilgit-Baltistan (GB)	<ul style="list-style-type: none"> • 90% of the population engaged in agriculture-related activities. • Only 2% of land is cultivable. • 80% of the population relies on subsistence farming. • Livestock contributes 40% to household farm income. • Challenges: Dependency on natural water flows, climate change impacts. 	<ul style="list-style-type: none"> • 78% access to safely managed and basic water sources. • 16.7% rely on surface water. • 82.1% have access to basic sanitation; 7.6% practice open defecation. 	<ul style="list-style-type: none"> • Untapped hydropower potential: Over 40,000 MW along the Indus River and tributaries. • Current energy demand exceeds 500 MW; current output is only 150 MW.
Azad Jammu and Kashmir (AJK)	<ul style="list-style-type: none"> • 13% of land is used for agriculture, with 92% being rain-fed. • Major crops: Maize, wheat, rice. • Average farm area per family: 1.76 hectares. • Challenges: Climate change impacts, seasonal water scarcity. • Opportunities: Integrated planning and management for sustainable water use. 	<ul style="list-style-type: none"> • 57% access to improved water sources. • 95% of the population has access to some form of sanitation. • 45% of school absences due to waterborne diseases. 	<ul style="list-style-type: none"> • Potential hydropower sites identified: 8,295.75 MW. • 28 operational projects. • Focus on socio-economic advancement through hydropower development.



Province/ Region	Agriculture	Domestic Water Access and Sanitation	Hydropower
Khyber Pakhtunk- hwa (KP)	<ul style="list-style-type: none"> Total land area: 8.352 million hectares; 1.868 million hectares cultivable. 0.957 million hectares irrigated; 0.911 million hectares rainfed. 90% of water used for agriculture. Challenges: Water scarcity, reliance on groundwater. 3.4 MAF water extracted through 32,218 tube wells/ dug wells. 	<ul style="list-style-type: none"> 83% access to safely managed drinking water. Urban vs. rural disparity (97% urban, 80% rural). 86.7% access to adequate sanitation, 47% have flush toilets. 	<ul style="list-style-type: none"> 53.34% of Pakistan's total hydropower capacity. Installed capacity: 5,792 MW. Significant reliance on canal and run-of-the-river systems.
Balochistan	<ul style="list-style-type: none"> Agriculture contributes 1/3 of provincial GDP. Engages almost 2/3 of the labor force. Heavy reliance on groundwater; challenges include droughts and aquifer depletion. 70% of farmers lack access to consistent water sources, rely on rainfall/ tube wells. Challenges: water scarcity and sanitation issues 	<ul style="list-style-type: none"> 70% access to water sources (tap, hand pumps, motor pumps, dug wells). Urban vs. rural disparity (85% urban, 72% rural). 30% rely on alternative sources; challenges in addressing water scarcity. 	-

Table 2: Summary of Existing Provincial Situation of Sub-Sectors



3.3 Legal Framework

The Eighteenth Amendment to the Constitution of the Islamic Republic of Pakistan, a landmark event in the constitutional history of Pakistan, was passed unanimously with support from all political parties in the Parliament and lauded by the provinces. One of the significant amendments it included was joint ownership of oil, gas and territorial waters.^[74]

Table 3 below provides a comprehensive overview of key legal frameworks related to Water Management in Pakistan.

1958	Pakistan Water and Power Development Authority (WAPDA) Act established WAPDA, which is responsible for the development and management of water and power resources in Pakistan, including major dams, reservoirs, and hydropower projects. ^[75]
1960	Indus Water Treaty was brokered by the World Bank. It fixed and delimited the rights and obligations of both countries concerning the use of the waters of the Indus River system. ^[75]
1991	Water Apportionment Accord (WAA) was signed amongst the provinces citing recognition of the need to establish an Indus River System Authority which was accepted subsequently for the implementation of the Accord. The Authority would have its HQs at Lahore (shifted to Islamabad) and having representation from all the provinces. ^[77]
1993/2010	National Environmental Quality Standards (NEQS) outlines National Standards for Drinking Water Quality (2010) and Liquid Industrial Effluents (1993). ^[78]
1997	Pakistan Environmental Protection Act (PEPA) establishes the framework for environmental protection in Pakistan, including the regulation of water pollution and the conservation of water resources. ^[79]
2001	Local Government Ordinances transferred responsibility for the delivery of water supply and sanitation services from the Provincial governments to newly created local government institutions. ^[80]
	Local Government Acts (LGAs) , passed by each province; these Acts contain provisions for irrigation systems, water and drainage management and groundwater use and rights including Sindh Irrigation Act (1879), Punjab Irrigation and Drainage Authority (PIDA) Act (1997), Khyber Pakhtunkhwa (KP) Water Act (2020), Balochistan Groundwater Rights Administration Ordinance (1978) among many others.

Table 3: Key Water Management Frameworks in Pakistan

[74] <https://ipc.gov.pk/SiteImage/Misc/files/Year%20Books/Final%20Report%20of%20Implementation%20Commission.pdf>

[75] <https://www.wapda.gov.pk/wapda-act>

[76] <https://www.britannica.com/event/Indus-Waters-Treaty>

[77] <https://mowr.gov.pk/Detail/NzZkZThlNWItYjczOC00NWY5LTk0ODYtZjJhMjBiYjc3YmZk>

[78] <https://environment.gov.pk/Detail/MDUzMDI1OGItYWYzZC00NzQ0LTlhZWItZjYzY2RkOTkyZGVh>

[79] <https://elaw.org/wp-content/uploads/archive/Law-PEPA-1997.pdf>

[80] https://assets.publishing.service.gov.uk/media/5c6c293140f0b647b35c4393/503_Water_Governance_Systems_Pakistan.pdf



3.4 Institutional Framework

Many stakeholders in Pakistan take part in management of the water resources as specified in their mandate. Table 4 below presents the key national and provincial actors pertaining to water management in the country with their roles in this context.

Year Established	Institution and Role
National	
1947	Ministry of Finance (MoF): Once the Project Concept-I (PC-I) is approved and the water related project is included in the Public Sector Development Program (PSDP), the MoF is responsible for allocating the required funds for the project. The MoF releases funds as per the approved budget and the project's financing plan.
1952	Ministry of Planning Development and Special Initiatives (MoPD&SI) is responsible for the appraisal and approval of PC-I documents for development projects, including those related to water management. After the approval of the PC-I, the project is included in the PSDP.
1958	Water and Power Development Authority (WAPDA) has been assigned the duties of investigation, planning and execution of projects and schemes for: Generation, Transmission and Distribution of Power. Irrigation, Water Supply and Drainage. Prevention of Water Logging and Reclamation of Saline Land.
1960	Pakistan Commissioner for Indus Waters (PCIW) is the part of the Permanent Indus Commission which is a bilateral commission consisting of officials from India and Pakistan, created to implement and manage the goals and objectives and outlines of the Indus Waters Treaty. The commission maintains and exchanges data and co-operates between the two countries.
1964	Pakistan Council for Research in Water Resources (PCRWR) is mandated to conduct, organize, coordinate and promote research on all aspects of water, specifically irrigation, drainage, surface & groundwater management, groundwater recharge, watershed management, rainwater harvesting, desertification control, water quality and overall environment.
1977	Office of the Chief Engineering Advisor/Chairman Federal Flood Commission (FFC) was established for the purpose of integrated flood management at national level.
1984	Pakistan Environment Protection Council (PEPC) is the main environmental policy-making body in the country, responsible for pollution control and preservation of the living environment.
1991	Pakistan Environmental Protection Agency (Pak-EPA): Their function is to prepare or revise, and establish the National Environmental Quality Standards (NEQS) with approval of Pakistan Environmental Protection Council (PEPC). These include standards for water quality.
1992	Indus River System Authority (IRSA) was established for regulating and monitoring the distribution of water sources of Indus Rivers in accordance with the Accord amongst the Provinces and to provide matters connected therewith and ancillary



	thereto.
2017	Ministry of Water Resources (MoWR): As a successor of Ministry of Water and Power at the federal level, this ministry is responsible for the formulation of national water policies, coordination between provinces, and oversight of major water projects.
Provincial	
-	Provincial Public Health and Engineering Departments are responsible for planning, execution and maintenance of drinking water supply and sanitation schemes in their respective domains.
-	Provincial Irrigation Departments operate and managing the irrigation network, maintain surface drainage systems and tube wells, controlling floods, constructing small dams for rainwater harvesting and promoting efficient water use for sustainable agriculture.
-	Provincial Agricultural Departments reclaim and cultivate unproductive land, promote efficient water use, provide training to empower farmers, and facilitate agricultural mechanization to boost productivity and improve livelihoods.
-	Rural Development Department: Are responsible for development of drinking water and sewerage infrastructure within areas with < 500 people.
-	Provincial Planning Departments is responsible for the appraisal and approval of PC-I documents for development projects of provincial importance, including those related to water management to be submitted to the MoF. They refer the approvals to MoWR given any project has National Level Implications or requires federal funding.
2001	Local Government Acts (LGAs), passed individually by each province, based on the premise that locally managed basic services would improve responsiveness to local needs and facilitate improved service delivery.

Table 4: Institutional Roles in Water Management[81][82][83][84][85]

These institutions are structured in a Top-bottom approach where financial allocations are done at the top and they are disbursed down till the union level. The figure 4 below details on this framework from national to local level

[81] https://www.frontiersin.org/files/Articles/1096747/fenvs-11-1096747-HTML-r1/image_m/fenvs-11-1096747-t003.jpg

[82] <https://mowr.gov.pk/Detail/NjYyMTM2ZTItdNDQzZC00YmE0LWI3NmQtZDRhY2lxYTFjNmNm>

[83] https://gsc1.sgs-suparco.gov.pk/ppsdp/about_us.aspx

[84] <https://www.finance.gov.pk/>

[85] <https://www.wapda.gov.pk/>

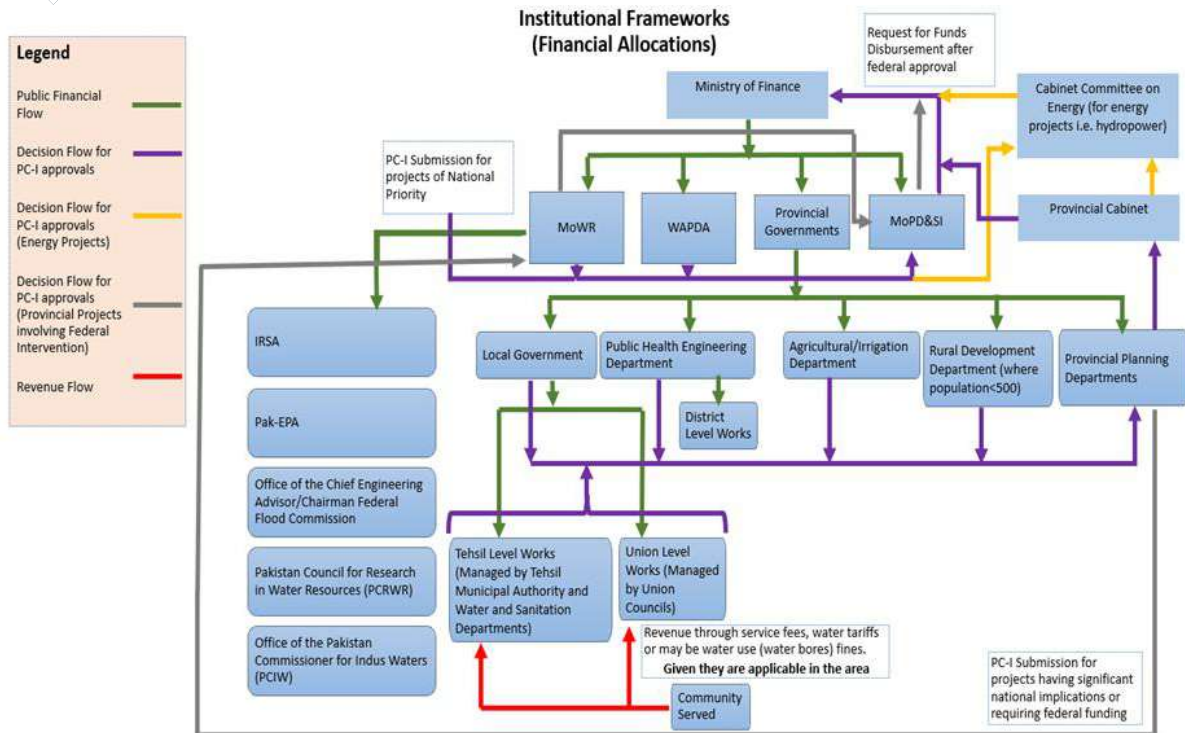


Figure 4: Institutional Framework for financial allocations in the Water Sector.[86][87][88][89][90][91][92]

The diagram above illustrates the financial flow, as demonstrated by the green arrows, from the MoF down to the Union, Tehsil, and District levels, ensuring that allocations are tailored to the specific scope of each institution. In contrast, the submission of Project Concept-I (PC-I) documents follows a bottom-up approach shown by purple arrows. Here, entities at the Union and Tehsil level submit their PC-Is to the relevant provincial departments. After a thorough review, these are forwarded to the provincial planning department. Upon approval, they proceed to the provincial cabinet, which then refers the request to the MoF. The PC-Is for the projects particularly in the domain of the provincial departments are drafted and forwarded directly by these departments to the provincial planning department. This path is followed by all provincial projects unless they involve energy sectors or have national implications that require federal funding. Subsequently, national departments submit PC-Is for national priority projects for scrutiny to the MoPD&SI for presenting the case to MoF.

For provincial projects needing federal intervention, indicated by the grey arrows, PC-Is are first submitted to the provincial planning department, which refers the case to the MoWR for review. Afterward, the document is forwarded to the MoPD&SI for final scrutiny before submission to the MoF.

Energy projects, shown by the yellow arrows, follow a slightly different route. The provincial cabinet reviews the PC-I and, if approved, refers the case to the Cabinet Committee on Energy (CCoE) before submitting a request to the MoF. National-level energy projects follow a similar process with PC-I documents being referred to CCoE for approval before reaching the MoF.

[86] https://gsc1.sgs-suparco.gov.pk/pspd/about_us.aspx

[87] <https://mowr.gov.pk/Detail/NjYyMTM2ZTI0NDQzZC00YmE0LWI3NmQtZDRhY2lyYTFjNmNm>

[88] <https://cabinet.gov.pk/SiteImage/Misc/files/Federal%20Cabinet/Cabinet%20Committees/Committees%202024/CCOE-24.pdf>

[89] https://pnd.punjab.gov.pk/our_functions

[90] <https://pjuia.gop.pk/Articles/Prospects%20of%20Water%20Governance.pdf>

[91] https://www.sciencedirect.com/science/article/pii/S258891252300019X?ref=pdf_download&fr=RR-2&rr=8b68197b9d3bf8cd

[92] https://assets.publishing.service.gov.uk/media/5c6c293140f0b647b35c4393/503_Water_Governance_Systems_Pakistan.pdf



Lastly, Union Councils, Tehsil Municipal Authorities, and Water and Sanitation Departments generate their revenues, marked by the red arrows, through service fees, water tariffs, or fines (such as those for groundwater use) if they are applicable in their jurisdictions. For example, water bills in Islamabad are collected by the Capital Development Authority (CDA), while in Lahore, the Water and Sanitation Agency (WASA) is responsible for billing.

3.5 Policy Framework

National:

Nationally, the federal government has introduced the **National Water Policy 2018**^[93], which aims to lay down a broad policy framework and set of principles for water security on the basis of which the provincial governments can formulate their respective Master Plans and projects for water conservation, water development and water management. Moreover, the **National Food Security Policy 2018**^[94] aims to promote sustainable food production systems (crop, livestock and fisheries) by achieving an average growth rate of 4% per annum and make agriculture more productive, profitable, climate resilient and competitive. Also, the **Power Generation Policy 2015**^[95] aims to enhancing hydropower generation in the energy mix.

Provincial:

At the provincial level, the water policies have been presented for optimal water management in the provinces including **Punjab Water Policy 2018**^[96], **Sindh Water Policy 2023**, **Integrated Water Resource Management Strategy Government of Khyber Pakhtunkhwa and Balochistan Drinking Water Supply Policy/Strategy 2015-2025**.

In the **Agriculture Sector**, there are **Punjab Agriculture Policy 2018**^[97], **Sindh Agriculture Policy 2018-2030**^[98], **Agriculture Policy KP (2015-2025)**^[99] and **Balochistan Agriculture Sector Policy and Strategy**^[100] aimed at addressing food security and promoting good agricultural practices in the province. For the **Hydropower Sector**, KP has developed its **Hydropower Policy 2016**^[101] for the promotion of hydropower fostering cost effective and clean energy generation in the province.]

3.6 Gaps and Weaknesses in the Current Policies and Regulations

The current framework for Pakistan's Water Resource Management (WRM) is presented with significant shortcomings that hinder the country's ability to effectively manage its water resources and ensure equitable access to clean water for all citizens. Figure 5 illustrates how these gaps impact sustainable water management practices across the country.

[93] <https://mowr.gov.pk/SitelImage/Misc/files/National%20Water%20Policy.pdf>

[94] <https://faolex.fao.org/docs/pdf/pak184963.pdf>

[95] <https://www.ppib.gov.pk/wp-content/uploads/2023/08/Power-Generation-Policy-2015-small.pdf>

[96] <https://faolex.fao.org/docs/pdf/pak191275.pdf>

[97] <https://agripunjab.gov.pk/system/files/Punjab%20Agriculture%20Policy.pdf>

[98] <https://faolex.fao.org/docs/pdf/pak191432.pdf>

[99] <https://faolex.fao.org/docs/pdf/pak173417.pdf>

[100] <https://faolex.fao.org/docs/pdf/pak173418.pdf>

[101] https://pedo.pk/uploads/policies/KP_Hydropower_Policy_2016.pdf

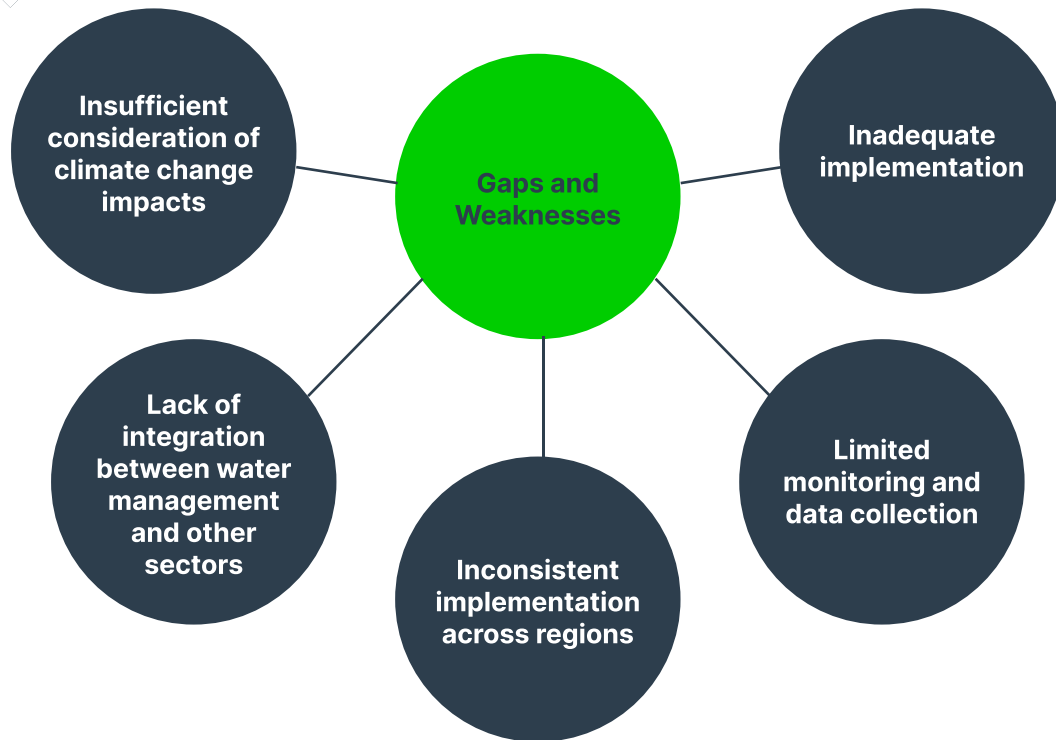


Figure 5: Gaps and Weaknesses in the Current Policies and Regulations.[102]

Expanding on the challenges mentioned in the figure above, the first key issue lies in the inadequate enforcement of existing regulations. Although Pakistan's water-related laws may appear comprehensive on paper, the implementation and enforcement processes are often weak. This results in widespread violations and a lack of accountability among key stakeholders, leading to unchecked water pollution and inefficiencies in water use. For instance, many industries continue to discharge untreated wastewater into rivers, causing severe damage to aquatic ecosystems despite regulations prohibiting such actions.

Additionally, the monitoring and data collection efforts related to water resources are insufficient. The absence of accurate and up-to-date data poses significant challenges for policymakers and researchers in understanding the availability of water resources, consumption patterns, pollution levels, and the impact of various industries on these resources. In particular, the lack of groundwater monitoring makes it difficult to accurately assess depletion rates, further complicating efforts to manage water resources sustainably.

Moreover, there are inconsistencies in WRM regulations across different regions of Pakistan. These disparities create unequal water distribution, exacerbating water shortages in certain areas. In some regions, weak enforcement allows illegal agricultural water extraction to continue unchecked, leading to overconsumption and the depletion of local water reservoirs.

Another critical gap is the lack of integration between water management and other key sectors, such as agriculture, industry, and urban development. This disconnect undermines sustainable WRM efforts by hindering coordinated decision-making. The agriculture sector, in particular, often overuses water resources due to policies that do not adequately address the need for appropriate irrigation systems and water-saving practices.

[102] https://www.sciencedirect.com/science/article/pii/S258891252300019X?ref=pdf_download&fr=RR-2&rr=8b68197b9d3bf8cd



Finally, the impact of climate change on water resources is often overlooked in current policies. Despite the increasing threats posed by changing precipitation patterns and water shortages, existing policies frequently fail to incorporate climate adaptation measures. As a result, there is a lack of clear guidelines for developing climate-resilient infrastructure and promoting technologies that enhance water-use efficiency.

These shortcomings collectively weaken Pakistan's ability to manage its water resources effectively, threatening both environmental sustainability and equitable access to clean water across the country.

4. Technology Analysis for Prioritization

Section 2 elaborated on the process of how the 9 technologies were shortlisted. This section explores the analysis of these shortlisted technologies, with a focus on the main components of the scoring criteria; legal, regulatory, and financial landscape, economic and technic feasibility, and inclusive development and climate impacts, as explained in section 2.1. These criteria are used to prioritize technologies based on their strengths and weaknesses, with provincial needs being paramount. The primary purpose of selecting these technologies is to improve the baseline of the sub-sectors discussed in section 3 of this report. Table 5 and Table 6 introduce the subsectors along with the shortlisted technology, with detailed analyses to follow.

Sub Sector	Sub-Sector Definition	Shortlisted Technologies
Agriculture	The science, art, or occupation concerned with cultivating land, raising crops, and feeding, breeding, and raising livestock; farming.[103]	<ol style="list-style-type: none">1. Leaky Dams for Water Storage2. Drip Irrigation System3. IoT Based Solar Water Pumps and Storage (Emerging)
Domestic	Activities belonging or relating to one's home, household, or family[104]	<ol style="list-style-type: none">1. Rainwater harvesting2. Chlorination3. Groundwater aquifer recharge through wastewater (Emerging)
Hydropower	The activity of harnessing mechanical energy for production of electricity from the potential energy of fast flowing or falling water with the help of turbines.[105]	<ol style="list-style-type: none">1. Runoff the river plants2. Micro and Small Hydro-Power Plants3. AI integrated Remote sensing and GIS (Emerging)

Table 5: Sub-sectors with their shortlisted technologies

[103] <https://www.dictionary.com/browse/agriculture>

[104] <https://www.dictionary.com/browse/domestic>

[105] <https://www.britannica.com/science/hydroelectric-power>



Definition of Technologies

Leaky Dams for Water Storage	Leaky dams are a form of Natural Flood Management (NFM). Barriers made of natural woody materials are laid within water channels and allow normal base-flows of water to pass through. When flood flows are higher, they create an obstruction to reduce the flow. They are designed to reduce the downstream flood peak by temporarily storing water by holding it back within the stream's channel or encouraging it to spill onto the banks behind the barrier and slowing the flow. [106]
Drip Irrigation System	Drip irrigation, also known as trickle irrigation or micro irrigation or localized irrigation, is an irrigation method allows water to drip slowly to the roots of plants, either onto the soil surface or directly onto the root zone, through a network of valves, pipes, tubing, and emitters. It is done through narrow tubes that deliver water directly to the base of the plant. [107] .
IoT Based Solar Water Pumps and Storage	An IoT-based solar water pump system combines solar energy, Internet of Things (IoT) technology, and water storage to efficiently supply water for various applications. They typically involve the integration of sensors, communication devices, and control systems. These components enable remote monitoring, data collection and control of the pump system optimizing its performance and efficiency [108]
Rainwater harvesting	Rainwater Harvesting is the collection and storage of rainwater that would otherwise have flown down the gutters into the drain. The water is collected from the roof, then re-used within the home or garden. [109]
Chlorination	Chlorination is a disinfection method that utilizes chlorine and its derivatives to eliminate microorganisms. Beyond disinfection, it also acts as an oxidizing agent for various substances like iron, manganese, cyanide, and aids in addressing taste and odor issues in water and wastewater treatment. It is usually done for the removal of pathogenic bacteria in water. [110]
Groundwater aquifer recharge through wastewater	Groundwater aquifer recharge through wastewater or broadly known as Managed aquifer recharge is the intentional recharge of water to suitable aquifers for subsequent recovery or to achieve environmental benefits. It is facilitated by the use of injection wells or ponds and infiltration basins. [111]
Runoff the river plants	Run-of-the-river hydroelectric systems are hydroelectric systems that harvest the energy from flowing water to generate electricity in the absence of a large dam and reservoir. [112]

[106] <https://flood.essex.gov.uk/our-work/leaky-dams/>

[107] https://icid-ciid.org/Knowledge/basic_term/20/Irrigation

[108] https://www.researchgate.net/publication/377022605_IOT_BASED_SOLAR_POWERED_PUMP_FOR_AGRICULTURAL_IRRIGATION_AND_CONTROL_SYSTEM#:~:text=IoT%2Dbased%20solar%20powered%20pumps,%2C%20data%20collection%2C%20and%20control

[109] <https://www.rainwaterharvesting.co.uk/download/content/download-brochures-and-manuals/rainwater-harvesting-information.pdf>

[110] <https://testbook.com/civil-engineering/chlorination-of-water>

[111] <https://www.watereducation.org/aquapedia-background/groundwater-replenishment>

[112] https://energyeducation.ca/encyclopedia/Run-of-the-river_hydroelectricity



Micro and Small Hydro-Power Plants	A micro hydro power (MHP)'plant' is a type of hydroelectric power scheme that produces up to 100 KW of electricity using a flowing stream or a water flow. The electricity from such systems is used to power up isolated homes or communities and is sometimes connected to the public grid. Small hydropower, on the other hand, refers to hydroelectric power plants below 10MW installed capacity. [113][114]
AI integrated Remote sensing and GIS	AI GIS is a combination of AI technology with various GIS functions, including spatial data processing and analysis algorithms (GeoAI) that incorporates AI technology, and a general term for a series technology of the mutual empowerment of AI and GIS. [115]

Table 6: Definition of technologies

4.1 Agriculture

In the Agriculture Subsector prioritized technologies involves Drip Irrigation Systems, and Leaky dams in the existing categories while IoT based Solar Pumps was prioritized as an emerging technology. The following section involves the in-depth analysis of these technologies aligning with the scoring criteria.

4.1.1 Drip irrigation system (Existing)

Drip irrigation, also referred to as trickle irrigation or micro irrigation, involves delivering water slowly to plant roots either onto the soil surface or directly to the root zone via a network of valves, pipes, tubing, and emitters. This method utilizes narrow tubes to supply water directly to the plant base. [116]

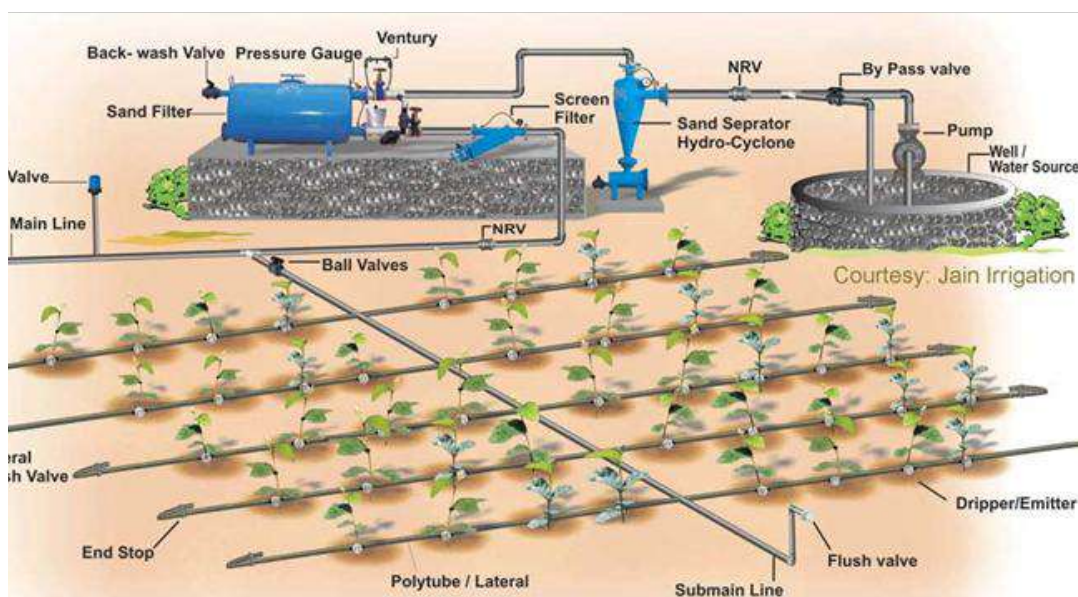


Figure 6: Layout of a Drip Irrigation System[117]

[113] [https://energypedia.info/wiki/Micro_Hydro_Power_\(MHP\)_Plants](https://energypedia.info/wiki/Micro_Hydro_Power_(MHP)_Plants)

[114] <https://www.ctc-n.org/technologies/small-hydropower>

[115] https://www.supermap.com/en-us/news/?82_2701.html

[116] https://icid-ciid.org/Knowledge/basic_term/20/Irrigation

[117] https://icid-ciid.org/Knowledge/basic_term/20/Irrigation



1. Legal, Regulatory and Financial Landscape

In Pakistan, the legal and regulatory framework concerning drip irrigation is evolving, with notable support from the **National Water Policy of 2018**, which emphasizes on water saving techniques like drip irrigation. Specific **standards and specifications** addressing drip irrigation involves **ANSI/ASAE and ISO standards in Pakistan**[118]. Also, **clear mechanism for implementation and installation of HEIS including drip irrigation exists in Pakistan**[119]. **State Bank of Pakistan has established clear guidelines for efficient agriculture water management financing**[120]. Financially, while **80% subsidy in Punjab** have facilitated enhanced yields with reduced water usage, the upfront investment required for setting up drip irrigation systems remains a significant barrier, [121] especially for small-scale farmers. Although the government allocated a substantial budget of **Rs. 3.67 billion**[122] for transitioning irrigation projects to solar-powered systems, the expense of installing drip systems persists as a challenge, even with subsidies on solar power plants.

2. Economic and Technical Feasibility:

Drip irrigation presents promising economic benefits such as significant water savings ranging from **30% to 70%**[123] and increased crop production by **up to 100%**. [124] However, technical challenges like **high initial setup costs** (ranging from Rs. **200,000 to 300,000**) [125], **susceptibility to emitter clogging, and suitability** concerns for certain crops hinder widespread adoption. Despite opportunities like reported increases in crop yield and time savings for women farmers, slow adoption rates and the ongoing depletion of groundwater resources (**1.2 million tube wells extracting around 50 million acre-feet of water annually**) [126] pose threats to the feasibility and sustainability of drip irrigation in Pakistan.

To further assess the feasibility on threats the technology offers, a study for Punjab was considered to be made part of this analysis.[127] The analysis compared the technology to traditional furrow irrigation techniques. It considered three fruit plants (olive, peach and citrus) and three vegetable plants (potato, onions and chilies). The analysis considered pumping costs, fixed costs (Laser Leveling Cost + 8 Daily Paid Labor @ 365 PKR/Day and Laser Leveling Cost + 8 Daily Paid Labor @ 365 PKR/Day for **Furrow** and (Total Cost of the System (Rs/ha)/Life of the Drip System (Years) + Pumping Cost of the System (Rs/ha)/ Life of the Solar Pump (Years)) for **Drip system**), depreciation cost (Labor Involved in Irrigation and Furrow Repairing for **Furrow** and repair and maintenance of drip parts such as damage or leakage in lateral lines, drip emitter clogging, etc. for **Drip** systems) and variable costs for both techniques.

The results of the study indicated that gross expenditures in the drip irrigation system were higher because of the high initial investment. However, the gross income in the drip irrigation system was high because of the good quality of produce and high yield. Furrow irrigation system consistently underperformed in the case of all the vegetables and fruit crops.

[118] https://ofwm.agripunjab.gov.pk/system/files/B1HEIS-PQD_0.pdf

[119] https://ofwm.agripunjab.gov.pk/system/files/B1HEIS-PQD_0.pdf

[120] <https://www.sbp.org.pk/acd/2011/C2-Annx.pdf>

[121] <https://www.dawn.com/news/1485906>

[122] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/#:~:text=Drip%20irrigation%20is%20an%20irrigation,du%20to%20evaporation%20and%20runoff.>

[123] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/#:~:text=Drip%20irrigation%20is%20an%20irrigation,du%20to%20evaporation%20and%20runoff.>

[124] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/>

[125] <https://www.dawn.com/news/1728236>

[126] <http://www.riazhaq.com/2021/04/groundwater-depletion-in-pakistan.html>

[127] <https://www.mdpi.com/2071-1050/13/20/11178>



The performance of vegetables was seen far less than fruit plants as they costed more compared to furrow techniques. However, the fruit plants costed way less compared to the furrow irrigation technique contrastingly. Still, a saving up to **86%** of irrigation water and increased yield by **26–33%**, as compared with the furrow irrigation method was still achieved overall.

Furthermore, the average cost of drip sets was calculated to be **PKR 50,000–150,000** per hectare for all given crops. It was also concluded that the gross expenditures of the drip irrigation set can be fully recovered in the **second year of crops and orchards**.

To further assess the technology, we gauged its economic viability based on a 2018 study across four provinces of Pakistan, focuses on low-head drip irrigation for mixed fruits in Punjab. [128] The total cost in 2018 was approximately 74,460 (**268USD**)[129] PKR per acre, with production and revenues amounting to around 92,425 (**333USD**)[130] PKR. Adjusted for 2024, the total cost is estimated to be **USD 522.5**[131], including a **10%**[132] contingency. Annual operation and maintenance costs are projected at **USD 10.45**[133]. Assuming a **5%**[134] annual increase in revenues from 2018 to 2024, the estimated revenue for 2024 is approximately **USD 446**. Using a **10%**[135] discount rate, the project shows a Net Present Value (NPV) of **USD 3,431**[136], an Internal Rate of Return (IRR) of **83%**[137], and a payback period of **1.2**[138] years, indicating strong profitability and quick investment recovery.

Sensitivity analysis supports the project's financial viability under varying economic conditions. Even with a **10%**[139] increase or decrease in total costs and annual revenues, the NPV remains positive, and the IRR stays high, suggesting robust profitability. However, the high IRR underscores the need for scrutiny to ensure realistic expectations and thorough project planning. In summary, the low-head drip irrigation project in Punjab **demonstrates significant financial viability** with substantial potential for profitability, highlighting the importance of detailed analysis and risk assessment.

Finally, the technology was observed for its performance in drought conditions given unavailability of water and overpressure on groundwater in such cases. So, a study[140] was made part of this analysis to see how the technology fosters drought resilience. The analysis considers a Days to Day Zero (DDZ) metric. Days to Day Zero (DDZ) measures the resilience of irrigated agriculture to drought. It concluded that water conservation and storage were the key drivers to sustain in a drought situation. It studied how well irrigated farming can withstand droughts in a semi-arid region, focusing on the 'Days to Day Zero' (DDZ) indicator. The findings highlight four key points. First, water storage and conservation help farmers maintain crop production during droughts by extending the time before water supplies run out. Second, while efficient water use at the farm level can help in the short term, it can lead to increased water withdrawals and larger irrigated areas over time, which reduces overall resilience during

[128] https://www.researchgate.net/publication/360486112_Adoption_and_cost-benefit_analysis_of_drip_irrigation_for_high-value_crops_in_Pakistan

[129] https://www.researchgate.net/publication/360486112_Adoption_and_cost-benefit_analysis_of_drip_irrigation_for_high-value_crops_in_Pakistan

[130] https://www.researchgate.net/publication/360486112_Adoption_and_cost-benefit_analysis_of_drip_irrigation_for_high-value_crops_in_Pakistan

[131] Authors calculations based on above mentioned study

[132] Authors calculations based on above mentioned study

[133] Authors calculations based on above mentioned study

[134] Authors calculations based on above mentioned study

[135] Authors calculations based on above mentioned study

[136] Authors calculations based on above mentioned study

[137] Authors calculations based on above mentioned study

[138] Authors calculations based on above mentioned study

[139] Authors calculations based on above mentioned study

[140] <https://doi.org/10.1016/j.scitotenv.2022.160263>



prolonged droughts. Third, water dynamics before and during a drought, such as water conservation and storage, play a crucial role in managing crop water needs, but excessive irrigation can hinder the refilling of storage during periods without drought. Lastly, the research suggests that while farmers can initially adapt to droughts, long-term resilience might require significant changes, such as better planning and management of irrigated areas, to avoid undermining future water availability. These insights can guide policies on irrigation, land use, and water management to improve resilience against droughts.

3. Inclusive Development and Climate Impacts

Drip irrigation presents significant potential for climate adaptation and inclusive development in agricultural practices, particularly in regions like Pakistan, where water scarcity and resource management are critical concerns. The technology's ability to **reduce water usage by 60%**^[141] compared to traditional flood irrigation methods, as well as its **50% reduction in fertilizer usage**, ^[142] contributes to **climate adaptation** by conserving water resources and minimizing agricultural runoff.

With a water-saving potential ranging from **30% to 70%**^[143], the study indicates that drip irrigation, combined with optimized irrigation scheduling, can lead to reductions in emissions of **CO₂, N₂O, and NO** by up to **62%**.^[144] Drip irrigation enhances climate adaptation efforts by promoting sustainable water management practices, aligning with targets proposed in the National Water Policy 2018. Furthermore, the technology's capacity to increase crop production by **20 to 100%** and boost crop yield offers opportunities for agricultural productivity in the face of climate variability and changing environmental conditions.

Inclusive development opportunities associated with drip irrigation extend beyond environmental considerations to socioeconomic impacts, particularly for women in agricultural communities. Reports from Nepal indicate that women utilizing solar-powered drip irrigation systems spent **50% less time**^[145] tending to their plots compared to traditional methods, freeing up time for other income-generating activities or education. Initiatives like the **Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP)** and the **Water and Agriculture Transformation project in Sindh** prioritize drip irrigation, aiming to improve water productivity, boost agricultural production, and enhance livelihoods. However, challenges in accessing subsidies and after-sales support highlight the need for robust policy frameworks and coordinated efforts to overcome barriers and maximize the climate resilience and inclusive development potential of drip irrigation technologies.

[141] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/>

[142] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/>

[143] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/#:~:text=Drip%20irrigation%20is%20an%20irrigation,du%20to%20evaporation%20and%20runoff>

[144] <https://www.sciencedirect.com/science/article/pii/S0167880922000937>

[145] Shrestha, G., Uprety, L., Khadka, M., & Mukherji, A. (2023). Technology for whom? Solar irrigation pumps, women, and smallholders in Nepal.



4. Socioeconomic Outlook

The technology was assessed on its socioeconomic outlook which has been summarized in table 7 below:

Emissions Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/Total Investment	Social Benefits
<p>A study indicates that drip irrigation, combined with optimized irrigation scheduling, can lead to reductions in emissions of CO₂, N₂O, and NO by up to 62%.</p>	<p>Using drip irrigation system has shown Increase in crop production by 20 to 100%.</p>	<p>Based on the study: 2018 study across four provinces of Pakistan, focuses on low-head drip irrigation for mixed fruits in Punjab Cost: 522.5 USD 2% operation and maintenance cost At a 10% discount rate NPV: 3431 USD IRR: 83% Payback Period 1.2 years</p>	<p>A water-saving potential ranging from 30% to 70%</p> <p>Women who utilized solar-powered drip irrigation systems in Nepal spent 50 per cent less time tending to their plots compared to traditional methods of hand watering.</p> <p>With a drip irrigation system, the leaves and stems of plants remain dry. It minimizes the risk of disease transmission.</p> <p>Drip irrigation systems can be used anywhere as they are adaptable to irregular terrain, flat terrain, vineyards, hillsides, oddly shaped gardens, irregular landscapes, or uneven soil texture.</p> <p>It minimizes nutrient runoff and saves fertilizer costs. Less fertilizer is needed when using drip irrigation.</p> <p>It fosters more livelihood opportunities</p>

Table 7: Socioeconomic outlook of Drip Irrigation



5. Summary (Drip Irrigation)

Strengths	Weaknesses
<p>S1. 60% less water compared to traditional flood irrigation in Pakistan[146].</p> <p>S2. Offers 50% reduction in Fertilizer usage[147] for agricultural activity in Pakistan.</p> <p>S3. Water saving potential ranging from 30-70%[148]which enhances climate adaptation through water conservation approach.</p> <p>S4. Increase crop production by 20 to 100%. [149]</p> <p>S5. Increased Crop Yield[150].</p> <p>S6. The adoption of drip irrigation has resulted in a 50% decrease in fertilizer usage. [151]</p> <p>S7. National Water Policy 2018[152] proposed targets involve the adoption of drip irrigation system.</p> <p>S8. Adaptable to irregular terrains.</p> <p>S9. Minimize nutrient run-off in crops.</p>	<p>W1. The cost of laterals which are used deliver water from pumping unit to the specific plant is high in case of drip irrigation [153].</p> <p>W2. Setting up a drip irrigation system can be expensive compared to traditional methods. This can be a barrier for some farmers, particularly those cultivating field crops. [154]</p> <p>W3. The small emitters used in drip systems are prone to clogging by impurities in the water. This necessitates proper filtration and potentially more maintenance. [155]</p> <p>W4. Drip irrigation might not be the most suitable option for all crops, especially those with extensive root systems. [156]</p> <p>W5. The effectiveness of drip irrigation can be reduced on uneven or sloped land.[157]</p> <p>W6. Slow adoption rates of drip irrigation systems in Pakistan present a puzzling scenario, especially considering the significant seasonal costs associated with groundwater pumping. [158]</p> <p>W7. Groundwater is depleting rapidly in Pakistan; the country has 1.2 million tube wells extracting around 50-million-acre feet of water every year which will impact drip irrigation negatively.[159]</p> <p>W8. A study from Andhra Pradesh, India, found that drip irrigation does not halt groundwater exploitation as farmers who saved water proceeded to sell it to other farmers.</p> <p>W9. May not be very effective in drought conditions.</p>

[146] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/>

[147] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/>

[148] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/#:~:text=Drip%20irrigation%20is%20an%20irrigation,du%20to%20evaporation%20and%20runoff>

[149] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/>

[150] Zhang, X., Xiao, G., Li, H., Wang, L., Wu, S., Wu, W., & Meng, F. (2020). Mitigation of greenhouse gas emissions through optimized irrigation and nitrogen fertilization in intensively managed wheat–maize production. *Scientific Reports*, 10(1), 5907.

[151] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/>

#:~:text=Drip%20irrigation%20is%20an%20irrigation,du%20to%20evaporation%20and%20run of.

[152] https://ffc.gov.pk/wp-content/uploads/2018/12/National-Water-Policy-April-2018-FINAL_3.pdf

[153] https://ffc.gov.pk/wp-content/uploads/2018/12/National-Water-Policy-April-2018-FINAL_3.pdf

[154] Usman, K. M., Muhammad, T., Majid, M., Ali, S. M., Shilan, R., Alireza, M., & Sergey, P. (2016). Drip irrigation in Pakistan: status, challenges and future prospects. *Russian Journal of Agricultural and Socio-Economic Sciences*, 56(8), 114-126.

[155] Usman, K. M., Muhammad, T., Majid, M., Ali, S. M., Shilan, R., Alireza, M., & Sergey, P. (2016). Drip irrigation in Pakistan: status, challenges and future prospects. *Russian Journal of Agricultural and Socio-Economic Sciences*, 56(8), 114-126.

[156] Usman, K. M., Muhammad, T., Majid, M., Ali, S. M., Shilan, R., Alireza, M., & Sergey, P. (2016). Drip irrigation in Pakistan: status, challenges and future prospects. *Russian Journal of Agricultural and Socio-Economic Sciences*, 56(8), 114-126.

[157] Usman, K. M., Muhammad, T., Majid, M., Ali, S. M., Shilan, R., Alireza, M., & Sergey, P. (2016). Drip irrigation in Pakistan: status, challenges and future prospects. *Russian Journal of Agricultural and Socio-Economic Sciences*, 56(8), 114-126.

[158] Reid Bell, A., Ward, P. S., Ashfaq, M., & Davies, S. (2020). Valuation and aspirations for drip irrigation in Punjab, Pakistan. *Journal of Water Resources Planning and Management*, 146(6), 04020035.

[159] <http://www.riazhaq.com/2021/04/groundwater-depletion-in-pakistan.html>



Opportunities	Threats
<p>O1. The micro-irrigation systems have been fitted in the water precious zones, like, Baluchistan, Northern areas, D.G. Khan, Kohat, Bahawal pur, Nowshera, Hari pur and Attock. [160]</p> <p>O2. Farmers in the province of Sindh have reported up to a 60% increase in crop yield after switching to drip systems. [161]</p> <p>O3. Women who utilized solar-powered drip irrigation systems in Nepal spent 50 per cent less time tending to their plots compared to traditional methods of hand watering. [162]</p> <p>O4. The Punjab Irrigated-Agriculture Productivity Improvement Project (PIPIP), initiated in 2012 with support from the World Bank, specifically targets the improvement of water productivity. The project aims to boost agricultural production, employment, and incomes. [163]</p> <p>O5. Through subsidies in Punjab farmers have successfully attained enhanced yields while utilizing 60% less water in contrast to conventional flood irrigation techniques. [164]</p> <p>O6. With an allocated budget of PKR. 3.67 billion, the government aims to transition existing irrigation projects to solar-powered systems. [165]</p> <p>O7. Sindh has initiated a Water and Agriculture Transformation project in collaboration with World Bank and has prioritized drip irrigation. [166]</p> <p>O8. HEIS can offer opportunities for women. Reduced water collection time due to increased efficiency could free up time for other income-generating activities or education.</p> <p>O9. Utilizing water storage or ponding techniques can foster drought resilient irrigation. [167]</p>	<p>T1. Drip irrigation is not ideal for all crops. Traditional flood irrigation might be better suited for row crops like wheat, maize, and rice. [168], all these 3 are major crops of Pakistan, producing 26 million tons of wheat and 8.2 million tons of Rice. [169]</p> <p>T2. Drip systems require an upfront investment PKR 200,000-300,000 [170] in pipes, emitters, and potentially pumps. This can be a barrier for small-scale farmers. [171]</p> <p>T3. Although the Pakistani government provided an 80% subsidy on solar power plants for farmers in 2018, the expense of installing drip irrigation systems remains prohibitive for many. [172]</p> <p>T4. Farmers frequently encounter challenges in accessing adequate after-sales support from both the agricultural department and system vendors. [173]</p>

Table 8: SWOT Analysis of Drip Irrigation

[160] Usman, K. M., Muhammad, T., Majid, M., Ali, S. M., Shilan, R., Alireza, M., & Sergey, P. (2016). Drip irrigation in Pakistan: status, challenges and future prospects. Russian Journal of Agricultural and Socio-Economic Sciences, 56(8), 114-126.

[161] <https://agricomplex.com.pk/drip-irrigation-system-revolution/#environmental-benefits-due-to-drip-irrigation-system-revolution>

[162] Shrestha, G., Uprety, L., Khadka, M., & Mukherji, A. (2023). Technology for whom? Solar irrigation pumps, women, and smallholders in Nepal.

[163] Reid Bell, A., Ward, P. S., Ashfaq, M., & Davies, S. (2020). Valuation and aspirations for drip irrigation in Punjab, Pakistan. Journal of Water Resources Planning and Management, 146(6), 04020035.

[164] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/#:-:text=Drip%20irrigation%20is%20an%20irrigation,du%20to%20evaporation%20and%20runoff.>

[165] <https://climatefinance.pk/cfpk-policy/drip-irrigation-for-agriculture/#:-:text=Drip%20irrigation%20is%20an%20irrigation,du%20to%20evaporation%20and%20runoff.>

[166] <https://projects.worldbank.org/en/projects-operations/project-detail/P16759>

[167] <https://doi.org/10.1016/j.scitotenv.2022.160263>

[168] <https://www.dawn.com/news/1485906>

[169] <https://api.gov.pk/TopStoryDetail>

[170] <https://www.dawn.com/news/1728236>

[171] http://www.waldeneffect.org/blog/Disadvantages_of_drip_irrigation/

[172] <https://www.dawn.com/news/1485906>

[173] <https://www.dawn.com/news/1485906>



4.1.2 Leaky Dam (Existing)

Leaky Dams, also known as Large Woody Debris (LWD), are a popular method for managing floods naturally. When placed strategically, they offer a cheap and effective way to lessen flood dangers, especially for entire watersheds. These structures come in many shapes and sizes, with advantages as varied as their designs. They can be simple dams built with local materials or more complex engineered structures. Regardless of their design, they all work by slowing down and storing water in the floodplain. This reduces flood peaks, water speed, and overall flood risk by reconnecting the river to the floodplain.^[174]

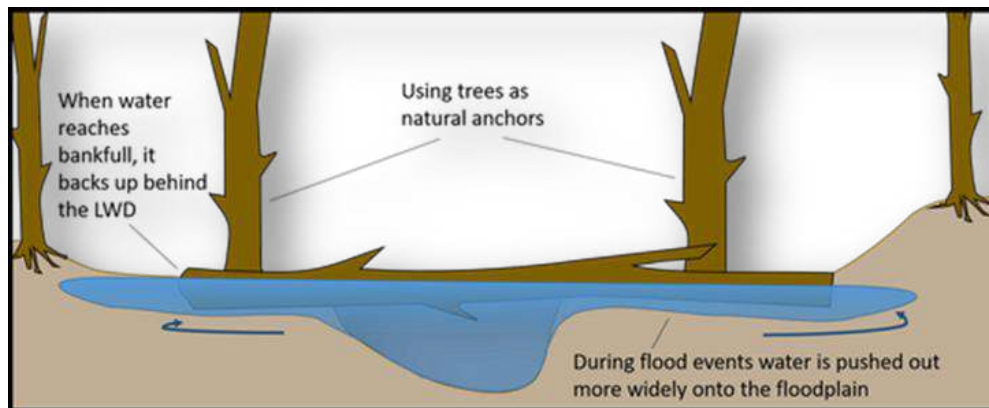


Figure 7: : Leaky Dams^[175]

1. Legal, Regulatory and Financial Landscape

The legal and regulatory framework surrounding leaky dams in Pakistan is currently supportive, with initiatives such as the **National Water Policy 2018** and the **Conservation Strategy 2023** prioritizing the construction of dams. These policies provide a solid foundation for the implementation and scaling up of leaky dam projects. **Hydropower policy 1995^[176]**, **The Punjab Irrigation, Drainage and Rivers Act 2023** for dams' installation on rivers^[177], similarly, **Water and Power Development Authority acts** as a regulatory authority for hydropower development in Pakistan. However, there may be a need for further specific regulations or guidelines to ensure proper implementation and maintenance of leaky dams, **particularly regarding sediment management and watershed management practices**.

From a financial perspective, leaky dams present both strengths and weaknesses. On one hand, their construction using **locally available materials like boulders, gravels, and wire mesh** makes them a **cost-effective solution for water conservation**, as highlighted by the successful implementation in Balochistan. A leaky dam construction can cost around **PKR120,000-150,000^[178]** (Conversion made from a case study of a leaky dam in England) ^[179]. However, the **limited storage capacity of these dams, such as the example in Balochistan with a capacity of only 11,000 m³^[180]**, raises concerns about their suitability for extensive irrigation needs. Thus, while leaky dams offer affordability, their capacity limitations may require careful financial planning and resource allocation for larger-scale projects.

[174] <http://www.sussexflowinitiative.org/news/more-than-just-a-few-bits-of-woody-debris>

[175] <http://www.sussexflowinitiative.org/news/more-than-just-a-few-bits-of-woody-debris>

[176] <https://www.ppib.gov.pk/wp-content/uploads/2023/08/PowerPolicy1995.pdf>

[177] <http://punjablaws.gov.pk/laws/2882.html>

[178] <https://thefloodhub.co.uk/wp-content/uploads/2021/06/NFM-Case-Study-Charlesground.pdf>

[179] <https://thefloodhub.co.uk/wp-content/uploads/2021/06/NFM-Case-Study-Charlesground.pdf>

[180] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>



2. Economic, and Technical Feasibility:

Leaky dams demonstrate strong economic **feasibility**, primarily due to their cost-effectiveness in construction **using locally available materials**. Additionally, their ability to **minimize evaporation losses, contribute to cleaner groundwater**, and potentially **reduce the severity of floods** can result in long-term cost savings and environmental benefits. However, challenges such as limited data on long-term impacts on groundwater recharge and the need for proper sediment management highlight the importance of thorough feasibility studies and ongoing monitoring and evaluation.

From a technical standpoint, leaky dams offer several strengths, including a relatively straightforward construction process and the potential **for improved groundwater recharge and climate resilience**. However, **weaknesses such as sediment accumulation and the dependence on effective watershed management practices** underscore the importance of technical expertise and proper maintenance to ensure optimal performance. Efforts to **improve design, such as incorporating adjustable gravel sheets** for extended water retention present opportunities to address technical challenges and enhance the overall feasibility of leaky dam projects.

To understand the dynamics of cost economics related to leaky dams, this analysis focuses on a leaky dam constructed in **Margat**^[181], **Balochistan**, by the Pakistan Council of Research in Water Resources (PCRWR) in 2002. This dam, with a catchment area of **1.79 km²** ^[182], a design flood discharge of **12.80 m³/sec**^[183], a storage capacity of **11,106 m³** ^[184], and a height of **4.9 meters**^[185], initially cost PKR. 1.6 million to build^[186]. To project the cost of a similar dam in 2024, the original expense was adjusted for inflation, resulting in approximately PKR 13,024,440 (**USD 47,019**). Adding a **10%**^[187] contingency for unforeseen expenses brings the total estimated cost to about PKR 14,326,884, or **USD 51,562** ^[188].

Though data on precise benefits is unavailable, hypothetical scenarios suggest several advantages. With its catchment area, the dam could reduce flood peaks by **0.5 m³/sec**, potentially avoiding around **USD 2,500** in annual flood damage. The dam's water storage capacity could enhance crop yields by an estimated **USD 5,000 to 7,000** annually, and reduced flooding could save approximately **USD 10,000**^[189] in property and agricultural damage. Additionally, improvements in water quality from sediment trapping could result in savings of about **USD 2,000 annually**^[190]. Overall, the estimated total benefits are **USD 20,500**, ^[191] with annual operation and maintenance costs of around **USD 1,031**^[192].

The financial analysis, using a 10% discount rate, reveals a Net Present Value (NPV) of **USD 125,159**^[193], an Internal Rate of Return (IRR) of **38%**^[194], and a payback period of **2.7 years**^[195]. Sensitivity analysis indicates that the project remains economically viable under various scenarios, though actual results could differ based on specific site conditions and local factors. The affordability of this technology will depend on site dynamics and the actual application for which detailed studies would be needed.

[181] <https://pcrwr.gov.pk/wp-content/uploads/2020/Water-Management-Reports/sustainable-grndwtr-in-balochistan.pdf>

[182 - 267] *Ibid.*

[186] *Ibid.*

[187] *Ibid.*

[188] Authors calculations based on related studies.

[189] Authors calculations based on related studies.

[190] Authors calculations based on related studies.

[191] Authors calculations based on related studies.

[192] Authors calculations based on related studies.

[193-195] Authors calculations based on related studies.



3. Inclusive Development and Climate Impacts:

Leaky dams have the potential to contribute to inclusive development by creating employment opportunities, particularly for women, in sectors such as construction and water management. With **only 22% of women^[196] currently participating in Pakistan's labor force**, the construction of dams represents an opportunity to promote gender equality and economic empowerment. Furthermore, successful implementation of leaky dams can lead to wider adoption in regions facing water scarcity, thereby enhancing resilience and promoting sustainable development.

However, the **effectiveness of leaky dams may be threatened** by climate-related factors such as **irregular rainfall patterns, as highlighted by the variation in annual rainfall across different regions of Pakistan**. Climate change-induced shifts in precipitation patterns could affect the availability and distribution of water, potentially impacting the effectiveness of leaky dams in replenishing aquifers and mitigating floods. Additionally, **challenges such as farmers' awareness of the benefits of leaky dams and upstream water use** further underscore the need for climate-resilient strategies and community engagement to maximize the positive impacts of leaky dam projects.

[196] <https://www.adb.org/sites/default/files/publication/832051/adb-brief-221-female-friendly-workplaces-urban-pakistan.pdf>



4. Socioeconomic Outlook:

The technology was assessed on its socioeconomic outlook which has been summarized in table 9 below:

Climatic Adaptation/ Social Benefits	Other Benefits/ Cost Savings	Capital Cost/Total Investment
<p>Leaky dams can potentially help in climate resilience by reducing the severity of frequent floods by an average of 10% in high-gradient streams.</p> <p>Leaky dams capture rainwater runoff and allow it to infiltrate the ground slowly, replenishing aquifers and increasing freshwater availability.</p> <p>They reduce the downstream flood peak by temporarily storing water by holding it back within the stream's channel or encouraging it to spill.</p> <p>With only 22% of women currently participating in Pakistan's labor force, the construction of leaky dams represents an opportunity to promote gender equality and economic empowerment.</p>	<p>By retaining water for longer periods, leaky dams minimize evaporation losses, particularly crucial in Balochistan's hot climate.</p>	<p>Based on study: leaky dam constructed in Margat, Balochistan</p> <p>Cost: USD 51,562</p> <p>Capacity: 11,106 m³</p> <p>At a 10% discount rate</p> <p>NPV: 125,159 USD</p> <p>IRR: 38%,</p> <p>Payback Period: 2.7 years</p>

Table 9: Socioeconomic outlook of Leaky Dams



5. Summary (Leaky Dams)

Strengths	Weaknesses
<p>S1. Leaky dams capture rainwater runoff and allow it to infiltrate the ground slowly, replenishing aquifers and increasing freshwater availability. [197]</p> <p>S2. Leaky dams can potentially help in climate resilience by reducing the severity of frequent floods by an average of 10% in high-gradient streams. [198]</p> <p>S3. By retaining water for longer periods, leaky dams minimize evaporation losses, particularly crucial in Balochis tan's hot climate. [199]</p> <p>S4. Leaky dams in Balochistan used locally available materials like boulders, gravels, and wire mesh, making them a cost-effective solution for water conservation. [200]</p> <p>S5. The construction process of leaky dams with tiered embankments and spillways is relatively straightforward. [201]</p> <p>S6. By allowing sediment to settle before water infiltrates the ground, leaky dams can contribute to cleaner groundwater. [202]</p> <p>S7. Concept of leaky dams has been well-received by both professionals and farmers in Balochistan. [203]</p>	<p>W1. Limited data on long-term impact it of leaky dams on groundwater recharge. [204]</p> <p>W2. Sediment accumulation can clog the spaces between rocks and hinder infiltration if not properly managed. [205]</p> <p>W3. The effectiveness of leaky dams depends on controlling grazing and implementing proper watershed management practices to reduce sedimentation. [206]</p> <p>W4. Limited storage capacity such as a dam constructed in Balochistan has a capacity of only 11,000 m³, which might not be sufficient for extensive irrigation needs. [207]</p>

[197] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[198] <https://www.sciencedirect.com/science/article/pii/S0022169423013914>

[199] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[200] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[201] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[202] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[203] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[204] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[205] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[206] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[207] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>



Opportunities	Threats
<p>01. PCRWR has installed leaky dams in Balochistan for recharging the Groundwater. Such successful implementations can be scaled up further. [208]</p> <p>02. Ongoing efforts to improve design such as incorporating adjustable gravel sheets for extended water retention. [209]</p> <p>03. National Water Policy 2018 and Conservation strategy 2023 prioritize the construction of dams.</p> <p>04. Successful implementation can lead to wider adoption of leaky dams in Balochistan and other regions facing water scarcity. [210]</p> <p>05. Leaky dams can be a valuable component of a comprehensive water management strategy that includes water conservation and efficient irrigation techniques. [211]</p> <p>06. Currently, only 22% of women take part in Pakistan's labor force. [212] Construction of dams can create employment opportunities for women.</p>	<p>T1. Irregular rainfall patterns due to climate change can affect the effectiveness of leaky dams. The annual rainfall over almost 90% [213] of the area varies from less than 50 mm in extremely dry areas to the west and south-west to just over 250 mm [214] in the upland areas in the north and central parts.</p> <p>T2. Farmers might not be aware of the benefits of leaky dams or lack the knowledge to maintain them properly.</p> <p>T3. Upstream water use can reduce the amount of water reaching the leaky dam, impacting its effectiveness.</p>

Table 10: SWOT Analysis of Leaky Dams

4.1.3 IoT Based Solar Pumps and Storage (Emerging)

Solar pump and storage systems are a combination of technologies that utilize solar energy to power water pumps and incorporate a storage solution to ensure water availability even during periods of low sunlight. Solar panels capture sunlight and convert it into electricity through photovoltaic cells. Water is drawn from wells or boreholes using solar water pumps. The pumped water is then stored in the storage tanks for later usage during low sunlight periods. Integrating internet technology (IoT) enhances the automation to turn the water pump on and off based on set conditions. Sensors like humidity gauges and solar panels help the system adjust watering schedules by itself, reducing manual work, saving time and making irrigation more efficient.

[208] <https://pcrwr.gov.pk/wp-content/uploads/2020/Water-Management-Reports/sustainable-grndwtr-in-balochistan.pdf>

[209] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[210] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[211] <https://unesdoc.unesco.org/ark:/48223/pf0000143819>

[212] <https://www.adb.org/sites/default/files/publication/832051/adb-brief-221-female-friendly-workplaces-urban-pakistan.pdf>

[213] <https://communities.adaptationportal.gca.org/placemarks/maps/view/101841>

[214] <https://communities.adaptationportal.gca.org/placemarks/maps/view/101841>

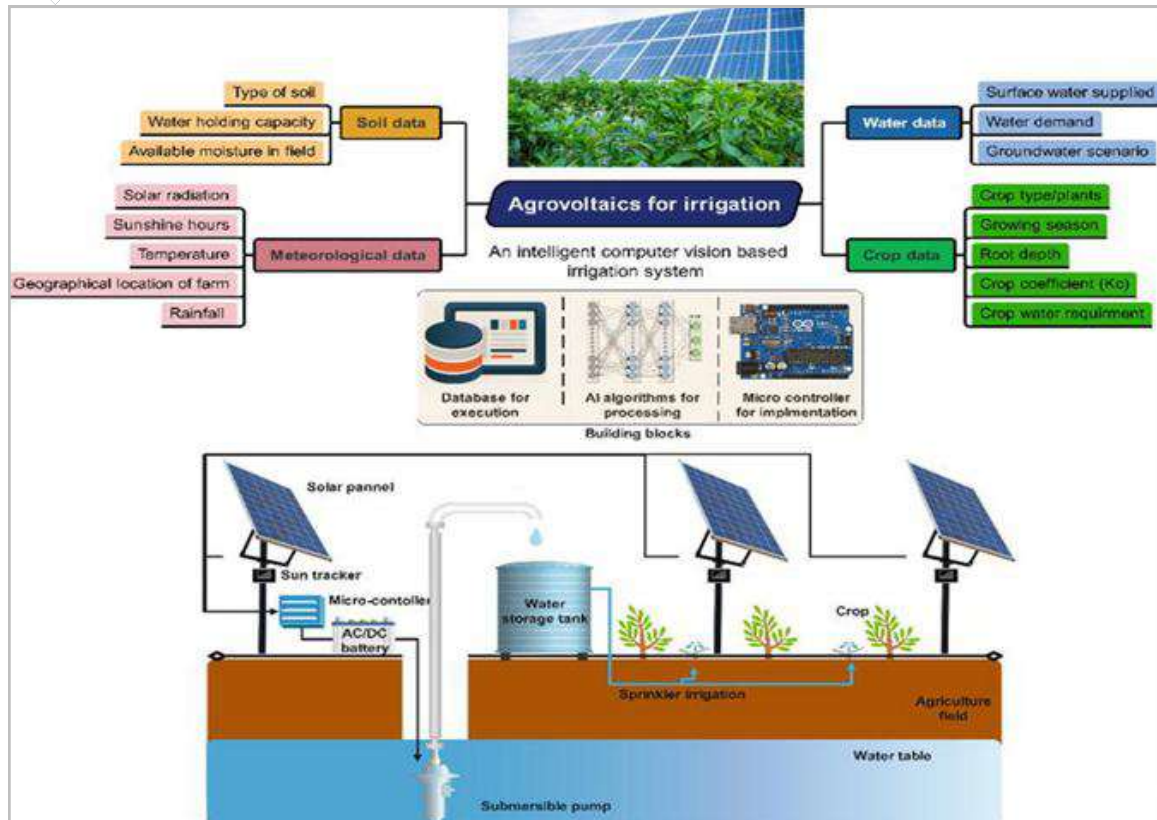


Figure 8: IoT Based Solar Pumps and Storage System[215]

Need of automated solar pumping in Pakistan:

Solar water pumps have emerged as a promising technology in Pakistan, offering a clean and reliable alternative to traditional methods. While government initiatives like the National Water Policy 2018 and subsidy programs[216] acknowledge the technology's potential, the scale of solar water pump adoption remains limited. This can be attributed to factors such as the high upfront cost of solar pump systems, which can be a major barrier for small-scale farmers. To increase the adoption pilot projects across Pakistan have successfully demonstrated the reliability and effectiveness of solar pumps for agricultural irrigation. Furthermore, government schemes offering free or subsidized pumps to low-income families and farmers can significantly enhance accessibility and accelerate the technology's uptake.

Looking ahead, integrating Internet of Things (IoT) technology with solar water pumps presents a powerful opportunity to unlock their full potential. By harnessing the power of sensors and real-time data analysis, IoT can transform irrigation practices in Pakistan. Pumps automatically adjust their operation based on factors like soil moisture and sunlight levels, ensuring crops receive the precise amount of water they need. This data-driven approach can significantly reduce water wastage, a critical concern in a country facing water scarcity. Automating pump operations can dramatically reduce the reliance on manual labor, freeing up farmers' time and resources. Moreover, the data collected by IoT sensors can provide valuable insights into irrigation practices, allowing farmers to make informed decisions and optimize their crop yields.[217]

[215] <https://www.intechopen.com/chapters/83628>

[216] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtd=e30%3D&_tp=eyJjb250ZXh0Ijp7ImZpcnNOUGFnZSI6Il9kaXJlY3QlLCJwYWdlIjoicHVibGlicXlYXRpb24ifX0

[217] <https://www.sciencedirect.com/science/article/pii/S2667345222000281>



In Pakistan, subsidies and implementation of conventional solar pumps and storage do exist, but such programs are absent for the SMART irrigation systems such as IoT integrated Solar Pumping systems. Pakistan. However, R&D and some prototypes^[218] made through educational institutions shows the potential of this technology to be piloted, yet there is no practical pilot application in the country.^[219]

Here, to understand the Legal, regulatory Landscapes, economic and technical feasibility, and climate aspects of conventional solar pumps are assessed to consider the potential of integrating SMART technologies like IoT with solar pumping in Pakistan.

1. Legal, Regulatory and Financial Landscape

In Pakistan, the legal and regulatory framework concerning solar pumping technology is evolving, with initiatives such as the **National Water Policy 2018**, which advises shifting to solar pumping through subsidies. The **National Electric Power Regulatory Authority (NEPRA)** sets regulations for connecting renewable energy sources to the national grid. However, challenges persist, such as **the absence of a specific national policy on solar technology for groundwater pumping in agriculture**. No directions, guidelines, or regulations for **integrating IoT** with pumping systems has been formulated yet. This gap creates uncertainty for stakeholders and may hinder the wider adoption of solar water pumps. Despite this, there are **regulations** for the import of solar instruments including solar cells, controllers, generators, and another associated instrument.^[220]

Financially, the cost of solar pumps ranges from **PKR 200,000 to PKR 500,000**^[221], cost of **750 gallons** water tank ranges from **PKR 30,000-40,000**^[222], while integrating the IoT SMART system will cost around **PKR 200,000**^[223] depending on capacity. This cost poses a significant barrier, particularly for small-scale farmers who may struggle to make such investments. Moreover, the challenge of a **100% up-front payment**^[224] further slows the growth of the solar pumping market.

Despite these obstacles, opportunities exist within the financial landscape. For instance, the government of Pakistan plans to provide free solar pumps to low-income families and poor farmers under the **"Free Solar Pump Scheme."** Additionally, subsidy programs like the one introduced in Khyber Pakhtunkhwa for Solar Irrigation Pumps (SIPs) in rainfed, and water-scarce regions aim to **incentivize adoption**.

2. Economic and Technical Feasibility:

Solar pumping technology offers several economic benefits, including **reductions in energy costs** for farmers by up to **70%**^[225]. This reduction, coupled with the potential for **50%**^[226] of

[218] <https://journals.uol.edu.pk/pakjet/article/download/1581/867/6220>

[219] <https://www.intechopen.com/chapters/83628>

[220] <https://www.commerce.gov.pk/wp-content/uploads/2019/06/SRO-604.pdf>

[221] <https://alphasolar.com.pk/solar-tubewell-price-in-pakistan/>

#:-:text=The%20solar%20tubewell%20price%20in%20Pakistan%20starts%20from%20345%2C000%20PKR,for%20the%20next%2025%20years.

[222] <https://pcrwr.gov.pk/wp-content/uploads/2020/Water-Management-Reports/Solar%20Powered%20Pumping.pdf>

[223] <https://www.mdpi.com/1996-1073/16/9/3860>

[224] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QlLCJwYXN0IjoicHViGjYXRpb24ifX0

[225] Goel, S., & Sharma, R. (2020). Economic Analysis of Solar Water Pumping System for Irrigation. In *Green Technology for Smart City and Society: Proceedings of GTSCS 2020* (pp. 157-167). Singapore: Springer Singapore.

[226] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QlLCJwYXN0IjoicHViGjYXRpb24ifX0



diesel- and electric-operated pumps to be converted to solar energy, could lead to a substantial reduction of **4200 MW**[227] in electricity consumption. Furthermore, reliable access to water through solar pumping enables multiple cropping seasons and cultivation of high-value crops, potentially increasing agricultural output by **20-40%**[228].

However, technical challenges exist, such as the requirement for technical expertise in the operation and maintenance of solar water pumps. Additionally, solar water pumps typically have lower flow rates compared to diesel pumps, and their effectiveness is diminished on cloudy days or during extended periods of low sunlight. Concerns also arise regarding uncontrolled pumping and the limited operating hours per day, as SIPs can only operate during sunlight hours.

The Sindh government initiated 11 schemes in 2017[229] to introduce solar-powered tube wells and pumping stations, aiming to bolster the agriculture sector. Additionally, a scheme worth Pakistan **PKR 802 million**[230] was launched to provide **subsidized solar water pumps** and tube wells to farmers, though progress remains unclear. The Water Resources Development Sector Project of 2018 plans to pilot approximately **160**[231] solar-powered drip irrigation systems in Baluchistan's Zhob and Mula river command areas, alongside other endeavors. Various pilot initiatives, primarily by the Pakistan Council of Research in Water Resources (PCRWR), have demonstrated the reliability and suitability of PV submersible DC pumps for agricultural use. [232]

To understand the dynamics of financial viability this analysis examines the economic viability of IoT-based solar pumps and storage systems using international data, as these technologies (Integrated with IoT) have not yet been piloted in Pakistan. The first case study of Rajasthan, India[233], distribution companies and farmers saw promising results. For distribution companies, an initial investment of **USD 579.13**[234] million yielded a Net Present Value (NPV) ranging from **USD 857.82** million at a **7% discount rate** to **-USD 96.95 million** at a **30% discount rate**, with an Internal Rate of Return (IRR) of **27.7%** and a payback period of **17 months**. Farmers invested **USD 86.48 million**, resulting in an NPV of **USD 1,478.03** million at a **7% discount rate** and **USD 367.78** million at a **30% discount rate**, with an IRR of **38.7%** and a payback period of **1.09 years**[322].

In Senegal, two projects[235] **demonstrated strong financial metrics. Project 1, with an initial investment of USD 38,296**[236], **had a financial NPV of USD 80,887**³²⁴ **and an economic NPV of USD 92,189**³²⁴, **yielding IRRs of 50% and 57%**³²⁴, **respectively. Project 2**³²⁴, **requiring an initial investment of USD 163,682**³²⁴, **resulted in a financial NPV of USD 432,365**³²⁴ **and an economic NPV of USD 503,263**³²⁴, **with IRRs of 54% and 64%**[237].

[227] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf

origin=figuresDialog_download&_rtd=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnNOUGFnZSI6Il9kaXJlY3QlLCJwYWdljoicHVibGlyYXRpb24ifX0

[228] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf

origin=figuresDialog_download&_rtd=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnNOUGFnZSI6Il9kaXJlY3QlLCJwYWdljoicHVibGlyYXRpb24ifX0

[229] https://solar.iwmi.org/wp-content/uploads/sites/43/2021/09/PAKISTAN-SITUATION-ANALYSIS-REPORT_final-version-3.pdf

[230] https://solar.iwmi.org/wp-content/uploads/sites/43/2021/09/PAKISTAN-SITUATION-ANALYSIS-REPORT_final-version-3.pdf

[231] https://solar.iwmi.org/wp-content/uploads/sites/43/2021/09/PAKISTAN-SITUATION-ANALYSIS-REPORT_final-version-3.pdf

[232] https://solar.iwmi.org/wp-content/uploads/sites/43/2021/09/PAKISTAN-SITUATION-ANALYSIS-REPORT_final-version-3.pdf

[233] <https://files.wri.org/d8/s3fs-public/2024-02/cost-benefit-analysis-solar-irrigation-pumps-rajasthan.pdf>

VersionId=acAyWRu47jsLtk4H_fxiVaCKGDO7.nnH

[234 - 335] Ibid

[324 - 346] Ibid

[322] https://pcrwr.gov.pk/wp-content/uploads/2021/08/Water-Treatment_final.pdf



Emission Reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/Total Investment	Social Benefits
<p>A potential for 50% of diesel- and electric-operated pumps converted to solar energy, could lead to a substantial reduction of 4200 MW. The conversion of diesel tube wells to solar-powered ones could offset around 5.025 million metric tons of CO₂ emissions annually</p>	<p>By harnessing the power of sensors and real-time data analysis, IoT can transform irrigation practices in Pakistan.</p>	<p>Based on study: IoT-based solar pumps and storage systems using international data from India and Senegal For companies Investment USD 579.13 million 1. 857.82 (7% discount rate) 2. -96.95 (30% discount rate) IRR 27.7% Payback Period 17</p> <p>For farmers Investment USD 86.48 million 1. 1478.03 (7% discount rate) 2. 367.78 (30% discount rate) IRR 38.7% Payback period 1.09</p>	<p>Reductions in energy costs for farmers by up to 70%. [242]</p> <p>Automating pump operation can dramatically reduce the reliance on manual labor, freeing up farmers' time and resources</p> <p>The implementation of solar pumps reduces labor for women in water-fetching tasks, promoting gender equality and enhancing economic opportunities for women in agriculture.</p> <p>Pumps that automatically adjust their operation based on factors like soil moisture and sunlight levels, ensuring crops receive the precise amount of water they need.</p> <p>IoT-operated solar tube wells provide a consistent and reliable source of water, which is crucial for irrigation, drinking, and other domestic uses. This reliability can significantly improve the quality of life for communities in areas where water access is otherwise limited or inconsistent.</p>

Table 11: Socioeconomic Outlook of IoT Based Solar Pumps and Storage

[242] Goel, S., & Sharma, R. (2020). Economic Analysis of Solar Water Pumping System for Irrigation. In *Green Technology for Smart City and Society: Proceedings of GTSCS 2020* (pp. 157-167). Singapore: Springer Singapore.



5. Summary (IoT Based Solar Pumps and Water Storage)

Strengths	Weaknesses
<p>S1. reductions in energy costs for farmers by up to 70%. [243]</p> <p>S2. Potential reduction in GHG emissions per unit of energy used for water pumping (CO₂-eq/kWh) of 95 to 97 percent as compared with pumps operated with grid electricity. [244]</p> <p>S3. Reliable access to water allows for multiple cropping seasons and cultivation of high-value crops, potentially increasing agricultural output by 20-40%. [245]</p> <p>S4. Studies suggests that the female-headed households as compared to male counterparts have a high drive to adopt solar PV technology. [246]</p> <p>S5. Reduce labor for women in water fetching tasks is reported in case of Solar pumps implementation. [247]</p> <p>S6. Solar Pumping has been given preference for subsidies in the National Water Policy 2018. [248]</p> <p>S7. diesel tube wells contribute around 5.025 million metric tons of CO₂ emissions annually which can be off set using solar Tube wells. [249]</p> <p>S8. Around 500 men and women are engaged in farming and running small enterprises in Punjab and Sindh with advantage of solar tube well pumps. [250]</p> <p>S9. Pakistan holds potential of 2.9MW of Solar Energy. [251]</p> <p>S10. Potential of electricity generation through solar is equivalent to energy demand of 40,000 villages. [252]</p> <p>S11. Pakistan holds PV power potential of 1200 kWh/kWp to 2100 kWh/kWp per year. [253]</p>	<p>W1. The cost of solar pump system can range from PKR 100,000 to PKR 500,000 depending on capacity. [254] For a small farmer making such investment is not easy.</p> <p>W2. Solar water pumps typically have lower flow rates compared to diesel pumps. [255]</p> <p>W3. PV solar pumping may cause uncontrolled Pumping. [256]</p> <p>W4. Solar water pumps are less effective on cloudy days or during extended periods of low sunlight. [257]</p> <p>W5. Absence of solar groundwater pumping policy [258]</p> <p>W6. Technical expertise for operation and maintenance of solar water pumps are required. [259]</p> <p>W7. Integrating IoT system with solar pumps can require approximately PKR 200,000 [260] capital which may not be possible without subsidies.</p>

[243] Goel, S., & Sharma, R. (2020). Economic Analysis of Solar Water Pumping System for Irrigation. In Green Technology for Smart City and Society: Proceedings of GTSCS 2020 (pp. 157-167). Singapore: Springer Singapore.

[244] <https://www.un-igrac.org/sites/default/files/resources/files/The%20benefits%20and%20risks%20of%20solar-powered%20irrigation%20-%20a%20global%20overview.pdf>

[245] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnNOUGFnZSI6Ii9kaXJlY3QlLCJwYVdlloicHVibGlyYXRpb24ifX0

[246] Ahmar, M., Ali, F., Jiang, Y., Wang, Y., & Iqbal, K. (2022). Determinants of adoption and the type of solar PV technology adopted in rural Pakistan. *Frontiers in Environmental Science*, 10, 895622.

[247] Shrestha, G., Uprety, L., Khadka, M., & Mukherji, A. (2023). Technology for whom? Solar irrigation pumps, women, and smallholders in Nepal.

[248] https://ffc.gov.pk/wp-content/uploads/2018/12/National-Water-Policy-April-2018-FINAL_3.pdf

[249] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnNOUGFnZSI6Ii9kaXJlY3QlLCJwYVdlloicHVibGlyYXRpb24ifX0

[250] <https://pakistan.un.org/en/stories>

[251] Hussain, F., Maeng, S. J., Cheema, M. J. M., Anjum, M. N., Afzal, A., Azam, M., ... & Iqbal, T. (2023). Solar irrigation potential, key issues and challenges in Pakistan. *Water*, 15(9), 1727.

[252] Hussain, F., Maeng, S. J., Cheema, M. J. M., Anjum, M. N., Afzal, A., Azam, M., ... & Iqbal, T. (2023). Solar irrigation potential, key issues and challenges in Pakistan. *Water*, 15(9), 1727.

[253] Hussain, F., Maeng, S. J., Cheema, M. J. M., Anjum, M. N., Afzal, A., Azam, M., ... & Iqbal, T. (2023). Solar irrigation potential, key issues and challenges in Pakistan. *Water*, 15(9), 1727.



Opportunities	Threats
<p>O1. The conversion of 50% diesel- and electric-operated pumps to solar energy could lead to a reduction of 4200 MW in electricity consumption. [261]</p> <p>O2. government of Pakistan plans to provide a free solar pump to low-income families and poor farmers under "Free solar Pump Scheme.[262]</p> <p>O3. Khyber Pakhtunkhwa has introduced a 50% subsidy program for Solar Irrigation Pumps (SIPs) in rainfed and water-scarce regions Reliable water source for remote communities not connected to the national grid. [263]</p> <p>O4. Punjab Irrigated Agriculture Productivity Improvement Project (PIAPIP) stands as the largest investment in this domain and should be explored further. [264]</p> <p>O5. Organizations such as the Agency for Barani Areas Development (ABAD) and PARC have also contributed to the installation of solar pumps in different regions of Pakistan. Around 210 solar pumps are installed by ABAD.[265]</p>	<p>T1. slow growth of the solar pumping market is attributed to the challenge of a 100% up-front payment cost [266]</p> <p>T2. As SIPs can only operate during sunlight hours, their operating hours are limited per day. [267]</p> <p>T3. Rising concerns that conversion of diesel pumping to PV solar will result in further groundwater depletion. [268]</p> <p>T4. Limited awareness among farmers about the long-term benefits and cost savings of solar water pumps can hinder wider adoption. [269]</p> <p>T5. There is no specific national policy on solar technology for groundwater pumping in agriculture [270]</p> <p>T6. In Sindh solar panel installation in kachu has raised concerns of groundwater exploitation.[271]</p>

Table 12: SWOT Analysis of IoT Based Solar Pumps and Storage

[254] <https://alphasolar.com.pk/solar-water-pump-price-in-pakistan/>

[255] <http://large.stanford.edu/courses/2017/ph240/xiao-s1/docs/self-jul08.pdf>

[256] Hussain, F., Maeng, S. J., Cheema, M. J. M., Anjum, M. N., Afzal, A., Azam, M., ... & Iqbal, T. (2023). Solar irrigation potential, key issues and challenges in Pakistan. *Water*, 15(9), 1727.

[257] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnN0UGFnZSI6Ii9kaXJlY3QlCjwYdWlljoicHVibGlyYXRpb24ifX0

[258] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnN0UGFnZSI6Ii9kaXJlY3QlCjwYdWlljoicHVibGlyYXRpb24ifX0

[259] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnN0UGFnZSI6Ii9kaXJlY3QlCjwYdWlljoicHVibGlyYXRpb24ifX0

[260] <https://www.mdpi.com/1996-1073/16/9/3860>

[261] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnN0UGFnZSI6Ii9kaXJlY3QlCjwYdWlljoicHVibGlyYXRpb24ifX0

[262] Hussain, F., Maeng, S. J., Cheema, M. J. M., Anjum, M. N., Afzal, A., Azam, M., ... & Iqbal, T. (2023). Solar irrigation potential, key issues and challenges in Pakistan. *Water*, 15(9), 1727.

[263] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnN0UGFnZSI6Ii9kaXJlY3QlCjwYdWlljoicHVibGlyYXRpb24ifX0

[264] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnN0UGFnZSI6Ii9kaXJlY3QlCjwYdWlljoicHVibGlyYXRpb24ifX0

[265] https://abad.punjab.gov.pk/water_resource_development

[266] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnN0UGFnZSI6Ii9kaXJlY3QlCjwYdWlljoicHVibGlyYXRpb24ifX0

[267] https://solar.iwmi.org/wp-content/uploads/sites/43/2021/09/PAKISTAN-SITUATION-ANALYSIS-REPORT_final-version-3.pdf

[268] https://solar.iwmi.org/wp-content/uploads/sites/43/2021/09/PAKISTAN-SITUATION-ANALYSIS-REPORT_final-version-3.pdf

[269] https://solar.iwmi.org/wp-content/uploads/sites/43/2021/09/PAKISTAN-SITUATION-ANALYSIS-REPORT_final-version-3.pdf

[270] https://www.researchgate.net/profile/Fiaz-Hussain/publication/370403569_Solar_Irrigation_Potential_Key_Issues_and_Challenges_in_Pakistan/links/645067d5809a53502140fb1a/Solar-Irrigation-Potential-Key-Issues-and-Challenges-in-Pakistan.pdf?origin=figuresDialog_download&_rtD=e30%3D&_tp=eyJjb250ZXh0ljp7ImZpcnN0UGFnZSI6Ii9kaXJlY3QlCjwYdWlljoicHVibGlyYXRpb24ifX0

[271] <https://www.thethirdpole.net/en/climate/solar-tubewells-suck-water-out-of-sindh-desert/>



4.2 Domestic

In the Domestic Subsector prioritized technologies involves Rainwater Harvesting, Chlorination in the existing categories while Groundwater Recharge through Wastewater was prioritized as an emerging technology. The following section involves the in-depth analysis of these technologies aligning with the scoring criteria.

4.2.1 Rainwater Harvesting (Existing)

Rainwater Harvesting is defined as direct collection of rainwater from rooftops and its storage in reservoirs for direct use or to be recharged into the groundwater by different suitable techniques through feasible structures for future use at time of need.[272]

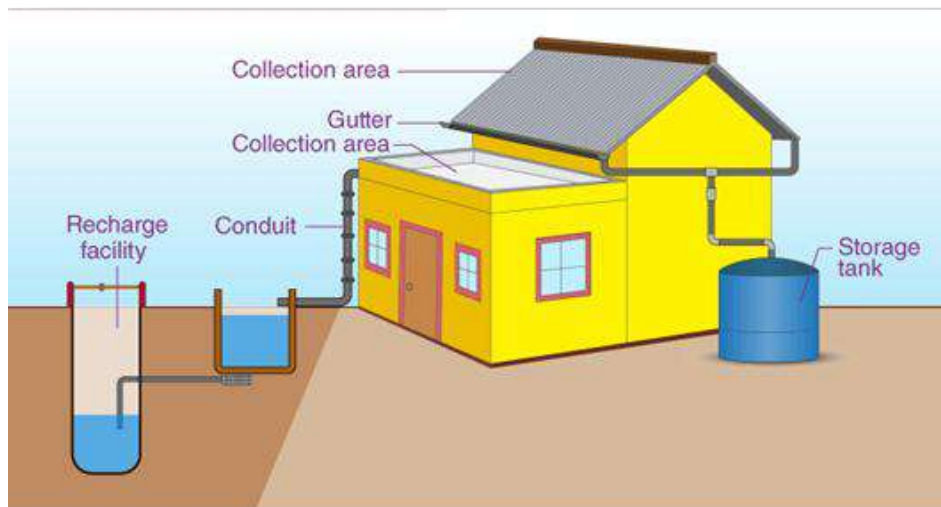


Figure 9: : House Rainwater Harvesting Systems[273]

1. Legal, Regulatory and Financial Landscape

Pakistan's National Water Policy 2018 and the **National Water Conservation Strategy 2023** promotes water conservation strategies by encouraging techniques like **rainwater harvesting**, indicating a supportive legal environment. However, the **absence of clear guidelines** no official data on the **instalment and use of harvesting systems**[274] can create confusion and hinder implementation. There are approximately **185 rainwater harvesting structures** already constructed in Pakistan, primarily earthen ponds, check dams, and ditches, concentrated in Balochistan and Sindh provinces.

The **Capital Development Authority (CDA)** in Islamabad has **implemented policies** to promote **rainwater harvesting** through **clause 5.6.6 of building and zoning regulations 2014**,[275] requiring all new buildings to include rainwater harvesting systems. This initiative aims to enhance water conservation efforts and mitigate water scarcity. Overall, the CDA's actions prioritize sustainable urban development and water resource management in Islamabad.

[272] <https://www.sciencedirect.com/topics/earth-and-planetary-sciences/rainwater-harvesting>

[273] <https://byjus.com/biology/rainwater-harvesting/>

[274] <https://dialogue.earth/en/climate/can-rainwater-harvesting-fix-pakistans-urban-flooding-problem/>

[275] <https://www.tandfonline.com/doi/abs/10.1080/1573062X.2020.1860239>



2. Economic, and Technical Feasibility:

Rainwater harvesting (RWH) is a widely employed technique in the northern regions of Pakistan, characterized by a humid climate with frequent rainfall. Cities like Nathiagali, Ayubia, Batgram, and certain parts of Abbottabad and Mansehra in Khyber Pakhtunkhwa heavily depend on RWH for their water supply, as these areas predominantly rely on perennial and seasonal streams. [276] The roofing systems in these regions typically consist of sloping steel sheets, which minimize water absorption and losses. Consequently, a significant amount of rainwater can be efficiently harvested without additional losses. Similarly, in remote areas of Azad Jammu and Kashmir RWH serves as the primary source of domestic water supply. Given the economic constraints in these areas, people cannot afford water tankers from private suppliers, making RWH their primary means of meeting water requirements. [277]

Potential of widespread implementation exists for rainwater harvesting systems as in government sector investments are available through Public Sector Development Program 2023-24, as total of PKR 50 million [278] were allocated for rainwater harvesting in Rural Areas of ICT, and PKR 10 million [279] for rainwater harvesting on an ongoing project at Kasana dam at Islamabad International Airport.

Our economic analysis of the rainwater harvesting project is based on a pilot project at Lawrence Road in Lahore, Pakistan. This project involves an underground concrete tank in Bagh-e-Jinnah Park, storing 6.4 million [280] liters of water for irrigating nearby parks and areas. The catchment area covers 25 acres, serving around 30,000 [281] residents and over 40,000 [282] daily motorists. The project cost PKR 150 [283] million (USD 920,000) and is estimated to save PKR 23 million (USD 140,000) annually from flood damage. Key assumptions for the analysis include a 20-year project lifespan [284], an 8% [285] discount rate, annual maintenance costs of USD 18,400 (2% [286] of the initial investment), and a water saving value of USD 0.000451 [287] per liter. The project can use 50% of its storage capacity annually, translating to water savings of USD 1,443. Total annual benefits are USD 141,443 [288], resulting in an annual cash flow of USD 123,043 [289] after maintenance costs.

Financial analysis shows a Net Present Value (NPV) of approximately USD 288,054 [290], with an Internal Rate of Return (IRR) of 12% [291] and a payback period of 7.5 years [292]. Sensitivity analysis reveals that the project's success heavily depends on achieving the projected flood

[276] Rashid, O., Awan, F. M., Ullah, Z., & Hassan, I. (2018, September). Rainwater harvesting, a measure to meet domestic water requirement, a case study Islamabad, Pakistan. In IOP Conference Series: Materials Science and Engineering (Vol. 414, No. 1, p. 012018). IOP Publishing

[277] Rashid, O., Awan, F. M., Ullah, Z., & Hassan, I. (2018, September). Rainwater harvesting, a measure to meet domestic water requirement, a case study Islamabad, Pakistan. In IOP Conference Series: Materials Science and Engineering (Vol. 414, No. 1, p. 012018). IOP Publishing

[278] https://www.pc.gov.pk/uploads/archives/PSDP_2023-24.pdf

[279] https://www.pc.gov.pk/uploads/archives/PSDP_2023-24.pdf

[280] <https://dialogue.earth/en/climate/can-rainwater-harvesting-fix-pakistans-urban-flooding-problem/>

[281] <https://dialogue.earth/en/climate/can-rainwater-harvesting-fix-pakistans-urban-flooding-problem/>

[282] <https://dialogue.earth/en/climate/can-rainwater-harvesting-fix-pakistans-urban-flooding-problem/>

[283] <https://dialogue.earth/en/climate/can-rainwater-harvesting-fix-pakistans-urban-flooding-problem/>

[284] <https://dialogue.earth/en/climate/can-rainwater-harvesting-fix-pakistans-urban-flooding-problem/>

[285] https://www.rainharvest.com/more/MastersProjectRainHarvest_200805.pdf

[286] https://www.rainharvest.com/more/MastersProjectRainHarvest_200805.pdf

[287] https://www.rainharvest.com/more/MastersProjectRainHarvest_200805.pdf

[288] The value of water savings is calculated using the monthly water consumption of a medium-sized family and the average tariff rate for 5-7 and 7-10 marla houses as proposed by the Punjab government. The cost per liter is determined by dividing the monthly tariff (1160.5 PKR) by the monthly consumption (15,780 liters), resulting in approximately 0.0736 PKR per liter. When converted to USD (2020), the cost per liter is approximately 0.000451 USD.

[289] Authors calculation based on above reference.

[290] Authors calculation based on above reference.

[291] Authors calculation based on above reference.

[292] Authors calculation based on above reference.



damage prevention savings. A 25%^[293] decrease in these savings would render the project financially unviable with a negative NPV. Besides monetary benefits, the project offers non-monetary advantages such as reduced energy consumption for water treatment, lower greenhouse gas emissions, improved public health outcomes by reducing flood risk and waterborne diseases, and support for urban green spaces. These benefits enhance biodiversity, provide recreational areas, and increase community involvement.

3. Inclusive Development and Climate Impacts

Social factors can influence the adoption of rainwater harvesting. **Traditional land tenure systems and limited community involvement can be hurdles.** Ensuring women have a say in decision-making and benefit from these systems is crucial for equitable water management. Studies have shown that rainwater harvesting empowers women by **alleviating the burden of water collection, freeing up time for education and income generation**^[294], for an estimated 51%^[295] of the population living in areas impacted by desertification rainwater harvesting can be a potential solution. Rainwater harvesting provides a more reliable water source closer to homes, which is particularly beneficial for women and children.

However, **limited access to finance for infrastructure development and maintenance**, estimated to be a significant challenge, poses a hurdle. **Unpredictable rainfall patterns and the risk of low rainfall or floods can also lead to crop failures and economic burdens** for farming households dependent on rainwater harvesting.

Rainwater harvesting offers a range of environmental benefits. It helps **stabilize groundwater levels, reduces land erosion, and mitigates flood risks by reducing peak flows** into major rivers by an unknown percentage. Capturing rainwater also helps manage stormwater runoff, preventing flooding and erosion. This contributes to building climate resilience in a country vulnerable to extreme weather events.

[293] Authors calculation based on above reference.

[294] <https://www.iied.org/sites/default/files/pdfs/migrate/10105IIED.pdf>

[295] <https://pcrwr.gov.pk/wp-content/uploads/2020/Water-Management-Reports/Pakistan's%20Deserts%20Land%20and%20Water%20Resources%20Development%202018.pdf>



4. Socioeconomic Outlook:

The technology was assessed on its socioeconomic outlook which has been summarized in table 13 below:

Climatic Adaptation/ Social Benefits	Other Benefits/ Cost Savings	Capital Cost/Total Investment
<p>Domestic rainwater harvesting offers a degree of independence from municipal water supplies, particularly during droughts or emergencies, adding to climate adaptation.</p> <p>The technology helps in stabilizing groundwater levels, reducing land erosion, and mitigating flood inflow to major rivers, contributing to community resilience.</p> <p>Installing a rainwater harvesting system increases water awareness and encourages individuals to be more mindful of their water usage. Communities that actively participate in rainwater harvesting not only save money on water bills but also contribute to the protection of the environment. The collective effort of the community in rainwater harvesting helps to create a sense of unity and shared responsibility towards water conservation.</p> <p>Rainwater harvesting improves access to clean drinking water, especially in regions experiencing water scarcity.</p>	<p>Rainwater harvesting reduces reliance on municipal water supplies, promoting sustainability and reducing pressure on freshwater resources.</p>	<p>PKR 150 million (USD 920,000), for community system which can hold 6.4 million litres of water, serving a catchment area of 25 acres Investment project cost PKR 150 million (USD 920,000) NPV: USD 288,054 IRR: 12% Payback period: 7.5 years For individual buildings rainwater harvesting system cost PKR 150,000 with capacity of 3,200 litres of water capture in one hour after 25 mm of rain.</p>

Table 13: Socioeconomic Outlook of Rainwater Harvesting



In conclusion, rainwater harvesting in Pakistan presents a strong case. Supportive legal frameworks, successful traditional practices, and potential for large-scale implementation, like the 0.3 million hectares of land covered by the spate irrigation system, highlight its strengths. However, addressing technical challenges like siltation, securing financing, and ensuring equitable water management are crucial for maximizing the technology's potential. By taking a holistic approach, rainwater harvesting can become a key tool for water security, climate resilience, and social development in Pakistan.

5. Summary (Rainwater Harvesting)

Strengths	Weaknesses
<p>S1. The technology helps in stabilizing groundwater levels, reducing land erosion, and mitigating flood inflow to major rivers, contributing to climate resilience. [296]</p> <p>S2. Surface runoff rainwater harvesting (RWH) has been extensively practiced in arid and semi-arid regions of Pakistan, particularly in rainfed areas. [297]</p> <p>S3. Rainwater harvesting reduces reliance on municipal water supplies, promoting sustainability and reducing pressure on freshwater resources. [298]</p> <p>S4. Collected rainwater can be used for non-potable purposes like laundry, toilet flushing, and gardening, lowering water bills. [299]</p> <p>S5. Capturing rainwater helps manage stormwater runoff, preventing flooding and erosion. [300]</p> <p>S6. Domestic rainwater harvesting offers a degree of independence from municipal water supplies, particularly during droughts or emergencies, adding to climate adaptation. [301]</p> <p>S7. Rainwater harvesting provides a closer, more reliable source, freeing up time for education, income generation opportunity for women[302]</p> <p>S8. NWP 2018[303] and National Water Conservation Strategy 2023[304] prioritize rainwater harvesting in its water conservation plans.</p>	<p>W1. Despite widespread practice, the number of rainwaters harvesting structures is inadequate to meet the growing water demand, especially with the increasing population. [305]</p> <p>W2. Major reservoirs in Pakistan suffer from siltation, reducing their water storage capacity, which affects the efficiency of rainwater harvesting systems reliant on these reservoirs. [306]</p> <p>W3. Frequent siltation of rainwater storage structures, high labor demands for reconstruction, and inadequate local capacity for identifying suitable catchments and construction sites pose technical challenges. [307]</p> <p>W4. Issues related to land tenure, limited community involvement, and perceptions that the technology is only suitable for water-scarce areas hinder its widespread adoption and effectiveness.</p> <p>W5. Reliance on donor funding for projects raises uncertainties about the sustainability and ownership of rainwater harvesting initiatives after project completion, affecting long-term viability and effectiveness. [308]</p>

[296] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[297] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[298] Hassan, I. (2016). Rainwater Harvesting—an alternative water supply in the Future for Pakistan. J. Biodivers. Environ. Sci, 8, 213-222.

[299] Hassan, I. (2016). Rainwater Harvesting—an alternative water supply in the Future for Pakistan. J. Biodivers. Environ. Sci, 8, 213-222.

[300] Hassan, I. (2016). Rainwater Harvesting—an alternative water supply in the Future for Pakistan. J. Biodivers. Environ. Sci, 8, 213-222.

[301] Hassan, I. (2016). Rainwater Harvesting—an alternative water supply in the Future for Pakistan. J. Biodivers. Environ. Sci, 8, 213-222.

[302] <https://www.iied.org/sites/default/files/pdfs/migrate/10105IIED.pdf>

[303] https://ffc.gov.pk/wp-content/uploads/2018/12/National-Water-Policy-April-2018-FINAL_3.pdf

[304] <https://pcrwr.gov.pk/wp-content/uploads/2023/02/National-Water-Conservation-Strategy-for-Pakistan-2023-27.pdf>

[305] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[306] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[307] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[308] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)



Opportunities	Threats
<p>O1. Approximately 185 rainwater harvesting structures have been constructed, including earthen ponds, check and retention dams, dikes, and ditches, primarily in the provinces of Balochistan and Sindh. [309]</p> <p>O2. Successful water harvesting practices in NWFP called rod kohi system; and sailaba and khushkaba systems in western Balochistan province to address the domestic and agricultural needs of water are already in practice. [310]</p> <p>O3. Pakistan boasts the world's largest indigenous rainwater harvesting system, known as the spate irrigation system. This innovative system covers approximately 0.3 million hectares (mha) of cultivated land within the country, with a potential expansion to cover an estimated 6.935 mha. [311]</p> <p>O4. Rebates, tax credits, and other government programs can encourage adoption of rainwater harvesting systems.</p> <p>O5. Developing and implementing water and agriculture policies specifically addressing rainwater harvesting can provide clear directives and support for technology adoption and management. [312]</p> <p>O6. In Islamabad, the CDA has regulated it for all new buildings to have a rainwater harvesting system, this can be replicated in other cities. [313]</p> <p>O7. In Pakistan about 51% of land resources are impacted by desertification and can utilize rainwater harvesting. [314]</p>	<p>T1. Traditionally, men control land and resources in Pakistan. Ensuring women have access to decision-making and benefits from rainwater systems is crucial. [315]</p> <p>T2. Limited access to finance for infrastructure development and maintenance poses a significant challenge, especially for government entities managing these systems. [316]</p> <p>T3. Unpredictable rainfall patterns and the risk of low rainfall or high floods associated with rainwater harvesting technology can lead to crop failures and economic burdens for farming households. [317]</p> <p>T4. Inadequate legal and regulatory frameworks, poor understanding of water rights, and inequitable distribution of water among users present regulatory barriers to effective implementation and management. [318]</p>

Table 14: SWOT Analysis of Rainwater Harvesting

[309] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[310] <https://sdpi.org/sdpiweb/publications/files/P29-Water%20Harvesting%20in%20Mountain.pdf>

[311] Khan, Q. U., & Sayal, O. U. (2019). Spate Irrigation: Impact of Climate Change with Specific Reference to Pakistan. In Irrigation-Water Productivity and Operation, Sustainability and Climate Change. IntechOpen.

[312] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[313] <https://tribune.com.pk/story/2411420/rainwater-harvesting-a-must-for-all-buildings>

[314] <https://pcrwr.gov.pk/wp-content/uploads/2020/Water-Management-Reports/Pakistan's%20Deserts%20Land%20and%20Water%20Resources%20Development%202018.pdf>

[315] <https://www.iied.org/sites/default/files/pdfs/migrate/10105IIED.pdf>

[316] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[317] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)

[318] [https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20\(29-3-17\).pdf](https://mocc.gov.pk/SitelImage/Misc/files/PAK%20TNA%20BAEF%20FINAL%20DEC%202016%20(29-3-17).pdf)



4.2.2 Chlorination (Existing)

A chlorination system is a method used in water treatment to disinfect water by adding chlorine. This chlorine kills bacteria, viruses and other harmful microorganisms that can cause waterborne diseases. Chlorine can be added in various forms, including chlorine gas, liquid sodium hypochlorite (bleach) or calcium hypochlorite tablets or granules. The chlorine reacts with the water, killing pathogens and preventing their spread.

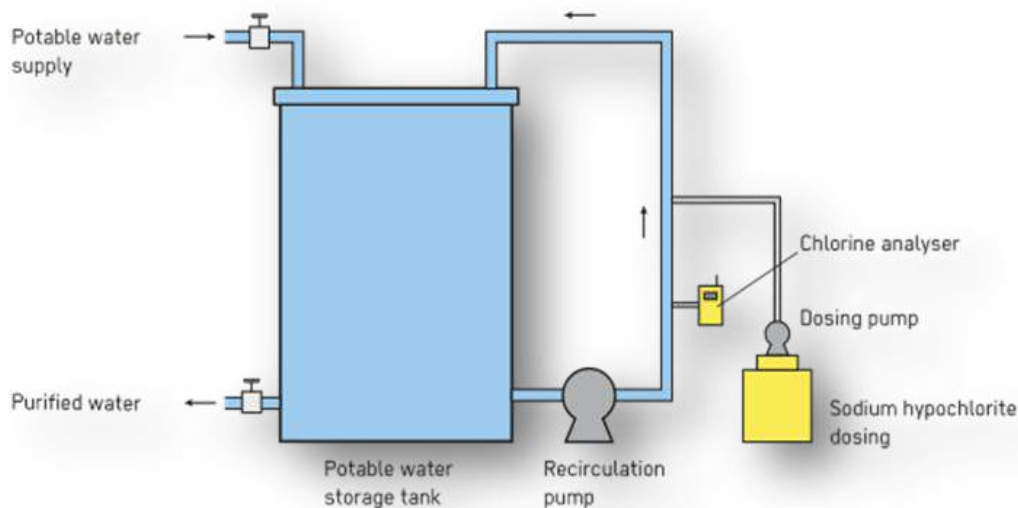


Figure 10: Chlorination System[319]

1. Legal, Regulatory and Financial Landscape

In Pakistan, the legal framework and regulatory standards surrounding water treatment and chlorination are influenced by international guidelines, particularly those set by the **World Health Organization (WHO)**. The **Karachi Water and Sewerage Board (KWSB)** adheres to **WHO standards** in its water treatment processes, ensuring the addition of chlorine to water supplies at appropriate levels.

The Public Health Engineering Department, Government of Balochistan, has collaborated with the Pakistan Council of Research in Water Resources (PCRWR) to install chlorination systems across various water supply schemes in eight districts of Balochistan. This indicates a proactive approach by the government towards ensuring the availability of safe drinking water.

Financially, the production of chlorine through WATA technology by local companies like Pakoswiss presents an economically feasible solution. Pakoswiss, with a production capacity of **360 liters of sodium hypochlorite per day**[320], contributes to meeting the demand for chlorine in water treatment processes.

However, despite the legal and regulatory frameworks in place, challenges persist in enforcing these standards, especially in **rural areas where access to clean water and proper sanitation**

[319] <https://www.emergency-wash.org/water/en/technologies/technology/chlorination>

[320] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf



facilities is limited. Additionally, there may be gaps in funding and financial support for extensive awareness campaigns needed to encourage the adoption of new water treatment practices.

2. Economic and Technical Feasibility

Technical challenges for chlorination remain, as evidenced by studies in rural Punjab showing **the persistence of pathogens like E. coli even after chlorination**. Addressing these **technical challenges** requires ongoing research and innovation in water treatment technologies, possibly integrating chlorine technology into new household water treatment systems (HWTS) to improve effectiveness.

Approximately **70% of Pakistan's surface and sub-surface water supply sources are not appropriate for drinking** due to significant organic, inorganic, and biological contamination. [321] Therefore, disinfection plays a significant role in the supply of safe drinking water. Chlorination offers a promising solution to the economic and technical challenges associated with traditional chlorine production. By producing **chlorine locally at a low cost**, disinfection through chlorination makes water treatment more affordable, particularly for marginalized communities. **The low concentration (0.65%) sodium hypochlorite** produced by WATA is not only cost-effective but also safer to handle, reducing the risks associated with concentrated chlorine. Chlorine tablets are also available in Pakistani market having the capacity to disinfect **20- 30 liters** of water per tablet.[322] A tablet with a disinfecting capacity of 1 liter can cost around PKR 30.[323]

Understanding the cost economics of Pakistan is complex, as it lacks studies on the economic analysis of chlorine-based disinfection in water treatment plants, so findings from other contexts are used to understand the costs and benefits. Historically, chlorination has been a low-cost method of ensuring safe drinking water. A study comparing chlorination and UV disinfection in India found UV disinfection saves up to **63%** of annual operation and maintenance (O&M) costs compared to chlorination. Another study in Colombia found that using aluminum hydroxychloride (PACl) + ferric chloride (FeCl₃) is the most cost-effective coagulant in drinking water treatment.

An IHS report analyzed water treatment chemicals in the US and Canada, noting that chlorine-based disinfection is reliable and cost-effective. While costs for small water systems are higher per unit of water treated, chlorine remains cheaper than most other technologies. A World Health Organization (WHO) study estimated the global costs and benefits of water supply and sanitation interventions to meet the Millennium Development Goals. It found that the **benefit-cost ratio** (BCR) for water interventions ranges from **0.6**[324] in Oceania to **3.7**[325] in South Asia, with a global return of **USD 2** [326] for every **USD 1** [327] invested.

[321] <https://iwaponline.com/jwh/article/13/1/270/28260/Monitoring-of-chlorination-disinfection-by>

[322] https://pcrwr.gov.pk/wp-content/uploads/2021/08/Water-Treatment_final.pdf

[323] <https://dawaai.pk/otc/-46585.html#:~:text=28.50%2FStrip%20Rs.>

[324] Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage.

[325] Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage.

[326] Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage.

[327] Global costs and benefits of drinking-water supply and sanitation interventions to reach the MDG target and universal coverage.



These studies suggest significant economic returns for Pakistan from investing in safe drinking water infrastructure, potentially yielding USD 3.7^[328] for every dollar invested. Such investments could also lead to public health improvements, reduced waterborne diseases, and saved time, particularly for women and children, facilitating more educational and economic activities. Considering the low market price of chlorine in Pakistan and other case studies conducted by WHO, it is evident that chlorination is one of the cheapest and most viable drinking water treatments available in Pakistan.

3. Inclusive Development and Climate Impacts

The provision of safe and disinfected water through chlorination has the potential to significantly impact inclusive development, particularly in addressing the needs of marginalized communities. With **approximately 21 million people**^[329] in Pakistan lacking access to clean water, chlorination offers a scalable solution to enhance water quality and reduce waterborne diseases, disproportionately affecting women and vulnerable populations.

However, **challenges persist in reaching remote and rural areas**, where surface water is commonly used for drinking without adequate chlorination at filtration stations. This underscores the importance of expanding chlorination efforts beyond urban centers to ensure equitable access to safe drinking water for all.

From a climate perspective, decentralized chlorine production technology aligns with sustainability goals by reducing reliance on centralized production facilities and minimizing carbon emissions associated with transportation. However, **the potential health impacts of chlorination disinfection byproducts, including cancer risks**, highlight the importance of carefully balancing the benefits of water disinfection with potential environmental and health concerns.

The low concentration chlorine produced locally by WATA is easier to store and transport compared to high concentration commercial chlorine, thereby **reducing carbon emissions associated with transportation**. Furthermore, the availability of alternative chlorine sources during disasters, stocked by NGOs and aid agencies, **enhances the resilience of water treatment systems**.

In conclusion, while chlorination presents opportunities for improving water quality and public health in Pakistan, addressing regulatory, technical, and equity challenges is essential to realizing its full potential while mitigating negative environmental and health impacts.

[328] Authors estimations

[329] <https://www.waterforwomenfund.org/en/project/water-for-women---pakistan.aspx>



4. Socioeconomic Outlook:

The technology was assessed on its socioeconomic outlook which has been summarized in table 15 below:

Climatic Adaptation/ Social Benefits	Other Benefits/ Cost Savings	Capital Cost/Total Investment
<p>Around 21 million people in Pakistan lacks clean water, by which women are particularly impacted.</p> <p>Chlorination can enhance the provision of safe and disinfected water to communities. According to the World Health Organization (WHO), unsafe water, sanitation, and hygiene cause an estimated 1.4 million deaths annually, chlorination effectively kills harmful bacteria and viruses in drinking water, significantly reducing the risk of waterborne diseases like cholera, typhoid, and dysentery improving public health.</p> <p>The low concentration chlorine produced locally by WATA is easier to store and transport compared to high concentration commercial chlorine, thereby reducing carbon emissions associated with transportation. Furthermore, the availability of alternative chlorine sources during disasters, stocked by NGOs and aid agencies, enhances the resilience of water treatment systems.</p> <p>Training local communities to manage and monitor chlorination systems empowers them to take control of their water supply and health outcomes. It builds local capacity and promotes community ownership of water safety initiatives.</p>	<p>Chlorine is a readily available and inexpensive disinfectant compared to many alternative methods.</p> <p>Chlorine is highly effective at killing a broad spectrum of bacteria, viruses, and other pathogens in water.</p>	<p>A tablet with disinfecting capacity of 1 liter can cost around PKR 30 in Pakistan.</p>

Table 15: Socioeconomic Outlook of Chlorination



5. Summary (Chlorination)

Strengths	Weaknesses
<p>S1. Chlorine is highly effective in eliminating pathogenic microorganisms from water, proven to reduce waterborne diseases [330]</p> <p>S2. Chlorine tablets are also available in Pakistani market having the capacity to disinfect 20- 30 liters of water per tablet.[331]</p> <p>S3. WATA technology produces chlorine locally at a low cost, making it affordable and economically feasible for the general population [332]</p> <p>S4. Pakoswiss a local company has a production capacity of 360 liters of sodium hypochlorite per day [333]</p> <p>S5. WATA technology produces low concentration (0.65%) sodium hypochlorite which is easy and safe to handle, eliminating the risks associated with concentrated chlorine.[334]</p> <p>S6. Low concentration chlorine produced by WATA is easier to store and transport compared to high concentration commercial chlorine [335]</p>	<p>W1. Encouraging people to adopt new habits for water treatment requires extensive awareness campaigns and support [336]</p> <p>W2. While pilot programs have been successful in urban areas, reaching the population in remote areas remains a challenge [337]</p>

[330] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[331] https://pcrwr.gov.pk/wp-content/uploads/2021/08/Water-Treatment_final.pdf

[332] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[333] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[334] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[335] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[336] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[337] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf



Opportunities	Threats
<p>O1. PCRWR has provided technical support to Public Health Engineering Department, Government of Balochistan for installation of Chlorination System at various water supply schemes in eight districts of Balochistan.[338]</p> <p>O2. Karachi Water and Sewerage Board (KWSB) is successfully adding chlorine to the water as per the standards set by the WHO. [339]</p> <p>O3. The importance of WATA equipment to cost-effectively produce onsite chlorine near the affected population is highly relevant which can be expanded further. [340]</p> <p>O4. Around 21 million people, particularly women get affected by unavailability of clean water in Pakistan. [341] Chlorination can enhance the provision of safe and disinfected water to communities.</p> <p>O5. Availability of alternative chlorine sources is not an issue in Pakistan, during disasters, NGOs and aid agencies often stockpile chlorine tablets. [342]</p> <p>O6. Approximately 70% of Pakistan's surface and sub-surface water supply sources are not appropriate for drinking due to significant organic, inorganic, and biological contamination.[343] Therefore, disinfection plays a significant role in the supply of safe drinking water.</p> <p>O7. There is an opportunity to develop new household water treatment systems (HWTS) powered by WATA technology to improve chlorine integration. [344]</p>	<p>T1. In most of the rural areas of Pakistan, surface water is used for drinking while chlorination is not done at filtration stations.[345]</p> <p>T2. Studies conducted in rural Punjab showed presence of E. coli even after chlorination[346]</p> <p>T3. Chlorination disinfection byproducts when ingested can result in health impacts such as occurrence of cancer.[347]</p>

Table 16: SWOT Analysis of Chlorination

[338] https://pcrwr.gov.pk/wp-content/uploads/2021/08/Water-Treatment_final.pdf

[339] <https://tribune.com.pk/story/2420001/kwsb-putting-chlorine-in-water-as-per-who-standards>

[340] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[341] <https://www.waterforwomenfund.org/en/project/water-for-women---pakistan.aspx>

[342] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[343] <https://iwaponline.com/jwh/article/13/1/270/28260/Monitoring-of-chlorination-disinfection-by>

[344] https://sswm.info/sites/default/files/reference_attachments/Khan%20%282016%29%20Scaling%20up%20HWTS%20in%20Pakistan.pdf

[345] <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5573092/pdf/BMRI2017-7908183.pdf>

[346] <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5573092/pdf/BMRI2017-7908183.pdf>

[347] <https://iwaponline.com/jwh/article/13/1/270/28260/Monitoring-of-chlorination-disinfection-by>



4.2.3 Groundwater Aquifer Recharge Through Wastewater (Emerging)

Groundwater recharge with reclaimed wastewater is an innovative water management technique that utilizes treated wastewater to replenish underground aquifers. Using treated wastewater for recharge reduces the reliance on freshwater sources like rivers and lakes for non-potable uses like irrigation or industrial processes. As the treated wastewater percolates through the soil and rock layers (vadose zone) before reaching the aquifer, it undergoes further natural purification. This additional filtration helps remove contaminants and improves water quality.

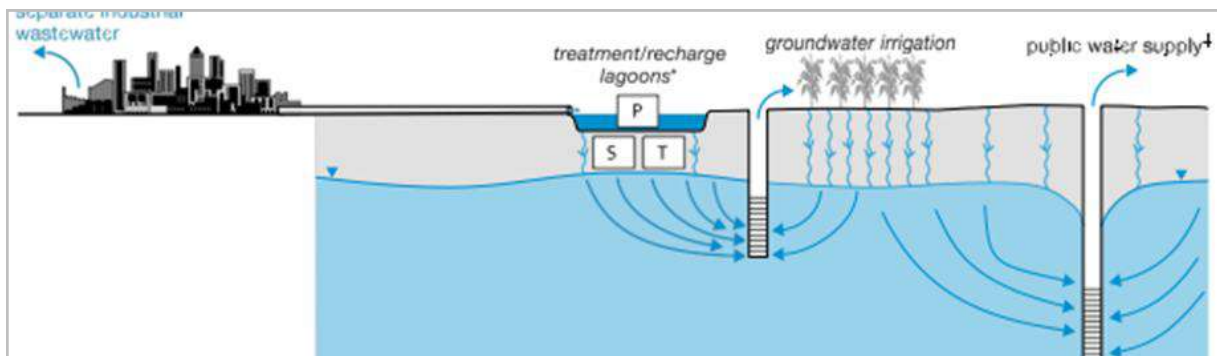


Figure 11: : Groundwater Aquifer Recharge through Wastewater[348]

1. Legal, Regulatory and Financial Landscape

Pakistan has made significant strides in establishing legal and regulatory frameworks to manage groundwater resources. **The National Water Policy (2018), Punjab Water Policy (2018), and Punjab Water Act (2019)** provide guidelines for managing abstraction, contamination, and licensing of groundwater use. These policies aim to address the challenges of over-abstraction and contamination, ensuring sustainable management of water resources.

Financially, there are opportunities for groundwater recharge projects through government initiatives and international funding. **The Economic Survey 2021-22** mentions exploring investments for groundwater recharge projects, contributing to community resilience. Additionally, the Recharge Pakistan Project, with an allocation of **PKR 6 billion**[349] from national resources, indicates a commitment to addressing groundwater challenges. Furthermore, funding from international sources like **the Green Climate Fund (GCF) is under review**, providing additional **financial support** for groundwater management initiatives, these can be leveraged to tap into the opportunity for **recharging groundwater through treated initiatives**.

2. Economic and Technical Feasibility

Replenishing depleted aquifers through artificial recharge with treated wastewater is a globally adopted strategy for water resource management. Studies indicate potential water savings of up to **5%**[350] for irrigation through wastewater recycling. However, selecting suitable sites for recharge remains a challenge.

[348] <https://www.intechopen.com/chapters/73757>

[349] <https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf>

[350] <https://www.mdpi.com/2073-4441/3/4/964>



Groundwater plays a crucial role in Pakistan's economy, providing **90% of domestic water** in rural areas and over **50% of irrigation water** nationally. [351] However, over-extraction, waterlogging, and contamination threaten the sustainability of groundwater resources.

Increased access to groundwater has created **opportunities** for smallholder farmers to **diversify their income** and enhanced their **resilience against droughts**. Farmers having access to groundwater reported **50-100%** more crop yields. [352] Additionally, adopting better irrigation methods can lead to **significant water savings, reducing energy demand and carbon footprint associated with groundwater extraction**. Ground recharge through wastewater in developed countries can cost an estimated of **USD 0.45 - USD 1.20 per cubic meter**[353] of recharge (including treatment and recharge system costs), depending on the characteristics of wastewater and the treatment method this cost can fluctuate.

To delve deeper into the understanding of groundwater recharge through wastewater this section involves understanding from numerous studies[354] which highlights the positive economic viability of groundwater aquifer recharge projects. The Pakistan Council of Research in Water Resources (PCRWR) has provided cost-benefit estimates for such a project in their report, "From Crisis to Sustainability: Managing Groundwater Recharge in Pakistan." [355] According to the report, the installation cost of a recharge well without a storage facility is approximately Rs. 0.3 million (**USD 1,908**)[356]. This estimate is based on 2021 market rates for a recharge well with a pit size of **4.2 m x 3.0 m x 2.1 m**, [357] a 60-meter deep well, and a 15 cm[358] diameter PVC pipe casing. The assumed lifespan of the recharge structure is 20 years, with annual maintenance costs estimated at 3%[359] of the total capital cost, amounting to USD 57[360].

The cost-benefit analysis compares the annual amount of rainwater recharged to the annual costs, including capital and maintenance expenses. Measurements at three sites indicate an average groundwater recharge of **2,834 m³** per year. The benefits are quantified using the Abiana method of water pricing, with a reported rate of Rs. 53 per cubic meter of water. This results in total annual benefits of PKR 150,202 (USD 951)[361].

For financial evaluation, a 5% discount[362] rate is applied. The analysis reveals a base case Net Present Value (NPV) of USD 9,233[363], an Internal Rate of Return (IRR) of **47%**[364], and a payback period of **2.1 years**[365]. These results demonstrate that the project remains

[351] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[352] https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/34-groundwater_management_in_pakistan_an_analysis_of_problems_and_opportunities.pdf

[353] Qadir, M., Boelee, E., Amerasinghe, P., & Danso, G. (2015). Costs and Benefits of Using Wastewater for Aquifer Recharge. *Wastewater*, 153-167. doi:10.1007/978-94-017-9545-6_9

[354] https://sawpa.gov/wp-content/uploads/2013/01/Att7_IG1_WSBen_1of1.pdf
<https://link.springer.com/article/10.1007/s11269-023-03483-3#abbreviations>
https://www.researchgate.net/publication/374602245_Cost-benefit_Analysis_of_Indirect_Groundwater_Recharge_Scheme_using_Recycled_Water_in_a_Semi-arid_Region

[355] <https://pcrwr.gov.pk/wp-content/uploads/2024/01/From-Crisis-to-Sustainability-Managing-Groundwater-Recharge-in-Pakistan-2023.pdf>

[356] Ibid.

[357] Ibid.

[358] Ibid.

[359] Ibid.

[360] Ibid.

[361] <https://file.pide.org.pk/pdf/PDR/207/Volume4/939-955.pdf>

[362] Authors Calculations

[363] Authors Calculations

[364] Authors Calculations

[365] Authors Calculations



financially viable under various scenarios, with NPVs ranging from **USD 6,869**^[366] to **USD 12,710**^[367], IRRs between **42%**^[368] and **52%**^[369], and payback periods from **1.9 to 2.4 years**^[370].

Results shows the positive viability of groundwater recharging interventions. However, these findings should be interpreted with caution due to limitations, such as the reliance on 2021 market values and the assumed water price to improve accuracy, refining the groundwater valuation and considering broader environmental and social benefits would be beneficial.

3. Inclusive Development and Climate Impacts

Groundwater management initiatives have the potential to promote inclusive development by increasing access to water resources, particularly for rural communities. **Women**, who often bear the burden of water collection, stand to benefit from **improved access to groundwater**, reducing the need to **travel long distances for water**. However, **challenges** such as waterlogging and salinity (Irrigation adds **16 million tons of salt** to the Indus Basin annually, threatening soil health and **agricultural production**) threaten the availability of safe drinking water, particularly in regions reliant on seepage from the Indus Basin Irrigation System.

A study in Spain using treated wastewater for Managed Aquifer Recharge (MAR) showed a **12-36% reduction in groundwater pumping energy**. The same study mentioned above also found that the energy savings from reduced pumping due to MAR resulted in a cut of about **11 tonnes of CO₂ emissions** annually. Additionally, these energy savings translated to a cost reduction of **EUR 3000 per year** for farmers on their pumping bills.^[371]

However, the **threat** of waterlogging (**waterlogging** still afflicts **35 percent** of the IBIS canal command area, mostly in the province of **Sindh**^[372]), the pumping of **61 billion cubic meters**^[373] of water annually exceeds the sustainable limit, leading to energy-intensive extraction processes that **emit 3.8 million metric tons of CO₂ annually**, recharging groundwater aquifer and controlling over-abstraction can effectively mitigate these emissions. ^[374] This underscores the importance of sustainable groundwater management in building resilience against droughts and ensuring public health and environmental sustainability.

[366] Authors Calculations

[367] Authors Calculations

[368] Authors Calculations

[369] Authors Calculations

[370] Authors Calculations

[371] <https://www.mdpi.com/2073-4441/14/22/3703>

[372] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[373] Government of Pakistan. National Water Policy; Ministry of Water Resources: Islamabad, Pakistan, 2018

[374] <https://pecongress.org.pk/images/upload/books/5-Making%20Agricultur%20Asad%20Sarwar.pdf>



4. Socioeconomic Outlook:

The technology was assessed on its socioeconomic outlook which has been summarized in table 17 below:

Climatic Adaptation/ Social Benefits	Other Benefits	Capital Cost/Total Investment	Social Benefits
<p>A study found that the energy savings from reduced pumping due to MAR resulted in a cut of about 11 tonnes of CO₂ emissions annually. [375]</p>	<p>Replenishing depleted aquifers through artificial recharge with treated wastewater is a globally adopted strategy for water resource management. Studies indicate potential water savings of up to 5% [376]</p>	<p>Based on study: PCRWR study 'From Crisis to Sustainability: Managing Groundwater Recharge in Pakistan' Cost: USD 1,908 for pit size of 4.2 m x 3.0 m x 2.1 m, a 60 m deep well, and a 15 cm diameter PVC pipe casing with annual maintenance cost 3% (USD 57) Discount Rate: 5% NPV: USD 9,233, IRR: 47%, Payback period: 2.1 years.</p>	<p>A study in Spain using treated wastewater for Managed Aquifer Recharge (MAR) showed a 12-36% reduction in groundwater pumping energy. Additionally, these energy savings translated to a cost reduction of EUR 3000 per year for farmers on their pumping bills. [377]</p>

Table 17: Socioeconomic Outlook of Groundwater Aquifer Recharge Through Wastewater

[375] <https://www.mdpi.com/2073-4441/14/22/3703>

[376] <https://www.mdpi.com/2073-4441/3/4/964>

[377] <https://www.mdpi.com/2073-4441/14/22/3703>



5. Summary (Groundwater Aquifer Recharge through wastewater)

Strengths	Weaknesses
<p>S1. Managing aquifer recharge through wastewater shows 12-36% reduction in groundwater pumping energy. [378]</p> <p>S2. Energy savings from reduced pumping due to MAR results in a cut of about 11 tonnes of CO₂. [379]</p> <p>S3. Study indicates energy savings from managed aquifer recharge translated to a cost reduction of EUR 3000 per year for farmers on their pumping bills. [380]</p> <p>S4. Groundwater supplies 90% of domestic water in rural areas, 70% nationally, and over 50% of irrigation water in Pakistan. It mitigates unreliable canal water and rainfall. [381]</p> <p>S5. The National Water Policy (2018), Punjab Water Policy (2018), and Punjab Water Act (2019) establish frameworks for managing abstraction, contamination, and licensing. [382]</p> <p>S6. Potential for financial incentives for recharge projects. Pakistan's Economic Survey 2021-22 mentions exploring investments for groundwater recharge adding to community resilience. [383]</p> <p>S7. High potential for financing as PKR 6 billion from national resources are allocated for Recharge Pakistan Project and under the review for funding from GCF. [384]</p> <p>S8. Groundwater resource development in Pakistan played a crucial role in facing hunger challenges, reducing poverty and achieving economic growth. [385]</p> <p>S9. Increase access to groundwater has created opportunities for smallholder farmers to diversify their income and enhanced their resilience against droughts. Farmers having access to groundwater reported 50-100% more crop yields. [386]</p>	<p>W1. Pakistan extracts 61 billion cubic meters of water from aquifers each year, exceeding the sustainable limit. [387]</p> <p>W2. Unregulated pumping has depleted groundwater and dried wells in Punjab. [388]</p> <p>W3. Only 20% of the population has access to safe drinking water due to salinity, improper wastewater disposal, and agricultural runoff (affecting 43% of irrigated land). Fecal contamination is high due to poor sanitation. [389]</p> <p>W4. Inadequate data collection has inhibited the ability to adopt evidence-based policies to improve groundwater management. [390]</p> <p>W5. Pumping 50 cubic kilometers (km³) of groundwater annually consumes over 6 billion kWh of electricity and 3.5 billion liters of diesel. This energy use translates to 3.8 million metric tons (mt) of CO₂ emissions per year. [391]</p>

[378] <https://www.mdpi.com/2073-4441/14/22/3703>

[379] <https://www.mdpi.com/2073-4441/14/22/3703>

[380] <https://www.mdpi.com/2073-4441/14/22/3703>

[381] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[382] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[383] https://www.finance.gov.pk/survey/chapters_23/Economic_Survey_2022_23.pdf

[384] <https://unfccc.int/sites/default/files/NDC/2022-06/Pakistan%20Updated%20NDC%202021.pdf>

[385] https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/34-groundwater_management_in_pakistan_an_analysis_of_problems_and_opportunities.pdf

[386] https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/34-groundwater_management_in_pakistan_an_analysis_of_problems_and_opportunities.pdf

[387] Government of Pakistan. National Water Policy; Ministry of Water Resources: Islamabad, Pakistan, 2018

[388] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[389] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[390] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[391] <https://pecongress.org.pk/images/upload/books/5-Making%20Agricultur%20Asad%20Sarwar.pdf>



Opportunities	Threats
<p>O1. Pakistan addressed groundwater challenges with the National Water Policy 2018 which identified priorities for management of groundwater. [392]</p> <p>O2. Punjab followed with its Water Policy in 2018 and Water Act in 2019. These focus on curbing over-abstraction and contamination with a licensing system for water use and disposal. [393]</p> <p>O3. Punjab have 0.34%, 13.29%, 60.68%, 25.26%, and 0.43% of the least, poorly, moderately, well-, and highly suitable sites for groundwater recharge. [394]</p> <p>O4. Punjab is developing a provincial Groundwater Management Plan. Khyber Pakhtunkhwa province passed a similar act in 2020. Sindh has a draft Water Policy underway to address waterlogging, salinity, and conjunctive water management. [395]</p> <p>O6. Increasing aquifer storage in Agro-Ecological zones is vital to enhance resilience against the negative effects of climate change. [396]</p> <p>O7. Women in rural areas of Pakistan participates actively in agriculture activities. They are Traveling long distances, sometimes up to 4 kilometers on foot, just to collect water. [397] Increase access to groundwater can ensure inclusive development effectively by provision of water resources near to them.</p>	<p>T1. Stringent treatment processes and ongoing monitoring are crucial. Inadequate treatment or lapses in monitoring could compromise the safety and effectiveness of the recharge project. [398]</p> <p>T2. Choosing the wrong aquifer could lead to clogging, reduced permeability, or contamination of existing freshwater resources. [399]</p> <p>T3. Fecal contamination in groundwater linked to poor WASH services contributes to high rates of child stunting (40% under five). [400]</p> <p>T4. Over-abstraction, waterlogging and contamination threaten the crucial role of groundwater as a life-sustaining resource, which has impacts on drought resilience, public health, and environmental sustainability. [401]</p> <p>T5. Excess irrigation in areas where groundwater levels are high is contributing to widespread waterlogging in Sindh. [402]</p>

Table 18: SWOT Analysis of Groundwater Aquifer Recharge Through Wastewater

[392] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[393] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[394] Afzal, M., Liu, T., Butt, A. Q., Nadeem, A. A., Ali, S., & Pan, X. (2023). Geospatial assessment of managed aquifer recharge potential sites in Punjab, Pakistan. *Remote Sensing*, 15(16), 3988.

[395] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[396] https://www.ctc-n.org/sites/www.ctc-n.org/files/resources/34-groundwater_management_in_pakistan_an_analysis_of_problems_and_opportunities.pdf

[397] <https://www.icimod.org/event/water-and-gender/>

[398] https://www.researchgate.net/publication/361408175_Managed_Aquifer_Recharge_Overview_and_Governance

[399] https://link.springer.com/chapter/10.1007/978-3-319-23576-9_16

[400] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[401] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>

[402] <https://www.worldbank.org/en/news/feature/2021/03/25/managing-groundwater-resources-in-pakistan-indus-basin>



4.3 Hydropower

In the hydropower sector, prioritized technologies involve Micro and Small Hydro-Power Plants, running off the River Plants in the existing categories, while AI integrates Remote Sensing and GIS, which was prioritized as an emerging technology. The following section involves the in-depth analysis of these technologies aligning with the scoring criteria.

4.3.1 Micro and Small Hydropower Plants (Existing)

Small hydro projects (SHPs) encompass installations below 25 MW, further subdivided into micro (up to 100 kW) category.[403] These projects harness the kinetic energy of water flow to power turbines, ultimately generating electricity. Water is directed from a stream to the forebay via a canal or intake ditch, where debris is filtered out by intake screens. Subsequently, the water is channeled through a penstock to the turbine and generator unit, where it undergoes conversion from mechanical to electrical energy through magnetic fields. The produced electricity is then transmitted via the transmission system to its intended destination.

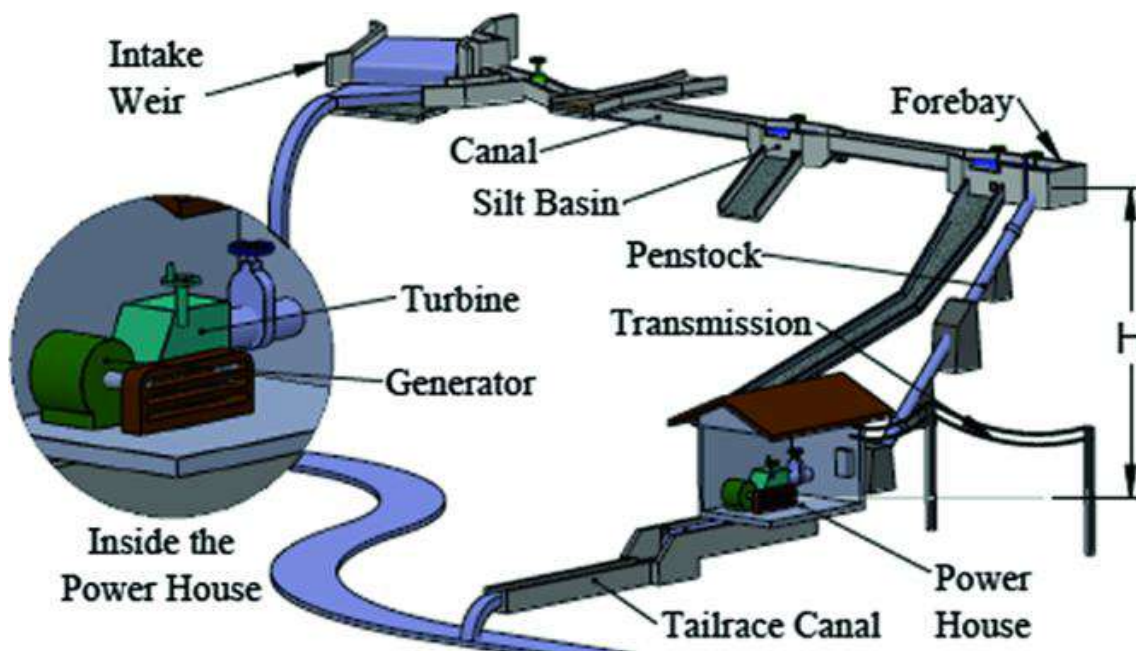


Figure 12: Small and Micro Hydropower Generation[404]

1. Legal, Regulatory and Financial Landscape

Pakistan aims to reduce reliance on hydrocarbons and increase renewable energy production, with a target of **producing 10%** of its total energy mix from renewables. MHPs offer a cost-effective and accessible solution to achieving this goal. Pakistan has made strides in establishing policies and guidelines to support the development of micro hydropower projects (MHPs). The **National Electric Power Regulatory Authority (NEPRA)** sets regulations for connecting renewable energy sources to the national grid. Provincial policies, such as the Khyber Pakhtunkhwa (KPK) hydropower Policy and Punjab guidelines for small hydropower projects, provide a framework for MHP implementation. These policies offer a supportive

[403] https://www.ctc-n.org/sites/default/files/UNFCCC_docs/ref20x01_35.pdf

[404] https://link.springer.com/chapter/10.1007/978-3-030-41952-3_6



environment for the growth of MHPs, facilitating project planning and execution. The cost benefits, cheap electricity solutions for remote areas, and foreign grants, such as a joint program between China and Pakistan, have increased its adoption throughout the country. Approximately a total of 1100 MHPs has been installed in the country combined by the Pakistan Council of Renewable Energy Technology (PCRET) and the Sarhad Rural Support Program (SRSP). [405]

2. Economic and Technical Feasibility

Pakistan holds significant potential for MHPs, boasting an estimated **50,000 MW capacity**, but only **14%** of that potential has been tapped, [406] indicating a **vast market** for future development. Additionally, MHPs are **domestically manufactured** in Pakistan, [407] reducing dependence on imports for core components. Furthermore, MHPs provide off-grid solutions for rural areas. A successful example of off-grid MHP is installed in the village of Jukhtai, KP region. [408]

The success of MHPs lies in their **near-zero emissions and ability to meet peak electricity demand**, making them a valuable renewable energy source in remote areas. Community involvement has been crucial, with local communities contributing **land, labor, and materials**, covering **20%** [409] of the project cost, while organizations like the Sarhad Rural Support Program bear the remaining **80%**. [410] This approach fosters a sense of ownership and ensures the sustainability of the projects. Notably, MHPs have had tangible economic benefits, with individuals like Sajjad Hakeem Khan **doubling their income** after being trained as operators for MHPs. Businesses, such as tailor Mohammad Nawaz's shop, have **experienced reduced operational costs and increased sales** due to uninterrupted electricity supply. [411]

Success stories like the Sarhad Rural Support Program installing **353 MHP** units in Khyber Pakhtunkhwa, benefiting over **927,495 people** and producing **29 MW** of energy, [412] demonstrate the economic and social viability of this technology. However, **seasonal variations** in water flow can **affect efficiency**. An **MHP in Shimshal Valley**, for example, only operated for **four months** [413] only due to insufficient winter flows.

The market of micro hydropower plants in northern rural areas of Pakistan establishes village-led operation and maintenance committees, fostering community ownership. Sarhad Rural Support Programme (SRSP) empowers these committees by building their **technical capacities** (e.g., maintenance training). The committees manage all aspects, including **setting tariffs, granting connections** (with a one-time fee of PKR 2,000 for domestic and PKR 4,000 for commercial users, covering cable costs as well) [414], **collecting revenue, and overseeing maintenance**. Additionally, a portion of the revenue is set aside for repairs and staff salaries, ensuring program sustainability. [415]

[405] Uddin, W., Zeb, K., Haider, A., Khan, B., ul Islam, S., Ishfaq, M., ... & Kim, H. J. (2019). Current and future prospects of small hydro power in Pakistan: A survey. *Energy Strategy Reviews*, 24, 166-177.

[406] <https://tech-action.unepccc.org/wp-content/uploads/sites/2/2018/01/pakistan-mitigation-tap.pdf>

[407] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[408] <https://www.dawn.com/news/1424033>

[409] <https://dialogue.earth/en/energy/small-hydropower-transforms-lives-in-pakistans-mountains/>

[410] <https://dialogue.earth/en/energy/small-hydropower-transforms-lives-in-pakistans-mountains/>

[411] <https://dialogue.earth/en/energy/small-hydropower-transforms-lives-in-pakistans-mountains/>

[412] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[413] <https://www.thethirdpole.net/en/energy/hydropower-pakistan/>

[414] <https://dialogue.earth/en/energy/small-hydropower-transforms-lives-in-pakistans-mountains/>

[415] <https://dialogue.earth/en/energy/small-hydropower-transforms-lives-in-pakistans-mountains/>



A study in Nepal analyzed the viability of a micro-hydropower plant (MHP) with an initial investment of **USD 25,000**[416]. This MHP has a capacity to generate **12.5 megawatt-hours**[417] (MWh) of electricity per year. Financial evaluations indicated positive project feasibility. The Net Present Value (NPV) after ten years was a positive **USD 19,025.82**[418], meaning the project generates more cash than it consumes over its lifespan. Additionally, the Internal Rate of Return (IRR) was a **high 26%**[419], exceeding the expected return on investment. The payback period, the time it takes to recover the initial investment, was only **3.5 years**. [420] These positive financial metrics suggest the MHP is a profitable and efficient way to generate electricity.

To delve deeper into the economic case of the 100-kW micro hydropower project, based on a similar project in **Jukhtai (Swat) in 2016**[421], estimates the total **project cost in 2024** to be approximately **USD 151,547**[422], including a **10% contingency**. The capital cost is broken down into feasibility and development (**USD 9,644–10,608**)[423], civil works (USD 62,000–68,196) [424], electromechanical equipment (**USD 48,222–53,041**) [425], transmission and distribution (**USD 11,022–12,124**) [426], and project management and engineering (**USD 6,889–7,577**) [427].

Annual operating and maintenance costs are estimated at **USD 2,756–7,577**[428]. The plant's annual energy production is projected to be **438,000–613,200**[429] kWh, generating revenues between **USD 35,040**[430] and **73,584**[431] based on Pakistan's feed-in tariffs. Financial analysis reveals a Net Present Value (NPV) of **USD 301,429**[432], an Internal Rate of Return (IRR) of **34%**[433], and a payback period of **2.9**[434] years. Sensitivity analysis confirms the project's feasibility and economic viability under various scenarios. The project also promises socio-economic and environmental benefits, including increased household electrification, reduced reliance on coal and oil, job creation, improved quality of life, and reduced CO₂ emissions. For 438,000–613,200 kWh energy production and referring to U.S. electricity net generation and resulting CO₂ emissions by fuel in 2022[435], the project can offset **630.72 metric ton to 883.01 metric ton CO₂ annually**[436] if it displaces coal and **192.72 metric ton to 269.81 metric ton CO₂ annually**[437] if it displaces gas-based generation. In summary, the 100-kW micro hydropower project in Pakistan demonstrates **strong financial viability** and significant socio-economic and environmental advantages, making it a promising investment.

3. Inclusive Development and Climate Impacts

MHPs promote environmental sustainability. They **reduce greenhouse gas emissions**. A study found that hydropower reduces greenhouse gas emissions per kilowatt-hour by 96.2% compared to natural gas, 92% compared to biomass, 61.5% compared to solar PV, and 51.3%

[416] <https://www.mdpi.com/2071-1050/15/19/14285>

[417] <https://www.mdpi.com/2071-1050/15/19/14285>

[418] <https://www.mdpi.com/2071-1050/15/19/14285>

[419] <https://www.mdpi.com/2071-1050/15/19/14285>

[420] <https://www.mdpi.com/2071-1050/15/19/14285>

[421] <https://dialogue.earth/en/energy/small-hydropower-transforms-lives-in-pakistans-mountains/>

[422] <https://www.cedengineering.com/userfiles/Small%20Hydro%20Project%20Analysis.pdf>

<https://pdhonline.com/courses/e502/e502content.pdf>

https://unfccc.int/resource/cd_roms/na1/mitigation/Module_5/Module_5_1/b_tools/RETScreen/Manuals/Hydro.pdf

https://www.researchgate.net/publication/371501853_A_Comprehensive_Study_of_Micro_Hydro_Plant_and_its_Potential_A_Case_Study

https://www.researchgate.net/publication/324568091_COST_ANALYSIS_OF_MINI_HYDRO_POWER_PLANT_USING_BACTERIAL_SWARM_OPTIMIZATION.

[423] Authors calculation based on above reference literature.

[424] <https://www.eia.gov/tools/faqs/faq.php?id=74&t=11>

[425] Authors calculation based on above reference literature.

[426 - 437] Authors calculation based on above reference literature.



4. Socioeconomic Outlook:

The technology was assessed on its socioeconomic outlook which has been summarized in table 19 below:

Emissions reduction/ Resource Conservation	Other Benefits/ Cost Savings	Capital Cost/Total Investment	Social Benefits
<p>Approximately mitigation potential of 100 billion tonnes of carbon dioxide have been saved in the last 50 years by using hydropower as an alternative to fossil fuels. Sarhad Rural Support Program has installed 353 micro hydropower units in the KPK province of Pakistan, benefiting 927,495 people and producing 29 MW of energy.</p> <p>For 438,000–613,200 kWh energy production and referring to U.S. electricity net generation and resulting CO₂ emissions by fuel in 2022[442], the project can offset 630.72 metric ton to 883.01 metric ton CO₂ annually if it displaces coal and 192.72 metric ton to 269.81 metric ton CO₂ annually if it displaces gas-based generation.</p>	<p>MHPs tend to prevent deforestation enhancing climate resilience because the use of wood for energy subdues, as was the case in Gilgit Baltistan</p> <p>MHPs installation creates job opportunities for youth in the process [443]</p>	<p>Based on study An example of project in Pakistan, Jukhtai (Swat) Cost: PKR 8,152,154 Investment 151,547 with USD 5,167 O&M Discount Rate: 10% NPV: USD 301,429 IRR: of 34% Payback period: 2.9 years</p>	<p>When implemented with environmental and socio-economic aspects in mind, it can simultaneously improve access to energy from renewable sources for remote and vulnerable rural communities, offer employment opportunities for youth, expand possibilities for growth for small-scale businesses, and contribute to combatting of climate change.</p> <p>Provides connections to local households and some shops.</p> <p>Small scale renewable energy solutions can provide more than just electricity. It can provide wider socio-economic development, improving education, healthcare, and the quality of life for rural and remote communities.</p>

Table 19: Socioeconomic Outlook of Micro and Small Hydropower Plants

[442] <https://www.eia.gov/tools/faqs/faq.php?id=74&t=11>

[443] <https://finmodelslab.com/products/hydroelectric-power-generation-swot-analysis>



5. Summary (Micro Hydro Power Plants)

Strengths	Weaknesses
<p>S1. Micro power plants can provide electricity to remote areas that may not connected to the main grid, fostering energy independence and inclusive development. [444], remote villages in the HKH region of Pakistan are an example[445]</p> <p>S2. Economically feasible as Pakistan has the potential to save about 120 million tonnes of coal and 83.3 billion liters of oil per year through micro hydropower projects[446]</p> <p>S3. The cost of power utilization for MHPs can be as low as PKR 100 per household each month[447], offering an affordable means of energy.</p> <p>S4. Approximately mitigation potential of 100 billion tonnes of carbon dioxide have been saved in the last 50 years by using hydropower as an alternative to fossil fuels[448]</p> <p>S5. MHPs tend to prevent deforestation enhancing climate resilience because the use of wood for energy subdues, as was the case in Gilgit Baltistan[449]</p> <p>S6. MHPs installation creates job opportunities for youth in the process [450]</p> <p>S7. MHPs ease the energy crisis and helps citizens in gaining additional hours for income generation activities[451]</p> <p>S8. MHPs are domestically manufactured in Pakistan[452]</p>	<p>W1. Micro power plants cannot meet the energy demands of large populations or industries.</p> <p>W2. Installing micro power plants can be expensive, particularly for individual households or small communities. Estimated cost is around PKR 8,152,154[453] for MHP in Pakistan.</p> <p>W3. During winters, the water flow for MHPs significantly decreases. For instance, the MHP in Shimshal Valley could only operate for four months due to insufficient water flow</p>

[444] <https://tech-action.unepccc.org/wp-content/uploads/sites/2/2018/01/pakistan-mitigation-tap.pdf>

[445] <https://www.thethirdpole.net/en/energy/small-hydropower-transforms-lives-in-pakistans-mountains/>

[446] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[447] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[448] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[449] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[450] <https://finmodelslab.com/products/hydroelectric-power-generation-swot-analysis>

[451] <https://tech-action.unepccc.org/wp-content/uploads/sites/2/2018/01/pakistan-mitigation-tap.pdf>

[452] <https://www.unido.org/our-focus/safeguarding-environment-clean-energy-access-productive-use-renewable-energy-focus-areas-small-hydro-power/world-small-hydropower-development-report>

[453] <https://www.dawn.com/news/1424033>



Opportunities	Threats
<p>O1. Developments in storage technologies like batteries can improve the reliability of renewable micro power plants.</p> <p>O2. Pakistan holds approximately 50,000 MW micro hydropower generation potential, but only 14 percent potential has been tapped.[454]</p> <p>O3. Sarhad Rural Support Program has installed 353 micro hydropower units in the KPK province of Pakistan, benefiting 927,495 people and producing 29 MW of energy. [455] This initiative shows a supportive environment for small-scale hydropower.</p> <p>O4. KPK government plans to construct up to 1000 units capable of producing 100MW of energy with assistance of ADB. [456]</p> <p>O5. Around 40% of potential locations for hydropower plants have been identified in Gilgit Baltistan. [457]</p> <p>O6. In KPK and AJK, where surveys suggest substantial potential (36% and 14%, respectively) for developing new hydropower plants. [458]</p> <p>O7. Through MPHs there is learning opportunities for students in the evenings and family members have additional time for social and economic activities. [459]</p> <p>O8. MHP of 350Kw in KPK has promoted gender equality and wellbeing of locals through inclusive development as better lighting allows for extended study hours for girls/boys and allows time saving for women who otherwise were spending long hours collecting wood along with improved quality of life. [460]</p> <p>O9. Micro power plants can be integrated into smart grids, allowing for efficient power management and optimization.</p> <p>O10. Better lighting generated by MHPs allows for extended study hours for girls and women. [461]</p> <p>O11. NEPRA policy for renewable energy for power development[461], KPK hydropower Policy[462], and Punjab guidelines for development of small hydropower projects[463] exists as a clear guideline for MHPs plants.</p>	<p>T1. The cost of MHPs can fluctuate in Pakistan due to political uncertainty and inflation, impacting project feasibility. The MHP in Jukhtai (Swat) cost Rs8,152,154 and provided connections to 315 households and some shops.[464].</p> <p>T2. Limited public knowledge about micro power plants and their benefits could hinder wider adoption. [465]</p>

Table 20: SWOT Analysis of Micro and Small Hydropower Plants

[454] <https://tech-action.unepccc.org/wp-content/uploads/sites/2/2018/01/pakistan-mitigation-tap.pdf>

[455] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[456] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[457] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[458] <https://www.paradigmshift.com.pk/micro-hydropower-pakistan/>

[459] <https://tech-action.unepccc.org/wp-content/uploads/sites/2/2018/01/pakistan-mitigation-tap.pdf>

[460] <https://s3.amazonaws.com/crawl.prod.proquest.com/fpcache/2dec9827b8424b1f20f7e84a642d634b.pdf?X-Amz-Security->

[461] <https://nepra.org.pk/Policies/RE%20Policy%20for%20Development%20of%20Power%20Generation%202006.pdf>

[462] https://pedokp.gov.pk/uploads/policies/Guidelines_to_KP_Hydropower_Policy_2016.pdf

[463] https://energy.punjab.gov.pk/system/files?file=File1_compressed.pdf

[464] <https://www.thenews.com.pk/print/92916-Villagers-overjoyed-as-65KW-power-station-becomes-functional-in-Swat>

[465] <https://finmodelslab.com/products/hydroelectric-power-generation-swot-analysis>



4.3.2 Run-off River Plants (Existing)

Run-of-the-river hydroelectricity, also known as ROR, is a form of hydroelectric power generation characterized by minimal or no water storage. Unlike traditional hydroelectric facilities that rely on reservoirs for water storage and regulation, ROR plants typically have limited or no storage capacity, with any storage being referred to as pondage.

The concept of ROR hydroelectricity has gained attention because of reduced environmental impact, potentially lower development costs compared to large hydro plants, and a wide range of potential sites. While it is an older technology, ongoing advancements continue to improve its efficiency and environmental performance.

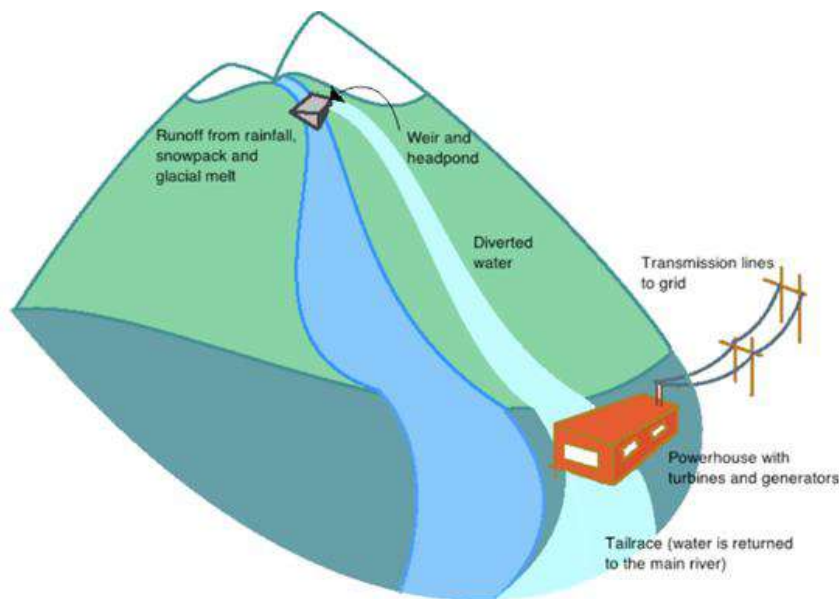


Figure 13: : GRun off River Plant[466]

1. Legal, Regulatory and Financial Landscape

Within Pakistan's legal and regulatory framework, the National Water Policy 2018 prioritizes the development of hydropower projects, recognizing their significance in meeting energy demands sustainably. **Hydropower policy 1995**[467] , **The Punjab Irrigation, Drainage and Rivers Act 2023** for dams' installation on rivers[468], similarly **Water and Power Development Authority acts as a** regulatory authority for hydropower development in Pakistan. The **National Electric Power Regulatory Authority (NEPRA) sets regulations** for connecting renewable energy sources to the national grid. Moreover, the policy encourages private sector engagement in hydropower development, fostering collaboration between the government and private entities. Additionally, clear guidelines exist for micro hydropower projects (MHPs) through **NEPRA's policy for renewable energy, KPK hydropower Policy**[469], and **Punjab guidelines for small hydropower projects**[470], providing a regulatory framework for their development.

[466] <https://www.linquip.com/blog/run-of-the-river-hydroelectricity/>

[467] <https://www.ppib.gov.pk/wp-content/uploads/2023/08/PowerPolicy1995.pdf>

[468] <http://punjablaws.gov.pk/laws/2882.html>

[469] https://pedokp.gov.pk/uploads/policies/Guidelines_to_KP_Hydropower_Policy_2016.pdf

[470] https://energy.punjab.gov.pk/system/files?file=File1_compressed.pdf



Financially, run-of-river plants in Pakistan have benefited from **subsidies** in the form of foreign investments, such as those from the **China Silk Road Infrastructure Fund, World Bank Investment Forum, and IFC**[471]. These investments have facilitated the development of projects like the Karot power plant, which generates **3.2 billion kilowatts**[472] **hours of clean energy annually**, benefiting approximately five million people. However, **financial uncertainties** may arise due to fluctuations in electricity generation, influenced by the volume of water in the river and weather conditions.

2. Economic and Technical Feasibility

Run-of-river plants offer several economic benefits, including job creation during the construction phase, as seen in the Karot power plant, which **employed over 4,000 people**[473]. Additionally, these plants contribute to **emission reduction** by displacing carbon-intensive energy sources like coal. For instance, the Karot plant helps **reduce 3.5 million tons (Mt)** [474] of **carbon dioxide emissions** annually and decreases the use of **1.4 Mt of coal equivalent per year**[475]. However, the variable nature of electricity generation based on river flow and weather conditions poses economic uncertainties.

Technical constraints such as **land acquisition issues**, as experienced in projects like the Gorkin-Matiltan Hydropower Project (GMHPP), can lead to delays (**2.5 years**[476] **in GMHPP**), affecting project timelines and increasing costs. GMHPP is a run-off river plant having the capacity of generating 84MW of electricity, the cost of the project is estimated **PKR 20,722 million**[477].

A feasibility report by PEDO[478] examined the economic viability of a run-of-river power plant in Chitral, Pakistan. The report predicts positive financial outcomes for the project. The total value of future benefits outweighs the total project costs, with a benefit-cost ratio exceeding **1.61**[479]. Additionally, the internal rate of return surpasses the expected cost of capital, reaching a profitable **24.37%**[480]. These findings suggest the run-of-river plant is a financially sound investment, generating more in benefits than it costs over time.

To delve deeper into the economic understanding, this section presents a cost-benefit analysis for a run-of-river hydropower project in Pakistan, using the Kari Muskhur Hydropower Project (**495MW**[481]) on the Mastuj River as a reference. The Kari Muskhur project includes significant structures such as a dam, sand trap, tunnels, a powerhouse, a residential colony, access roads, and bridges. By leveraging data from this comprehensive feasibility study, the economic and financial implications of similar hydropower developments in Pakistan are assessed.

The economic and financial analyses of the project evaluated its viability over a seven-year construction period, which includes one year for pre-construction, five years for construction, and one year for the Defect Liability Period (DLP). Key assumptions for this analysis included a price datum of June 2019, a custom duty rate of **5%**[482], an opportunity cost of capital at **12%**[483], an operation and maintenance cost set at **1.5%**[484] of the base cost per annum, and an interest rate of **6.62%**[485].

[471] <https://www.power-technology.com/projects/karot-hydropower-project-jhelum-river/>

[472] <https://www.power-technology.com/projects/karot-hydropower-project-jhelum-river/>

[473 - 475] <https://www.power-technology.com/projects/karot-hydropower-project-jhelum-river/>

[476] <https://pedokp.gov.pk/Main/psp/36>

[477] <https://pedokp.gov.pk/Main/psp/36>

[478] https://pedokp.gov.pk/uploads/downloads/Executive_Summary3.pdf

[479] https://pedokp.gov.pk/uploads/downloads/Executive_Summary3.pdf

[480 - 485] Ibid



The financial analysis results, converted to USD for comparability, are promising. The project shows a Net Present Value (NPV) of **USD 1,546 million**^[486], an Internal Rate of Return (IRR) of **15.69%**^[487], and a Benefit-Cost Ratio (BCR) of **2.71**. The economic analysis also indicates strong performance, with an NPV of **USD 387 million**^[488], an IRR of **24.37%**^[489], and a BCR of **1.61**^[490]. The sensitivity analysis reveals the project's robustness. Even under scenarios of a **10%**^[491] cost overrun, a **10%**^[492] decrease in benefits, or both combined, the project maintains positive IRRs ranging from **13.28%** to **14.51%**^[493]. These findings demonstrate the run of river dam economic soundness and its ability to withstand various financial pressures, making it an attractive investment opportunity in Pakistan's renewable energy sector.

3. Inclusive Development and Climate Impacts:

Run-of-river plants offer opportunities for inclusive development by involving women in hydropower committees, enhancing their participation in decision-making processes. Furthermore, scaling up run-of-river projects, as evidenced by the identification of **150 potential sites**^[494] with a total capacity of **18,698 MW in KPK**^[495], presents significant opportunities for **economic growth and job creation**.

From an environmental perspective, the **diversion of significant quantities of water from rivers without precautionary measures** can impact environmental conditions, highlighting the importance of careful planning and mitigation strategies. However, threats to inclusive development and climate impacts persist, such as delays caused by land acquisition issues, as seen in the GMHPP project. Moreover, **climate variability, including unpredictable snowfall patterns, can affect construction activities and operational efficiency**, highlighting the need for adaptive strategies in project planning and implementation.

[486] Ibid

[487] Ibid

[488] Ibid

[489] Ibid

[490] Ibid

[491] Ibid

[492] Ibid

[493] Ibid

[494] <https://nepra.org.pk/Policies/Hydel%20Potential%20in%20Pakistan.pdf>

[495] <https://nepra.org.pk/Policies/Hydel%20Potential%20in%20Pakistan.pdf>



4. Socioeconomic Outlook:

The technology was assessed on its socioeconomic outlook which has been summarized in table 21 below:

Emissions reduction/ Resource Conservation	Capital Cost/ Total Investment	Social Benefits
<p>Karot power plant which is a run off river scheme in Pakistan, generates 3.2 billion kilowatt hours of clean energy annually, benefiting approximately five million people. Karot plant helps reduce 3.5 million tons (Mt) of carbon dioxide emissions annually and decreases the use of 1.4 Mt of coal equivalent per year</p>	<p>Based on study: Kari Muskhur Hydropower Project Capacity (495MW) Cost: O&M 1.5% of cost Discount Rate: 12% NPV: 1,546 million USD IRR: 15.69% BCR: of 2.1</p> <p>Gorkin Matiltan Hydropower Plant Cost: PKR 20,722 million</p>	<p>Runoff rivers have huge potential of creating jobs such as in case of Karot power plant, which employed over 4,000 people</p> <p>The water from the system flows downstream to irrigate small plots of agricultural land which benefits the local farmers.</p> <p>Run-of-river plants can provide electricity to rural or remote communities that may not be connected to the national grid. Access to electricity improves quality of life by enabling better healthcare (e.g., refrigeration of medicines), education (lighting for schools), and communication (charging of mobile phones).</p>

Table 21: Socioeconomic Outlook of Run-of-River Power Plants



5. Summary (Run-Off River Plants)

Strengths	Weaknesses
<p>S1. Run-of river plants possess potential of producing clean energy. The Karot Power Plant can generate 3.2 billion kilowatt hours of clean energy annually, providing electricity to a population of approximately five million people. [496]</p> <p>S2. Run-of river plants ensure inclusive development and create employment. In Karot Power Plant more than 4,000 people during its construction phase were employed. [497]</p> <p>S3. Run-of river plants possess emission reduction potential. The Karot Plant helps in emission reduction of 3.5 million tons (Mt) of carbon dioxide emissions a year and reduces the use of 1.4Mt of coal equivalent a year. [498]</p> <p>S4. Development of hydropower projects is a high priority objective of National Water Policy 2018. [499] Also, it encourages government to engage the private sector for hydropower development.</p> <p>S5. NEPRA policy for renewable energy for power development[500], KPK hydropower Policy[501], and Punjab guidelines for development of small hydropower projects[502] exist as a clear guideline for MHPs plants.</p>	<p>W1. The amount of electricity that stations generate varies depending on the volume of water in the river. [503]</p> <p>W2. The environmental conditions of the section of the river from which the water is diverted could be affected when significant quantities of water are diverted from the river without precautionary measures.[504]</p> <p>W3. Although run-of-river plants can produce electricity constantly, the output levels depend on the weather.[505]</p>
Opportunities	Threats
<p>O1. Subsidies in the form of foreign investments such as China Silk Road Infrastructure Fund, World bank Investment Forum and IFC has been previously utilized in run of river plants. [506]</p> <p>O2. Huge opportunity of scaling up exists. In KPK, about 150 potential sites, with a total capacity of 18698 MW were identified which are run of river projects. WAPDA has also launched the Ghazi Barotha run of river plant.[507]</p> <p>O3. Runoff plants can provide opportunities to enhance inclusive development through participation of women in hydropower committees with enhanced decision making.[508]</p>	<p>T1. Examples (Gorkin-Matiltan Hydropower Project (GMHPP)) exist where construction activities can get restricted depending on snowfall conditions which vary significantly. [509]</p> <p>T2. Land acquisition can cause delays as in case of GMHPP land ownership resulted in more than 2.5 years delay in the project[510]</p>

Table 22: SWOT Analysis Run-off River Plants

[496-498] <https://www.power-technology.com/projects/karot-hydropower-project-jhelum-river/>

[499] https://ffc.gov.pk/wp-content/uploads/2018/12/National-Water-Policy-April-2018-FINAL_3.pdf

[500] <https://nepra.org.pk/Policies/RE%20Policy%20for%20Development%20of%20Power%20Generation%202006.pdf>

[501] https://pedokp.gov.pk/uploads/policies/Guidelines_to_KP_Hydropower_Policy_2016.pdf

[502] https://energy.punjab.gov.pk/system/files?file=File1_compressed.pdf

[503-505] <https://www.ctc-n.org/technologies/run-river-hydropower>

[506] <https://www.power-technology.com/projects/karot-hydropower-project-jhelum-river/>

[507] <https://nepra.org.pk/Policies/RE%20Policy%20for%20Development%20of%20Power%20Generation%202006.pdf>

[508] <https://www.unido.org/sites/default/files/unido-publications/2023-11/How%20Small%20Hydropower%20Empowers%20Women%20C%20Closes%20Gender%20Gaps%20and%20Can%20Do%20More.pdf>

[509-510] <https://pedokp.gov.pk/Main/psp/36>



4.3.3 *AI Integrated GIS and Remote Sensing for Water Management (Emerging)

Geographic Information Systems (GIS) serve as a critical technology for water resource management. GIS facilitates the spatial analysis and visualization of water resource data. This encompasses the creation of high-resolution maps depicting water treatment facilities, reservoirs, pipelines, and distribution networks. Additionally, GIS enables the integration of population density data and other relevant information. Through this comprehensive geospatial framework, authorities can monitor the entire water system's performance, pinpoint areas experiencing high demand or potential leakage events, and strategically choose locations for new infrastructure development. Furthermore, GIS empowers the analysis of water supply scenarios, including demand forecasting for specific regions. This analytical capability provides valuable insights for formulating effective water resource management strategies, ultimately promoting sustainable resource utilization.[511]

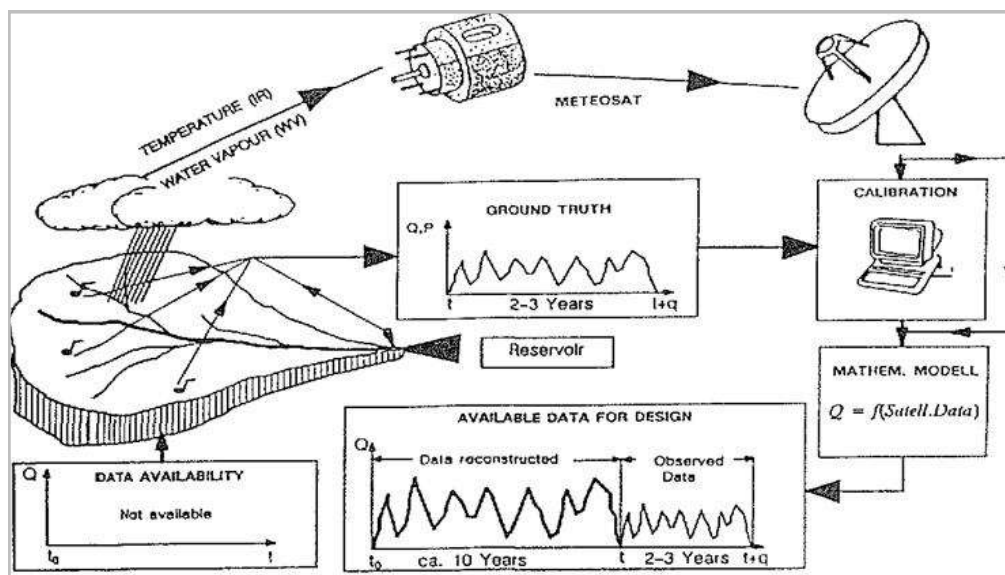


Figure 12: GIS and Remote Sensing for Water Resource Management[512]

Currently, RS and GIS provide valuable data on water sources, flow patterns, and environmental impacts. This information is crucial for selecting hydropower plant locations, predicting water availability, and minimizing environmental damage. However, traditional methods rely on experts to analyze data, which can be time-consuming and lack real-time insights. AI can significantly improve this process. AI algorithms can analyze vast amounts of RS data much faster than humans, automating tasks and identifying trends. This allows experts to focus on strategic decision-making. Additionally, AI can analyze real-time sensor data from hydropower plants, enabling early detection of problems and proactive maintenance. AI can also be used to simulate future scenarios, like droughts or population growth, helping Pakistan plan for long-term water security and sustainable hydropower generation. By integrating AI with RS and GIS, Pakistan can unlock several benefits. Increased efficiency in water usage will lead to more hydropower generation with less waste. Real-time data and predictive analytics will empower stakeholders to make informed decisions. Finally, AI-driven scenario modeling allows for long-term planning to ensure hydropower remains a viable source of clean energy.

[*] Prioritized to align with Ministry of Water Resources' recommendation to align NDC Technology Roadmap with National Flood Management Plan

[511] <https://www.sglgis.com/gis-for-water-resource/#:~:text=GIS%20can%20be%20highly%20beneficial,irrigation%20systems%20and%20soil%20moisture.>

[512] Schultz, G. A. (1997). Use of remote sensing data in a GIS environment for water resources management.



1. Legal, Regulatory and Financial Landscape

The legal and regulatory framework surrounding GIS and remote sensing in Pakistan is supportive, with the **National Space Policy** prioritizing their utilization. Additionally, strategic priorities outlined in the **National Water Policy 2018** and the **Water Conservation Strategy 2023** highlight the importance of GIS and remote sensing technologies for water resource management. The **Surveying and Mapping Act 2014** further promotes research activities and collaboration in the field of remote sensing and GIS, providing a conducive environment for their application in water management. From a financial perspective, while GIS technology is available in Pakistan through government departments such as **Planning and Development (P&D)**, with notable examples like the **GIS Lab in P&D**, and NGOs like **WWF** and **University of Punjab**, challenges such as limited access to advanced hardware and software, as well as the need for specialized skills and training, may pose financial barriers to widespread implementation. However, there is a dire need for policy directives for the inclusion of artificial intelligence integrated systems with RS and GIS to enhance the speedy adoption of this emerging technology in Pakistan.

2. Economic and Technical Feasibility:

Pakistan faces a critical water challenge, with **per capita water availability** dropping from **5,237m³/year in 1962** to a mere **1,188m³/year in 2021**^[513]. Remote Sensing (RS) and Geographic Information Systems (GIS) offer powerful tools to address this crisis. GIS and remote sensing offer significant **economic and technical feasibility advantages**, such as the ability to create highly accurate watershed maps and integrate data from various sources for comprehensive water resource assessment. These technologies can potentially **reduce the number of groundwater monitoring wells required**, leading to **cost savings** and improved efficiency in water management.

However, **challenges** such as **inadequate data for large-scale groundwater modeling and limited real-time monitoring capabilities** hinder their full technical feasibility. Environmental benefits include the potential for improved groundwater resource assessment and modeling, which can contribute to effective water allocation and conservation efforts. With existing groundwater modeling efforts using GIS being limited by inadequate data in terms of spatial coverage and temporal resolution, there is a need for further data collection and refinement to enhance the technical feasibility of these technologies.

Considering the economic analysis, the integration of AI into hydropower projects shows promise for optimizing energy production and minimizing environmental impact. For instance, incorporating the cost of establishing a GIS lab (**USD 88,333**^[514]) into a financial analysis of hydropower projects, along with a **10%**^[515] increase in benefits, results in a projected NPV of **USD 262,395**^[516], an IRR of **23%**^[517] and a payback period of **4.3**^[518] years. Sensitivity analysis indicates that the project remains financially viable across various scenarios, with NPVs ranging from **USD 195,054** to **USD 349,594**^[519], IRRs from **21% to 26%**^[520], and payback periods between **3.8 to 4.8 years**^[521].

[513] Habib et al., Water availability, use and challenges in Pakistan - Water sector challenges in the Indus Basin and impact of climate change, Food and Agriculture Organization (FAO) of the United Nations, Islamabad, 2021.

[514] Estimation from local sources

[515 - 521] Authors calculations



Overall, while the initial investment and ongoing costs are considerable, the long-term benefits justify the expense, making implementation feasible in Pakistan. The widespread adoption of AI, GIS, and remote sensing technologies could significantly address Pakistan's water management challenges, provided implementation challenges are effectively managed.

3. Inclusive Development and Climate Impacts:

GIS and remote sensing technologies have the potential to contribute to inclusive development by facilitating data-driven decision-making for sustainable groundwater use. However, **challenges** such as **limited access to advanced hardware and software**, as well as the **underrepresentation of women in the remote sensing community**, may hinder inclusive development efforts.

Climate impacts, such as decreasing per capita water availability and the need for effective water allocation and conservation, underscore the importance of utilizing GIS and remote sensing for water management. Hydropower avoids emissions of about around **9% of global annual CO₂ emissions**.^[522] GIS and RS are important tools in calculating emissions from hydropower and bridging climate change mitigation with sustainability frameworks.^[523] However, **threats** such as the **need for robust cybersecurity measures** to safeguard sensitive groundwater data and **limited access to advanced hardware and reliable internet connectivity** in some areas of Pakistan highlight the need for careful consideration of these factors in implementing GIS and remote sensing technologies for water management.

AI integration can significantly contribute to inclusive development and climate change mitigation. AI can analyze **social and economic data alongside hydropower potential** to identify potential impacts on local communities, promoting equitable distribution of benefits. AI-powered platforms can facilitate communication and collaboration among stakeholders for transparent and **inclusive decision-making**.

As climate change disrupts weather patterns, AI becomes a crucial tool for adaptation. AI can analyze **climate projections** to optimize hydropower plant operations for **varying water availability scenarios** and mitigate the impact of extreme weather events on reservoir capacity through sediment management with AI-powered systems.

[522] <https://www.iea.org/events/iea-at-cop27-the-role-of-hydropower-in-achieving-climate-resilience>

[523] http://www.iwmi.cgiar.org/Publications/Other/PDF/the_greenhouse_gas_emissions_estimates_of_hydropower_reservoirs_in_vietnam_using_g-res_tool-bridging_climate_change_mitigation_with_sustainability_frameworks.pdf



4. Socioeconomic Outlook:

The technology was assessed on its socioeconomic outlook which has been summarized in table 23 below:

Emissions reduction/ Resource Conservation	Other Benefits	Capital Cost/Total Investment	Social Benefits
<p>Hydropower avoids emissions of about around 9% of global annual CO₂ emissions. GIS and RS are important tools in calculating emissions from hydropower and bridging climate change mitigation with sustainability frameworks.^[524] In Pakistan since 1962-2021 per capita water availability decreased from 5,237m³/year to 1,188m³/year. GIS is an important tool for the assessment of effective water allocation and water conservation.</p>	<p>This technology can potentially reduce the number of groundwater monitoring wells required, leading to cost savings and improved efficiency in water management.</p> <p>AI can analyze high-resolution satellite imagery and LiDAR data to monitor reservoir sedimentation in real-time, optimizing dam operations and power generation. AI algorithms can analyze vast datasets for improved flood forecasting and streamflow prediction, ensuring sustainable hydropower generation</p>	<p>Estimates not available, as it is complex to quantify the cost of GIS software's used for the application. Similarly, the expert human resources and skills required for the Application of AI can vary case to case.</p> <p>Based on study: Setting up a GIS lab for hydropower plants</p> <p>Cost: Assumptions from GIS lab setup USD 88,333+ additional cost USD 232,995) with 10% increase for benefits (USD 59,743) NPV: USD 262,395 IRR: 23% Payback period: 4.3</p>	<p>We can develop better scenarios, which can support better dialogues (based on politically neutral information), which can result in better agreements in politically charged transboundary water negotiations.</p> <p>AI can analyze remote sensing data to detect changes in water levels, soil moisture, and weather patterns, allowing for early detection of potential flooding events. This enables the implementation of early warning systems that can alert communities and authorities, reducing the risk of loss of life and property.</p> <p>Remote sensing combined with AI can detect and monitor pollution in water bodies by analyzing changes in water color, temperature, and chemical composition. This helps identify sources of contamination and take corrective actions to protect public health.</p> <p>By continuously monitoring water quality, AI systems can ensure that communities have access to safe drinking water, reducing the risk of waterborne diseases and improving overall public health.</p>

[524] http://www.iwmi.cgiar.org/Publications/Other/PDF/the_greenhouse_gas_emissions_estimates_of_hydropower_reservoirs_in_vietnam_using_g-res_tool-bridging_climate_change_mitigation_with_sustainability_frameworks.pdf



Emissions reduction/ Resource Conservation	Other Benefits	Capital Cost/Total Investment	Social Benefits
			Integrating AI and GIS in water management provides educational opportunities for local communities, students, and professionals. This helps build capacity and awareness about water conservation and management practices.

Table 23: Socioeconomic Outlook of AI Integrated GIS and Remote Sensing for Water Management



5. Summary (AI Integrated GIS and Remote Sensing for Water Management Remote Sensing and GIS)

Strengths	Weaknesses
<p>S1. National Space policy prioritize the utilization of GIS and Remote sensing. [525]</p> <p>S2. GIS can create highly accurate watershed maps using remote sensing data, replacing time-consuming traditional methods This is crucial for understanding groundwater recharge and flow patterns. [526]</p> <p>S3. GIS can potentially reduce the number of groundwater monitoring wells required for comprehensive assessment, leading to cost savings [527]</p> <p>S4. GIS technology is available in Pakistan. Gov department such as P&D [528] has a GIS Lab. NGOs like WWF and University of Punjab [529] are notable examples which have developed labs for remote sensing and GIS.</p> <p>S5. GIS allows for integrating data from various sources like piezometric observations, precipitation data, and land cover maps This comprehensive view facilitates better understanding of groundwater systems. [530]</p> <p>S6. GIS enables analysis of spatial relationships between surface features and groundwater potential, supporting targeted groundwater exploration and management strategies. [531]</p> <p>S7. Preparation of an inventory of water resources through remote sensing and GIS technologies and leveraging technology is a strategic priority of National Water Policy 2018. [532] Also, GIS & Remote sensing is a priority intervention by Water Conservation Strategy 2023. [533]</p>	<p>W1. Existing groundwater modeling efforts using GIS are limited by inadequate data in terms of spatial coverage and temporal resolution. This restricts their applicability for large-scale groundwater management in the Indus Basin. [534]</p> <p>W2. Manual data collection through the existing network of piezometers is limited to, hindering real-time monitoring capabilities [535]</p> <p>W3. Effective utilization of advanced GIS techniques may require specialized skills and training, potentially limited in some regions of Pakistan. [536]</p> <p>W4. less than 30% [537] of all researchers worldwide are women and similar ratios are seen in the remote sensing community.</p>

[525] <https://suparco.gov.pk/wp-content/uploads/2024/01/National-Space-Policy.pdf>

[526] <https://www.mdpi.com/2071-1050/13/17/9686>

[527] https://www.mdpi.com/2073-4441/14/20/3342?utm_campaign=releaseissue_waterutm_medium=emailutm_source=releaseissueutm_term=titlelink118

[528] <http://lupajk.gov.pk/gislab.php#:~:text=The%20GIS%20Lab%20established%20under,AJ%26K%20for%20all%20Line%20Departments.>

[529] <http://rsgcrl.pu.edu.pk/>

[530] <https://www.mdpi.com/2071-1050/13/17/9686>

[531-536] <https://www.mdpi.com/2071-1050/13/17/9686>

[537] <https://www.frontiersin.org/research-topics/29593/women-in-remote-sensing-2022/magazine>



Opportunities	Threats
<p>O1. In Pakistan since 1962-2021 per capita water availability decreased from 5,237m³/year to 1,188m³/year.^[538] GIS is an important tool for the assessment of effective water allocation and water conservation.^[539]</p> <p>O2. The surveying and mapping act 2014 promotes research activities and collaboration of field of remote sensing and GIS.^[540] Utilizing this for water management is a potential opportunity.</p> <p>O3. Hydropower avoids emissions of about around 9% of global annual CO₂ emissions.^[541] GIS and RS are important tools in calculating emissions from hydropower and bridging climate change mitigation with sustainability frameworks.^[542]</p> <p>O4. Combining GIS with remote sensing data like precipitation estimates, digital elevation models (DEMs), and land cover maps offers opportunities for improved groundwater resource assessment and modeling at the Indus Basin scale. ^[543]</p> <p>O5. Integration of GIS with groundwater management policies can facilitate data-driven decision-making for sustainable groundwater use and regulation enforcement. ^[544]</p>	<p>T1. Safeguarding sensitive groundwater data stored within GIS platforms requires robust cybersecurity measures. ^[545]</p> <p>T2. Limited access to advanced hardware, software, and reliable internet connectivity in some areas of Pakistan can impede widespread GIS implementation. ^[546]</p>

Table 24: SWOT Analysis of AI Integrated GIS and Remote Sensing for Water Management

[538] Habib et al., Water availability, use and challenges in Pakistan - Water sector challenges in the Indus Basin and impact of climate change, Food and Agriculture Organization (FAO) of the United Nations, Islamabad, 2021.

[539] <https://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/130168/filename/130379.pdf>

[540] http://na.gov.pk/uploads/documents/1397721138_588.pdf

[541] <https://www.iea.org/events/iea-at-cop27-the-role-of-hydropower-in-achieving-climate-resilience>

[542] http://www.iwmi.cgiar.org/Publications/Other/PDF/the_greenhouse_gas_emissions_estimates_of_hydropower_reservoirs_in_vietnam_using_g-res_tool-bridging_climate_change_mitigation_with_sustainability_frameworks.pdf

[543] <https://www.mdpi.com/2071-1050/13/17/9686>

[544] <https://www.mdpi.com/2071-1050/13/17/9686>

[545] <https://www.mdpi.com/2071-1050/13/17/9686>

[546] <https://www.mdpi.com/2071-1050/13/17/9686>



4.4 Screening Outcomes

Referring to the screening criteria elaborated in section 2.1, the following results were achieved after the detailed analysis in section 4 above and gauging the performance of the technologies on the basis of defined metrics. The results are as portrayed in the Tables 25, 26 and 27 below:

Major Group	Legal, Regulatory, and Financial Landscape						
Group Score	15						
Criteria	Are there any clear guidelines or regulations for this technology?		Do existing financial structures exist to invest in this technology in Pakistan? (i.e. Existing bankable projects? PPP? Targeted financing facilities?)		Is there an opportunity for private sector investment in this technology?		
Scoring for each criterion	Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Total
Criteria Weightage	5%		5%		5%		15
Technologies	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	
Agriculture							
Drip Irrigation	5		5		5		15
Remarks	Existing standards and guidelines are <u>there with</u> along with clear mechanisms for implementation and installation of drip irrigation. Private sector opportunities are there due to existing subsidies and cost savings.						
Leaky Dams	3		3		2		8
Remarks	Moderate policy emphasis as hydropower policy and regulation exists but specific guidelines on leaky dams are not available. Financial projects from government (PCRWR projects). Private sector is lacking investment in this domain.						
IoT Based Solar Pumps and Storage	2		3		3		8
Remarks	No specific policies exist for either solar pumping or solar pumping integrated with IoT. However, there is emphasis of its adoption NWP 2018. Financial structure is available for solar pumps in Pakistan which can be tapped for integrating IoT with it. Perceived benefits of IoT opens opportunities for private sector such as startups to intervene.						
Hydropower							
Micro & Small Hydropower	5		3		5		13
Remarks	Provincial and Federal Hydropower Policy is existing, NEPRA regulations are in place for connecting to off grid stations, economic feasibility provides opportunity for private investments (NGO like SRSP are present)						
Run Off River Plants	5		3		4		12
Remarks	Existing Policy and regulatory framework, perceived economic benefits and opportunities for private sector.						
AI Integrated Remote Sensing and GIS	2		3		2		7
Remarks							



Domestic							
Rainwater Harvesting	3		4		3		10
Remarks	Absence of clear guidelines on rainwater harvesting systems but CDA has obligated all new buildings to install Rainwater harvesting systems. Cost Effectiveness and water saving potential offers opportunity for private sector. Existing Projects in the northern areas.						
Chlorination	3		4		4		11
Remarks	No clear policy directives, for regulation WHO guidelines are followed. Economic benefits as it is a cheap solution for disinfection, opportunities for private sector investments.						
Groundwater Recharge through Wastewater	3		3		2		8
Remarks	Policies and regulations are available for groundwater abstraction but there is no clear guidelines for recharging groundwater through wastewater treatment. Projects exists for groundwater recharge but utilization of treated wastewater is lacking. Private sector can indulge in the treatment technologies and infrastructure investments.						

Table 25: : Evaluation of scoring criteria based on legal, regulatory and financial landscape of Pakistan

Major Group	Economic and Technical Feasibility												
Group Score	30												
Criteria	Does this technology efficiently minimize the use of energy and other resources?		Does this technology promote efficiency in the management and delivery of the waste sector?		Is this technology affordable?		Is this technology successfully in use in Pakistan? or there is a potential for a pilot?		Do the skills to implement and operate this technology exist in Pakistan?		Does Pakistan have the capacity to inculcate skills training for this technology through its research and technology institutions ?		
Scoring for each criterion	Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Individual score (scale of 1-5)		Total
Criteria Weightage	5%		5%		5%		5%		5%		5%		30
Technologies	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	
Agriculture													
Drip Irrigation	4		5		4		4		5		5		27
Remarks	Drip irrigation provides potential of water saving, minimize fertilizer usage and increases crop production. Enhances livelihood and Potential time and cost saving for farmers and women.												
Leaky Dams	3		4		3		4		4		3		21
Remarks	Economically and technically sound, local material is used for its construction, Existing pilot projects and moderate emphasis on capacity building												
IoT Based Solar Pumps and Storage	5		4		4		1		3		3		20



Remarks	Provides high efficiency and reduces energy consumptions, labor, time and mechanical input affordable with subsidies available otherwise high capital cost for farmers.											
Hydropower												
Micro & Small Hydropower	4		3		4		4		4		4	23
Remarks	Hydropower schemes like micro and small plants shifts towards renewable energy potentially saving Pakistan around 120 million tonnes of coal and 83.3 billion liters of oil annually. It is affordable but upfront cost can be high for community driven engagements. Despite this, it provides cheap electricity to remote areas.											
Run Off River Plants	5		4		3		4		3		4	23
Remarks	Techno economically feasible and successful in Pakistan, yet due to large scale, issues like land acquisition and unwanted delays can lengthen the project.											
AI Integrated Remote Sensing and GIS	2		2		3		2		2		3	14
Remarks												
Domestic												
Rainwater Harvesting	4		5		4		4		4		4	25
Remarks	Affordable and successfully used in Pakistan. Promotes efficiency in water delivery and conservation. Existing capacities for implementation are there.											
Chlorination	2		4		4		4		3		3	20
Remarks	Economically feasible and have positive health impacts, but concerns regarding by products are there. Locally produced at cheap price and available in varying capacities.											
Groundwater Recharge through Wastewater	4		4		3		1		2		2	16
Remarks	Economically the cost can vary depending on the methods of treatment and it can have health impacts which needs to be clearly taken into consideration, Improves the water recharge and reduces availability on freshwater resources.											

Table 26: : Evaluation of scoring criteria based on Economic and Technical Feasibility of Pakistan

Major Group	Inclusive Development and Climate Impacts						
Group Score	30						
Criteria	Does this technology possess emission reduction potential?	Does this technology contribute to building resilience and adaptive capacity in Pakistan?	Does this technology enhance the quality of life in target communities ?	Does this technology contribute to inclusive development and just transition?	Does this technology have any negative/positive impacts on women and/or minorities or youth and children?	Does this technology address gender specific needs and promote social equality?	
Scoring for each criterion	Individual score (scale of 1-5)	Individual score (scale of 1-5)	Individual score (scale of 1-5)	Individual score (scale of 1-5)	Individual score (scale of 1-5)	Individual score (scale of 1-5)	Total
Criteria Weightage	5%	5%	5%	5%	5%	5%	30



Technologies	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Agriculture												
Drip Irrigation	4		2		4		4		4		4	22
Remarks	Drip irrigation, combined with optimized irrigation scheduling, can lead to reductions in emissions of CO ₂ , N ₂ O, and NO by up to 62%.											
Leaky Dams	3		2		4		2		2		2	15
Remarks	Overall enhancement of targeted communities in terms of water provisions and adequate storage.											
IoT Based Solar Pumps and Storage	3		2		4		3		3		3	18
Remarks	Enhances the targeted communities, saves time for women in agriculture											
Hydropower												
Micro & Small Hydropower	4		3		4		3		3		3	20
Remarks	SRSP(NGO) empowers Micro hydro committees by building their technical capacities (e.g., maintenance training). The committees manage all aspects, including setting tariffs, granting connections. Provides good community engagement and benefits and income generation opportunities.											
Run Of River Plants	5		4		4		3		3		3	22
Remarks												
AI Integrated Remote Sensing and GIS	2		3		1		2		2		2	12
Remarks												
Domestic												
Rainwater Harvesting	2		3		4		3		3		3	18
Remarks	No data available for direct emission reduction through rainwater harvesting. Moderate positive impacts, implementation of rainwater harvesting free up time of women for water collection, enhances the life of targeted communities											
Chlorination	1		3		2		3		3		3	15
Remarks	No data available for direct emission reduction through chlorination but positive health impacts through disinfected water provision. Threat of chlorinated by products exists which can be potentially harmful. Moderately enhances the life of targeted communities.											
Groundwater Recharge through Wastewater	4		2		2		2		1		2	13
Remarks	Studies show that this method of groundwater recharge can potentially improve targeted communities and have positive climate impacts											

Table 27: : Evaluation of scoring criteria based on Inclusive Development and Climate Impacts



Technologies	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Agriculture												
Drip Irrigation	4		2		4		4		4		4	22
Remarks	Drip irrigation, combined with optimized irrigation scheduling, can lead to reductions in emissions of CO ₂ , N ₂ O, and NO by up to 62%.											
Leaky Dams	3		2		4		2		2		2	15
Remarks	Overall enhancement of targeted communities in terms of water provisions and adequate storage.											
IoT Based Solar Pumps and Storage	3		2		4		3		3		3	18
Remarks	Enhances the targeted communities, saves time for women in agriculture											
Hydropower												
Micro & Small Hydropower	4		3		4		3		3		3	20
Remarks	SRSP(NGO) empowers Micro hydro committees by building their technical capacities (e.g., maintenance training). The committees manage all aspects, including setting tariffs, granting											

Table 27: : Evaluation of scoring criteria based on Inclusive Development and Climate Impacts

Table 25, 26 and 27 tabulate the scores achieved by each technology against the metrics mentioned with the consolidated scores of each technology as shown in Table 28 below.

Technology	Category	Sub-sector	Scores	Rank
Drip Irrigation	Existing	Agriculture	64	1 st
Leaky Dams	Existing	Agriculture	44	6 th
IoT Based Solar Pumps and Storage	Emerging	Agriculture	46	1 st
Micro & Small Hydropower	Existing	Hydropower	56	3 rd
Run-of-river plants	Existing	Hydropower	57	2 nd
AI Integrated Remote Sensing and GIS	Emerging	Hydropower	33	3 rd
Rainwater Harvesting	Existing	Domestic	53	4 th
Chlorination	Existing	Domestic	46	5 th
Groundwater Recharge through Wastewater	Emerging	Domestic	37	2 nd

[*] Prioritized to align with Ministry of Water Resources' recommendation to align NDC Technology Roadmap with National Flood Management Plan



The results give us two of the five requisite technologies from the agricultural sub-sector, that are **Drip Irrigation** (64 points out of 75) and **IoT Based Solar Pumps and Storage** (46 points out of 75), with one being in the existing and the other being in the emerging category. It is pertinent to note here that IoT based Solar Pumps and Storage ranked highest amongst the emerging category finalizing it for this category.

Moving further, the results give us two of the five requisite technologies from the hydropower sub-sector, that are **Micro and Small Hydropower** (56 points out of 75) and **Run-Of-River Power Plant** (57 points out of 75), with both being in the existing category. **AI-integrated Remote Sensing and GIS**, an emerging solution for water resource management, received a relatively low score but was discussed extensively with the Ministry of Water Resources (MoWR). The solution is being selected for the NDC technology roadmap based on it being prioritized under the MoWR's umbrella project, Flood Protection Sector Project III (FPSP-III). Finally, the results give us **Rainwater Harvesting** (53 points out of 75) from the domestic sector adding to the existing category.

5. Conclusion and Way Forward

Based on the scoring criteria and stakeholder feedback, the prioritized water management technologies in Pakistan included both existing and emerging solutions. Owing to the total scores from all three criteria's, Legal, Regulatory, and Financial Landscape, Economic and Technical Feasibility and Inclusive Development and Climate Impacts, Drip Irrigation ranked first, followed by Run off The River Plant, Micro and Small Hydropower, and Rainwater Harvesting among existing technologies. For emerging technologies, IoT Based Solar Pumps and Storage was prioritized as a leading option. These results have been tabulated as shown in Table 29 below:

Technologies	Category	Rank
Drip Irrigation	Existing	1st
IoT Based Solar Pumps and Storage	Emerging	1st
Run Off the River Plant	Existing	2nd
AI Integrated Remote Sensing and GIS	Emerging	3rd
Micro & Small Hydropower	Existing	3rd
Rainwater Harvesting	Existing	4th

*Table 29: : Summary of Outcomes



Following this phase, a detailed roadmap will be established to guide the implementation of the prioritized technologies. This roadmap will present a summarized version of the comprehensive document, with special emphasis on the selected technologies, enabling the Global Green Growth Institute (GGGI) to effectively pitch these technologies to potential investors. The roadmap will outline specific actions required for the deployment and scaling of each prioritized technology. It will define the roles and responsibilities of key stakeholders, including government agencies, private sector partners, and local communities.

Capacity building will be emphasized to ensure local stakeholders are equipped with the knowledge and skills needed for successful technology adoption. Policy recommendations will be offered to create an enabling environment for technology transfer and innovation in the water and waste sectors. Sustainability and inclusivity will be central to the roadmap, ensuring that the benefits of technological advancements are equitably distributed and that vulnerable populations are considered in all planning stages.

By developing and implementing this comprehensive technology roadmap, we aim to drive significant advancements in Pakistan's water and waste management sectors, contributing to the nation's climate resilience and sustainable development goals. This roadmap will be instrumental for the GGGI in securing investment and support for these critical technological interventions.



Annexures

Annex-I Water Technical Committee and Technology Technical Committee Composition

Institution	Department/District Offices/Institution	Gender
MoWR, Federal Flood Commission	DEA- Civil CEA/CFCC	M
PBS	CSO Pak. Beureau of Stat Islamabad.	M
Department of Irrigation in provinces	Deputy Director (Environmental & Social Safeguard) SPRU (Irrigation), Punjab	M
	Director PMC (Irrigation) Irrigation Department, Khyber Pakhtunkhwa (KPK).	M
	Irrigation Department, Sindh.	M
	Director General, Agriculture	M
	Planning Officer, Agriculture, Irrigation, Livestock and ESMA, Azad Jamu & Kashmir (AJK)	M
	Deputy Secretary, Water Management and Irrigation department Gilgit-Baltistan (GB)	M
Energy	Energy Dep Punjab.	F
	Planning Officer Tourism Department Khyber Pakhtunkhwa, (KPK)	F
	Director Alternate Energy Sindh	M
	Deputy Director Balochistan	M
	Superintending Engineer Power division Gilgit-Baltistan, (GB)	M
	Power Development Organization PDO	M



	Azad Jammu & Kashmir (AJK)	
WASA	Deputy Director, WASA	F
	Deputy Director Adnan Shaikh Assistant Director	M
	Additional Secretary PHED Balochistan	M
	PHED Khyber Pakhtunkhwa, (KPK)	M
	Executive Engineer Work Department, Gilgit-Baltistan, (GB)	M
	Executive Engineer, PWD PHE Division-II, Mirpur Azad Jammu Kashmir (AJ&K)	M
	Punjab	Assistant Chief (Env. & CC)/P&D Board , NDC Focal Punjab
Sindh	Secretary ECC & CD, NDC Focal	M
KPK	Director, EPA KPK NDC Focal	M
Balochistan	DD EPA, NDC Focal	M
GB	Scientific Officer, EPA , NDC Focal	F
AJK	DD, Environmental Protection Agency ,NDC Focal	M



Focal Persons/Designation	Institution	Gender
Joint Secretary	Ministry of Science and Technology, Islamabad	M
SO IF-2	Ministry of Industries & Production, Islamabad	M
Director General	Ministry of Information Technology and Telecommunication	M
	Ministry of Poverty Alleviation and Social Safety	M
Director General (PCRET)	Pakistan Council of Renewable Energy Technologies (PCRET)	M
Chairman	Pakistan Council of Scientific & Industrial Research (PCSIR)	M
Section Officer (Commerce)	Industries and Commerce Department, Sindh	M
DoCC	Climate Change & Coastal Development, Directorate of Climate Change (DoCC), Govt. of Sindh	
Manager Planning	Industries, Commerce and Technical Education Department, KP	M
Deputy Director, EPA	Environment Protection Agency, KP	M
Assistant Director	Science & Technology and Information Technology Department, KPK	M
Assistant Chief, P&D Board Punjab	Planning and Development, (P&D) Punjab	M
(PAS) & Managing Director	Industries, Commerce, Investment and Skill Development Department, Punjab	M
Director	Industries and Commerce Department	M



Director General	Science and Information Technology Department, Balochistan	M
Deputy Director (Climate Change)	Environment Protection Agency, Balochistan	M
Deputy Director (IT)	Information Technology Department GB	M
Assistant Director Labour	Industries and Commerce Department GB	M
Deputy Director	Department of Industries, Commerce and Labor, AJK	M
Deputy Director, Climate Change	Environment Protection Agency, AJK	M
Planning Officer	Planning and Development, (P&D) AJK	M
CEO, AWF Mr. Kamran Naeem WASH Specialist	Experts	M



Annex-II First Stakeholder Feedback Waste & Water Technical Committee Meeting

Name	Department	Province
1. Muhammad Luqman Hakeem	Energy & Power Department, GoKP	KPK
2. Engr Ubaid Ullah	PHED Khyber Pakhtunkhwa	KPK
3. Dr Ali Asghar Mahessar	Irrigation Department, Sindh Province	SINDH
4. Sardar Rafique	AJK EPA	AJK
5. Uzair Naqvi	AJK PEDO	AJK
6. Dr. Arif Shah	Agriculture Extension Balochistan	BALOCHISTAN
7. Mumtaz Ali	Director, EPA	KPK
8. Rizwan Ali	Planning & Development Board Punjab	PUNJAB
9. Shahnawaz	Energy Department, Sindh	SINDH
10. Shahzad Shabir	Director EPA	Gilgit
11. Engineer Zahid Hussain	Superintendent Engineer	Power Division
12. Waris Ali	Director SEPA	SINDH
13. Waqas Abdullah	Assistant Director Agriculture	Muzaffarabad, AJK
14. Dr. Farooq	CSO Pak. Bureau of Stat Islamabad	Federal
15. Abdul Khaliq	Deputy Director, Energy	Balochistan
16. Imran Mukhtar	Executive Engineer, PWD PHE Division-II,	Mirpur Azad Jammu Kashmir (AJ&K)
17. Abdul Qadeer Kakar	Additional Secretary, PHED	Balochistan
18. Shahid Habib	Deputy Director (Environmental & Social Safeguard) SPRU (Irrigation)	Punjab
19. Mehfooz Kazi,	Director Alternate Energy	Sindh
20. Zafar Iqbal	Superintending Engineer Floods	Federal



Annex-III First Technology Roadmap Committee Meeting

Name	Department	Gender	Province/ Region
21. Dr. Sardar Rafique	Environmental Protection Agency	Male	AJK
22. Khawaja Imran	PSID	Male	Punjab
23. Ahmad Rajwana	Ministry of Finance	Male	Federal
24. Ahmed Ali	Ministry of Poverty Alleviation and Social Security	Male	Federal
25. Azeem Sajjad	Ministry of Information Technology and Telecommunications	Male	Federal
26. Waqas Abdullah	Agriculture	Male	AJK
27. Asim Javed	Punjab Food Authority	Male	Punjab
28. Farah Ather	Punjab Food Authority	Female	Punjab
29. Amir Habib	Science and Technology	Male	KPK
30. Dr. Taza Gul	Science and Technology	Male	KPK
31. Niazullah	Independent Technology Expert	Male	-
32. Engr. Ali	Engineering Development Board, Ministry of Industries and Production	Male	Federal
33. Omar Shahid	KPEZDMC	Male	KPK
34. Dr. Tahir Mehmood	Pakistan Council of Renewable Energy Technology	Male	Federal
35. Babar	JD Policy, MoITT	Male	Federal
36. Ibrar Hussain	IT Department	Male	GB
37. Engr. Khan	IT Department	Male	GB
38. Azeem Sajjad	MoIT and Telecommunications	Male	Federal
39. Imran Ali Shah	Ministry of Poverty Alleviation and Social Safety	Male	Federal
40. Uzair Naqvi	Power Development Organization	Male	AJK



Annex-IV Second Water Technical Committee Meeting

Name	Department	Gender	Province
1. Engr Ubaid Ullah	PHED Khyber Pakhtunkhwa	M	KPK
2. Dr. Ali Asghar Mahessar	Irrigation Department	M	Balochistan
3. Uzair Naqvi	AJK PEDO	M	AJK
4. Sonia Soomro	Strategic Advisor – Sindh Solar Energy Department	F	Sindh
5. Waqas Abdullah	Assistant Director Agriculture	M	Muzaffarabad, AJK
6. Abdul Qadeer Kakar	Additional Secretary, PHED	M	Balochistan
7. Shahid Habib	Deputy Director (Environmental & Social Safeguard) SPRU (Irrigation)	M	Punjab
8. Niaz Ahmed	Energy Department	M	Sindh
9. Mishal Zahra	EPA	F	GB
10. Dr. Asghar Ali	Irrigation Department, Sindh	M	Sindh