



The Role of Hydropower in Ensuring Water Security in Pakistan: An Analysis

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Abstract

This study explores the role of hydropower in boosting water security in Pakistan by moderating river flows, effective flood management, and water storage in reservoirs during dry seasons. The qualitative method is used in this research to analyze the role of hydropower plants in securing water flows. Data collection included articles and newspapers related to water and resources. Furthermore, in Pakistan, major hydropower projects include the Tarbela and Mangla dams, which contribute to resilient water management, agricultural productivity, and climate resilience. Additionally, the study focuses on how Pakistan faces many challenges, including governance issues, policy barriers, environmental issues, and climate change. These findings suggest that they improved hydropower development projects by adopting sustainable strategies and enhancing water resources in Pakistan, or promoting renewable energy targets. The Change in weather, melting of glaciers, and extreme rains disrupt the hydropower system and necessitate long-range water storage planning. The chemicals released from hydropower require modern innovations and mechanisms for controlling them, which have an impact on the ecosystem. There is a need to modernize the system from old to new for the development of energy. The study concludes that hydropower plays a crucial role in securing water sustainability and uses a renewable energy source to reduce dependency on fossil fuels, building infrastructure for advanced hydropower projects for eco-friendly growth and economic development. Hydropower plants can minimize the risk of environmental and climate change issues, and they support irrigation and agriculture. Pakistan can take important steps to overcome water scarcity, achieve sustainable development, and ensure energy security.

Keywords: Sustainable development, infrastructure, climate change, water management, Irrigation

Introduction

Water is an essential element for human survival, sustainable development, and



a country's economic growth. Currently, countries are prioritizing efforts on the management and conservation of available water resources more than in previous years. Since 2000, Pakistan has faced recurring droughts due to declining river discharges and lower rainfall. Pakistan is located in the western part of the Indo-Pak subcontinent. Its borders are shared with Iran to the west, Afghanistan to the northwest, China to the northeast, and the disputed region of Jammu and Kashmir. According to a 2003 article by Khan and colleagues, the Indus Basin includes the river valleys of the Indus and its tributaries, such as the Kabul, Jhelum, Chenab, Ravi, Beas, and Sutlej, which together form the world's largest irrigation system. The increasing water demand, driven by rapid population growth, is expected to rise more than six times worldwide as the global population expands. Pakistan's primary source of water is the Indus River system (IRS), which fulfills the country's water needs and irrigates its agricultural land. As an agricultural nation, Pakistan's agriculture sector significantly contributes to GDP growth. Pakistan is blessed with all four seasons and a distinctive climate. The monsoon season and rainfall occur from July to September each year. Pakistan has faced issues of excessive drought and extreme flooding, particularly in 2022 and 2025. Water security is a serious challenge for the country. Rising global temperatures due to climate change have also affected Pakistan's weather patterns, leading to higher temperatures each year. Pakistan encounters many challenges in managing water resources, including unequal capital distribution between rural and urban areas (Ishaque, Mukhtar & Tanvir, 2023).

Ineffective governance intensifies the situation and leads to the wastage of water. To resist these challenges, take further steps to implement water management strategies, improve infrastructure, and enforce strict regulations. These measures are very important to secure sustainable water usage and safeguard the societies of Pakistan, strengthen the economy, and develop the environmental socio-economic dynamics. (Bukhari, Khan & Noreen, 2024) Due to carbon dioxide reduction gases, low economic production, and climate change, environmental arise. There is a need for low carbon various sectors, especially in electricity production. According to the U.S. Environmental Protection Agency, generating electricity by burning fossil fuels is the largest source of carbon dioxide emissions in the United States, accounting for about 30 percent of the nation's total greenhouse gas emissions in 2014. On the other hand, most departments and financiers are in support of hydroelectric dams for renewable energy production. The officials emphasize utilize power that the energy generated through hydropower is reliable because it includes less low fetch, provide long-lasting process, develops large organizations, and stores energy for a long time. While the hydropower can control water level, manage fluids that damage crops, and provide clean water. The hydropower system of energy production and management of water is also accepted by the panel on climate change.

In addition to drinking water, the main applications are food and energy production. Providing water for floods, farming, washing, and utilization has been essential for human existence up to the present day. Rivers often connect areas with high rainfall and drier areas downstream, so they are an important means of transporting fresh water. It is an infinite, renewable natural resource and the basis of life and health, which makes it a significant challenge. Climate change and water scarcity, population growth, and rapid economic development



in many regions of the world will increase the pressure on water resources. India and Pakistan belong to one of the regions under water stress and are facing global climate change, and are combined with the power of the hydrological system in these countries.

Literature Review

Pakistan has major water reservoirs, although it faces a problem with water storage due to a lack of facilities and water governance organizations, and climate change is a major cause. The population is currently 225 million, and it is expected to reach 250 million by 2025. The destructive effects of climate change harm water management and increase the risk of severe floods and droughts each year. These challenges create greater demand for water for industrial, agricultural, or domestic purposes. Inadequate water sources have created a gap between demand and supply, with accessible water being used inefficiently and groundwater and surface water being misused due to population growth. Water scarcity is a major challenge and a national security concern for Pakistan. (Ishaque, Mukhtar & Tanvir, 2023)

The maldistribution and ineffective usage of water resources have a significant impact on agricultural production, the effectiveness of hydropower generation, and especially on improving economic hydro-electric production. In the agricultural sector, bad water management particularly jeopardizes yield potential intensify food uncertainty and economic unpredictability. Insufficient distribution of water and poor irrigation intensify further challenges, ignore rural development, and worsen the socio-economic development. Furthermore, inefficiency in water resources management diminishes the existence of hydraulic power generation. They can depend on the constant flow of water for electricity production. Ineffective management of water disrupts hydropower plants' production, enabling them to fulfil electricity demands, and intensifying the energy shortage. Mismanagement cannot only affect the availability of electricity in industrial, domestic, agriculture but also affect sustainable economic growth and development. The ineffective usage of water resources hurts the agriculture sector, compromises hydropower development, and leads to a problem of economic instability and energy Crisis. (Nasim, 2015)

By storing, controlling, and releasing river flows in a controlled and predictable way, hydroelectric projects in Pakistan aid in maintaining the water levels required to push water through the nation's vast gravity-based irrigation canal network (WAPDA). In order to ensure sufficient hydraulic head at barrages and canal headwords for diversion into the Indus Basin Irrigation System, large multipurpose dams like Tarbela and Mangla capture excess water during the monsoon, snowmelt, and glacier melt seasons and release it during dry periods (World Bank).

Research Objectives

- To analyze the role of water management in Pakistan from the perspective of hydroelectric power.
- To understand the role of hydroelectric power in improving water management in Pakistan.
- To examine the role of hydroelectric power in ensuring good and affordable electricity for the sustainable development of the country.



- To recommend the hydroelectric power to bear water management policies in Pakistan.

Research Questions

- What is the impact of hydroelectric power on ensuring water security in Pakistan?
- How is hydroelectric power different from other renewable energy sources in contributing to water management and generating affordable energy in Pakistan?
- Which strategies ensure hydroelectric power to make electricity useful for us?
- Why does building hydroelectric dams help to store monsoon rainwater?
- How do hydroelectric projects help to maintain the water levels needed to push water through Pakistan's massive irrigation system?

Research Methodology

The qualitative method is used in this research to analyze the role of hydroelectric power in maintaining water management, flood control, sustainable development, and enhanced technology innovations for electricity production and developed economic growth in Pakistan. An analytical research design is opted to understand and analyze the importance of the usage of new technologies in projecting the hydropower projects in Pakistan. Pakistan has major water resources, and its better utilization is more important to future development. We use existing literature, research articles, newspapers to understand the strategies of hydropower plants, and visual videos on sustainable development and agencies' reports also help to focus on their problems.

Construction of Waterways

The construction of important waterways continued from 1900 to 1997. Each of them has played an important role in establishing the irrigation system. Due to this, this system is on the path of development. The construction of the Bamba Nawala Ravi Bedian, Dipalivar, and Baloki Suleman canals is clear proof of this. The Indus Waters Treaty, signed with India, gave a new impetus to the irrigation system, as the rest of the waters were owned by Pakistan. Dams were built on the waters that came under the national ownership of Pakistan, including Mangla, Tarbela, and Rusak. Which play a fundamental role in the irrigation system of Pakistan. There are 16 barrages, 2 headworks, and 44 canals that irrigate more than 40 million acres of land. Pakistan's water resources are of two types: natural and artificial sources. The natural system includes tube wells, and the artificial system includes the Tarbela and Mangla Dams, which enhance water availability. (Afzal et al, 2020). Due to an increase in the population of Pakistan, the situations of water floods, storm weather, and melting of glaciers have caused the death of a lot of people and damaging of agriculture and the houses of People. For these multiple purposes, there is a need of production of hydropower. Hydropower plants help to control the flow of water. On the basis of hydroelectric power, multiple dams are constructed, including the Tarbela dam, Mangla dam, Biraj dam, and others. The Indus River plays the most important role in agriculture because it provides water for irrigation. (Siddiqi et al., 2012)



Connection of Hydropower Plants and Renewable Energy

Hydropower plants are a major contributor to the electricity generation and renewable energy in the industrial field, worldwide, far more favour in nuclear power plants. Development in hydro power faced many problems in governance, administrative problems, and security issues in the process of hydropower generation. Tarbela dam provides the other basic needs because it manages to control the stormwater flow and fluids. The Operational planning of the Terbela dam relies on a single part of the system providing reliability, which contributes to the issues. The dam is situated in an area that is susceptible to climate change because of anticipated variations in precipitation and snowmelt. While the cause of bad climate change may cause high levels of inflows to occur in an earlier month, this suggests that, in order to reduce the inflows and storage of flood volume, the filling of the reservoir should begin earlier. Additionally, it indicates that early crop production, which increases yield, is impacted by climate change. This alteration in the season of bad production of sowing would necessitate minimal falling of limbs and early irrigation releases from the reservoir. (Rafique et al.,2020)

Promoting a viable development of hydropower projects to ensure agricultural development in Pakistan and provide water facilities to moisten the soil for better growth of field and enhance economic growth. Hydropower is essential for the agricultural process, the operational reliability of electricity generation, and sustainable development. Hydrology is an important element for managing the large Indus basin and water resot researches. Every group started research on the management of water reservoirs, but all have different aspects. Management in the Indus basin have gain support from international organizations and aims to remove poverty in the third world and provide equal allocation of resources in every region. In parallel, the installation and proper work of hydropower projects must have a continual flow of water for hydroelectricity generation and installations. So, the availability of water resources and pass into the turbines or the interruption of energy generation for domestic and industrial purposes. Prioritize the development and maintenance of hydrological development and justify the agriculture productivity, infrastructure development, and secure food storage. (Johnston et al., 2014) Rivers, lakes, and man-made water reservoirs play a vital role in ensuring economic development and sustainable food storage. Governments can guarantee food security or economic development in a country. The Indus River irrigates many lakes in Pakistan and provides socio-economic development. Effective management of these resources is essential for agricultural, industrial, or domestic needs. Similarly, equal distribution of available water resources for better livelihood, economic prosperity, and food security. The government should prioritize economic development and implemented policy of sustainable water resources. Promote hydropower plans, water conservation, and implement policies. (Qureshi, 2018).

Need for Building Water Storage Capacity

Furtherance of the shortage of water storage, experts claim that water waste is a pressing issue in the entirety of the nation. There are certainly multiple domains that define how the problem occurs, although these are the most important aspects. Yearly rainwater outflow towards the ocean, as well as an issue with the sprinkler system, may lead to flooding and evaporation. The issue at hand will be



categorized into difficulties involving worth as well as volume to a considerable degree. At the moment, unprotected waterway drainage systems squander 52 MAF annually, whereas deficient storage facilities for water, including dam accumulation, squander approximately 38 MAF towards seawater (Khalid & Begum, 2013). The Indus Valley River System Authority (IRSA) estimated that each year the value of water spilled into the oceans is twenty-one billion dollars (Guramani, 2017). The shortage of water, inappropriate consumption of water, and crumbling structures are only a few of the difficulties that the agricultural sector has to contend with. The issues mentioned above are being made harder by global warming, which particularly affects the accessibility of water from fluctuations in rainfall, including the melting of glaciers (Lee et al., 2023).

Initially, dams that produce electricity could potentially be used as a military weapon (e.g., when state actors utilize them to suspend or cut off water supplies during a conflict between nations). Following that, during armed battles, state actors might attack them. Third, to further their objectives, non-state terrorists may target dams. Fourth, dams are capable of helping pursue political objectives like creating businesses or eliminating poverty. Fifth, issues over development in society and the economy may center on water supply or dams. (Rothfelder, 2003). Projects involving hydro can exacerbate economic concentration and/or diminish ethnic minorities and cultures by facilitating the privileged control of supplies, according to another corroborating perspective. (Wolf, 2007). In spite of the management of water reservoirs and their utilization being in scared condition and not properly stored, they are wasted due to their misallocation and insufficient water policies. Formulation of polices for economic development for successive generations or self-sufficiency objectives. Water resources management is crucial for agriculture practices, industrial growth, and power generation sectors. A comprehensive approach is better for resource management, generating electric power, and making infrastructure for sustainable development. (Jones, 2020)

Despite the extensive irrigation system, water scarcity is not being met, which is causing Pakistan to face many challenges. Which is an obstacle to the country's development. Pakistan's irrigation system is very extensive, including canal networks, barrages, and dams that increase agricultural and dairy nutrition. Its importance is very clear, but despite this, the nation is facing water scarcity. The increasing causes of water scarcity are, among others, climate change and population expansion, which are causing further obstacles to water scarcity. It harms sectors such as agriculture and industrial energy. Limited access to water is reducing crop production and severely weakening the economy. To solve these challenges, water management methods will have to be taught, and water conservation will have to be improved. If Pakistan eliminates these obstacles, it can implement its development plans and progress (Mirza, 2012). The initial phase in determining the possible use of water reserves, especially in a drainage arrangement, for creating electricity, is hydroelectricity evaluation. This particular type of investigation's primary purpose is to establish how it is feasible to transform the water circulation infrastructure's energy reserves into electrical power (Bogati et al., 2025). Another of those earliest alternative energy methods for producing electrical power is hydroelectric. The state of Pakistan has a vast network of rivers that supply irrigation and water to the country's crop cultivation industry, other businesses, especially in the basin of the Indus River. Multiple head-regulating channel openings and cascades along this pathway may



intercept the water and generate energy. They serve as potential sites for the construction of modest to moderate-sized hydroelectric power plants (Loots et al., 2015)

Hydropower Plants for Irrigation System

Irrigation is not only a regional problem in Pakistan but also a political concern of all stakeholders, for instance, which means it involves quite some time for coalitions and regions to reach a consensus on an arrangement so that measures can be established in a manner subsequently appropriate across all regions. Thus, for the country to effectively safeguard the water that it has, the country will need to take into consideration each component of its geography and comprehend the basic developments. With the goal to give specific targets, desired outcomes, methods for execution, plus time frames for implementation, regulations must be compact (Zhang et al., 2020). The open admission concerning water constraints throughout situations of limited supplies, nevertheless, is probably the most important exclusion. Regional disputes are increasing as a consequence of this marginalization, particularly in the lower riparian territories, including Karachi and the downstream regions like Punjab and KPK (Naushad, 2021). For the goal to bring about greater effectiveness and equitable administration of water throughout Pakistan, these shortcomings need to be overcome. Disputes throughout the country, as well as the two nations, could have been precipitated by a shortage of water. Both nations, having weapons of mass destruction, endure a centuries-old hostility, managing the water sources that comprise the Indus Basin. That worldwide water challenge has been made severe through warming temperatures, an important contributor responsible for dwindling accessibility to water, and therefore has the possibility of escalating into an ongoing dispute. (Shamas, 2016)

Analysis

It was acknowledged that Pakistan faced many challenges linked to water insufficiency, ineffective irrigation, high flood risks, and mismanagement in hydropower projects. This study highlighted a deep understanding of the hydropower range and its structural planning. The research shows that the Tarbela and Mangala dams help to store the excessive water for monsoon rains and melted glaciers. Our government needs to be more focused on hydropower plant projects to generate electricity instead of the use of thermal power plants, and reduce our dependency on fossil fuels. Pakistan's current dams are insufficient to store water such as Tarbela Dam is one of the largest dam which is situated on the Indus River, Mangla dam has also a major dam for storing approximately 7.4 to 7.5 million Acre Feet water has located on the Jhelum river, Diamer-Bhasha Dam is under construction dam, Dasu Dam is one of the run-of the river dam which is situated on the Indus river and Mohmand dam is also under progress. Although dams can help generate electricity and control flood risks, and uplift economic growth to provide water for industrial and agricultural purposes.

The effectiveness and sustainability of hydropower systems are constrained by fragmented governance, antiquated reservoir operating regulations, and insufficient incorporation of climate considerations into planning. Thus, integrated water resource management, increased irrigation efficiency, efficient groundwater regulation, climate-resilient planning, and



improved institutional coordination are all necessary to achieve sustainable water security, according to the research. The crisis will continue to threaten Pakistan's food security, economic expansion, environmental sustainability, and social stability in the absence of prompt and thorough reforms. The lateral (inside administrations) as well as downward (within entities) interaction, alignment, and accomplishment responsibilities are becoming particularly difficult and frequently divided because of the structure of institutions, capacity of organizations, and governmental viewpoint. Central, along with regional institutions, together with additional connected agencies, had significantly different legislative obligations regarding weather and water management. (Yasin et al., 2021). In wealthy nations, the environmentally friendly utilization of recovered wastewater over laundering, harvesting, and numerous applications distinct from consumption is gaining ground, although countries with fewer financial resources have begun to follow suit. There are currently not enough collaborations between the public and private sectors, without sufficient rules regarding the beneficial utilization of recycled sewage throughout the country. Drinking water management problems typically arise from inefficiencies brought about by ineffective ecological laws, as well as the shortage of organizational ability regarding oversight and sway. (Basharat H. Bashir, 2012). Throughout the world, water has become an essential component providing nutrition for both people as well as plants & animals. Whenever talking about providing the ordinary public's access to pure, safe water to consume, the country nevertheless remains deficient. The primary provider of clean water supporting the citizens of Pakistan, along with crops, depends on the Indus River Valley System (also known as the IRS).

Every region uses up its supply allowance comparatively immediately as a consequence of inefficient water management for agriculture. At important times of the season, significant agricultural products remain short of irrigation. For optimal utilization of the water readily accessible, a method of drip irrigation should be promoted incrementally. Karachi constantly proclaim concerning the federal administration's disparate allocation of funds for irrigation. Sharjeel Memon, the Sindh Province Information Minister, reportedly urged the federal government of Pakistan focus on the serious shortage of drinking water within the Sindh region. Furthermore, the 1991 water agreement, which guaranteed the prudent distribution of water throughout every region, ended up coming to the federal government's attention. For the distribution of the water resources across the regions, the Pakistan Water Apportionment Accord 1991 was formulated. Regardless, the agreement fails to state the precise percentage of the water distributed to each of the regions. (Ishaque et al., 2023).

Conclusion

This research concludes that hydropower has a vital role in ensuring water security for Pakistan, controlling flood risks, and generating clean and affordable energy resources. Pakistan's water resources will be under more strain as the country's population increases. Even more severe health risks could result from poor sanitation, which is already uncommon. These issues prompt us to look to our customs for answers, the most crucial of which is reverence for water. The present research explores the country's potential for hydropower as well as attempts to clarify the reason why Pakistan's long-term development relies entirely on smaller and large-scale hydroelectric development. The country could



reduce its fuel shipment cost plus simultaneously address the issue of electric power emergencies whenever it takes advantage of its abundant hydroelectric as well as additional environmentally friendly power capabilities. Massive hydroelectric plants disrupt important ecological functions; they nevertheless provide a stable, cheap, and mostly carbon-free source of electrical power that is seen as superior to petroleum and coal. Although Pakistan's transition to a renewable power economy will be extremely difficult, there is definitely an alternative. From this context, hydroelectric power might serve as the main form of electricity generation within a renewable-starved country like Pakistan, and an extensive or domestic source of energy might provide the most promising alternative.

The present investigation looked into the challenges that develop during expanding the consumption of hydroelectric power, as well as identified an ideal way to reduce the problems that arise during the realization technique. Four variables: weather, physical structures, social and cultural context, and finances, have been selected for this investigation. The study analyses actual power generation shortage due to various factors, applying an empirical scale. Based on the information that was compiled, physical structures have a bigger influence on renewable energy problems compared to social and cultural context, finances, and ecological problems. The present study shows that when it comes to dealing with power generation crises, infrastructure factors become a need for becoming informed.

Recommendations

The challenges that Pakistan faced related to integrated water security management and developing a sustainable structure. There is a need for an effective policy structure, community involvement, stable high-tech involvement of WAPDA, and climate change institutions to make policies for the modern and better future of Pakistan.

- **Build the System of Storage**

Due to heavy rain in monsoon seasons or amidst unpredictable environmental fluctuations, and had caused severe flow that cannot be controlled, the government of Pakistan and the management offices need to install more barrages or dams for Seasonal water Storage that can be used in the future.

- **Strategies and Policies for Development**

The national agencies relating to water management and electricity production through the use of hydropower, and the departments or institutions, formed the strategies for the production of eco-friendly energy. The WAPDA needs to play its role in management. Their Priority involved the schedules, proper guidelines, and policies for better irrigation and control of extreme water floods.

- **Technology and Projects for Energy Production**

There are four major dams that are built for the Storage of water and for the production of electricity. The largest dam is Diamer Bhasha Dam, the second one is for the agricultural production, and the water management is Mohmand Dam, the other ones are Bunji Dam and Akhori Dam. Technological and modern tactics are used for energy production. Meetings and International conferences on the national level are held for people who are related to the agricultural sector.



- **Encourage the use of modern irrigation methods and the integration of renewable energy**

Encourage the use of cutting-edge irrigation technologies and the integration of water resources with renewable energy projects by proposing legislative measures based on sustainability and economic development research. The implementation of fiscal incentives, such as tax credits and subsidies, for the adoption of water-efficient cultivation procedures, the promotion of public-private partnerships to accelerate innovation in water-energy nexus projects, and the alignment of policies with universal climate obligations to support resilience and future-proof development are some of the policy implications.

Improve Creek Direction and Water Works

Promote laws that update drainage infrastructure and digital drainage regulations based on research findings about reducing dehydration and soil erosion. This program entails making calculated ventures to modernize culverts and sewerage systems, implementing high-tech solutions for effective water management and monitoring, and providing targeted subsidies to encourage cultivators to use smart farming methods. and programs for specialized assistance.

- **Encourage Policy Discussion and Discord Settlement**

Stress the value of organized policy discussions and legal procedures for settling interprovincial water disputes, backed by studies on argument resolution and stakeholder engagement. Establishing official negotiation procedures under a rule sovereignty structure, holding top-ranking discussions with representatives of nongovernmental organizations and provincial authorities to promote agreement on cooperation arrangements, and using ambassador coverage to promote throughfare talks and settle complicated water disputes are some of the policy ramifications.

- **Educate the Public and Put Conservation Measures into Action**

Promote laws that raise general understanding of preservation and responsible water management practices by utilizing broadcasting tactics and behavior modification research. Through the implementation of pricing mechanisms to encourage responsible water use, strategic allocation in public online coverage to increase information on water efficiency, and the establishment of nonprofit communities to incorporate water dialogue education into the course of study and civic involvement programs are all part of this initiative.

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