FEASIBILITY ANALYSIS AND DESIGN OF PUMP STORAGE HYDROPOWER PLANT AT TARBELA DAM

FINAL YEAR PROJECT BY UG 2020

By

Leader - 345581 Alyshba Ahmed

Member 1 - 3339093 Sojhla Khan

Member 2 - 346885 Muhammad Shoaib

Member 3 - 331339 Muneer Ahmed

School of Civil and Environmental Engineering

NUST Institute of Civil Engineering

National University of Sciences and Technology, Islamabad, Pakistan

YEAR 2024

This is to certify that the

Final Year Design Project Titled

FEASIBILITY ANALYSIS AND DESIGN OF PUMP STORAGE HYDROPOWER PLANT AT TARBELA DAM

Submitted by

Leader - 345581 Alyshba Ahmed

Member 1 – 3339093 Sojhla Khan

Member 2 – 346885 Muhammad Shoaib

Member 3 – 331339 Muneer Ahmed

has been accepted towards the requirements

for the undergraduate degree

in

(Bachelor of Civil Engineering)

Dr Zafar Iqbal

Designation (Asst. Prof)

NUST Institute of Civil Engineering

National University of Sciences and Technology,

Islamabad, Pakistan

ABSTRACT

Electricity generated by certain renewable energy resources is intermittent, making it challenging to match supply with demand. Therefore, large-scale energy storage systems are essential to balance supply and demand effectively, ensuring grid stability and reliability Unlike other forms of energy storage pumped storage hydropower plants (PSHPs) have low environmental impacts and are sustainable as well. Pumped storage hydropower is the most efficient storage technology and has proven to be a well-grounded power storage technology, especially in that era when the power demand is at its peak. This thesis comprises an encompassing feasibility analysis and design proposal for PSHPs at the Tarbela dam in Pakistan. A pumped storage hydropower plant of two reservoirs lower and an upper reservoir. The feasibility analysis appraises the mechanical and environmental suitability of the suggested PSH plant. Attention is paid to optimizing the design to maximize the energy output and minimize construction costs, lighten the environmental impacts. By Leveraging the topographical elements and hydraulic potential of the site, the proposed project assures and advances significantly Pakistan's energy security while mitigating carbon emissions and environmental deterioration.

TABLE OF CONTENTS

Table of Contents

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of the study:

Pakistan has never had such a serious energy crisis as it has today. There is a growing demand-supply imbalance that has caused frequent load shedding. The insufficient generation capacity of our plants is one of the key causes of this large imbalance. There is a reduction in generation by hydro in winter, depletion of natural gas reserves, and due to increasing circular debt, the country faces unavailability of furnace oil. Pakistan needs a renewable and sustainable energy conservation and generation strategy. (Manzoor et al., 2021)

According to data collected from the Institute of Strategic Studies Islamabad in the months of May to August, the country's system capacity was about 21,200 MW whereas the demand was 28,200 MW, leading to an acute shortfall of 7000 MW. This energy crisis largely affects Pakistan's residential and commercial sectors, which comprise 97% of total consumers, leading to crises that lead to inflation and hindrance in economic activities. Similarly, in the industrial sector, frequent and long power breakouts decrease the productivity rate. This situation is repelling investors because they prefer to shift their businesses from Pakistan to other countries, such as Bangladesh. (Anwar, 2008)

The international energy landscape is perceiving a fundamental change toward long-lasting and recyclable sources of power, driven by aspects of climate change and energy stability. Within this context, hydropower plants surged as a primary principle of the transformation to a clean power source, suggesting a trustable and adaptable means of electricity. Among the different forms of hydropower, PSHPs stand out as perfect energy storage (Shah, S. A. A., & Solangi, Y. A. (2019))

Importantly suited to meet the challenges posed by intermittent renewable sources such as wind and solar. Pumped storage hydropower plants play a crucial role in flood prevention, lighting the effect of intense weather events. In addition, the reservoirs affiliated with PSHPs assist as indispensable sources of fresh and contained water, a resource that is necessary for drinking and agriculture objectives.

1.2 Problem Statement:

Power demand is not constant. It varies based on the time of day, day of the week, and seasonally. Though coal and nuclear plants are well suited for supplying base load generation requirements, they are poorly equipped for supplying peak load requirements. Because we lack the technology to cater for peak load requirements electricity load shedding occurs throughout the day to compensate for this. Therefore, other types of power plants are needed to supply intermediate and peak power to meet the demands of consumers and one of the most notable examples is of Pump Storage Hydropower system.

No technology in Pakistan can store power at such a massive scale to be utilized when the need is high and PSHP is the answer to that. The availability of a sustainable and clean energy source is the need of this time as the world is heading towards the integration of variable and renewable energy sources to reduce carbon footprint.

The project close by includes the strategic design and accomplishment of a pumped storage hydropower plant at Tarbela Dam, concentrating on using the existing reservoir as the lower reservoir and developing an additional upper reservoir. The main challenge is engineering a pumped storage hydropower (PSH) plant that is harmoniously incorporated with the current infrastructure of the Tarbela Dam while mitigating any potential operational disturbances. Economic feasibility is a central aspect of this project. The design and construction of the PSH plant must be economically sustainable, with a focus on budget-friendly without compromising on effectiveness and longevity.

1.3 Objective of the project:

The objective of this study is to diligently and comprehensively explore the various dimensions included in the enforcement of Pumped storage hydropower plants at Tarbela Dam, centering on these key areas.

1. Assessment for the reservoir site selection
2. Design Development for PSHP:
3. Analysis of energy storage and capacity:
4. Economic Viability and Sustainability Evaluation

1.4 Significance of the study:

This study holds immense significance in the context of renewable energy development in Pakistan. The successful implementation of a PSH plant at Tarbela can serve as a model for future renewable energy projects. It can boost and elevate the country's energy retention and production capability.

This section looks at the investigation of cutting-edge technologies that have the prospect of being uninterruptedly incorporated into the design of the Pumped Storage Hydropower plants. The aim is to recognize and understand emerging technologies that can increase the overall effectiveness, continuity, and adaptability of the plant. This can consist of advancement in turbine design, smart grid assimilation, or building material that is related to project goals by investigating industrial inventions, this portion contributes to thinking forward for the study approach, by guaranteeing that Pumped storage hydropower plants at Tarbela are at the leading edge of technological improvement in the field.

According to the 47th edition of the report on power system statistics by NTDC fossil fuel plants are the highest energy production plants in Pakistan which is not ideal for a country like Pakistan which is ranked 7th most impacted region by climate change.

This conducts a deep judgment of the project's impacts on the regional community, investigating its harmony with social enhancement goals. This includes a judgment of potential social gains, strategies to engage the community, and project role in developing a comprehensive quality of life. In addition, it also analyses negative effects on the community, with a focus on deciding those strategies that mitigate the negative impacts. By focusing on the social dimensions, this section delves into a complete understanding of the PSH plants' impact on the human ecosystem, trusting that they are combined with wider societal goals and values.

Season	Peak Timing	Off-Peak Timing
Dec to Feb	5 PM to 9 PM	Remaining 20 hrs
Mar to May	6 PM to 10 PM	--do--
June to Aug	7 PM to 11 PM	--do--
Sep to Nov	6 PM to 10 PM	--do--

Table 1.1 Peak/Off-Peak Timings - Power Information Technology Company

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction:

According to (Brandi A., 2004), "With increasing concerns regarding global warming and a push towards energy independence, renewable technologies are becoming increasingly popular. However, their variable nature limits the ability of renewable technologies to provide a larger portion of the power supply. Pumped storage hydropower is a proven large-scale energy storage technology that allows for better integration of renewable energy into the power grid by allowing storage of excess energy for later use" (p. 68).

Pumped Storage Power Plant is a machine and a system used to generate power or electricity. In research, Brandi A. A. (2004) has revealed, "Pumped storage hydropower is a technology that stores low-cost off-peak, excess, or unstable electrical energy."

This chapter will revolve around the definition and basic concept, early examples and evolution, Description of pumped storage plants working, Various parameters classification, Choice of location and influencing factors, Types and selection of hydraulic turbines, Selection of potential sites for reservoirs, Barriers in the selection of Potential sites, Operation of Pumped hydropower storage combining it with variable renewable energy - a summary, role in grid stabilization, economic feasibility and cost analysis, successfulness of pumped storage projects, pumped storage projects - Cross-border cooperation, research gaps and future research.

2.2. Definition and Basic Concept:

2.2.1 Definition:

A pumped storage power plant is an electricity generating plant operated by a higher altitude flowing water downward altitude.

2.2.2 Basic concept:

Through the pressure of water, a pumped storage power plant operated, moving from an upper region to a lower region to move a turbine for electricity generation.

2.2.3 Early Examples and Evolution:

We can observe that humans are always passionate about using water for their benefit in case of necessity and need. Twasif H. C. (2021), has cited, " The evolution of the modern hydro turbine began in the mid-1700s. But the idea of Pumped-storage hydropower came on the scene in the late 1900s." Moreover, the researcher has cited, "the first Pumped storage hydro plant was in 1909 in Switzerland."

Furthermore, according to Anas Aref Al-Garalleh (April 2017) in Europe, "Over 80% of it was commissioned between 1960 and 1990." Also, the researcher has noted the starting year of PHES in Japan, "Although the initial PHES scheme (11 MW) was designed in 1968, and then the second in 1975." In the USA, according to the researcher, "most of PHES stations in the United States were designed in the period 1960 - 1990 (Yang & Jackson, 2011)." To sum it up, Anas Aref Al-Garalleh (April 2017) has pointed out, " In India, the first pumped storage system was the 770 MW Nagarjunasagar plant, which was completely commissioned in 1981."

2.2.4 Description of Pumped Storage Plants Working:

In short, in any upper region, dams are constructed to store water. Then, for electricity generation, water is utilized. Also, turbines are installed for electricity generation in a lower area. The water flows from the higher region downward, with its pressure moving the installed turbines to a lower region; so, electricity is generated.

2.3 Choice of Location and Influencing Factors:

In brief, the choice of location and influencing factors are the key elements that make the Pumped Storage Power Plants successful. The researcher, Anas Aref Al-Garalleh (April 2017), in the research, Design of a Pumped Hydroelectric Energy Storage (PHES) system for Jordon, has discussed two important factors i.e. The geographic location of the candidate site and energy storage.

The geographic location of the candidate site: "The geographic locations for installation of PHES system should be situated on high elevation areas such as hill or mountain and also it should be near to the water sources" (Anas Aref Al-Garalleh, April 2017). Moreover, the researcher added, "In general, the PHES system consists of two reservoirs with high elevation difference." "The upper reservoir is on top of a mountain, whereas the lower reservoir is at the bottom of the mountain" (Anas Aref Al-Garalleh, April 2017). According to Anas Aref Al-Garalleh, April 2017, "The nature of the site should be able to keep water, and the elevation between the upper and lower reservoirs should be high enough to allow construction of PHES." "For a certain power station, the reservoir storage requirement and the capacity of the water conduit is inversely proportional to the head" (Anas Aref Al-Garalleh, April 2017). Further, the researcher has said that the distance of water condit has to be as short as possible. "Reservoir candidate locations should have the least excavation work to reduce the capital cost of construction" (Anas Aref Al-Garalleh, April 2017). Finally, according to Anas Aref Al-Garalleh (April 2017), "The candidate sites should be located near the grid to reduce power transmission costs."

Energy storage: "To determine the amount of energy that can be stored by the PHES system in a dam" (Anas Aref Al-Garalleh, April 2017).

2.4 Types of PSHP:

There are two majorly known types of PSHP as follows:

2.4.1 Open loop systems:

In this system, the plant solely depends on the water stored in the upper reservoir for electricity production with no other sources of water inflows.

2.4.2 Closed-loop system:

this system involves a mix of pumped water and natural inflows to generate electricity.

2.5 Configuration of PSHP:

The three common configurations of PSHP are the following:

2.5.1 Four units:

A system of separate pumps and turbines coupled to a motor and generator respectively. This system is outdated since it occupies a lot of space.

2.5.2 Three units:

Separate pumps and turbines are coupled to a single reversible motor/generator. In this system, the efficiency of the pump and turbine can be optimized.

2.5.3 Two units:

A reversible pump/turbine coupled with a reversible motor/generator. This system takes up the least amount of space and has lower installation costs. More than 95% of PSHP in the world use this configuration. However, it has relatively lower efficiency compared to the other systems.

The PSHP system cycle efficiency is the ratio between the energy supplied while generating and the energy consumed while pumping. This efficiency depends on both the pumping efficiency (ηp) and the generation efficiency (ηg). It is given as:

$$\eta = \eta p \times \eta g \qquad (2.1)$$

For a standard PSHP, it ranges between 70-85% [1]. PSHP can switch from pumping to generation mode and vice versa in 180 to 240 seconds.

2.6 Classification of Turbines:

Turbines are used to convert hydraulic energy to mechanical energy. They are generally classified into two types i.e. impulse and reaction turbines. Impulse turbines only utilize the kinetic energy of water whereas the reaction turbine uses both the pressure and kinetic energy of moving water to spin the runner. The use of these turbines for electricity generation largely depends on the head availability. Impulse turbines, such as the Pelton turbine are suitable for high heads of up to 500-1800m. In comparison, reaction turbines such as the

Francis turbine are suitable for medium heads generally from about 20-700m. This type of turbine is mostly used for conventional hydraulic energy generation. It can also act as a reversible turbine in which it can function as both a turbine and pump, hence acting as a two-unit system.

2.7 Selection of Potential Sites for Reservoirs:

The selection of sites for potential sites for reservoirs is of utmost importance. To make pumped storage power plants successful and more effective consideration of sites for potential sites for reservoirs cannot be ignored. SERWAN M. J. BABAN and KAMRUZAMAN WAN-YUSOF (2003) in their study, Modelling Optimum Sites for Locating Reservoirs in Tropical Environments, have recorded, "Reservoir site investigations are always carried out by a team of specialists". Further, the researchers added, "Factors influencing reservoir and dam site selection include economy, hydrology and hydraulics, topography, geology, points of abstraction and supply, as well as environmental considerations."

The researcher, (Akour & Al-Garalleh, 2019).in the research, Design of a Pumped Storage Hydropower Plant (PSHP) system for Jordon, has discussed two important factors i.e. The geographic location of the candidate site and energy storage. The general layout of the PSHP system consists of two reservoirs with high elevation difference (Akour & Al-Garalleh, 2019).. While the lower reservoir is located at the base of the mountain, the upper reservoir is situated atop the. Further, the researcher has said that the distance of water conduit must be as short as possible. Energy storage means to calculate the amount of energy that can be accumulated by the PSHP system in a reservoir.

2.7.1 Hydraulic Head:

The exact difference between the higher and lower reservoir's water levels is known as the hydraulic head. The capacity of the water conduit and the amount of reservoir storage needed for a particular power plant are inversely correlated with the head (Akour & Al-

Garalleh, 2019). The higher the head, the higher will be the energy stored and high-power output. The lack in hydraulic head can be compensated by large volume and discharge. However, a large head is preferable because of cost issues. In the literature (Görtz et al., 2022), a minimum hydraulic head of 50m is chosen for their case study. In the case study of (Alvarez, 2020), several potential sites with varying hydraulic heads are used in which the minimum hydraulic head is 50m. So 50m is the most used minimum hydraulic head in general. There's no limitation on the higher end.

2.7.2 Hydraulic Slope:

The ratio of hydraulic head to horizontal distance between upper and lower reservoir is called Hydraulic Slope. The higher the hydraulic slope, higher will be the overall project efficiency (Görtz et al., 2022). To filter the best places rather than the entire potential, the minimum requirement for the hydraulic slope is set at 0.1 (Görtz et al., 2022). Maximum Hydraulic Slope limit is 10 (Wickramarathna, 2011). For the majority of pumped storage projects, the length to head ratio ranges from 2 to 10, with smaller numbers denoting higher scores (Kucukali, 2014).

2.7.3 Slope in the Reservoir Area:

Small ground slopes are necessary to determine the best places for dams. As a result, regions are arranged based on their ground slopes, which range from 0% to the maximum area slope that is appropriate (Görtz et al., 2022). The best slope range(flatness) for building upper reservoir is 0-5 degrees (Ghorbani et al., 2019; Lacal Arántegui et al., 2011; Lu et al., 2018).

2.7.4 Reservoir Area:

Since the goal is cost-effective PHES, a minimum reservoir capacity of one million m3 is thought to be comparable to a standard criterion in the literature (Ghorbani et al., 2019; Lacal Arántegui et al., 2011). To put this volume in a ring dam type reservoir of a depth of 20 m, an area of 50,000m2 will be required (Görtz et al., 2022). According to other literatures (Ghorbani et al., 2019; Lacal Arántegui et al., 2011), an additional area of 20,000m2 is added to the total to compensate additional civil works and safety margins.

2.7.5 Search/Buffer Distance:

The buffer distance criterion means the search radius around the river line. A smaller buffer distance means greater the numerical performance while ignoring some potential outlying sites (Görtz et al., 2022). Generally the value for this is chosen according to the site's location and it depends on the distance of upper reservoir from the river. To ensure that no viable locations are missed, the buffer is set to the higher end (20 km) of the values of earlier research (Ghorbani et al., 2019; Lacal Arántegui et al., 2011).

2.7.6 Human Presence:

The social environment considerations are: number of directly impacted houses (resettlement), area of the lost land that the local communities depend on for their daily needs, and relocation (Kucukali, 2014). The limitation in case of inhabited area is that ff a new construction is within 200 meters of an inhabited area, a new reservoir must be chosen (Lacal Arántegui et al., 2011).

2.7.7 Transport Infrastructure:

By transportation infrastructure we mean public transport roads, railway lines and bridges etc. If these sorts of infrastructure are within 100 meters of the site where the reservoir is to be constructed, then that site will not be considered viable and a new site will be chosen (Lacal Arántegui et al., 2011).

2.7.8 Grid Infrastructure:

The potential sites should be located near the grid infrastructure to decrease power transmission costs (Akour & Al-Garalleh, 2019). The closer the PSHP is located near the already present transmission lines, the lower will be the costs of connection to the grid. Hence, the distance to the grid connection should be small, and the feasibility is inversely proportional with the grid connection distance (Kucukali, 2014). If the transformation site doesn't have a hydro-dam, then there should be good grid facilities within 20 km. If there isn't, the change to PHS won't be possible (Lacal Arántegui et al., 2011).

2.8 Barriers in Selectin of Potential Sites:

Barriers while selecting a potential site vary from place to place, country to country, and project to project. However, some barriers need to be kept in consideration while planning for the inspection of a potential site or site. Researchers, Roberto L. A., Institute, Petten, Niall F. and Paul L., Cork (2012), in their research, Analysis of the potential for transformation of non-hydropower dams and reservoir hydropower schemes into pumping hydropower schemes in Europe, have pointed out some barriers, which are: "Topographical Barriers, such as geology, hydrology, and infrastructure; Economic Barriers, such as electricity market analysis and capital cost; Social Barriers, such as inhabitant sites and navigation Trans-boundary issues; Environmental Barriers, such as conservation issues, fisheries and environmental benefits; and Water Supply Barriers, such as water resources, chemical and physical water quality and biological water quality.

2.8.1 Economy:

Cost analysis is based on the type of land (cropland, forest or built-up) that needs to be impounded (Legg, 1992; Avery and Berlin, 1992). Other than that, for a pumped storage hydropower project to be cost efficient, the cost difference should be large to recover energy lost in the pumping/generating cycle, initial capital costs, as well as operation and maintenance costs (Antal, 2014). Usually, the PSHP systems are cost effective at sites with high heads (means low volume required). Which results in smaller reservoir sizes, reduced civil works, smaller pump-turbine, motor-generator size, and hence lower investment costs (Hayes, 2009). Potential reservoir locations should have the least excavation work, so that the capital cost of construction is as small as possible (Akour & Al-Garalleh, 2019).

2.8.2 Hydrology and Hydraulics:

In general, a dam must be built where there is an adequate storage space for power needs, irrigation, flood control, and/or water supply (Baban & Wan-Yusof, 2003) (ASCE-USCOLD, 1967). It is important to survey and investigate the groundwater in the reservoir and dam sites, including depth of the groundwater, type of the groundwater, type of the aquifer(s), corrosiveness of the groundwater and salts contents etc (Al-Ansari et al., 2019).

2.8.3 Topography:

The site's topography determines its surface layout, including its size and shape, as well as the ratio between its surface and volume (Baban & Wan-Yusof, 2003). Topography plays a key role in decision making of the type of dam that needs to be constructed. A small channel segment requiring the least amount of materials for dam building is a preferred dam (Thomas,1976; Stephens, 1991).

2.8.4 Geology and Geography:

Geology plays a very important role for choosing an adequate and leak proof foundation or reservoir (ASCE-USCOLD, 1967; Avery and Berlin, 1992; Legg, 1992). Igneous rocks like granite, metamorphic rocks like quartzite, and sedimentary rocks like thick-bedded, flat-lying sandstones and limestones are some of the best materials for a desired foundation and abutment (Avery and Berlin, 1992). The ideal places for the installation of PHES systems should be found close to water supplies and in high elevation regions, such as hills or mountains (Akour & Al-Garalleh, 2019) The site's characteristics should allow it to retain water, and the difference in elevation between the higher and lower reservoirs should be sufficient to allow the construction of PSHP (Akour & Al-Garalleh, 2019)

2.8.5 Points of Abstraction and Supply:

This will establish the head of water that is accessible for the demand and abstraction locations. It also tells us whether the supply will be with the help of gravity or by pumping. The distance from the demand center will also determine how long the pipelines are to carry the water (Schwab et al., 1996). Well planned water supply management in dam related purposes is important for regulating the continuously changing water discharge and reducing the disparities between water supply and water demands (Badr et al., 2023).

2.8.6 Environmental Considerations:

Environmental Considerations include settlement relocation, flooding agricultural land, drowning wildlife and flooding areas with archaeological value (Thomas, 1976). By implementing certain reduction measures, such as maintaining controlled flows in the reservoir to improve fish and aquatic life and applying water aeration techniques to preserve the reservoir's water quality, the negative environmental effects of dams and reservoirs can be reduced (Murphy, 1977; Kok et al., 1996). There are two important constraints that deal with environmental issues related to the water in reservoir and surrounding environment. The first constraint relates to the environmental criteria for quality of the flow downstream of the hydropower plants. The second constraint relates to the regular variations in water levels that the hydroelectric system's operation causes inside the reservoirs (Alic et al., 2023).

2.9 Operation of Pumped Hydro Power Storage Combining It with Variable Renewable Energy - A summary:

To enable development in hydropower or pump storage power plants, some key factors are required to be adopted. The organization, IRENA (2020), in the research, Innovative Operation of Pumped Hydropower Storage, has summarized as:

1. Establishing regulatory frameworks that incentivize and remunerate the innovative operation of PHS.
2. Increasing digital operation of PHS systems.
3. Leveraging existing infrastructure by retrofitting PHS facilities.
4. Investing in public-private RD&D projects."

2.10 Role in Grid Stabilization:

In general, Pumped storage power plants play a pivotal role in grid stability. Once water is stored for electricity generation, there can be fewer chances of electricity generation as compared to other renewable energy sources, such as wind energy or solar energy because disruption in the wind and solar energy occurs any time; as the wind stops, wind energy projects leave working, and when clouds cover the sun, the solar energy generating projects also stop working. Therefore, it can be concluded that Pumped hydropower plants play a role in grid stabilization.

2.10.1 Economic Benefits and Challenges:

2.10.1.1 Job Creation and Economic Growt:

In a widespread study analyzing the economic sustainability of pumped-storage hydropower plants, (Mensah et al., 2022) dig into the various aspects such as economic growth, job creation, revenue generation, tax implications, and strategies for addressing high initial investment and regulatory hurdles. It also focuses on the energy potential of implementing PHP operated by renewable energy sources such as wind, solar, etc.

Primarily focused on Brazil, the estimation of unit cost was determined using the investment data and power installed.

2.10.1.2 Revenue Generation and Tax Implications:

One of the economic benefits emphasized by (Mensah et al., 2022) is the potential for revenue generation through pumped-storage hydropower plants. PHP's role is to provide a steady and reliable energy source, attract investments, and create revenue streams. Furthermore, the paper discusses tax implications, shedding light on the financial aspect that impacts the government and project stakeholders. Understanding the tax dynamics is crucial for policymakers and investors to ensure a sustainable economic model.

2.10.2 Addressing High Initial Investment and Regulatory Hurdles:

(Mensah et al., 2022) dive into the financial aspects, evaluating scenarios using Net Present Value (NPV) [**Error! Reference source not found.**] and Levelized Cost of Electricity (LCOE) $LCOE = \sum_{t=1}^{m} \frac{\frac{C_n}{(1+i)^n}}{\frac{E_n}{(1+i)^n}}$ (1.2) methods. When NPV is positive and tariff is greater than LCOE, this indicates economic feasibility and generates profit.

$$NPV = \sum_{t=1}^{m} \frac{E_n \cdot T - C_{om}}{(1+i)^n} - I \qquad (2.3)$$

$$LCOE = \sum_{t=1}^{m} \frac{\frac{C_n}{(1+i)^n}}{\frac{E_n}{(1+i)^n}} \qquad (1.4)$$

Where:

•E_n =Annual produced energy;

•T =Energy sales price;

• i =Interest rate;

•m =Lifespan of the project;

•C_{om} =Operational and maintenance costs;

• I =Capital costs;

•C_n =Cost of electricity for each year; and

•n =Number of years.

2.11 Successfulness of Pumped Storage Projects:

Pumped storage projects might have been successful in many countries of the world, and in some countries, these might have faced failures. But specifically in the context of the USA, positive revelations are observed from the researcher, Brandi A. A. which are: "In recent years the Federal Energy Regulatory Commission has granted numerous preliminary permits in over 22 states for new pumped storage hydropower facilities in the United States, which would suggest that pumped storage hydropower technology will continue to become an increasingly valuable part of the power grid in the United States and increase our ability to utilize renewable energy sources."

2.12 Pumped Storage Projects - Cross-Border Issues:

There may be some issues at the cross-border level while installing pumped storage projects as the lands can be up and down, as well as political rivalries. The researchers Niall F. and Paul L., Cork (2012), in their research, "Analysis of the potential for transformation of non-hydropower dams and reservoir hydropower schemes into pumping hydropower schemes in Europe" have highlighted, "If the region in another country up and down the river is not in the same country, placing a dam in one region may affect flood risks or water supply issues in another country. This could be a potential barrier to the development of PHS due to political sensitivity."

2.13 Research Gaps:

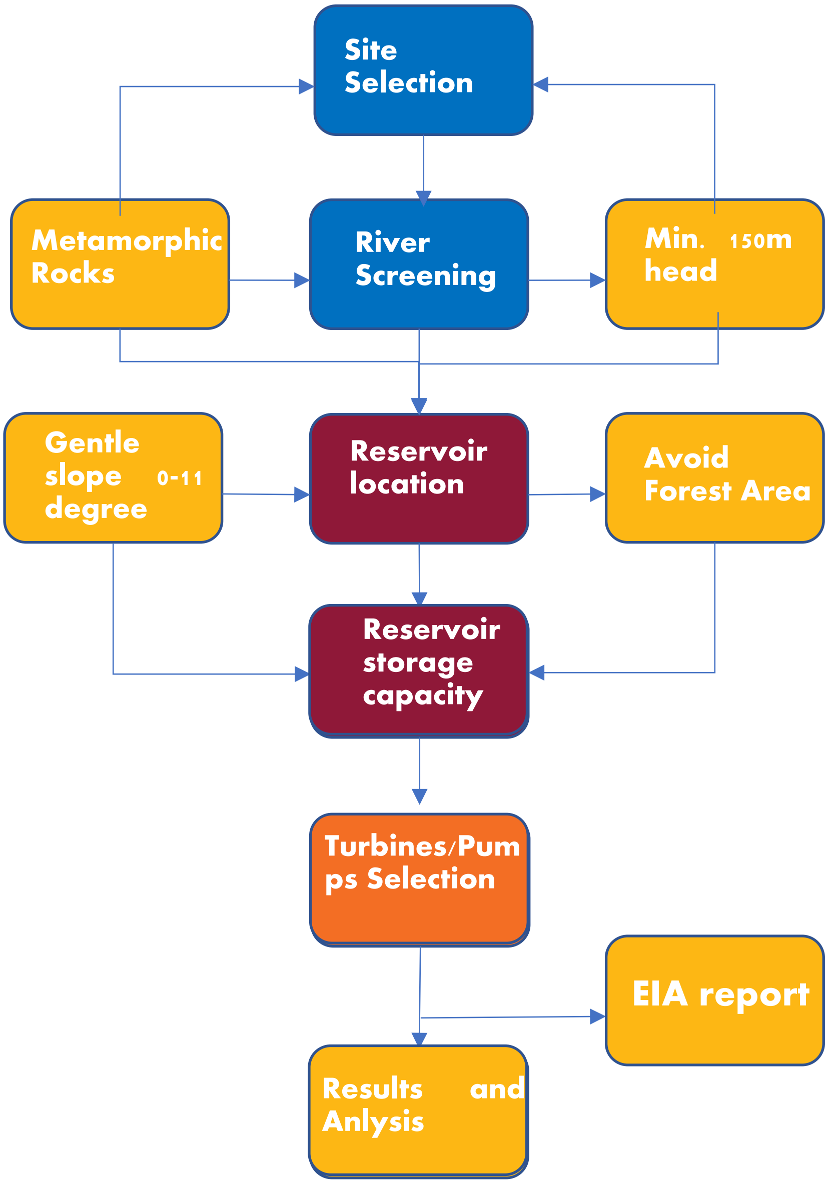
While reviewing the literature it came to the surface of the available literature that researchers have explored every aspect of pumped storage power plants or hydropower plants. We noticed that there still exist many research gaps, as framing a hypothesis is not difficult. As per the available research, we have found that researchers have left unexplored integration of aquaculture, agriculture, integrated farming, and industrial development with renewable energy sources - pumped storage hydropower plants, wind energy generation plants, and solar energy generation plants - for economic comparison to know the best suitable project for economic development and Gross Domestic Products (GDP) extension. However, the area that has remained unexplored may be studied in the Asian Continent, especially in South Asia, Central Asia, and other Asian regions, as well as separately in each country of the world. Also, the gap can be filled by conducting international research.

Moreover, according to the researchers Muhammad S. J., Tao M., Jakub J., and Muhammad Y. A. (2020), "Hybrid storage like PHS-battery is an emerging option to supplement the weakness of each other will be a promising field for future research."

CHAPTER 3

METHODOLOGY

3.1 Flowchart for Methodology:



Objectives	
1	
2	
3	
4	

3.2 Parameters for site selection:

The first step in the methodology includes describing and depicting the criteria directing the selection of the site for the PSHP. This necessitates a systematic understanding and analysis of factors impacting the suitability of the decided area, considering factors such as regional, geographical, hydrological, and infrastructure examination.

3.2.1 Geographic assessment:

The desired or most satisfactory material rock types for the reservoir would be igneous rocks such as granite; metamorphic rocks, such as quartzite; sedimentary rocks such as thick-bedded and flat-lying sandstones and limestones (Avery and Berlin, 1992). Also, a site where there is an active fault should never be considered (ASCE-USCOLD, 1967).

3.2.2 Topography:

The most suitable condition for this criterion is that the site's topography determines its surface layout, including its size and shape, as well as the ratio between its surface and volume, basically tells us the type of dam that needs to be constructed (Baban & Wan-Yusof, 2003). Ring dam structure is usually used at plateaus of low mountains (Görtz et al., 2022).

3.2.3 Hydrology and Hydraulics

The best suitable conditions for this criterion are that a dam must be built at a site where there is enough storage space for power requirements, irrigation, flood control, and water supply (Baban & Wan-Yusof, 2003) (ASCE-USCOLD, 1967).

3.2.4 Infrastructure assessment

Infrastructure assessment examines the existing resources and logistical encouragement available in the proximity of the proposed area. This consists on examination of the mobility infrastructure network, access to building development materials, and proximity to the urban areas.

A thorough infrastructure examination guarantee that the selected site facilitates seamless project accomplishment and minimize potential challenges logistically.

3.2.5 Technical Feasibility:

It comprises an exhaustive judging of the engineering and technological facets of the given Pumped Storage Hydropower plant. This includes an in-depth evaluation of plant design, equipment, and overall technical arrangement. The purpose is to ascertain the feasibility and efficiency of the selected technical solutions in gaining the desired energy retention and production output.

3.2.6 Environmental Feasibility:

The most suitable site would be if settlement relocation, flooding agricultural land, drowning wildlife and flooding areas with archaeological value are avoided (Thomas, 1976).

3.2.7 Social Feasibility:

Social feasibility assessment appraises the project's impacts on the regional community and wider societal variations. This includes an all-encompassing examination of social structures, cultural awareness, and prospect benefits or disruptions to the population. The main goal is to guarantee that the PSH project participates positively in the social fabric and connects with the desires of the regional population.

3.3 Reservoir Selection Criteria:

3.3.1 Hydraulic head:

The most suitable minimum hydraulic head requirement is 150m (Görtz et al., 2022b).

3.3.2 Hydraulic slope:

The most suitable minimum Hydraulic Slope requirement is 0.1 (Görtz et al., 2022b).

3.3.3 Slope in reservoir area:

This parameter is also used as a quality measure. For a detailed evaluation of the area, the best slope ranges are (0-5%, 0-7%, 0-10%) (Görtz et al., 2022).

3.3.4 Reservoir area:

The most suitable minimum reservoir area is 50,000m3 to have one million m3 capacity (Görtz et al., 2022).

3.3.5 Buffer distance:

To ensure that no suitable locations are missed, the buffer is set to the higher end (20 km) of the values of earlier research (Ghorbani et al., 2019; Lacal Arántegui et al., 2011).

3.3.6 Human presence:

The suitable criteria is that if a new construction is within 200 meters of an inhabited area, a new reservoir must be chosen (Lacal Arántegui et al., 2011).

3.3.7 Transport infrastructure:

The most suitable criteria is that if there is transportation infrastructure located within a 100-meter radius of a transformation site, the conversion to PHS (Pumped Hydro Storage) will be considered unfeasible (Lacal Arántegui et al., 2011)

3.3.8 Grid Infrastructure:

The most suitable requirement of this criteria is that if the transformation site doesn't have a hydro-dam, there must be good grid facilities within 20 km. If there isn't, the change to PHS won't be possible (Lacal Arántegui et al., 2011).

3.4 Demand:

The demand and usage of energy vary by season of the year and hour of the month. The demand and usage of energy cannot be ever the same it increase, or decreases based on the season. For instance, the demand for energy decreases and in summer increases. Also, energy is consumed more when people are at home and less consummated when they are at their workplace.

3.5 Design:

The design components of PSHP at Tarbela Dam in Pakistan consist of the following essential components.

3.5.1 The Higher Reservoir:

An immense and massive reservoir was instituted at a high altitude to collect water for the period of peak energy usage time. When the energy usage increases the water in this reservoir works to fulfill the energy needs.

3.5.2 downstream reservoir:

Another reservoir is the downstream reservoir which was installed at a lower summit to store and gather water admittance electricity is available, which will be pumped back to the upper reservoir in off-peak hours.

3.5.3 Turbines and Generators:

Superior effective turbines and generators are used to modify the potential energy of the stored water into electricity in periods of peak or high demand.

3.5.4 Pumps:

High productivity and capable are mandatory to transfer water from the higher reservoir to downstream reservoir on the period of low demand periods.

3.5.5 Penstocks and powerhouse:

Large pipes or conveyance are required to transfer water from downstream reservoir to upper reservoir. These are required to transfer water when the electricity demands are low. There is also a generating station or facility housing turbines, producers or generators and other necessary equipment for power generation.

3.6 Data collection:

3.6.1 Sources for Data Collection:

The research enterprises employ a multidimensional approach for data gathering, harnessing different sources to guarantee a wide-ranging understanding of the hydrological location at Tarbela Dam. Fundamental data consist of the water and power development authority WAPDA, from which a variety of hydrological data will be encouraged. This data grouping contains primary variables such as cloudburst, vaporization and desiccating, daily maximum and minimum temperature, sediment distributions recorded at various rain instruments, relative humidity percentages, and the complete infusion and emission of water at Tarbela Dam. The methodical documentation of these features daily is imperative to build a delicate understanding of the hydrological variations of the given PSH project location. Additionally, a Digital Elevation Model is a crucial dataset in judging the topographical delicate variations of the study location. The DEM is achieved by the Pakistan Meteorological Department PMD, primarily with a successive contingency plan consisting of the production of a google earth engine for a more particular 30 meter determination. This dual extended approach guarantees the availability of short topographical information required for correct project planning and design.

3.6.2 Usage:

The gathered hydro-logical data will be employed and leveraged to develop a thorough hydro logical model customized specifically for the suggested pumped storage hydro-power plants at Tarbela. This high-tech modeling endeavor is designed to support as a fundamental for strategic deliberation, project deciding, and future research enterprises. The wealth of hydro-logical data acquired and purchased from WAPDA, consisting of downpour, evaporation, daily temperature climaxes, sediment accumulation, relative steaminess, and water inflow and outflow, at Tarbela dam., will be consolidated and integrated datasets. These datasets form the framework of the hydro logical model, contributing a a variety of representation of the water mechanics in the study area. Subsequent utilization of this datasets go past the immediate requirements of PSHP. Configuration it as it as a very precious resource for wider hydrological research attempts. This dataset will be effectively fed into hydrological modeling software, which enables it to create the best model for the Pumped Storage Hydropower plants.

CHAPTER 4

RESULTS

4.1 Study Area:

The location of the study area is Tarbela Dam, mainly located in the Swabi district. The latitude and longitude of the area are 34.0875° N and 72.6990° E respectively. The reservoir capacity is 14.3 billion cubic meters and is fed by the Indus River. This site also has existing grid infrastructure which makes it highly suitable.

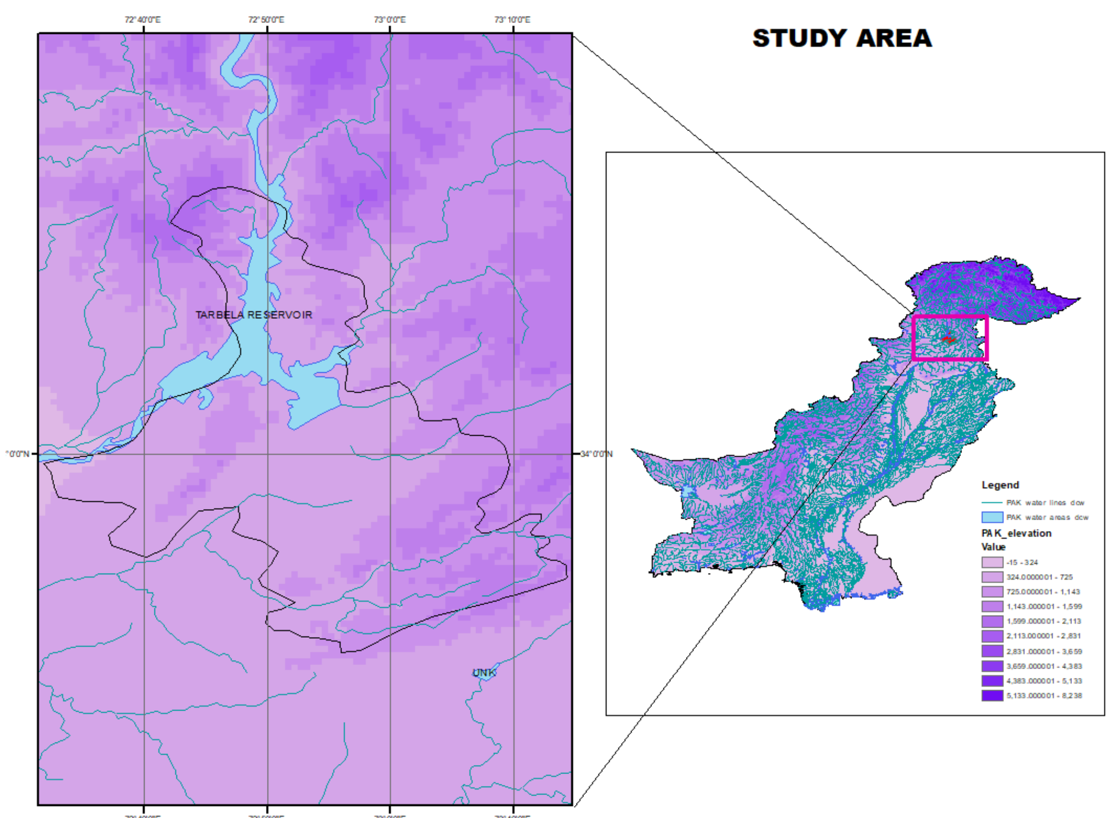


Fig. 4.1 Study Area

4.2 Feasibility analysis for site selection:

4.2.1 Hydrology and Hydraulics:

As per the criteria selected(Görtz et al., 2022) Our reservoir's hydraulic head is 480m. As per the criteria selected (Görtz et al., 2022), our reservoir has a hydraulic slope of around 0.4 which is well above the requirement. As per the criteria selected (Görtz et al., 2022), our average slope in the reservoir between two extreme points in the reservoir is around 13%.

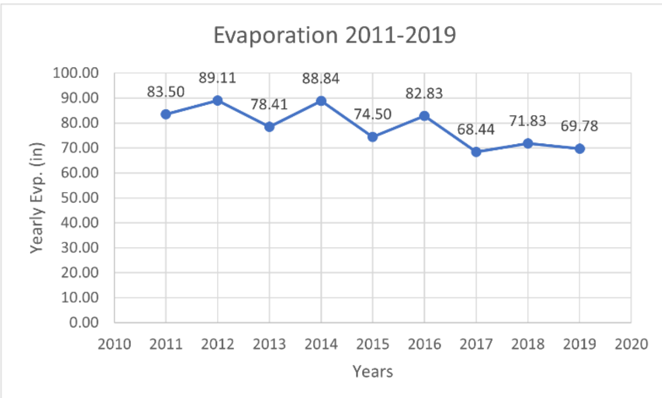


Fig.4.2 Evaporation 2011-2019

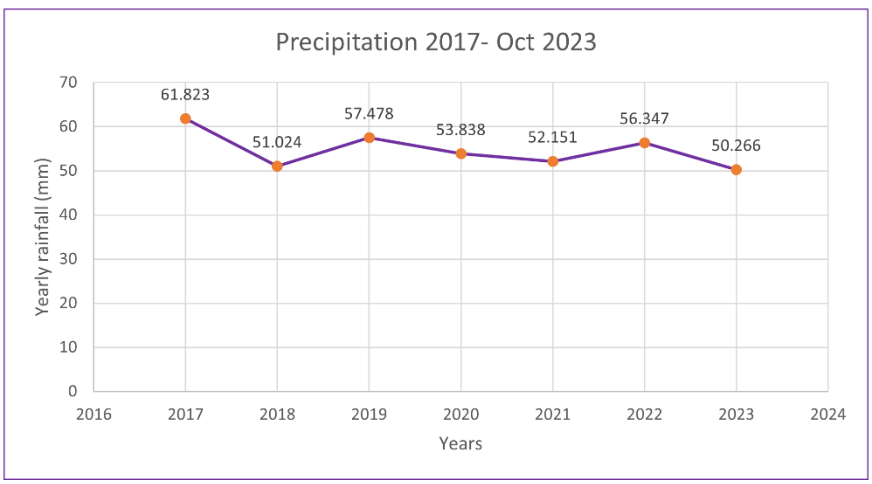


Fig. 4.3 Precipitation 2017-2023

~~1.~~ **4.2.2 Topography:**

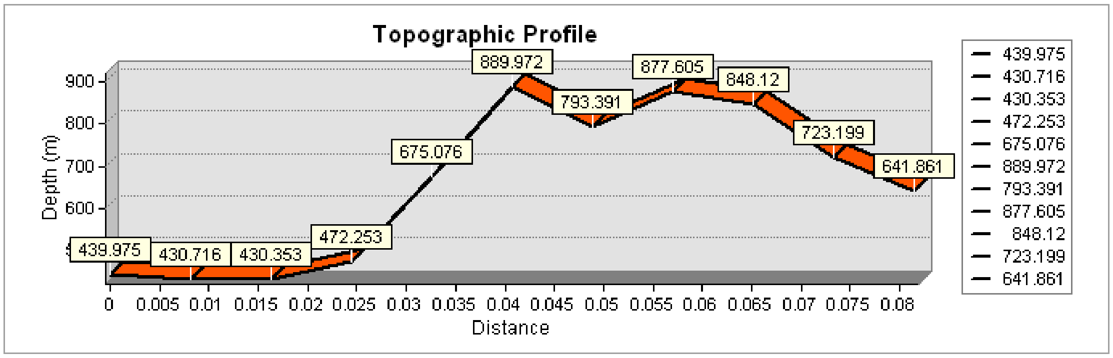


Fig. 4.4 Topographic Profile

4.2.3 Geology:

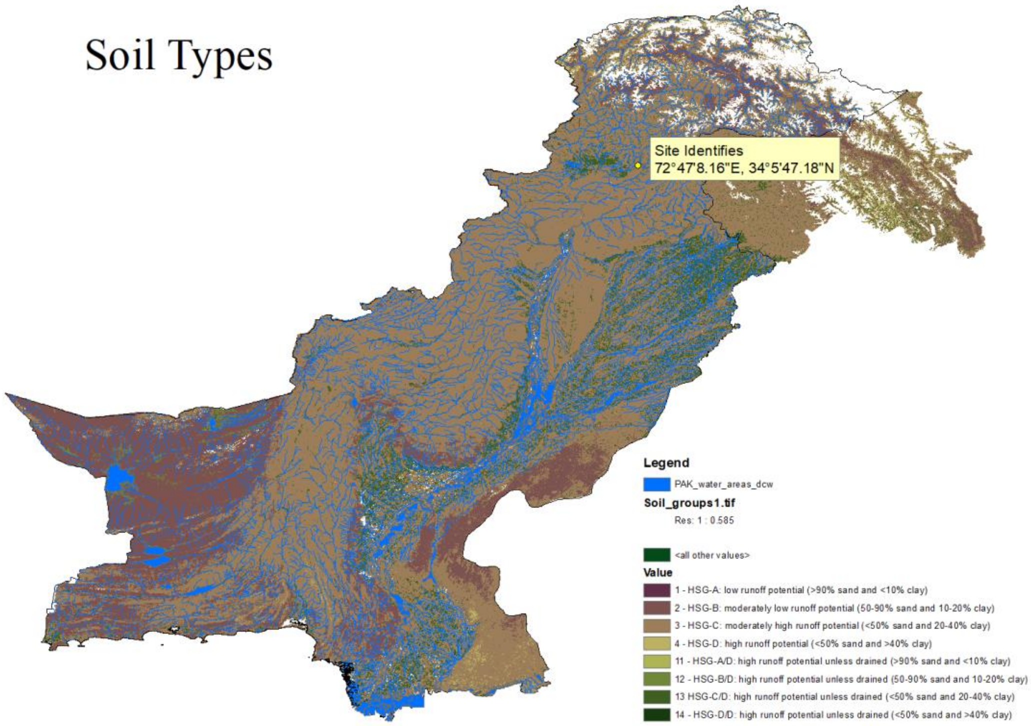


Fig. 4.5 Soil Types

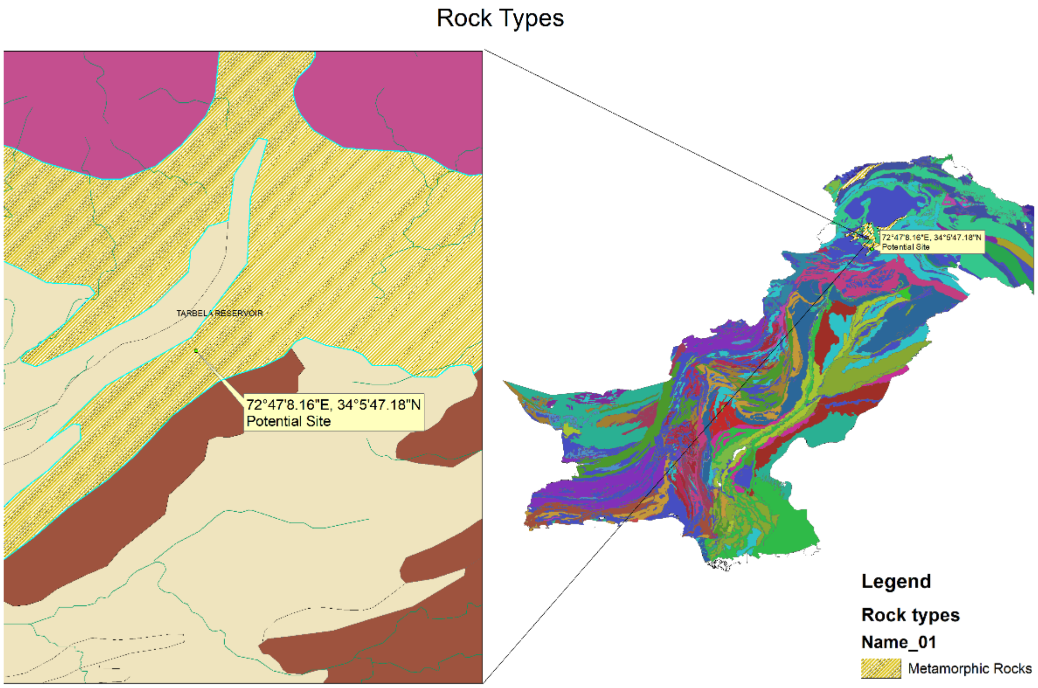


Fig. 4.6 (a) Rock Types

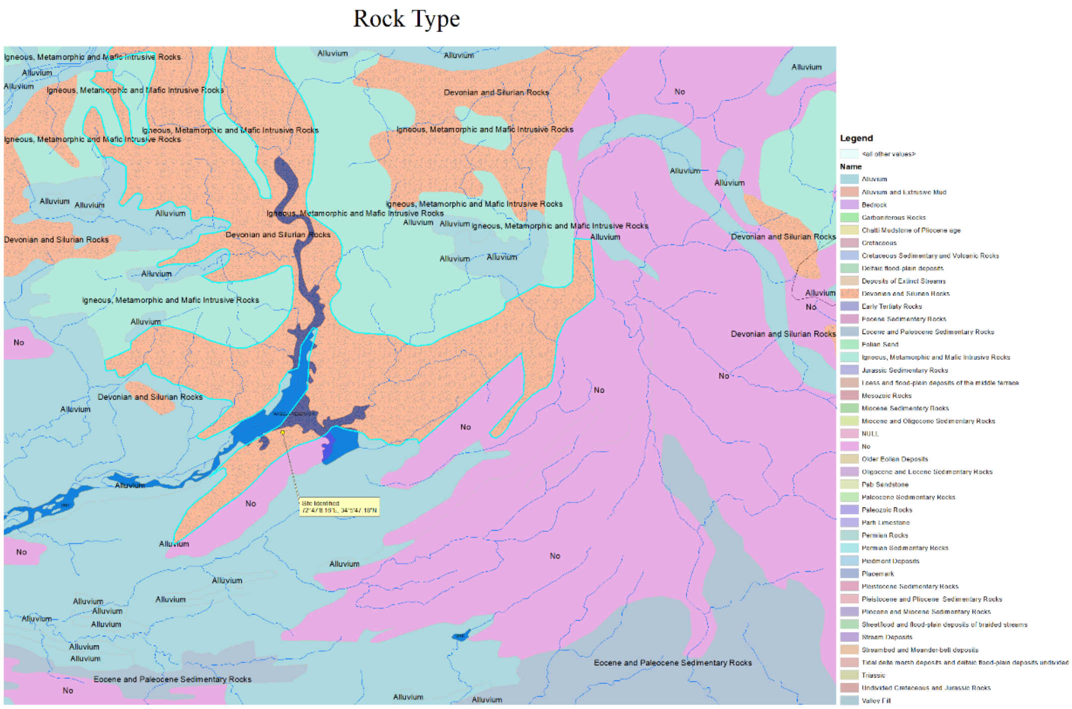


Fig. 4.6 (b) Rock Types at Tarbela

4.2.4 Potential Sites:

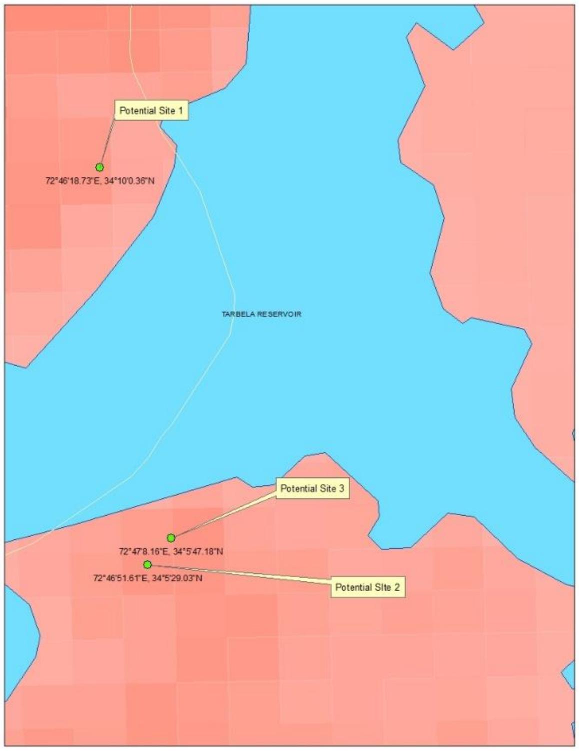


Fig. 4.7 Potential Sites for upper reservoir construction

Criteria:

1. Hydraulic head

2. Minimum hydraulic slope

3. Slope in the reservoir

4. Human presence

5.Transportation infrastructure

6. Grid infrastructure

4.3 Turbine selection for case study

For the selection of the appropriate turbine, hydraulic parameters such as the potential head H, volumetric flow rate Q, and the required power P should be known. Figure 1.1 illustrates the relation between these parameters for different turbines. In this case, the flow rate is set to Q = $40m^3/s$ and the head is H = 480m, and accordingly Francis turbine is the best option.

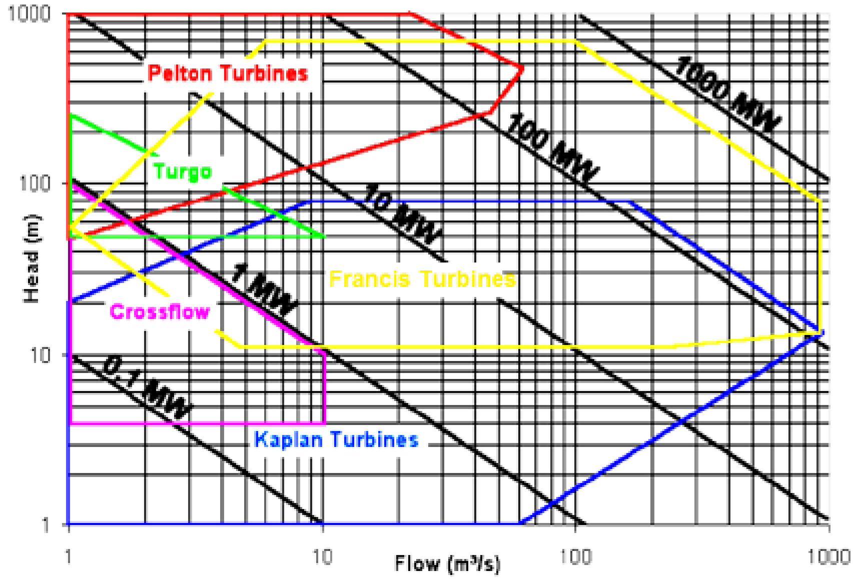


Fig 4.8 Power capacity P (MW) of the main hydraulic turbines with heads (m)

But this is not enough to make efficient decisions. Another parameter of rotational speed Ns is often used to decide on the best machine. It can be calculated by:

$$Ns = \frac{N \times P^{1/2}}{H^{5/4}} \qquad (4.1)$$

Where: H is the head in ft, P is the Power output in hp, and N is the speed in rev/min of the runner.In this work where we have H = 480m (dash ft), P = 150 MW (2.01×10^4 hp) which is typical for a unit of Francis turbine, then N(RPM) can be obtained from Fig 1.2 which is a selection chart for the Francis turbine that gives the relation between the head (m), flow (m^3/s), power (MW), penstock diameter (m) and runner speed N (RPM).

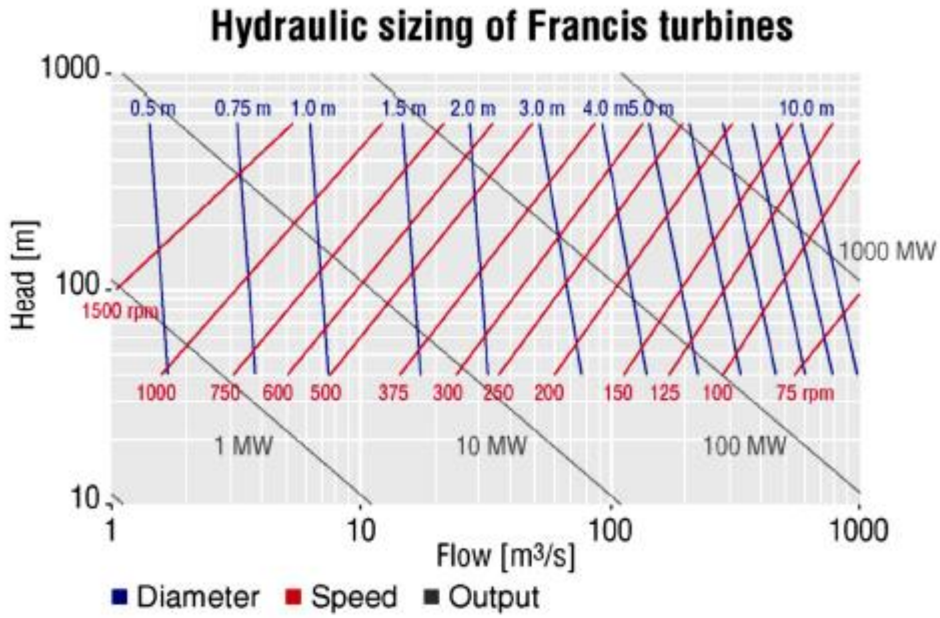


Fig. 4.9 Selection chart for Francis turbines (Meier, 2011)

After matching the values of H, P, and Q in the chart, the approximate inlet diameter is about 1.9m, and the runner speed is found to be 750 RPM. So, it is possible now to calculate the Ns by substituting values of N, P, H, and Q to eq 1.2.

$$Ns = \frac{1500 \times 25753.63^{\frac{1}{2}}}{1430.45^{\frac{5}{4}}}$$

Ns = 27.36

Figure 4.9 shows the ranges of specific speed appropriate to different types of turbines. As the value of our Ns falls in the category of Francis turbine, it proves that Francis will be appropriate for our project.

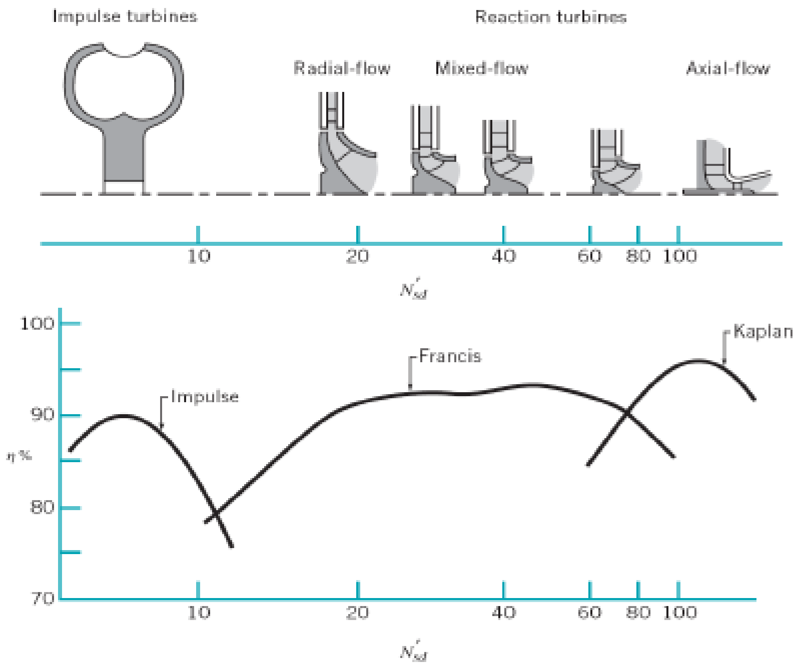


Fig. 4.10 Typical turbine cross sections and maximum efficiencies as a function of specific speed (‘’Turbines,’’ 2008.)

4.3.1 Storage system's components:

The storage system consists of four components: the upper reservoir, lower reservoir, powerhouse, and penstock.

4.3.1.1 Upper reservoir:

The site of the upper reservoir is selected as shown in figure 4.7. The total volume assumed is approximately 734000 m^3 which is appropriate regarding the available head and flow rate.

4.3.1.2 Lower reservoir:

The lower reservoir is the reservoir of the Tarbela dam which has a capacity of 14.3 billion cubic meters and a maximum depth of more than 450 ft.

4.3.1.3 Powerhouse:

The powerhouse would be located at the end of the penstock near the lower reservoir. The power output of the pump-turbine system is calculated by the following set of equations.

Rated power output from turbine

$Pt = \rho \times g \times Q \times H \times \eta_t$ (4.2)

Where,

Pt = power output of the turbine (W)

ρ = density of water (kg/m^3)

g = gravitational acceleration (m/s^2)

Q = flow rate of water (m^3/s)

H = head (m)

η_t = turbine efficiency

Calculating for flow rate of $5m^3/s$ we get,

Pt = 1000 x 9.8 x 40 x 480 x 0.898

Pt = 169141 kW

Pt = 169 MW

The storage capacity of the upper reservoir is 734000 m^3 so the time to generate the rated output continuously is 5.09 hours.

In pumping mode, the power required to pump the rated discharge into the upper reservoir is given by:

$P_P = \frac{\rho \times g \times h \times Q}{\eta p}$ (4.3)

Where,

Pp = power output of the pump (W)

ρ = density of water (kg/m^3)

g = gravitational acceleration (m/s^2)

Q = flow rate of water (m^3/s)

H = head (m)

η_p = pump efficiency

Substituting values we get,

$$Pp = \frac{1000 \times 9.8 \times 480 \times 40}{0.898}$$

Pp = 220670.4 kW

Pp = 220 MW

4.3.1.4 Penstock:

It is the pipe extending from the upper to the lower reservoir carrying the water. The total length of the pipe is approximately 1100 m. Therefore, the H/L ratio is 0.436 (480/1100) which is within acceptable range [2].

4.3.1.5 Pipe Diameter:

The optimized diameter for the penstock pipe is calculated by an iterative method.

The parameters for a single penstock pipe are as follows:

Flow rate in single pipe Q = 20 m^3

Length of the pipe L = 1100 m

Minimum allowable head loss hl = 25 m

Dynamic viscosity of water υ = 1.006 x 10^{-6}

Absolute roughness of pipe (commercial steel) ε = 0.0000457 m

Iteration 1:

Assume the value of friction factor f = 0.013, and calculate the assumed diameter of the pipe using Darcy Weisbach equation =

$$D = \left(\frac{8fLQ^2}{2n\,lg\,\pi^2}\right)^{1/5} \qquad (4.4)$$

Substituting values we get,

D = 1.8001 m

From this value of diameter, we find the flow conditions.

Q = 20 m^3

A = π/4 x D^2 = 2.545 m^2

v = Q/A = 7.857 m/s

Re = vD/ v = 1.41 x 10^7

Using these flow conditions and assumed diameter find a new value of friction factor using Jain equation.

$$f = \frac{1.325}{\left[ln(\frac{e}{3.7D}+\frac{5.74}{R_e^{0.9}}\right]^2} \qquad (4.5)$$

f_1 = 0.011962

the percentage difference between assumed f and new f is found to be 7.9%. iterations are performed again till the percentage difference is lesser than 1, which means the value of diameter is accurate. Hence diameter is calculated again using the f_1.

D = 1.77 m

Determine flow conditions =

Q = 20 m^3

A = 2.4618 m^2

v = 8.123 m/s

Re = 1.44 x 10^7

Using these conditions and new D find f_2 and its percentage difference from f_1.

f_2 = 0.01192

% difference = 0.3

Since the difference is below 1, we have found the final value of f, and from this find the final D and flow conditions.

D = 1.76 m

Q = 20 m^3

A = 2.45 m^2

v = 8.133 m/s

Re = 1.439 x 10^7

This shows that two penstocks of diameter 1.76 m would be needed to accommodate a flow rate of 20 m^3 to charge and discharge the reservoir in 5.09 hours.

Environmental impact assessment results:

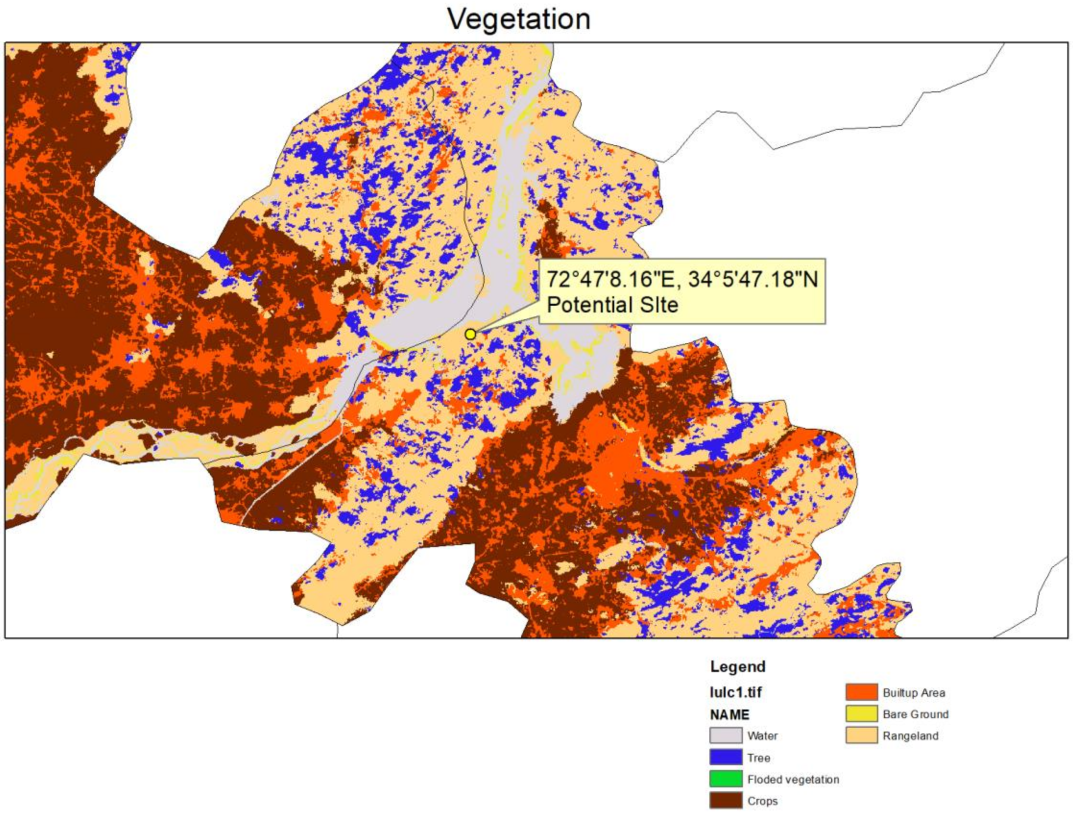


Fig. 4.11 Vegetation

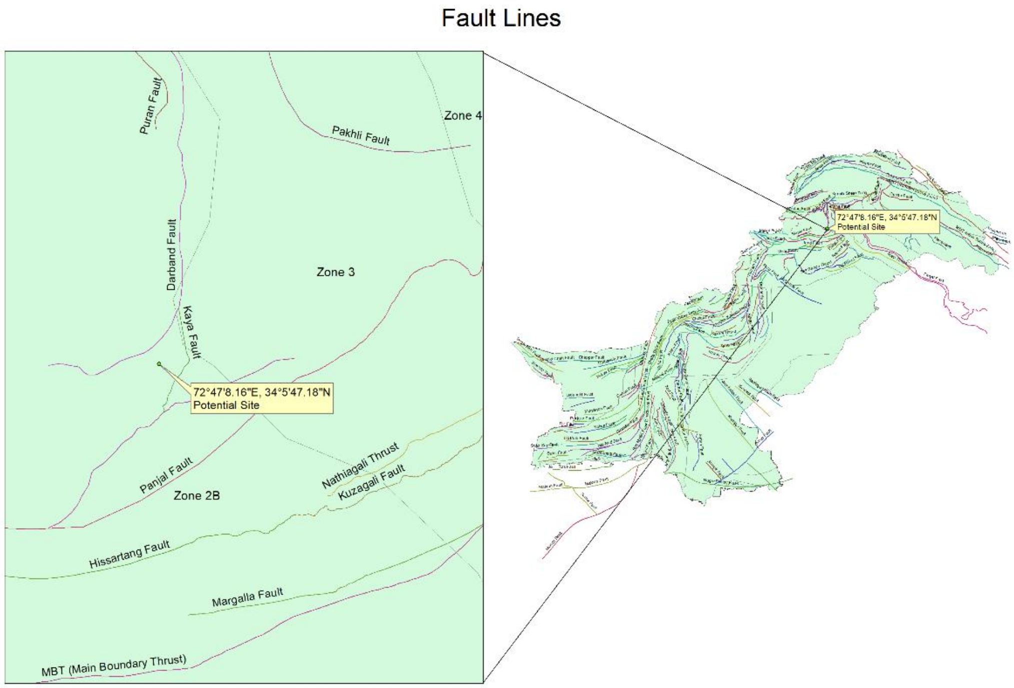


Fig. 4.12 Fault lines at selected site

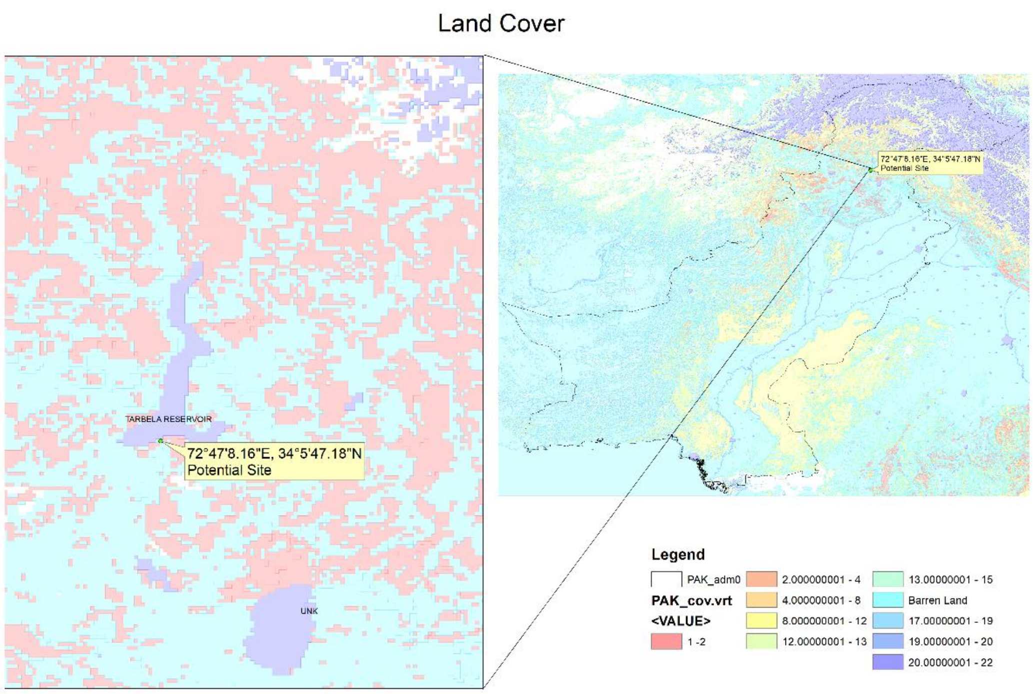


Fig. 4.13 Land use

As per the criteria selected (Lacal Arántegui et al., 2011), our site is well away from the inhabitant area by around 500m.

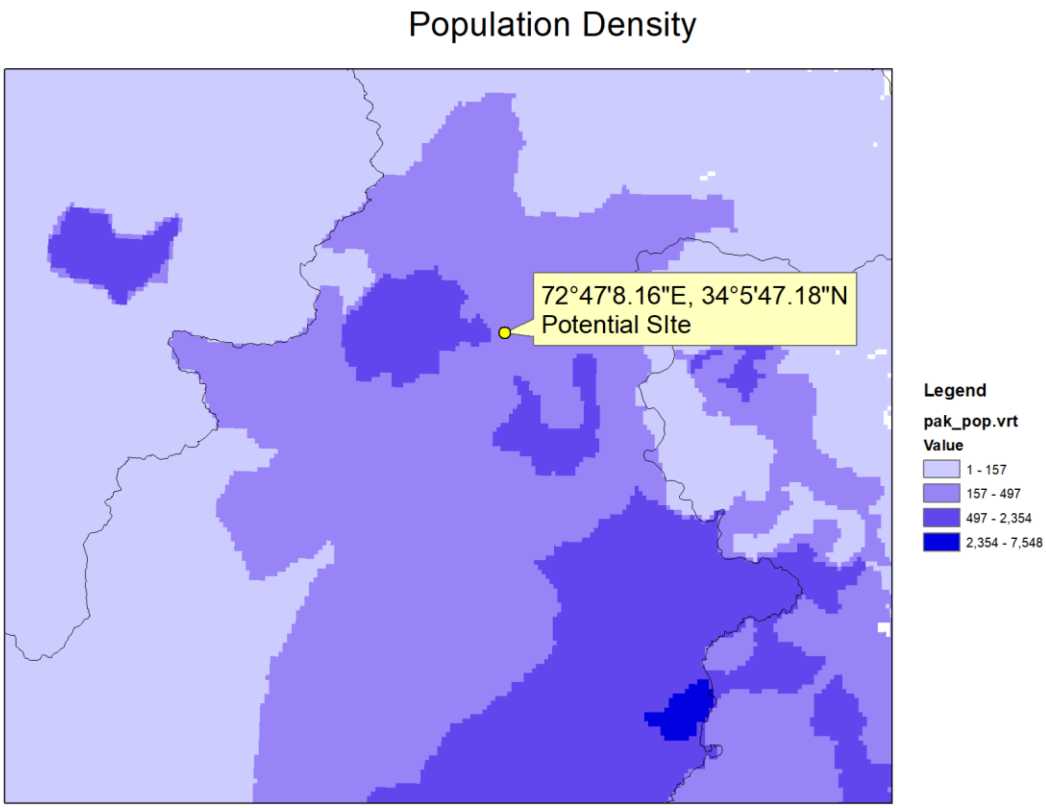


Fig. 4.14 (a) Population density around selected site

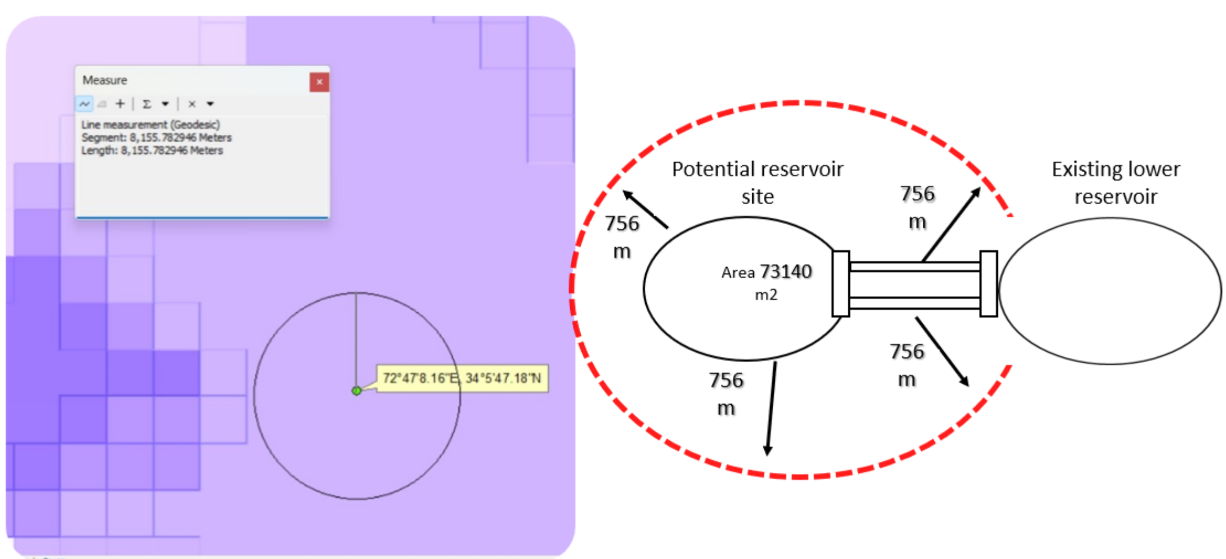


Fig. 4.14 (b) Population Density criteria and results

Cost-benefit analysis:

The cost-benefit analysis of PSHP is done based on the numerical metrics. This analysis is done to express the impact and services of a plant in physical units that can be monetized. In the case of PSHP, the quantity of electricity consumed and produced in kWh in peak and off-peak hours respectively, is multiplied by the price of electricity per kWh.

In this case, the volume of the upper reservoir was taken as 80000 m^3 and the flow rate is 5 m^3/s hence the pumping time is calculated by dividing the volume by the flow rate. The time comes out to be approximately 4.44 hrs. So, the pump energy can be found as:

$E_P = P_P x t$ (5.1)

Where,

Ep = Pump energy

Pp = Pump power

t = time

Ep = 105844 kWh

Similarly, turbine energy can be found,

Et = 85353.1 kWh

Knowing the peak and off-peak prices of electricity we can find the difference between the cost of pumping and generation of electricity.

CATEGORY	PEAK PRICE (Rs/kWh)	OFF-PEAK PRICE (Rs/kWh)
RESIDENTIAL	24.33	18.01
COMMERCIAL	24.94	18.97
AGRICULTURE	21.94	14.69
INDUSTRIAL	22.12	16.22

Table 4.1 NEPRA Tariffs for 2022

Peak price for residential = 85353.1 x 24.33 = Rs. 2076641.02

Off-peak price for residential = 105844 x 18.01 = Rs. 190625

Difference = 2076641.02 – 190625 = Rs. 170389

This shows that the electricity produced is sold at a higher rate at peak hours, than the amount used to produce it at off-peak hours resulting in a daily net profit of about Rs 1.7 lacs.

CHAPTER 5

5.1 CONCLUSION

Establishing a Pumped Storage Hydropower Plant (PSHP) at Tarbela Dam is a significant development for Pakistan's energy industry. It addresses important issues related to energy security by utilizing renewable resources, which decreases dependency on fossil fuels and lessens the negative effects of climate change J. Tao & M. Waqas (2022). The chosen location satisfies all requirements for a successful PSHP, guaranteeing maximum performance and sustainability, as shown by the feasibility study and design has several benefits was studied by J. A. Mouawad, A. H. Al-Mohammed, (2021) The financial viability of this endeavor is demonstrated by the fact that integrating the PSHP into the national grid will improve power supply stability and reliability was studied by many researchers Feng, Chang, Ding, & Mai (2020) during periods of peak demand while also yielding considerable economic benefits due to differential pricing between peak and off-peak hours as per the IHA report. Also, the initiative is in line with important Sustainable Development Goals (SDGs), including expanding sustainable industrialization (SDG 8), building resilient infrastructure (SDG 9), and encouraging affordable and clean energy (SDG 7). The project not only promises financial benefits but also aligns with Sustainable Development Goals by promoting clean energy, infrastructure development, and environmental sustainability. The PSHP project has significant environmental benefits since it lowers CO2 emissions, supports international efforts to mitigate climate change, and improves the management of water resources, which is essential for meeting both agricultural and energy needs studied by Punys, Baubly, & Steller, J. (2013). In summary, the PSHP at Tarbela Dam is a ground-breaking project that establishes a standard for Pakistan's next renewable energy projects. It also serves as an example of how creative energy solutions can promote environmental sustainability, secure energy security, and spur economic progress. Future suggestions for improving overall efficiency and operational performance for a more resilient and sustainable energy infrastructure include adding variable renewable energies (VREs) like wind power to further optimize energy storage and increasing reservoir capacities to support additional PSHP projects. By implementing these tactics, the PSHP will be able to effectively support Pakistan's energy sustainability and security. As a result of this project's success, Pakistan may become the region's leader in the use of renewable energy sources and the management of water resource Establishing a Pumped Storage Hydropower Plant (PSHP) at Tarbela Dam is a significant development for Pakistan's energy industry. It addresses important issues related to energy security by utilizing renewable resources, which decreases dependency on fossil fuels and lessens the negative effects of climate change J. Tao & M. Waqas (2022). The chosen location satisfies all requirements for a successful PSHP, guaranteeing maximum performance and sustainability, as shown by the feasibility study and design has several benefits was studied by J. A. Mouawad, A. H. Al-Mohammed, (2021) The financial viability of this endeavor is demonstrated by the fact that integrating the PSHP into the national grid will improve power supply stability and reliability was studied by many researchers Feng, Chang, Ding, & Mai (2020) during periods of peak demand while also yielding considerable economic benefits due to differential pricing between peak and off-peak hours as per the IHA report. Also, the initiative is in line with important Sustainable Development Goals (SDGs), including expanding sustainable industrialization (SDG 8), building resilient infrastructure (SDG 9), and encouraging affordable and clean energy (SDG 7). The project not only promises financial benefits but also aligns with Sustainable Development Goals by promoting clean energy, infrastructure development, and environmental sustainability. The PSHP project has significant environmental benefits since it lowers CO_2 emissions, supports international efforts to mitigate climate change, and improves the management of water resources, which is essential for meeting both agricultural and energy needs studied by Punys, Baubly, & Steller, J. (2013). In summary, the PSHP at Tarbela Dam is a ground-breaking project that establishes a standard for Pakistan's next renewable energy projects. It also serves as an example of how creative energy solutions can promote environmental sustainability, secure energy security, and spur economic progress. Future suggestions for improving overall efficiency and operational performance for a more resilient and sustainable energy infrastructure include adding variable renewable energies (VREs) like wind power to further optimize energy storage and increasing reservoir capacities to support additional PSHP projects. By implementing these tactics, the PSHP will be able to effectively support Pakistan's energy sustainability and security. As a result of this project's success, Pakistan may become the region's leader in the use of renewable energy sources and the management of water resources.

References:

Khan, M., & Ahmad, S. (2023). Renewable energy adoption in Pakistan: Current status and future prospects. Journal of Energy Policy and Planning, 45(3), 123-136.

Institute of Strategic Studies Islamabad. (2024). Energy capacity and demand analysis: May to August 2024. Strategic Energy Reports, 12(2), 98-105.

Ali, R., & Hussain, N. (2022). Impact of energy shortages on economic activities in Pakistan. Economic Review of Pakistan, 37(4), 241-256.

Malik, A., & Shah, P. (2021). Pumped storage hydropower: A sustainable solution for renewable energy integration. International Journal of Renewable Energy Systems, 29(1), 85-101

Siddiqui, T., & Farooq, Z. (2020). The multifunctional role of pumped storage hydropower plants in flood prevention and water resource management. Journal of Hydropower and Environmental Studies, 22(3), 200-215.

Baban, S. M. J., & Wan-Yusof, K. (2003). Modelling Optimum Sites for Locating Reservoirs in Tropical Environments. In *Water Resources Management* (Vol. 17). http://nativenet.uthscsa.edu/archive/nl/9409/0019.html

Ghorbani, N., Makian, H., & Breyer, C. (2019). A GIS-based method to identify potential sites for pumped hydro energy storage - Case of Iran. *Energy*, *169*, 854–867. https://doi.org/10.1016/j.energy.2018.12.073

Görtz, J., Aouad, M., Wieprecht, S., & Terheiden, K. (2022). Assessment of pumped hydropower energy storage potential along rivers and shorelines. *Renewable and Sustainable Energy Reviews*, *165*. https://doi.org/10.1016/j.rser.2021.112027

Lacal Arántegui, Roberto., Leahy, Paul., Fitzgerald, Niall., & European Commission. Joint Research Centre. Institute for Energy and Transport. (2011). *Pumped-hydro energy storage potential for transformation from single dams (Analysis of the potential for transformation of non-hydropower dams and reservoir hydropower schemes into pumping hydropower schemes in Europe).* Publications Office.

Akour, S. N., & Al-Garalleh, A. A. (2019). Candidate Sites for Pumped Hydroelectric Energy Storage System in Jordan. *Modern Applied Science*, *13*(2), 116. https://doi.org/10.5539/mas.v13n2p116

Alic, A., Schäffer, L. E., Toffolon, M., & Trovato, V. (2023). Optimal price-based scheduling of a pumped-storage hydropower plant considering environmental constraints. *Energy Systems*. https://doi.org/10.1007/s12667-023-00614-y

Anwar, Z. (2008). *Zahid Anwar Margalla Papers*.

Baban, S. M. J., & Wan-Yusof, K. (2003). Modelling Optimum Sites for Locating Reservoirs in Tropical Environments. In *Water Resources Management* (Vol. 17). http://nativenet.uthscsa.edu/archive/nl/9409/0019.html

Badr, A., Li, Z., & El-Dakhakhni, W. (2023). Dam System and Reservoir Operational Safety: A Meta-Research. In *Water (Switzerland)* (Vol. 15, Issue 19). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/w15193427

Görtz, J., Aouad, M., Wieprecht, S., & Terheiden, K. (2022). Assessment of pumped hydropower energy storage potential along rivers and shorelines. *Renewable and Sustainable Energy Reviews*, *165*. https://doi.org/10.1016/j.rser.2021.112027

Kok, M., Hogeweg, M., & De Jonge, T. (1996). *Modelling floods and damage assessment using GIS* (Issue 235). IAHS Publ. https://www.researchgate.net/publication/265919679

Lacal Arántegui, Roberto., Leahy, Paul., Fitzgerald, Niall., & European Commission. Joint Research Centre. Institute for Energy and Transport. (2011). *Pumped-hydro energy storage potential for transformation from single dams (Analysis of the potential for transformation of non-hydropower dams and reservoir hydropower schemes into pumping hydropower schemes in Europe).* Publications Office.

Manzoor, S., Ahmed Usmani, R., & Asim, M. (2021). Renewable Energy and Energy Crises in Pakistan. In *PSYCHOLOGY AND EDUCATION* (Vol. 58, Issue 2). www.psychologyandeducation.net