COST-BENEFIT ANALYSIS OF LARGE DAMS IN PAKISTAN

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بسم الله الرحمن الرحيم

DEDICATED TO OUR BELOVED AND RESPECTED PARENTS, TEACHERS AND FAMILIES.

This is to certify that the research work of the

BE Civil Engineering Project titled

COST-BENEFIT ANALYSIS OF LARGE DAMS IN PAKISTAN

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(Photo Source: DAWN.com)

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and Syndicate

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List of Abbreviations

CFS-Cubic Feet per Second

IBIS-Indus Basin Irrigation System

HEP-Hydro Electricity Power

MAF -Million Acre Feet

MW-Mega Watt

NFPP-National Flood Protection Plan

WAPDA-Water and Power Development Authority

WCD-World Commission on Dams

Abstract

Water scarcity is a pressing issue and one for which the severity will only increase with every passing day for many countries globally. Pakistan is amongst the countries that has seen a drastic reduction in the availability of freshwater per person. From 1950-2000, Pakistan's availability of freshwater per person reduced by 77%. At the moment, the value is alarmingly lesser than the critical limit of 1000 cubic metres per person per annum. Water conservation and sustainable solutions for gaining the most out of every drop of water are essential to ease the situation.

Amongst some of the more feasible and necessary measures, having large dams outweighs the rest. It has been over 35 years since the multi-purpose Khanpur dam was constructed in 1984. Likewise, the major dams that support the backbone of the economy till now-Tarbela and Mangla date back to 1976 and 1965. Even today, the agrarian economy of Pakistan reaps humongous benefit from these two dams. It is unfortunate that no other large dam has been brought to operation since then; consequently, the water scenario for Pakistan only deteriorates.

This study takes into the account the functions of a large dam in Pakistan for highlighting the benefits we derive from them. The three primary functions of power generation, water regulation for agriculture and flood mitigation were used for calculations. Owing to its significance, the cost-benefit analysis is carried on Tarbela dam in three domains mentioned above. The costs incurred by the large dams were placed on one side and the benefits derived were calculated and placed on the other side. As expected, the benefits largely outweighed the costs of the dam. The analysis shows that if all the annual profits generated by Tarbela in all three areas are considered at present worth, it recovers all its cost within three and a half years only.

The analysis puts light on the further profits that the large dam will provide and lead to pave path for the economic prosperity of Pakistan. The clear results of the analysis strongly support the construction of the Diamer Bhasha dam and evidently do not leave room for much argument against large dams.

CHAPTER 1

INTRODUCTION

1. Introduction

1.1 Background

Water is an indispensable resource for the development and sustainable growth of a country's economy. Moreover, water is the component of life required for the very existence of mankind and all beings. The water availability conditions in Pakistan are deteriorating by every passing day. For an agrarian country such as Pakistan in which the economy is dependent primarily on a single source, it becomes crucial in ensuring the effective utilization of water resources (Ali, Baloch, & Masood, 2017).

According to water management authorities, Pakistan will face a shortage of 31MAF by 2025 which was only 11MAF in 2004. In just 20 years we would have increased our water shortage by 3 times instead of reducing it (Ten Year Perspective Development Plan 2001-11, 2000). This water stress is not going to ease any soon. The ever-growing demand resulting from the rapidly growing population and climate changes are major reasons. Likewise, the increase in urbanisation and reduction in overall water quality and management techniques add to the problem (Ali, Baloch, & Masood, 2017).

According to international standards if a country's per capita availability is less than 1700 meter cube, it falls into the water stress category and its the sign of an alarming situation. Furthermore, if it drops below 1000 meter cubic then it is a real alarming situation for the stakeholder to take some effective steps and this situation is water scarcity. If we discuss Pakistan particularly, we will notice that Pakistan has reached the list of countries facing water scarcity and its water availability per capita is declining at an enormous rate. By the end of 2025 we have 659 cubic meter per capita available which is even lower than the dangerous limit (Draft State of Enviorment Report, 2005).

To allow the efficient integration of the groundwater resources, dams are required. Dams will not just be used as storage structures and water regulation but will also be used extensively for flood routing and power generation (Tariq & Giesen, 2012). Even though large dams are the urgent need of the hour, there are a few arguments that go against the building of these. They just point out the social-environmental concerns of dam construction. This repot will put emphasis on the constructive aspects in which dams are to be used in the country.

1.2 Problem Statement

For much time now, there have been raising concerns now regarding the huge costs incurred in the construction of large dams. Many think that this is not an investment that pays off in the long term. The unnecessary economic arguments are presented mostly even more strongly than the reasonable social and environmental ones. In this research we find whether the construction of large dams bring more benefits or more undesirable consequences to Pakistan in the long term?

This research analyses the affirmative aspects of large dams by utilising the example of the world's largest earth filled dam-Tarbela dam. It presents these aspects which outweigh the few adverse consequences that may arise.

1.3 Aims and Objectives

Aim:

To find and elaborate the long term cost-benefit of building a large dam will have in the economy by utilising the example of Tarbela Dam.

Objectives:

- Finding out the damages secured due to the flood routing made possible at Indus due to Tarbela Dam.
- Finding out the ease that Tarbela Dam has provided in power generation and calculating the cost per unit of the power.
- Finding out the cost benefits in crop production due to water regulated through Tarbela Dam.

1.4 The Methodology of the Study

Analysis has been conducted on the performance of the previous large dam-Tarbela situated on the river Indus. Data for over ten years has been considered for this research and the work done is distributed in three main categories:

Flood mitigation, irrigation and agriculture and power generation.

The cost of the benefits derived from these sectors was calculated and compared with the costs of the dam construction itself. Along with this, the costs to be incurred in a scenario where a dam is not present were also discussed to conclude better results. This part was analysed using the standard water pumps.

CHAPTER 2

LITERATURE REVIEW

2. Literature Review

2.1 Introduction

As the world population is increasing at a tremendous rate with limited resources that will lead the world to the next world war. Water is one of the prime sources for living and constitutes 97% of the earth, but the availability of freshwater which is usable for humans and all other creations is limited recourse. Freshwater accounts for 2.5-2.75% only, including a small percentage of 1.75–2% which is frozen in the form of glaciers, and snow, 0.5–0.75% comprises as groundwater and the moisture in soil, while a meagre value of less than 0.01% of the 3% is found in lakes, rivers, and swamps.

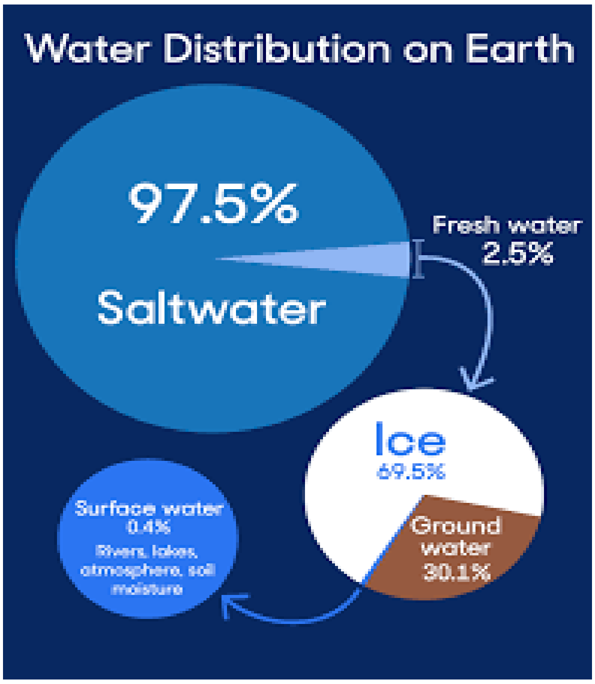


Figure 1 Water Distribution on Earth

Source: Newsela.com

2.1.1 Storage Capacity of Water for Different Countries

Some countries have enough water storage capacity for their entire population, but some are laying in water scare lists. The storage capacity of water in the world is not equally distributed, the following graph compares the water condition of Pakistan with the rest of the world.

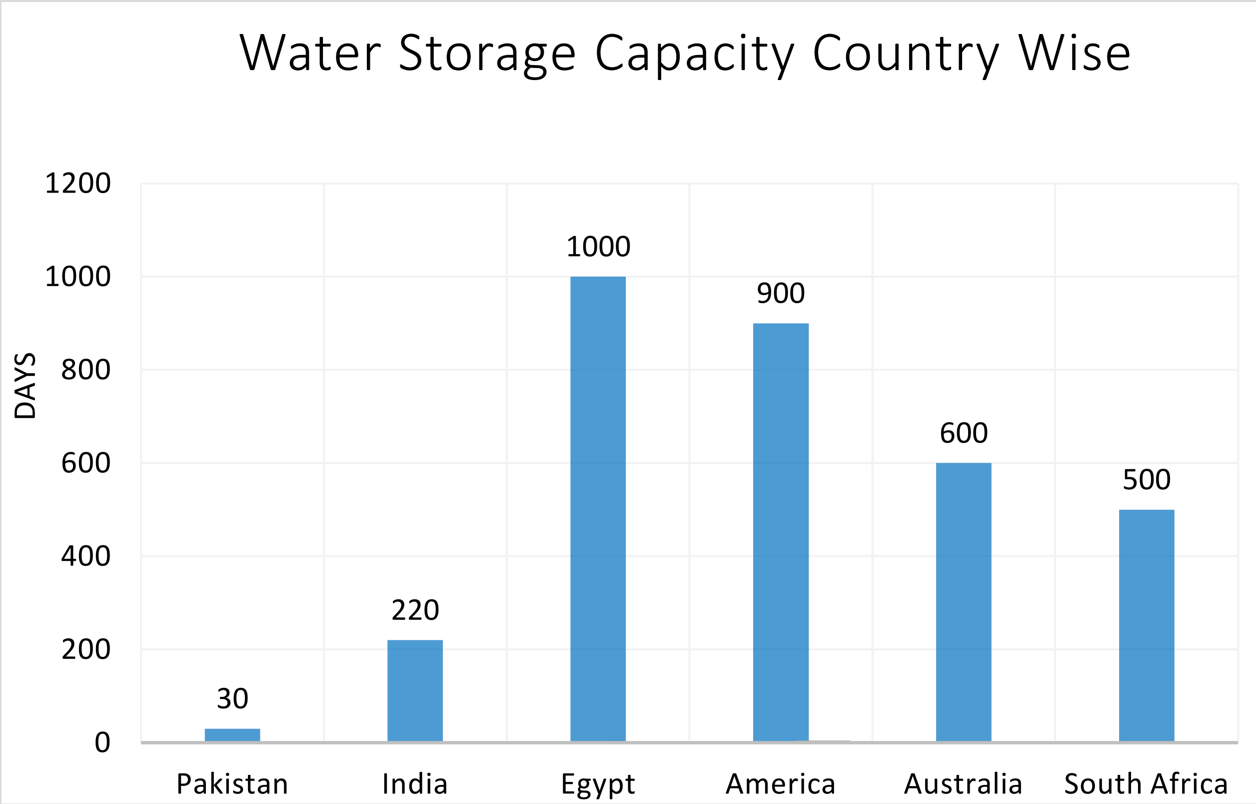


Figure 2 Water storage capacity of different countries

(Source: The Nation-2013)

Annual Losses of Pakistan to Arabian Sea

Pakistan's government is more concerned regarding the building of dams by India instead of making their own. Currently Pakistan is wasting about 30 MAF of water into Arabian sea as a waste product. This 30 MAF is equals to ten trillion gallons which is easily more than enough for the population of 500 million people. By looking at water scenario of Pakistan we can say that water availability and supply is not a problem, but its efficient use is a major question mark to our governments.. (Ilyas, 2018)

Water Availability per Capita

Per capita availability of water in Pakistan is constantly decreasing sine our independence. From 5300 cubic meter, we are currently at 659 cubic meters. We have made our way to become a water scarce country from being a water stressed country.

The 2025 has been marked critical limit for Pakistan, if we do not increase our water storage capacity then it will be most alarming situation

Trends of water availability through many decades is shown in the table (Draft State of Enviorment Report, 2005).

Year	Population (Million)	Per Capita Availability (cubic meter)
1951	34	5300
1961	46	3950
1971	65	2700
1981	84	2100
1991	115	1600
2000	148	1200
2013	207	850
2025	267	659

Water Stress > 1700m^3 Water Scarcity > 1000m^3

Table 1 Per Capita Water Availability and Population

(Source: Draft State of Environment Report 2005)

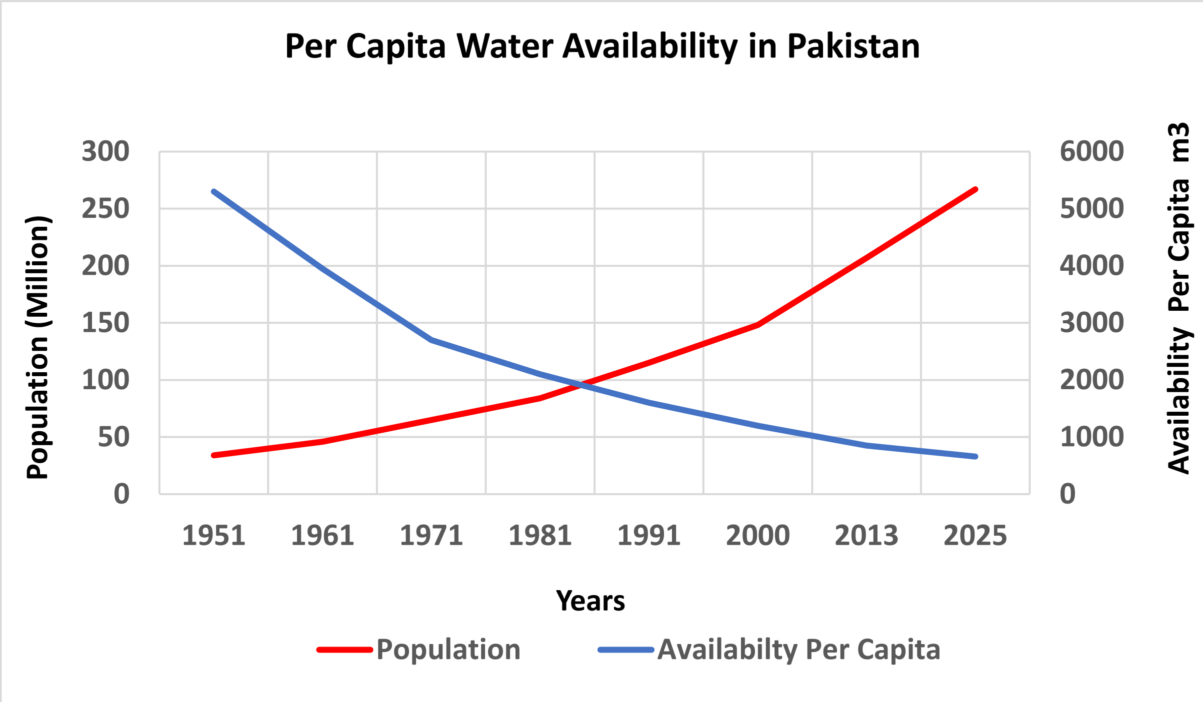


Figure 3 Graph of per capita water availability and population

If proper consideration was not made to this issue, then it will push the world toward crises. The most feasible and long term solution to this is to increase the storage capacity of freshwater, which can be done through the construction of large water reservoirs in the form of dams or increasing groundwater tables and other such methods.

The Indus basin irrigation system consists of three large dams, 85 small dams, 19 barrages and 12 inter river link canal along with 45 canal commands (Mountjoy, 2010). Pakistan has extensive network of canals and is considered best in the world. Pakistan line irrigation diagram for all the available surface water with their respective discharges have been shown below.

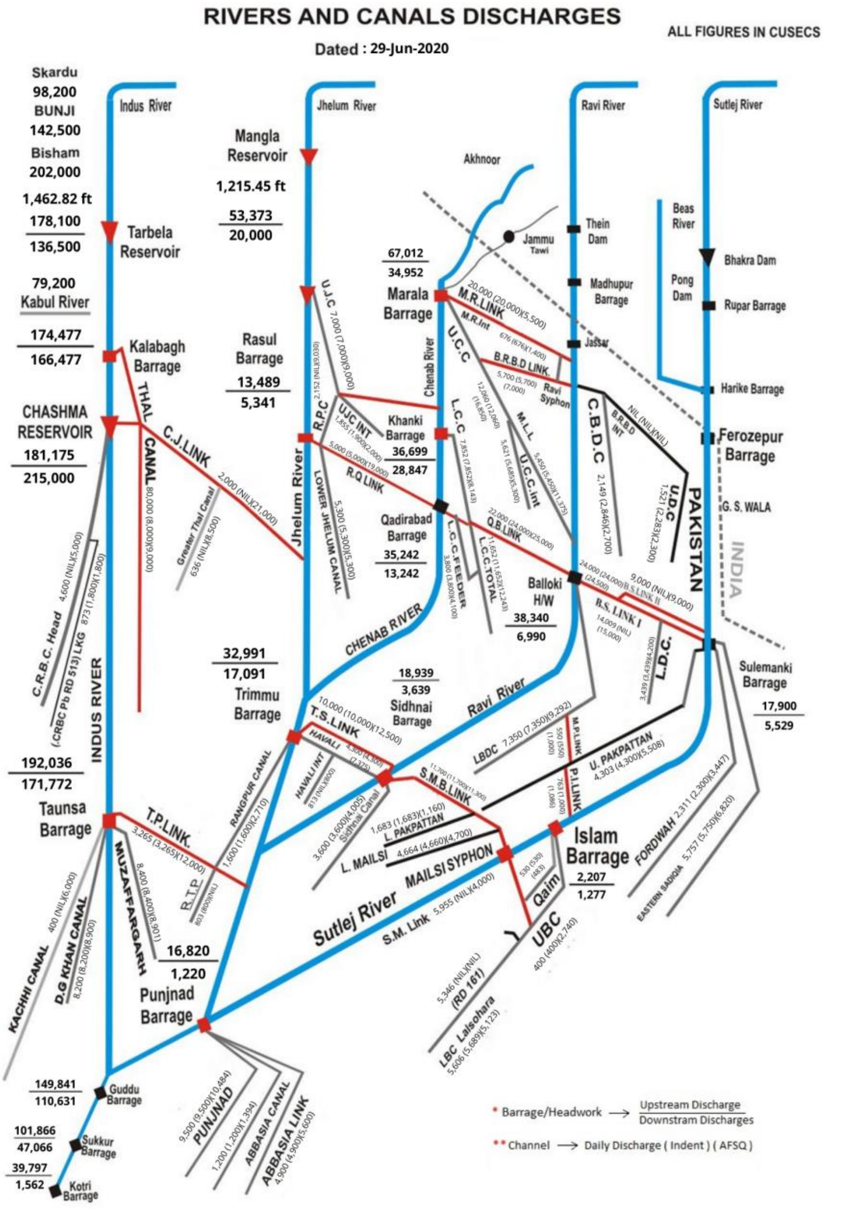


Figure 4 Irrigation network Pakistan

Pakistan`s Water Scenario

Year	2004	2025
Availability	104 MAF	104 MAF
Requirement (including drinking water)	115 MAF	135 MAF
Overall Shortfall	11 MAF	31 MAF

Table 2 Water Requirement and Shortfall 2004 and 2025

We need both short-term as well as long-term policies and plans to conserve and manage water before it runs out. Short term actions include better water management and causing public awareness regarding not to waste water in each household. However, thinking of long-term plans, dams need to be constructed but only after extensive strategic and bold decisions keeping in mind the matters of national interest.

2.2 Effects of Dams

Comparison Between Small and Large Dams

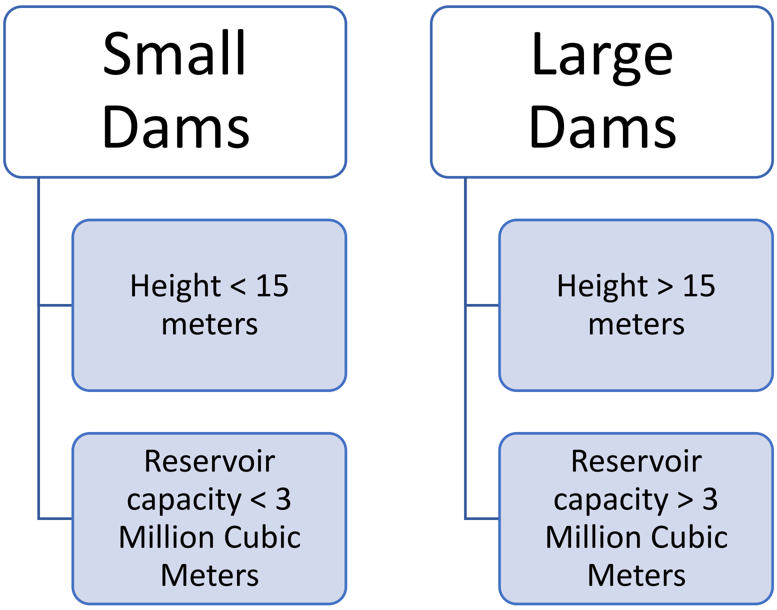


Figure 5 Major Characteristics of Small Dams and Large Dams

Developed countries worldwide have constructed thousands of Dams to increase their water storage facilities, electricity demands and mitigating floods. Dams are broadly categorized as small and large dams. They are classified on basis of their height and volume of reservoir they create.

A comprehensive comparison of the number of large dams of different countries is shown in table below[1]. Number of people depending on a single large dam can also be seen.

Country	**Total Dams**	**Large Dams**	**Population**	**People Depending on a Large Dam**
China	87,000	23,841	1.393 Billion	58,430
USA	90,000	9,263	327.17 Million	35,320
India	5300	4,408	1.353 Billion	306,942
Pakistan	-	162	212.22 Million	1,310,000
Brazil	17,259	1,365	209.5 Million	153,480

Table 3 Dam Statistics of Different Countries

Sources: (China, 2020), (Number of Dams by Country Members, 2020), (National Inventory of Dams, 2020), (ONLY 4% OF BRAZIL'S DAMS INSPECTED - REPORT, 2016)

It is visible that population depending on a large dam in Pakistan is the highest among other countries i.e. about 4 times greater than India and almost 37 times greater than USA.

Though Dams are built worldwide keeping in view the benefits they give (flood mitigation, agriculture, and power generation), their negative effects are mostly ignored. Everyone sees he outcome of the dam construction but do not ponder upon the sacrifices after which it has been built.

Benefits Derived from a Large Dam

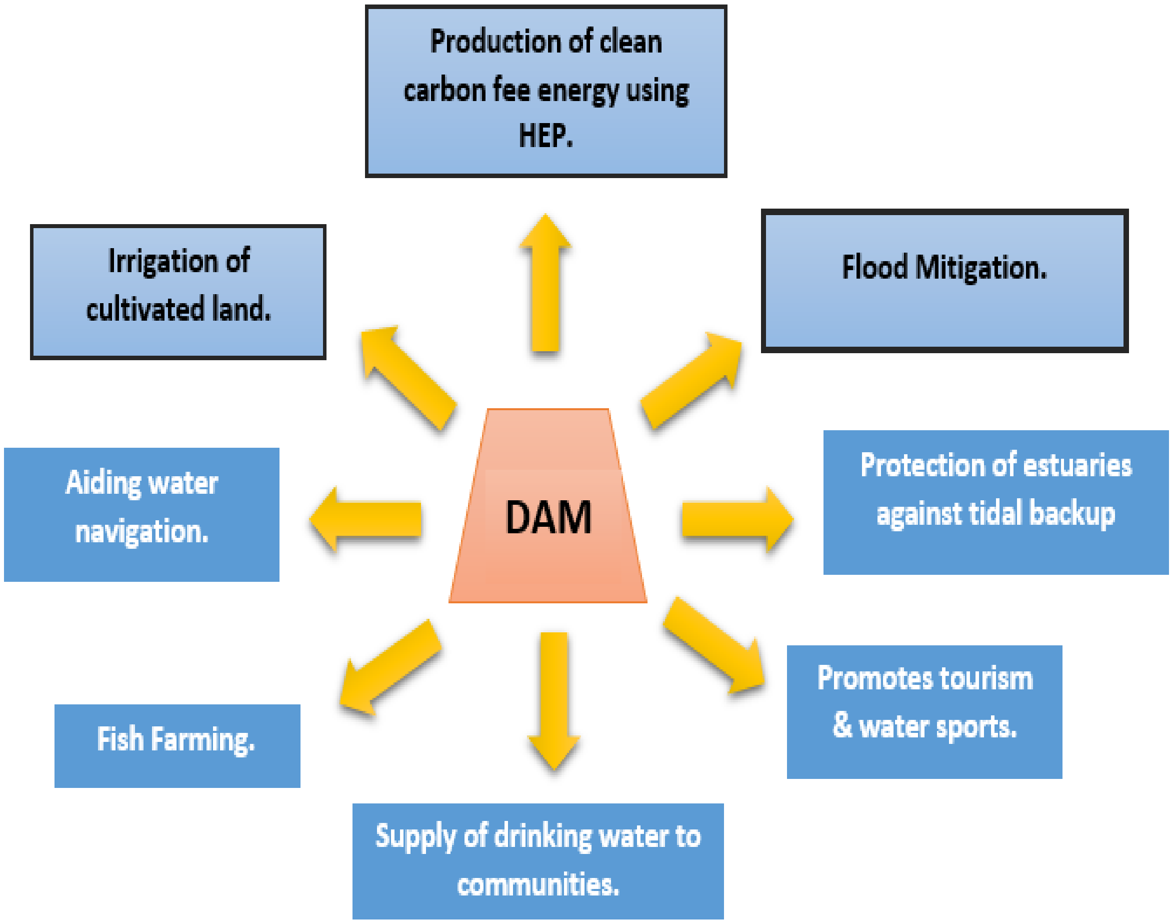


Figure 6 Advantages of Dams
Source: The Environmental and Social Acceptability of Dams (2016)

Construction of a dam begins when millions of people are displaced from their hometowns, thousands of villages are abandoned, hundreds of kilometres of infrastructure nearby is destroyed, the environment and habitat is seriously affected, and the economy of the country receives a serious setback. In some cases, even more destruction is caused to the surroundings keeping in view a city population nearby, ancient sites and rare plant or animal species.

When discussing the bad effects of dams, large dams are more significant when compared to small dams and cause more devastation as discussed below:

- People Displaced: The most serious social impact that dams cause is the displacement of people living in the surroundings of the proposed dam site. By giving them a few compensations, these people who used to live there for generations are forced to move out leaving everything behind and to migrate to a totally new place. World Commission on Dams says due to construction of dams about 40-80 million people have been displaced worldwide in last 60 years (Human Impacts of Dams, 2020).
- Environment affected: The second most important thing is the way in which the construction of dams destroys nature. Be it be the beautiful landscapes, sites of cultural or religious importance, ruins of ancient civilizations, developed towns or cities nearby or network of roads or highways, everything is submerged to 100 of kilometres whenever construction of dams start.
- Thirdly, cost by which large dams are built is so high that even the economy of a well-developed country is significantly undermined. For a developing country, if it takes such a foolish step, decades would be needed to pay back the price and to stable their economy.

Keeping such effects in mind, many international and national organizations are actively raising voice against the construction of large dams. Many countries as well take a firm stand against the construction of dams which directly or indirectly affect the water coming to their lands.

People displaced worldwide due to large dams

Large dams being mega projects utilize thousands of acres of land for dam construction, spillways, grid stations and other facilities. Such valuable land comes at the cost of great social unrest when population in millions is displaced from their hometowns and thousands of villages are abandoned. In India only, it has been reported that due to such mega projects about 33 million people were displaced (Roy, 1999). Hence, there is no doubt that large dams are responsible for large scale displacement as shown in the diagram on the next page.

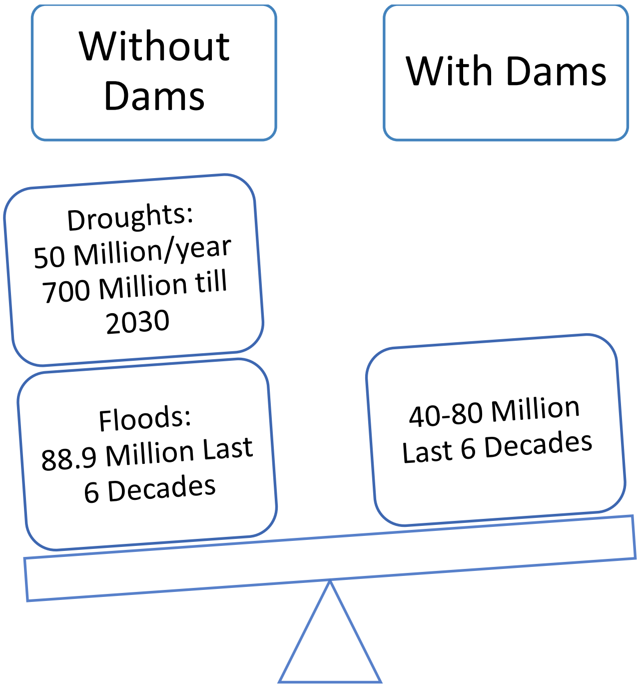


Figure 7 Comparison between people displaced due to dams and in absence of dams.

But the damages which a society can observe in the absence of dams can't be also denied. In the absence of dams, a nation can face serious flooding and droughts conditions as there will be no reservoirs to mitigate floods and store water for future usage. Population of about 88.9 million has been displaced worldwide due to serious flooding in the past 60 years (Number left homeless from natural disasters, Flood, 2019). Moreover, 55 million people are displaced worldwide every year as said by World Health Organization due to drought and about 700 million people are expected to get displaced till 2030 (Drought, 2020) . So when compared with the people displaced due to dams, the number of people displaced due to disasters caused by absence of dams prove to be extremely high.

Effects of Dam on Agriculture

Water is considered to be a source of life and is considered to have a drastic impact on ecological balance. Water as a natural resource of any country in terms of social, economic, political, and strategic viewpoint. The value of this essence of life increases by thousand fold when we consider the fact that almost 800 million people suffer from hunger and production of food need to have an increase of 60 percent more food by the year 2050 (Hayat, 2016).

Pakistan has agriculture base economy which consumes about 95 percent of the water resources of country. Almost 55 MAF water has been pumped out from ground through one million tube wells. This figure is 20 percent more than the water available for in the canals. (Abubakar, 2019)

If the availability of water is not enhanced for future needs, then the sustainability of the agricultural system and its potential to fulfil the needs of the ever-increasing population will be endangered causing famines in near future and death of millions of people by hunger. About 104 MAF water is supposed to Indus basin canals, out of which only 38 MAF is available for during the Ravi season. The main reasons of water shortage are:

1. Variability of surface water availability in different seasons due to global warming.
2. Incredible reduction in the water storage capacity of major reservoirs due to silting.
3. Significant increase in industrial and domestic water demand.
4. Poor efficient irrigation system results in huge losses.
5. Depletion of ground water table due to over exploitation.

Pakistan being an agricultural dependent country and due to increasing population needs to increase its crop producing capacity by 15% in order to fulfil its requirement of food (Kahlown & Majeed, 2003).

Water Demand for Agriculture Over the Years (MAF)

Crops	1990	2000	2025
Wheat	26.27	28.8	56.91
Rice	18.78	22.24	16.68
Cotton	13.68	15.71	19.35
Sugar cane	11.35	13.41	13.93
Other crops	28.93	30.59	46.74
Total with 70% loses	168.32	188.28	261.14

Table 4 Agricultural Water Demand over the Years

Source: Water resources situation in Pakistan: challenges and future strategies (2003)

Pakistan is an agriculture based country the data has been collected to focusing on the revenue generated by the agriculture.

Annual flow through Indus river system is about 151.8 MAF out of which 103.81MAF is used for irrigation purposes. We receive most of water in the three months of July to October. Only 55 percent of water for irrigation purpose is available at farm gates. Almost 42 percent is infiltrated to the ground and 3 percent is lost as evaporation.

Benefit of Dams on Flood Mitigation

Pakistan has been the target of floods of varying magnitudes up till now. Moreover, the perils from floods will not be any less in the future. The increased flows of glacial melts coupled with the decreasing storage capacity in reservoirs show that there are possibilities of even larger floods in the future. Therefore, it is up to us that whether we succumb to the destruction caused by flood or counter the natural hazard and mitigate it to reap benefits from it instead.

It has tried to incorporate both hard and soft solutions to cope with these floods. The hard solutions constitute of structural measures such as dams, drainage works and embankments while the soft measures comprise of watershed and efficient land use planning as well as flood warning systems. Mr. Asif H. Kazi writes in his paper- Flood Control and Management that extensive structural planning needs to be done in order to design flood protection facilities. These will fare well rather than depending upon just the local approach of dealing with emergencies. Dams dampen the intensity of flow consequently attenuating the frequency and size of the flood peaks. This is extremely useful especially during flood season where failure to do so can wreak massive losses on human lives, property, agriculture and the economy on the whole (Mountjoy, 2010).

Throughout the globe, water is not uniformly distributed with respect to temporal and spatial measures. Accordingly, dams and their reservoirs have become indispensable in keeping an even distribution of water. The reservoir simply stores the excess water when not required and providing it during shortage. As mentioned earlier, dams are built with multiple purposes to be achieved. Amongst these purposes, flood mitigation or control do not rank as the chief aims. In fact, many dams do not consider the aspect of flood mitigation upon design. It is when they see the benefits and effects that they realize the importance of this purpose afterwards.

There are more than 45,000 large dams around the world but only 10% are built with flood control as the primary aim. Many developed nations have utilized the construction of dams to a favourable extent to gain maximum benefit from the water they can. For instance, intricate and planned measures regarding flood mitigation have been successfully implemented in regions of Mississippi, Damodar, Nile, Missouri, and Tennessee rivers. The reservoirs of the Damodar valley in India have been effective in about 75% of attenuation of the high floods it faces. Moreover, the Pong dam goes on to reach a remarkable value of 90% in flood moderation (Mountjoy, 2010).

Flood Mitigation without Dams

Apart from setting up strong structural bodies such as dams, there are other techniques in which flood control is possible. Other methods include high flow diversions, catchment management and channel improvements along the path of the flood. The areas prone to flooding need to be zoned according to the flood plain regulation. For dampening the impact of flooding the following measures are to be considered:

1. Disaster preparedness on a larger scale
2. Education for creating awareness amongst the masses
3. System for post-flood recovery that includes flood insurance and relief policies

For minimizing the chance of damage caused by floods, the following need to be adapted:

1. Development and revision of policies on an extensive level
2. Construction of facilities and buildings for emergencies
3. Flood proofing and floodplain regulation
4. Modern flood forecasting and warning techniques

It is important that the authorities adapt a more proactive rather than a reactive approach to deal with this natural hazard (Mountjoy, 2010).

National Flood Protection Plans (NFPPs)

In 1977, the Federal Flood Commission was established. Its primary purpose was to prepare the National Flood Protection Plans (NFPPs) on a national level. Previously, the flood protection schemes were left to the provincial governments. The programs range from measures of construction of flood protection structures to improvement of radar techniques and spreading awareness amongst the local population. By 2017, four NFPPs have been executed that cover a period of almost 40 years (Tariq & Giesen, 2012).

<table>
<tr><th>NFPP</th><th>Sub Projects</th><th>Schemes</th><th>Period</th><th>Cost (PKR billion)</th></tr>
<tr><td>NFPP-1</td><td>-</td><td>350</td><td>1978-1987</td><td>1.730</td></tr>
<tr><td rowspan="2">NFPP-2</td><td>NADP</td><td>257</td><td rowspan="2">1988-1997</td><td>4.860</td></tr>
<tr><td>FPSP-1</td><td>170</td><td>2.541</td></tr>
<tr><td rowspan="3">NFPP-3</td><td>FSPP-2</td><td>101</td><td rowspan="3">1998-2007</td><td>4.165</td></tr>
<tr><td>NADP</td><td></td><td>3.415</td></tr>
<tr><td>Flood System for Lai Nallah</td><td></td><td>0.348</td></tr>
<tr><td>NFPP-4</td><td>-</td><td></td><td>2009-2017</td><td>30</td></tr>
<tr><td colspan="4">TOTAL</td><td>47.059</td></tr>
</table>

Table 5 Details of National Flood Protection Plans

The amount of money spent on NFPP's do not include the cost of a major dam yet so much money has been utilised for the preventive measures against floods in the country. Building a large dam will require less than one fourth of this cost and provide benefit for many decades to come.

2.3 Tarbela Dam

Photo 1: Tarbela Dawn (Source: DAWN.com)

Tarbela Dam is located on the river Indus in district Swabi, at 130 KM from the capital Islamabad. It stands as one of the largest earth and rock filled dams in the world (Tarbela Dam, 2020). Completed in 1976, the Tarbela Dam was constructed under the umbrella of Indus Basin Project (IBP) which also included the Mangla dam.

The catchment area of Tarbela dam sees a principal inflow of glacial flow and the melted snow-capped peaks in the north (Asianics Agro-Dev. International (Pvt) Ltd., 2000). Owing to its location, about 90% of the annual river inflow comprises of snowmelt. Rainfall in the catchment area upstream accounts for the rest of the inflow. It is this rainfall that also plays a pivotal part in leading to flooding in the basin (Flood Management Manual- Tarbela Reservoir , 2011).

Predicted and Actual Effects

Although the primary objective included replacement flows and regulation of the Indus Basin Irrigation System (IBIS), other purposes were also planned. These include the following:

1. To aid in increasing food production especially regarding wheat
2. Allowing to supply water during the low flow season so that agriculture is not affected to a significant extent.
3. Generation of 2100 MW of relatively cheap hydropower.

The massive but principal task of Tarbela was to secure that the irrigated lands of the country are not deprived of water supply after India's diversion of the eastern rivers. For this reason, about two third of the reservoir capacity was held for replacement purposes while the remaining one third was designed for supplemental irrigation. The latter was essential to bring many additional regions into cultivation by maximizing cropping potential through the utilization of canal systems.

The WCD report of Tarbela Dam mentions that according to the Lieftinck Report, the contribution of Tarbela in the annual irrigation supply in IBIS was an average value of 9.3%. This figure constitutes the 21% of rabi and 3% for kharif abstractions. Therefore, it is correct to say that Tarbela along with Mangla have been successful in accomplishing their aims of replacing water lost to India as well as increasing regulated supply for irrigation.

Effect of Tarbela on Agriculture

The agriculture sector benefited immensely from these improvements as there were marked increases in the cultivated and irrigated lands after Tarbela Dam. From 1974-75 to 1997-1998, the cultivated area saw an increase from 19.6 mha to 22.0 mha. Likewise, the irrigated area increased from 13.3 mha to 18.0 mha in the period 1974-75 to 1997-1998. This figure is even slightly higher than the predicted figure around 2000 which was calculated to be 17.0 mha (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

After its construction, the availability of water for the irrigation purpose has also increased from 95.8 MAF to 104.57MAF. The water value in South Asia for wheat is 0.6kg/m3 (lowest ever recorded value) (Abid, Sadiq, Gabriel, & Ahsan, 2011). It means that if we talk in terms of wheat only Tarbela has increased our wheat production capacity by 6.5Million Metric Tons. Tarbela has provided an extra 8.77MAF water to our agriculture sector for more and better quality of crops yield. As it has a positive impact on both Rabi and Kharif crops (Tariq S. M.).

Season	Initial Water Quantity (1962-1967)/ MAF	After Mangla (1967-1976)/ MAF	After Tarbela (1976-2003)/ MAF	Additional Water	
				Quantity (MAF)	Percentage %
Kharif	62.38	65.02	67.7	5.39	8.6%
Rabi	28	30.78	36.80	8.80	31.4%
Total	90.38	95.80	104.57	14.19	15.7%

Table 6 Effects of Mangla and Tarbela on Rabi and Kharif

Source: Role of Tarbela dam in water regulation of Indus river and its effects. (2011)

All the provinces of Pakistan have significant water development potential which will not only contribute to agriculture but also to the economy of Pakistan (Kahlown & Majeed, 2003).

Province	Water Development Potential (MAF)	Water Productivity in Economic Terms ($0.15 Per Cubic Meter in South Asia)
Punjab	2.7	$499.56m
KPK	7.3	$1350.67m
Baluchistan	7.86	$1454.28m
Sindh	0.78	$144.32m

Table 7 Water Development Potential of Provinces

Source: (Merrett S. , 1997) (Molden, 2001)

Even though Tarbela covered the loss of water from the eastern rivers to India and played a significant part in bulging the agricultural produce, the overall objective has not yet been exploited to the fullest. The increasing population of the country and the demand of more crops needs to be met. Otherwise we cannot increase self-sufficiency and will have to continue bearing the burden of importing staple crops such as wheat (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

Effect of Tarbela on Power Sector

As mentioned previously, hydropower generation was an eminent aim of Tarbela dam. The initial design had plans for the staged development of twelve generators, each of a capacity of 175 MW which provides a total of 2100 MW. This plan was to be executed by 1980. The predicted figure of annual power generated at 2100 MW was 112,600 GWh. Upon reaching its full capacity in 1993, the annual power generated was 14,300 GWh. Promisingly, this shows a 13% increase from the original estimated value. As mentioned in the Tarbela Dam report for the WCD, as of 1998, the total installed capacity that Pakistan had was 15,844 MW. This includes hydropower, thermal as well as independent power producers. Amongst all these, Tarbela accounted for 28% of the annual generation need for WAPDA’s national grid system (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

When talking about flood control, Tarbela enjoys a pivotal position. Although, flood control and mitigation were not the purpose planned when it was stood up in 1976. As a bonus of supplying water for irrigation and cheap electricity, Tarbela played a major part in attenuation of flood peaks especially during the monsoon season when filling occurs from June to August (Mountjoy, 2010). This shows how the potential of large dams is underestimated in terms of flood protection.

Social and Environmental Effects of Tarbela

One of the direct affects by the dam that needs attention and proper planning is the displacement of people and land for the dam. For Tarbela Dam, the estimated value of villages and people were 100 and 80,000, respectively. In reality however, around 120 villages and 96,000 people were amongst the affectees. The increase of 20% was to occur as such large projects bring many associated --- with them. However, there should be a window for an increase or decrease in number and every single individual must be compensated. The results of 1996 survey presented the facts that still 1953 families had not received possession of any land. The areas facing inundation included the State of Amb in the Hazara Division, tribal areas of Mansehra, District Swabi and Alpuri Tehsil. The government has set laws regarding resettlement in the Land Acquisition Act of 1984 that attends to all those under the process of resettlement and displacement. On the other hand, many locals refuse to abide by the conditions and feel robbed from their former belongings (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

Inefficiency and unnecessary delay of the authorities towards and the unawareness amongst the locals regarding the issue has caused this problem to surface as a major obstruction in the path of many feasible future dams. Other consequences include the corruption of officials, devaluation of the currency due to prolonged delays and the unavailability of livelihood for the resettled people in the new regions. This led to lowering of the social status of those affected. Apart from the number of people to be displaced, many were indirectly affected and not accounted for by any authority. These include the inhabitants of land downstream that thrived on flood based agriculture. Likewise, the reduction of fish coming downstream adversely affected many fishermen in the region.

According to information provided by WAPDA as well as NGO reports, the total land required for Tarbela was 33221 ha. This comprised of 22579 ha (70% of the total land required) for the reservoir. Plus, the area for roads and working sites made up 2% and 18.3% respectively. The land was resettlement was distributed in the provinces of Punjab and Sindh (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

Social Pros of the Tarbela Dam Project

1) Introduction of mechanised farming techniques.
2) The Project and its sub projects brought employment opportunities for many.
3) The increase in the literacy rate of women.
4) Dam construction has increased the awareness amongst people.
5) The unnecessarily enormous power in the hands of the feudal lords has been reduced.
6) Fisheries production has seen growth.
7) Increased opportunities for higher education and social activities for the young generation.

Social Cons of the Tarbela Dam Project

1) Agricultural land and forests have been abolished.
2) Increase in the pollution of drinking water.
3) Resettlement has not been done properly.
4) Families have been divided and they like they have lost their identity.
5) Crops which were locally grown and used, now must be obtained from the market at a cost.
6) Shift in occupations makes it difficult for the locals.

Environmental and Ecological Effects

The pressure on the environment are not just subjected to the construction of the dam body alone. The changes occurring consequently due to hydropower and irrigation are also responsible and all these add up to environmental effects. Sadly, an environmental impact assessment (EIA) was not carried out at the design and execution of Tarbela but now this is a vital part in every project.

The various ecosystems blooming on and near the Indus have seen changes due to Tarbela. From the ecosystem at upper Indus plains of Punjab to the Indus Delta, all have been impacted directly or indirectly by Tarbela. The construction of the dam has hurt the fauna of the region and many fish species coming downstream have been reduced in quantity. These species depend on the seasonal flooding for breeding but that is not the case anymore. These include the species of Mahseer, catfish, snow trout, Tor puttitora. Further down, the species of the Indus dolphin, the smooth coated otter, and the hog deer face considerable threat. For the purpose of water regulation, the onset of barrages have further accentuated the tension of valuable species such as the dolphins that thrive in the Indus near Sukkur and Guddu barrages (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

For the reclamation of agricultural lands and revival of plantations, the thorn forests and greenery have been cleared. These were also a natural habitat to various plant and animal species. The loss of natural habitat also occurred when the forests in the upstream of Tarbela were depleted. Naturally, this led to more eroded and sediment material in the hilly regions (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

On the other hand, Tarbela is also responsible for the reduction in the sediment load carried in the river Indus. This leads to the decrease in the amount of sediment and nutrients in the soil from flowing down the river towards the delta. Waterlogging and salinity have proven to be a nuisance for irrigated land in any region. Tarbela may have contributed a bit to this although not directly. Supply from Tarbela added with the inefficient irrigation system have led to a serious issue of salinity. Salinity in soil has caused a severe reduction of 25% of the major crop production. Although every aspect is not directly impacted by the Tarbela Dam, the supplementary canals and barrages have also put part in environmental consequences (Asianics Agro-Dev. International (Pvt) Ltd., 2000).

2.4 Diamer Bhasha Dam

The much awaited project of Diamer Bhasha Dam is now ready for constructed on the Indus River. The dam site will be 315 kilometres upstream of the site of the Tarbela Dam. The location will be 180 km below Gilgit town and nearly 40 km downstream of Chilas which is the district headquarters of Diamer in Gilgit-Baltistan (WAPDA, 2011).

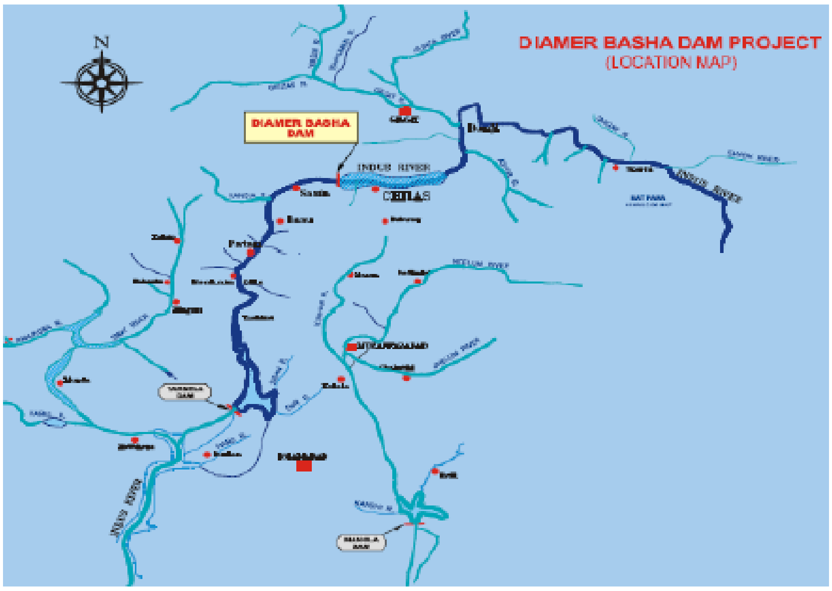


Photo 2 Location of Diamer Bhasha dam (Source: Diamer Bhasha Dam Project WAPDA)

Diamer Bhasha dam will be constructed as a roller compacted (RCC) dam which will be till now the highest dam of Pakistan with a height of 272m. The dam has been planned to consist of 14 gates and a reservoir that will have a gross storage capacity of 8.1 MAF. The dam has been planned with a high priority on power generation with an expected production capacity of 4500 MW.

The national water storage capacity is currently 38 days and after Diamer Bhasha dam it will see an increase to 48 days (Maqsood, 2018). Diamer Bhasha will play a pivotal part in flood mitigation. The reservoir at Diamer Bhasha will hold an amount of 8.1 MAF gross storage with a 6.4MAF of live storage available for water regulation and irrigation purposes. The presence of Diamer Bhasha will regulate water before it enters Tarbela. A cost of $ 15.03 million (2.3 billion PKR) is estimated to be saved from flooding damages annually after Diamer Bhasha.

According to the WAPDA Flood Management Manual 2011, the valley downstream of Tarbela can take around 500,000 cusecs without leading to visible damages. However, for flow values greater than 600,000 which tend to fall into the very high category, the risk for villages and side valleys to be inundated is very high. Therefore, the damage to life and property will be more than lesser intensity floods. Holding some water at the Diamer Bhasha dam to reduce the inflow at Tarbela will control the release from Tarbela downstream.

CHAPTER 3

METHODOLOGY

3. Methodology

3.1 Introduction

The literature above shows the benefits of having large dams in a country. When dams are planned, a very detailed and extensive feasibility analysis is carried out. Most dams are built with the purposes of water regulation for crops and hydel power generation in mind. Another significant area in which the dam serves which is flood routing and mitigation is not given much attention initially. For bringing all analysis and results especially flooding analysis to light, a research methodology has been adopted. The study is not just based on wordy paragraphs but has been supported by data from over 50 years.

The methodology basically consists of three broad steps for this research. They are as follows:

1. Data collection and preparation
2. Analysis of the data
3. Results

These main steps are shown in detail on the following page as a flowchart linking all the processes. Since, there was not any practical laboratory testing or field work involved, there are no sections for materials and experimental results.

The initial step taken in methodology was to collect all the data regarding the water resources of Pakistan. This included inflows and outflows of large dams, power generation capacity, past floods in Pakistan, the damages due to flood, and the storage capacity of major water reservoirs of Pakistan. The data that was acquired was studied to filter the accurate and most suitable data for our project purposes. Next the data was refined to make it useable by omitting the ambiguous and unverified values. The data collected was sorted carefully to be categorically used for analysis and computations in three areas.

The areas under analysis are:

1. Flood routing by dams

2. Water regulation for irrigation by dams
3. Power generation by dams

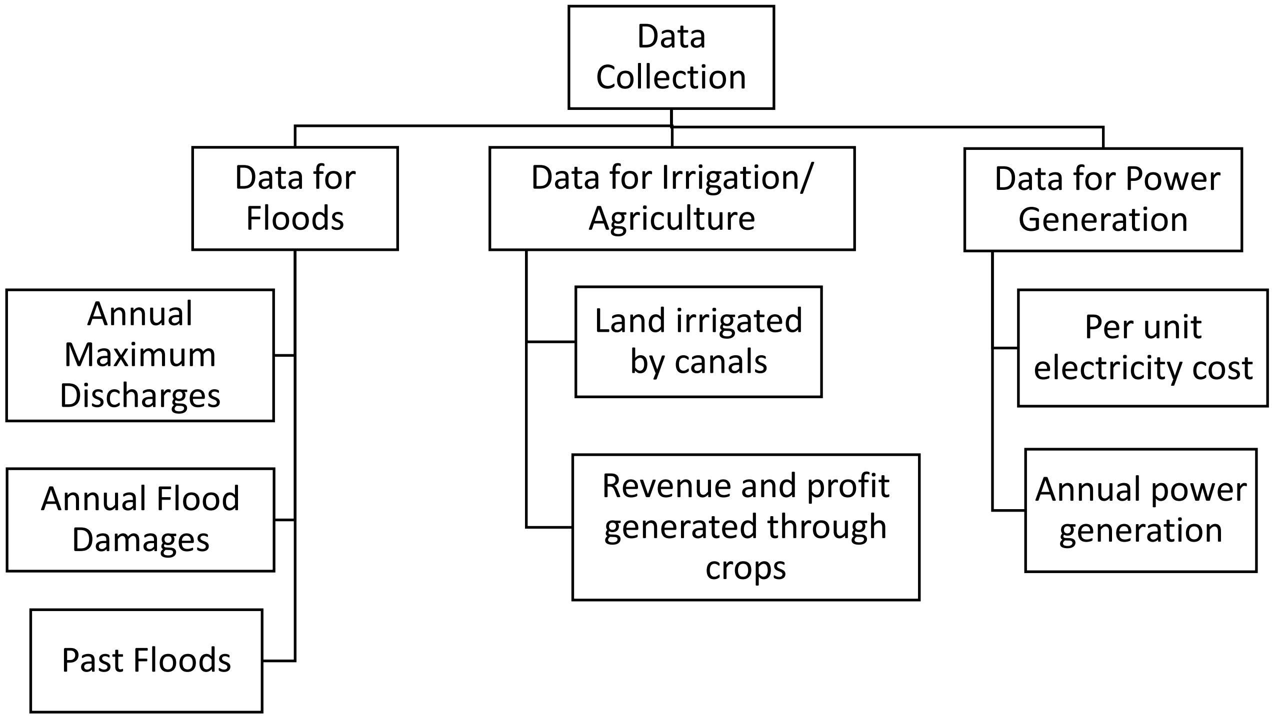


Figure 8 Flowchart for Data Collection

3.2 Flowchart of Methodology

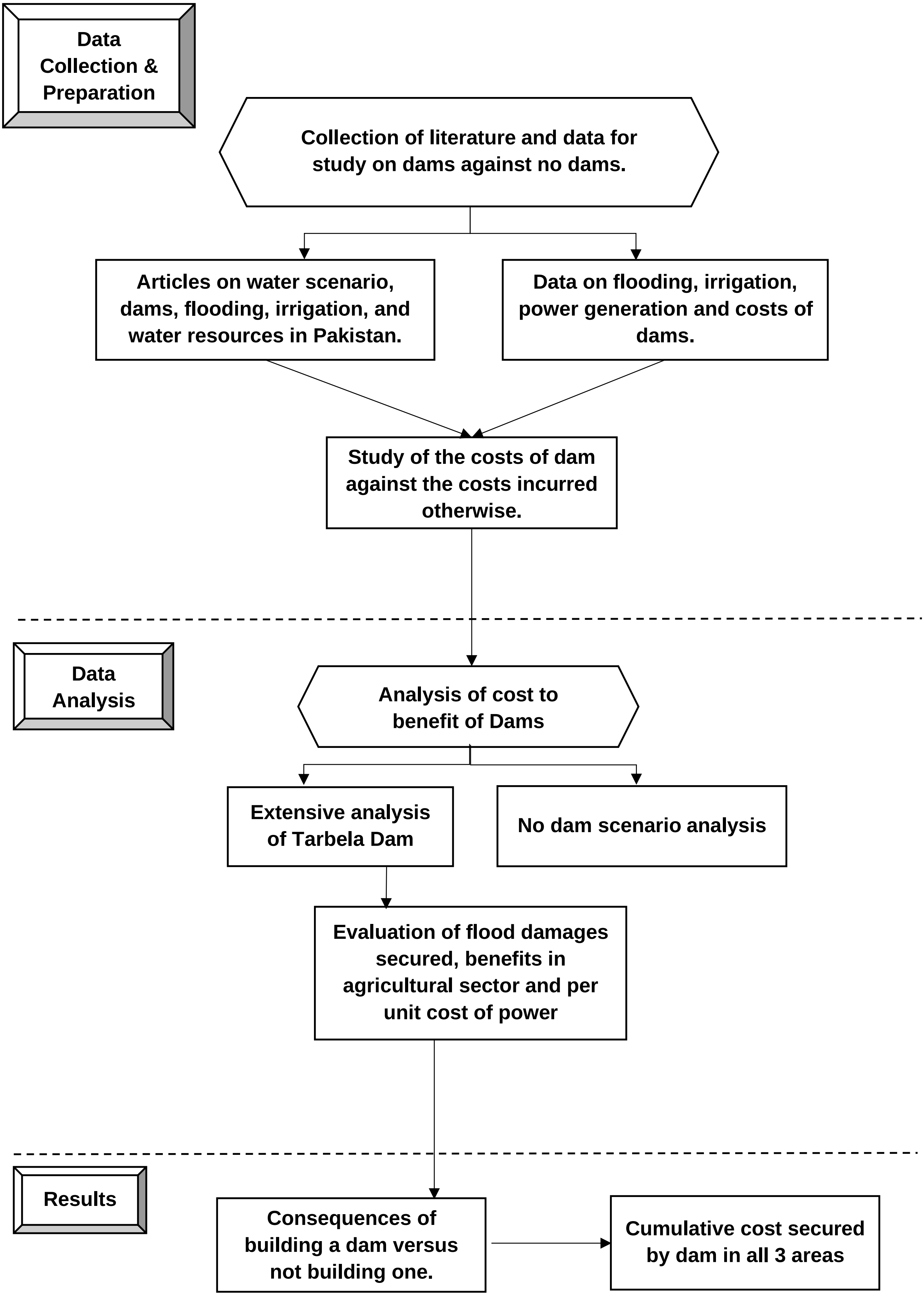


Figure 9 Schematic Diagram of Methodology

3.3 Explanation

Flooding

The main aim is to calculate the cost-benefit analysis of large dams in Pakistan. The main study has been carried around Tarbela dam with light put in other areas too. The results will show that despite the seemingly large costs they demand initially, large dams fulfil all the costs and extend to provide profits for any sectors especially the three highlighted for this research.
Finally, the benefits of all these three areas will be combined to show how enormous the result are which we are neglecting because of a few minor concerns.
All the data that has been sorted has been organised and presented in tables throughout. For the calculation of damages secured by dams through flood mitigation, data of Tarbela dam's maximum inflow and outflow values were used. The data is presented in the table below.

Annual Maximum Inflow and Outflow Values at Tarbela

Year	Max. Inflow	Max. Outflow	Year	Max. Inflow	Max. Outflow
1974	354,000	386,000	**1994**	420,000	403,000
1975	426,000	423,000	**1995**	495,000	432,000
1976	349,000	425,000	**1996**	402,000	375,000
1977	436,000	393,000	**1997**	400,000	471,000
1978	434,000	420,000	**1998**	366,000	348,000
1979	336,000	472,000	**1999**	382,000	373,000
1980	308,000	430,000	**2000**	372,000	244,000
1981	330,000	307,000	**2001**	294,000	230,000
1982	347,000	487,000	**2002**	343,000	298,000
1983	380,000	433,000	**2003**	338,000	350,000
1984	337,000	336,000	**2004**	273,000	270,000
1985	345,000	340,000	**2005**	401,000	373,000
1986	390,000	443,000	**2006**	460,000	373,000
1987	329,000	357,000	**2007**	348,000	292,700
1988	480,000	476,000	**2008**	325,000	258,700
1989	510,000	497,000	**2009**	326,000	306,800

1990	401,000	417,000	**2010**	835,000	604,000
1991	340,000	367,000	**2011**	268,000	270,000
1992	520,000	522,000	**2012**	293,000	260,800
1993	370,000	339,000	**2013**	400,000	364,900

Table 8 Annual Maximum Inflow and Outflow at Tarbela

The losses from the flooding disasters were used to measure the damages occurred and the damages secured by dams especially Tarbela dam. The data for this purpose for retrieved from the annual flood report 2018 and is displayed on the next page. The flood report by the ministry of water resources Pakistan does not contain data for damages incurred in all years. The direct losses are not present in the present worth value. Since the value of Pakistani rupee kept depreciating in terms of US dollars so the present worth has been calculated in the analysis section for final results. Besides the direct losses, the table also shows the number of villages affected, the area under the impact of flooding and most importantly the number of lives lost.

Major Flood Events and their Damages in Pakistan

Sr. No.	Year	Direct Losses (USD Million)	Lives Lost	Villages Affected	Flooded Area (Sq.-Km)
1	1950	488	2190	10,000	17,920
2	1955	378	679	6,945	2,480
3	1956	318	160	11,609	74406
4	1957	301	83	4,498	16003
5	1959	234	88	3,902	10424
6	1973	5134	474	9,719	41472
7	1975	684	126	8,628	34931
8	1976	3485	425	18,390	81920
9	1977	338	848	2,185	4657
10	1978	2227	393	9,199	3597
11	1981	299	82	2,071	4191
12	1983	135	39	643	1882
13	1984	75	42	251	1093
14	1988	858	508	100	6144

Sr. No.	Year	Direct Losses (USD Million)	Lives Lost	Villages Affected	Flooded Area (Sq.-Km)
15	1992	3010	1008	13,208	38758
16	1994	843	431	1,622	5568
17	1995	376	591	6,852	16686
18	2010	10,000	1985	17,553	160000
19	2011	3730	516	38,700	27581
20	2012	2640	571	14,159	4746
21	2013	2000	333	8,297	4483
22	2014	440	367	4,065	9779
23	2015	170	238	4,634	2877
24	2016	6	153	43	-
25	2017	-	172	-	-
26	2018	-	88	-	-
Total		**38,171**	**12,418**	**197,273**	

Table 9 Damages by Floods in Pakistan

Analysis and Graphs have been formulated by arranging the acquired tabulated data. They are presented in the analysis and results section.

General trend lines have been marked to ease the understanding and to get clear results. Under each heading, specified above analysis has been performed and cost-benefit ratio was calculated. To conclude the water importance some analysis is performed to get the results in numerical form for ease of understanding. The basic concept of every analysis is to find out the cost-benefit ratio and to make a conclusion of whether dams are favourable for the economy of Pakistan or not.

CHAPTER 4

ANALYSIS

4. Analysis

4.1 Flood Routing

Dams can be efficiently used to mitigate floods and reduce the damages caused. Every year in Pakistan, the monsoon rains bring havoc in the form of floods and results in loss of precious lives, infrastructure, and the country's economy. The following study shows that constructing a dam reduces high flood peaks into low floods and secure billions of dollars annually.

To support the construction of large dams as necessary structures for the country, an analysis on the amount of damages secured due to dams owing to floods has been performed. Data comprising of 12 years flooding damages and discharges has been used for computations on Excel. Data comprises of the following years: 1975, 1976, 1977, 1978, 1981, 1988, 1992, 1994, 1995, 2010, 2011 and 2012. Unavailability of authentic data accounts for the large gap from 1995 to 2010.

The table below shows the maximum outflow discharge measured at Tarbela rim station in an ascending order. Flood damages in millions (USD) of the respective year have also been tabulated alongside. The damages incurred are calculated at the present worth.

Year	Maximum Outflow (x1000/cfs)	Flood Damages due to Discharge ($US Million)
2012	260.8	2948.16
2011	270	4251.60
1981	307	556.14
1977	393	628.68
1994	403	1567.98
1978	420	4142.22
1975	423	1272.24
1976	425	6482.10
1995	432	699.36
1988	476	1595.88
1992	522	5598.60
2010	604	18600.00

Table 10 Flood Damages due to Maximum Discharge

Using the graphical representation of the data above, a cubic equation of the viable trend in both the quantities was obtained. Using extensive interpolation through the equation, the damages from the period of 1977-2013 were evaluated for discharge. The data for the values of inflow and outflow were used to determine the damages caused by the respective discharges. It is obvious that the presence and functioning of dams led mitigation as seen by the difference in outflow from inflow. The graph below shows the trend line as the dotted curve from which the data for further analysis is derived.

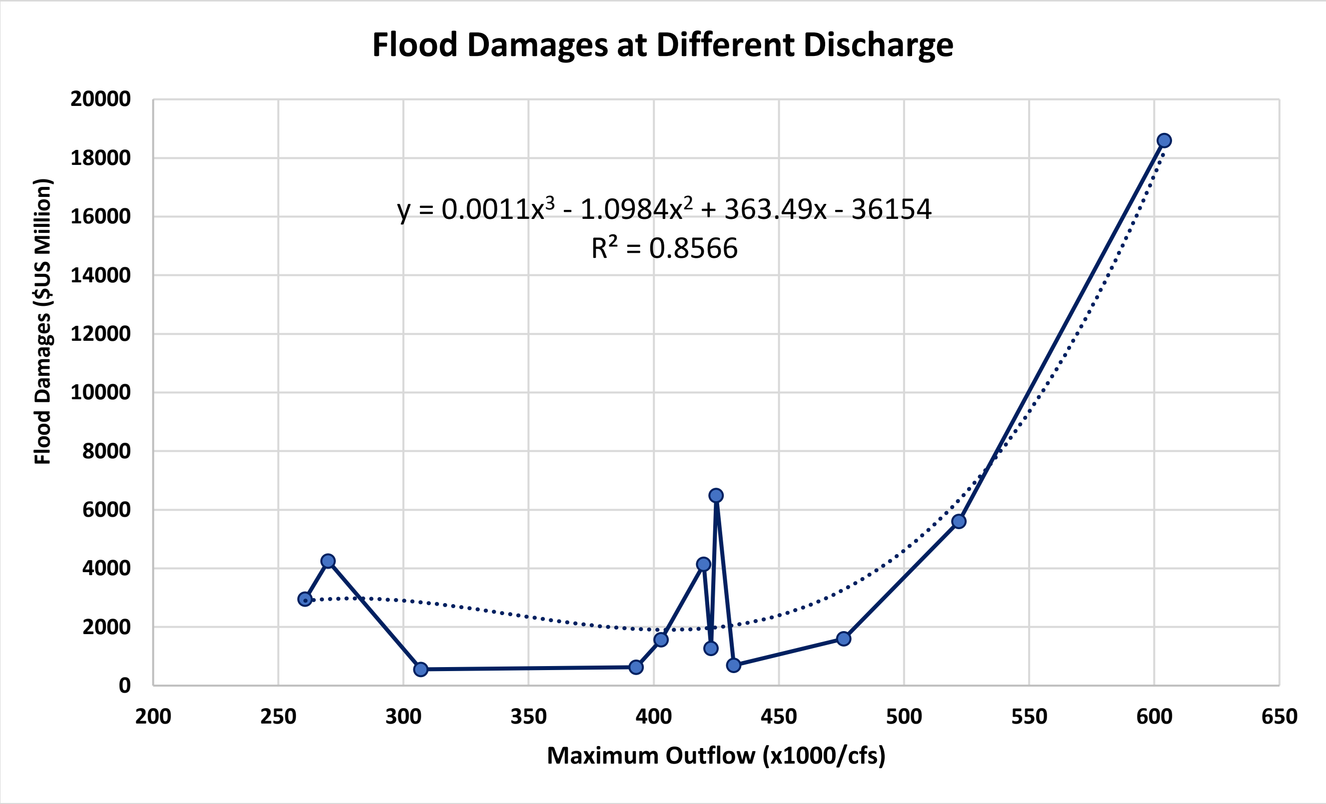


Figure 10 Graph of Damages against Maximum Outflow with Trendline Equation

The obtained data for the damages have been tabulated below. The damages secured per year and the accumulated damages secured are also evaluated alongside as shown on the next page. It is to be noted that there were many years during the 31 year period where there were not any damages secured. This was due to the reason that flood did not occur that year or the dam had to let more outflow for some safety reason. The original value of 2010 derived from the equation has been halved for the reason told below.

Year	Max Inflow (x1000)	Damages Inflow	Max Outflow (x1000)	Damages Outflow	Damages Secured	Accumulated Damages Sec
1977	436	4696.2352	393	3819.0911	877.1441	877.1441
1978	434	4631.584	420	4250.84	380.744	1257.8881
1979	336	3700.0352	472	6376.7872	0	1257.8881
1980	308	3742.2256	430	4510.24	0	1257.8881
1981	330	3712.64	307	3742.2157	0	1257.8881
1982	347	3679.8997	487	7410.6337	0	1257.8881
1983	380	3722.44	433	4600.2631	0	1257.8881
1984	337	3697.9687	336	3700.0352	0	1257.8881
1985	345	3682.9775	340	3691.96	0	1257.8881
1986	390	3791.360	443	4944.3061	0	1257.8881
1987	329	3714.7135	357	3671.1707	43.5428	1301.4309
1988	480	6901.04	476	6631.3552	269.6848	1571.1157
1989	510	9448.16	497	8225.6647	1222.4953	2793.611
1990	401	3910.9927	417	4184.5367	0	2793.611
1991	340	3691.96	367	3678.3817	13.5783	2807.1893
1992	520	10522.24	522	10751.6672	0	2807.1893
1993	370	3684.64	339	3693.9245	0	2807.1893
1994	420	4250.84	403	3938.3341	312.5059	3119.6952
1995	495	8054.2025	432	4569.6032	3484.5993	6604.2945
1996	402	3924.4352	375	3700.0625	224.3727	6828.6672
1997	400	3898.000	471	6315.4577	0	6828.6672
1998	366	3676.7552	348	3678.4976	0	6828.6672
1999	382	3733.5232	373	3693.1051	40.4181	6869.0853
2000	372	3690.0272	244	3122.68	567.3472	7436.4325
2001	294	3724.16	230	2727.04	997.12	8433.5525
2002	343	3686.3761	298	3733.6576	0	8433.5525
2003	338	3695.9296	350	3676	19.9296	8453.4821
2004	273	3597.1751	270	3566.24	30.9351	8484.4172
2005	401	3910.9927	373	3693.1051	217.8876	8702.3048
2006	460	5699.56	373	3693.1051	2006.4549	10708.7597
2007	348	3678.4976	293	3720.210445	0	10708.7597
2008	325	3722.6875	259	3414.728707	307.9587927	**11016.71849**
2009	326	3720.7552	307	3742.193459	0	11016.71849
2010	835	70964.600	604	25063.816	45900.784	56917.50249
2011	268	3543.5536	270	3566.24	0	56917.50249
2012	293	3721.1611	261	3447.328307	273.8327928	57191.33529
2013	400	3898.000	365	3675.21851	222.7814901	57414.11678

Table 11 Damages Secured due to Inflow and Outflow

The damages and losses that have been safeguarded every year, but the data for 36 years shows how much losses have been prevented. The data from 1995 shows that a significantly large amount of US $3484.5 Million had been secured. The notorious floods of 2010 had caused destructive losses on a large scale. As shown above, the presence of dams contributed to dampen the damages of floods worth a tremendous figure of US $ 56917.5 million. This value has been halved as the figure obtained from the trendline is too drastic to be analysed. The trend in the graph is increasing exponentially while the actual damages are not expected to grow that way; this is the reason the damages for of 2010 have been reduced to a half. The values of the accumulated damages secured have been graphically presented as shown below.

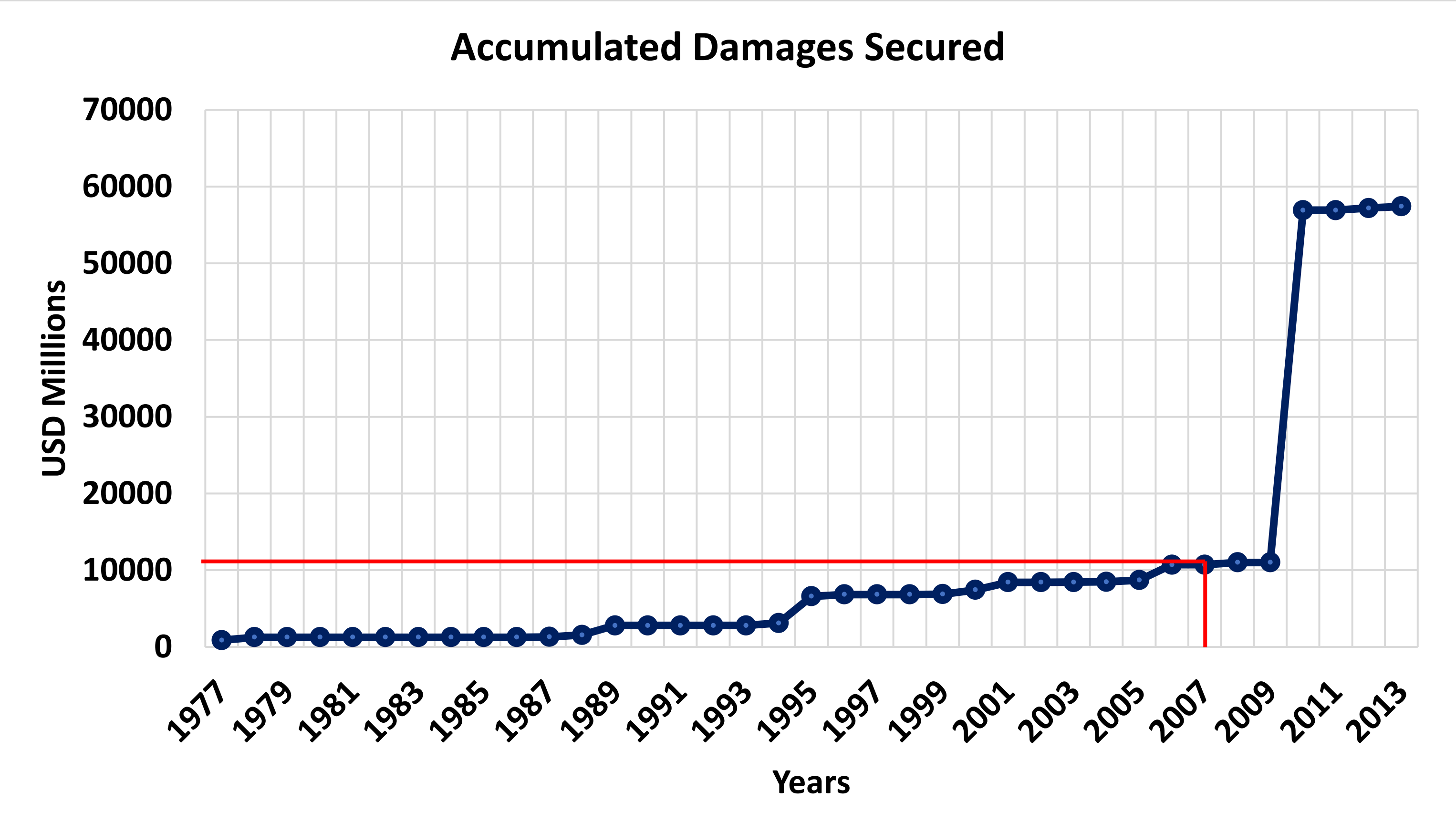


Figure 11 Graph of Recovery of Tarbela Dam's Cost by Flooding Damages Secured

A total of US $5,7414.1 million have been secured in the flooding events of 36 years. Damage due to natural hazards such as floods are nearly impossible to stop completely but as shown through the analysis above, a significant amount of damage can be reduced if the dams are utilized with the aim of flood mitigation in mind. It is to be noted that the results of the floods of 2010 are so large that they cause the visible spike in values of the accumulated damages. Even alone the 2010 damages secured were enough for presenting the significance of dams for flood prevention reasons. The analysis puts light out on the humongous damages we have saved ourselves from due to flood alleviation by dams in the country.

The damages secured in 31 years cover the cost of Tarbela dam. Of all the colossal amount of damages we have endured, the cost required in the building of large dams seems negligible. In fact, considering the value of damages secured of US $57 billion in 35 years can alone compensate for the service many dams such as Diamer Bhasha will provide against their cost.

4.2 Agriculture

Pakistan has two cropping seasons:

- **Kharif**

  Kharif crops are sown in April-June and harvested during months of October-December. Major Kharif crops are rice, sugarcane, cotton, maize, moong, mash, bajra and jowar.

- **Rabi**

  Rabi crops are sown in October-December and harvested during the months April-May. Major Rabi crops are wheat, gram, lentil (masoor), tobacco, rapeseed, barley, and mustard.

Pakistan's agricultural productivity is dependent upon the timely availability of water.

Water Recourses

Water is not a static resource like land, but occurs in a very dynamic cycle of rain, runoff, and evaporation, with enormous temporal and spatial variations as well as variations in quality that govern its value to people and ecosystem. Canal head withdrawals during the Kharif season in the year 2017 during the months of (April-September) was 69.97 MAF. Meanwhile in Rabi season in the year 2017-18 the canal head withdrawal below rim station was 24.16 MAF (Division, 2017-2018). These are shown in the table below.

Canal Head Withdrawals (Below Rim Station) MAF

Provinces	Kharif (Apr-Sep) 2017	Rabi (Oct-Mar) 2017-18
Punjab	35.51	12.76
Sindh	31.37	9.75
Balochistan	2.07	1.12
KPK	1.02	0.59
Total	69.97	24.16

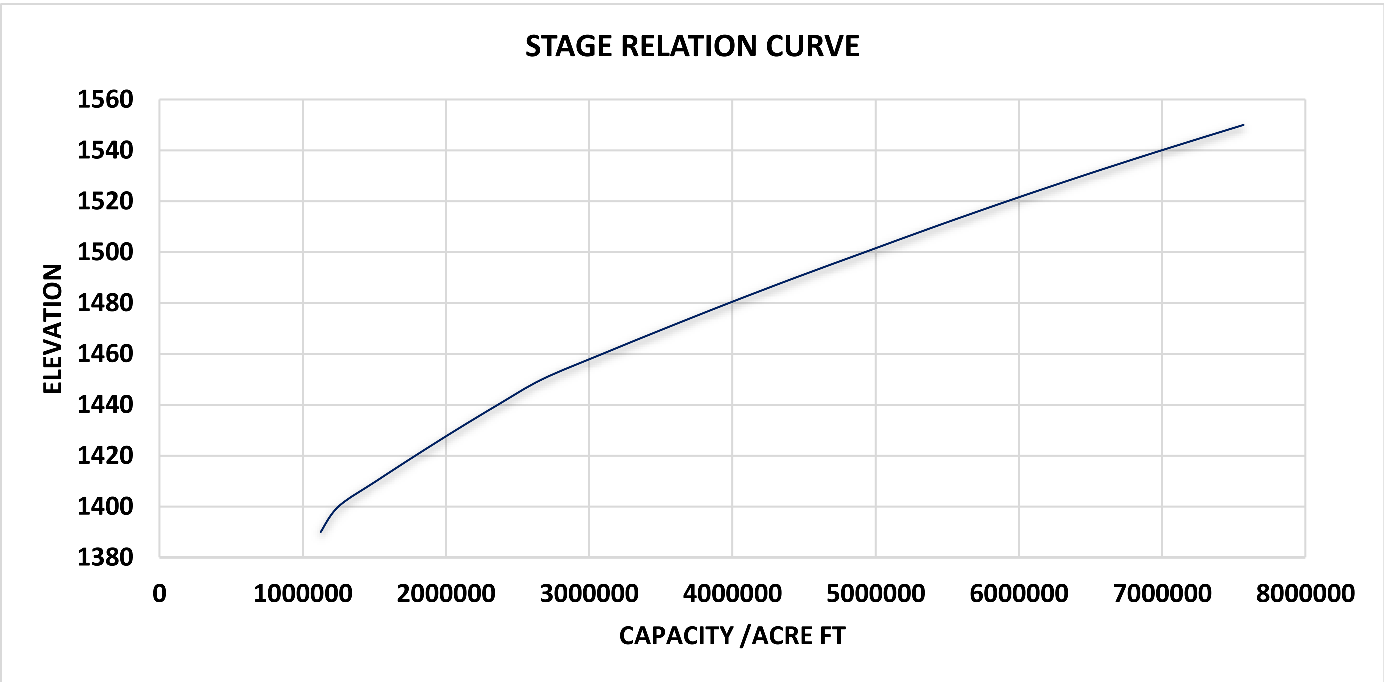
Table 12 Canal Head Withdrawals of Province

The productivity of water is low attributed to high water losses, inefficient water application methods, low water availability at critical crop growth stage, sub-optimal mix of crops, poor economic allocation of water etc.

What is Stage Relation Curve?

A stage-relation curve shows the relation between the elevation of a reservoir and the volume of water present at that elevation. The measurements are taken by noting down readings at different gauge stations. These curves help in understanding discharge rates of a reservoir, its mean operating level and consequently the excess amount of water that is stored is in a dam as compared to its minimum storage level.

The following graph is made by plotting capacity of reservoir at different levels ranging from 1390 the minimum operating level and 1550 being the highest possible level of reservoir. This graph is further is used to evaluate the excess amount of water that is available every year on average for the purpose of irrigation.



Stage Relation curve gives us the idea of the water storage available in the dam at a particular reservoir level. The x-axis and y-axis show the storage capacity and the reservoir level, respectively. SRC of Tarbela dam has indicated at the elevation of 1392 feet, there is zero water available for regulation and at the height of 1550 feet it has maximum capacity of 6.7MAF. The water level will vary between 1392 feet to 1550 feet and live storage will undulate in between zero to 6.7MAF.

For the finding of profit generated in agriculture sector because of Tarbela dam, we have analysed the stage relation curve of Tarbela dam to get the storage capacity available for respective years. Afterwards profit in agriculture department per year is taken as $0.15 per cubic meters. Water available at respective years is simply multiplied by the cash value of water to get the profit of that year (Flood Forecasting Division, 2019).

Firstly, all the elevation depths of all respective years have been collected. Then the storage value of each year has been noted through the stage relation curve. The storage value of each year is multiplied by the cash value of water to get the profit in agriculture sector of those respective years.

The data available of reservoir elevation is not been found since 1977. So, we interpolated the values of depth by using the authentic data available from 2011 to 2019. The cost value of water $0.15 is taken lowest value of south east Asia to incorporate the losses of water till crop fields. This per cubic meter value is converted in per acre ft so to multiply directly with the total available storage (Merrett S. , 1997).

This value is calculated in terms of agriculture sector and we can simply use this value to calculate the benefits in the agriculture sector. The added water present in the Tarbela (Molden, 2001). The table on the next page shows the profits per year and cumlative valuesa as well.

Years	Reservoir Elevation	Available Storage	Cost per MAF/187.5$ per AF ($ US Million)	Cumulative benefits ($ US Million)
1977	1550	6.25	1171.875	1171.875
1978	1550	6.25	1171.875	2343.75
1979	1550	6.25	1171.875	3515.625
1980	1550	6.25	1171.875	4687.5
1981	1550	6.25	1171.875	5859.375
1982	1550	6.25	1171.875	7031.25
1983	1550	6.25	1171.875	8203.125
1984	1550	6.25	1171.875	9375
1985	1550	6.25	1171.875	10546.875
1986	1550	6.25	1171.875	11718.75
1987	1550	6.25	1171.875	12890.625
1988	1550	6.25	1171.875	14062.5
1989	1550	6.25	1171.875	15234.375
1990	1550	6.25	1171.875	16406.25
1991	1550	6.25	1171.875	17578.125
1992	1549.5	6.2	1162.5	18740.625
1993	1550	6.25	1171.875	19912.5
1994	1550	6.25	1171.875	21084.375
1995	1550	6.25	1171.875	22256.25
1996	1550	6.25	1171.875	23428.125
1997	1549.8	6.21	1164.375	24592.5
1998	1550	6.25	1171.875	25764.375
1999	1550	6.25	1171.875	26936.25
2000	1550	6.25	1171.875	28108.125
2001	1550	6.25	1171.875	29280
2002	1550	6.25	1171.875	30451.875
2003	1550	6.25	1171.875	31623.75
2004	1550	6.25	1171.875	32795.625
2005	1550	6.25	1171.875	33967.5
2006	1550	6.25	1171.875	35139.375
2007	1550	6.25	1171.875	36311.25
2008	1550	6.25	1171.875	37483.125
2009	1550	6.25	1171.875	38655
2010	1550	6.25	1171.875	39826.875
2011	1545	5.94	1113.75	40940.625
2012	1540	5.64	1057.5	41998.125
2013	1535	5.44	1020	43018.125
2014	1540	5.64	1057.5	44075.625
2015	1506	3.94	738.75	44814.375
2016	1535	5.44	1020	45834.375
2017	1543	5.64	1057.5	46891.875
2018	1545	5.94	1113.75	48005.625
2019	1545	5.94	1113.75	49119.375

Table 13 Annual profits due to water since 1977

Profit in each year is shown in the graph below. In 2015 a dip has been observed which is due to very less inflow in Tarbela in that year, so water storage has not reached to some maximum limit.

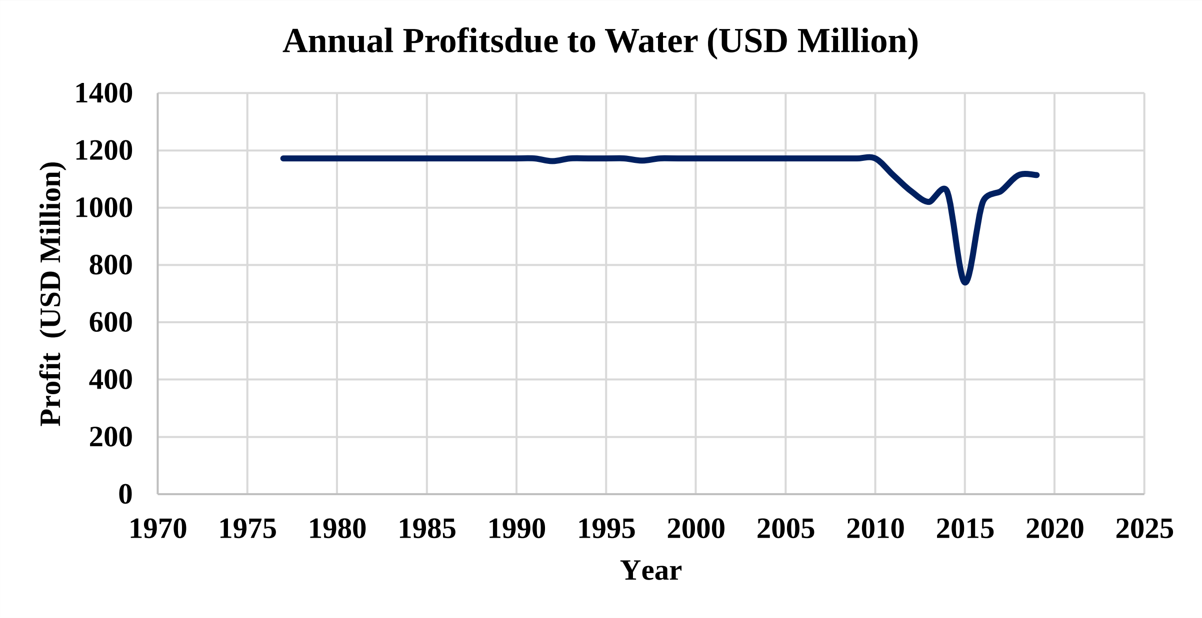


Table 14 Graph of Annual Profits due to Water since 1977

The graph below is depicting the cumulative profit, simply by adding the profit of each year.

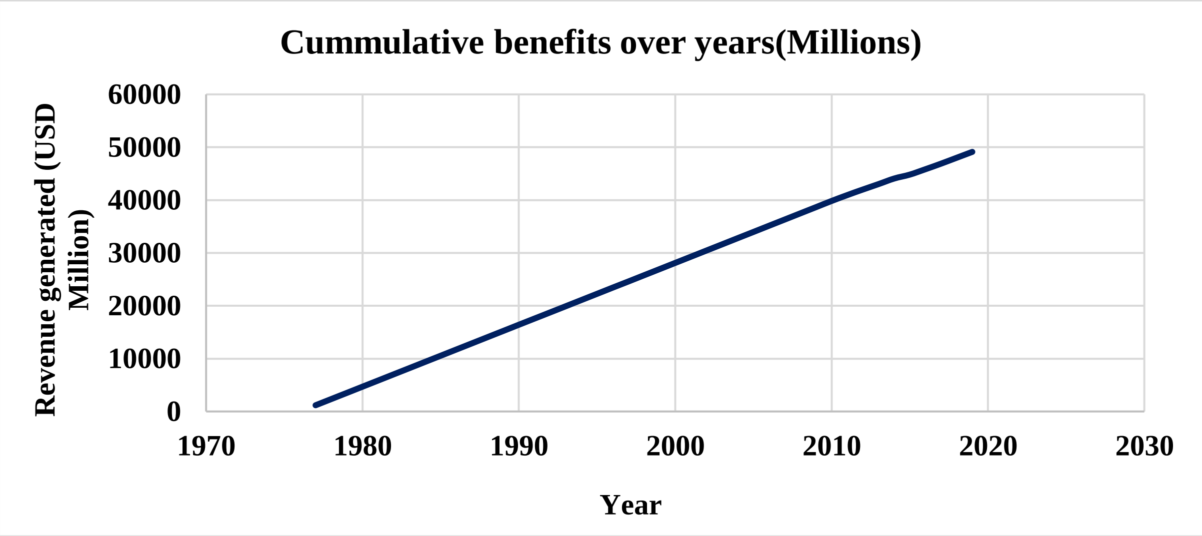


Figure 12 Graph of Recovery of Tarbela Dam's Cost by Agriculture

The value of water is about 10-20 % of the total revenue generated by the crop. By which we will have a profit of $879M in the year 2017 which is equivalent to $904M in the year 2020. If we continue to earn profit with this trend without any variation, then hypothetically we will be able to recover the cost of Diamer Bhasha dam in 13 years and Tarbela Dam in 6 years.

4.3 Power Generation

Before analysis, we arranged all the data of Power generated in front of their respective years. Three main analyses have been performed under this heading.

All the performed analysis has been done upon present cost and all monetary terms are in Dollars (2020). The electricity produced by Tarbela dam and profit generated has been calculated.

For this purpose, operational cost on 1MW has been calculated and multiplied by the total number of MW produced in that particular year. To avoid the over estimation, we used half electricity production for calculation of revenue generated. All the analysed data has been arranged in table form and graphs have been plotted using table's data. Upon x-axis Years has been placed and on y-axis profit generated by production of electricity has been plotted.

Upon analysis we noticed, Tarbela dam has completed its Capital cost in 15 years only from electricity production. Present cost of Tarbela $6.34 Billion has been received up to 1992. After that we are simply generating profit of $1078.6Millions every year.

Year	MV	Average Production	Profit of One Year	Cumm Profit in $Millions	Cumm Profit in $Billions
1977	700	350	217.0925806	217.0925806	0.217092581
1978	700	350	217.0925806	434.1851613	0.434185161
1979	700	350	217.0925806	651.2777419	0.651277742
1980	700	350	217.0925806	868.3703226	0.868370323
1981	700	350	217.0925806	1085.462903	1.085462903
1982	700	350	217.0925806	1302.555484	1.302555484
1983	700	350	217.0925806	1519.648065	1.519648065
1984	700	350	217.0925806	1736.740645	1.736740645
1985	1750	875	542.7314516	2279.472097	2.279472097
1986	1750	875	542.7314516	2822.203548	2.822203548
1987	1750	875	542.7314516	3364.935	3.364935
1988	1750	875	542.7314516	3907.666452	3.907666452
1989	1750	875	542.7314516	4450.397903	4.450397903

1990	1750	875	542.7314516	4993.129355	4.993129355
1991	1750	875	542.7314516	5535.860806	5.535860806
1992	**1750**	**875**	**542.7314516**	**6078.592258**	**6.078592258**
1993	3478	1739	1078.639994	7157.232252	7.157232252
1994	3478	1739	1078.639994	8235.872245	8.235872245
1995	3478	1739	1078.639994	9314.512239	9.314512239
1996	3478	1739	1078.639994	10393.15223	10.39315223
1997	3478	1739	1078.639994	11471.79223	11.47179223
1998	3478	1739	1078.639994	12550.43222	12.55043222
1999	3478	1739	1078.639994	13629.07221	13.62907221
2000	3478	1739	1078.639994	14707.71221	14.70771221
2001	3478	1739	1078.639994	15786.3522	15.7863522
2002	3478	1739	1078.639994	16864.99219	16.86499219
2003	3478	1739	1078.639994	17943.63219	17.94363219
2004	3478	1739	1078.639994	19022.27218	19.02227218
2005	3478	1739	1078.639994	20100.91217	20.10091217
2006	3478	1739	1078.639994	21179.55217	21.17955217
2007	3478	1739	1078.639994	22258.19216	22.25819216
2008	3478	1739	1078.639994	23336.83215	23.33683215
2009	3478	1739	1078.639994	24415.47215	24.41547215
2010	3478	1739	1078.639994	25494.11214	25.49411214
2020	4888	2444	1515.900000	-	-

Table 15 Profits due to Power Generation

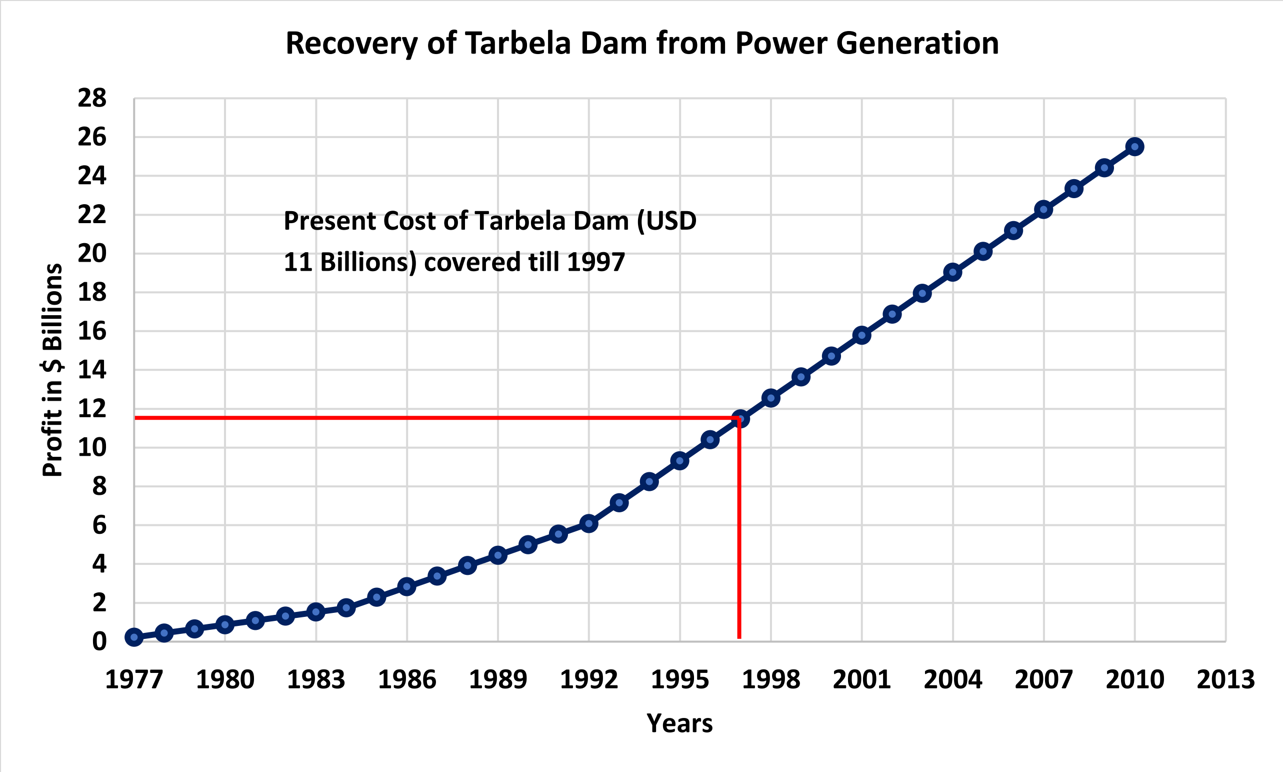


Figure 13 Recovery of Tarbela Dam's Cost by Power Generation

4.4 Annual Profits Generated by Tarbela (USD Million)

*Present worth of Tarbela dam: US $11 Billion

Function	No. of Years for Cost Recovery
Power Generation	20
Agriculture	11
Flooding	31
TOTAL (All 3 combined)	7.5

Table 16 Years needed to Recover Tarbela Dam's Cost in all Areas

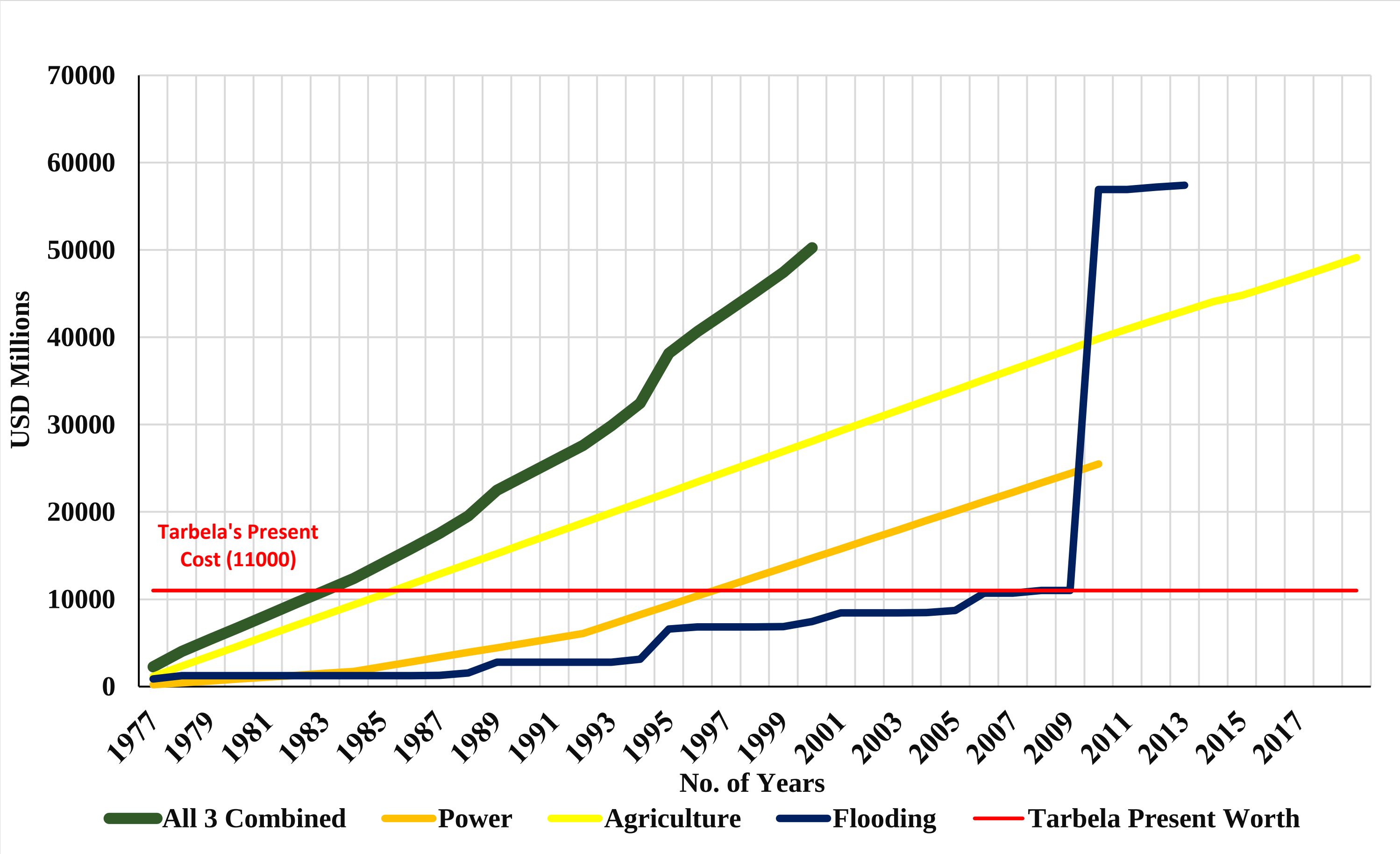


Figure 14 Combined Graph of Cost Recovery of Tarbela from all Areas

As shown in graph above, the benefits provided by Tarbela dam each have a different duration in which they will fulfil the present-day cost of the dam. The dotted red line marks the present-day cost of US $11 Billion of Tarbela. Above the line is the profit region only.

Cost Fulfilment and Profit Generation from Tarbela Dam (USD Millions)

Years	Annual Cost Recovery Flooding	Annual Cost Recovery Agriculture	Annual Cost Recovery Power	Annual Combined Recovery	Cumulative Combined Recovery
1977	877.1441	1171.875	217.0925806	2266.11	2266.112
1978	380.744	1171.875	217.0925806	1769.71	4035.823
1979	0	1171.875	217.0925806	1388.97	5424.791
1980	0	1171.875	217.0925806	1388.97	6813.758
1981	0	1171.875	217.0925806	1388.97	8202.726
1982	0	1171.875	217.0925806	1388.97	9591.694
1983	0	1171.875	217.0925806	1388.97	10980.66
1984	0	1171.875	217.0925806	1388.97	**12369.63**
1985	0	1171.875	542.7314516	1714.61	14084.24
1986	0	1171.875	542.7314516	1714.61	15798.84
1987	43.5428	1171.875	542.7314516	1758.15	17556.99
1988	269.6848	1171.875	542.7314516	1984.29	19541.28
1989	1222.4953	1171.875	542.7314516	2937.1	22478.38
1990	0	1171.875	542.7314516	1714.61	24192.99
1991	13.5783	1171.875	542.7314516	1728.18	25921.18
1992	0	1171.875	542.7314516	1714.61	27626.41
1993	0	1171.875	1078.639994	2250.51	29876.92
1994	312.5059	1171.875	1078.639994	2563.02	32439.94
1995	3484.5993	1171.875	1078.639994	5735.11	38175.06
1996	224.3727	1171.875	1078.639994	2474.89	40649.94
1997	0	1171.875	1078.639994	2250.51	42892.96
1998	0	1171.875	1078.639994	2250.51	45143.47
1999	40.4181	1171.875	1078.639994	2290.93	47434.41
2000	567.3472	1171.875	1078.639994	2817.86	50252.27
2001	997.12	1171.875	1078.639994	3247.63	53499.9
2002	0	1171.875	1078.639994	2250.51	55750.42
2003	19.9296	1171.875	1078.639994	2270.44	58020.86
2004	30.9351	1171.875	1078.639994	2281.45	60302.31
2005	217.8876	1171.875	1078.639994	2468.4	62770.72
2006	2006.4549	1171.875	1078.639994	4256.97	67027.69
2007	0	1171.875	1078.639994	2250.51	69278.2
2008	307.9587927	1171.875	1078.639994	2558.47	71836.68
2009	0	1171.875	1078.639994	2250.51	74087.19

Table 17 Complete Cost Recovery of Tarbela Dam

Graph of the table is plotted below.

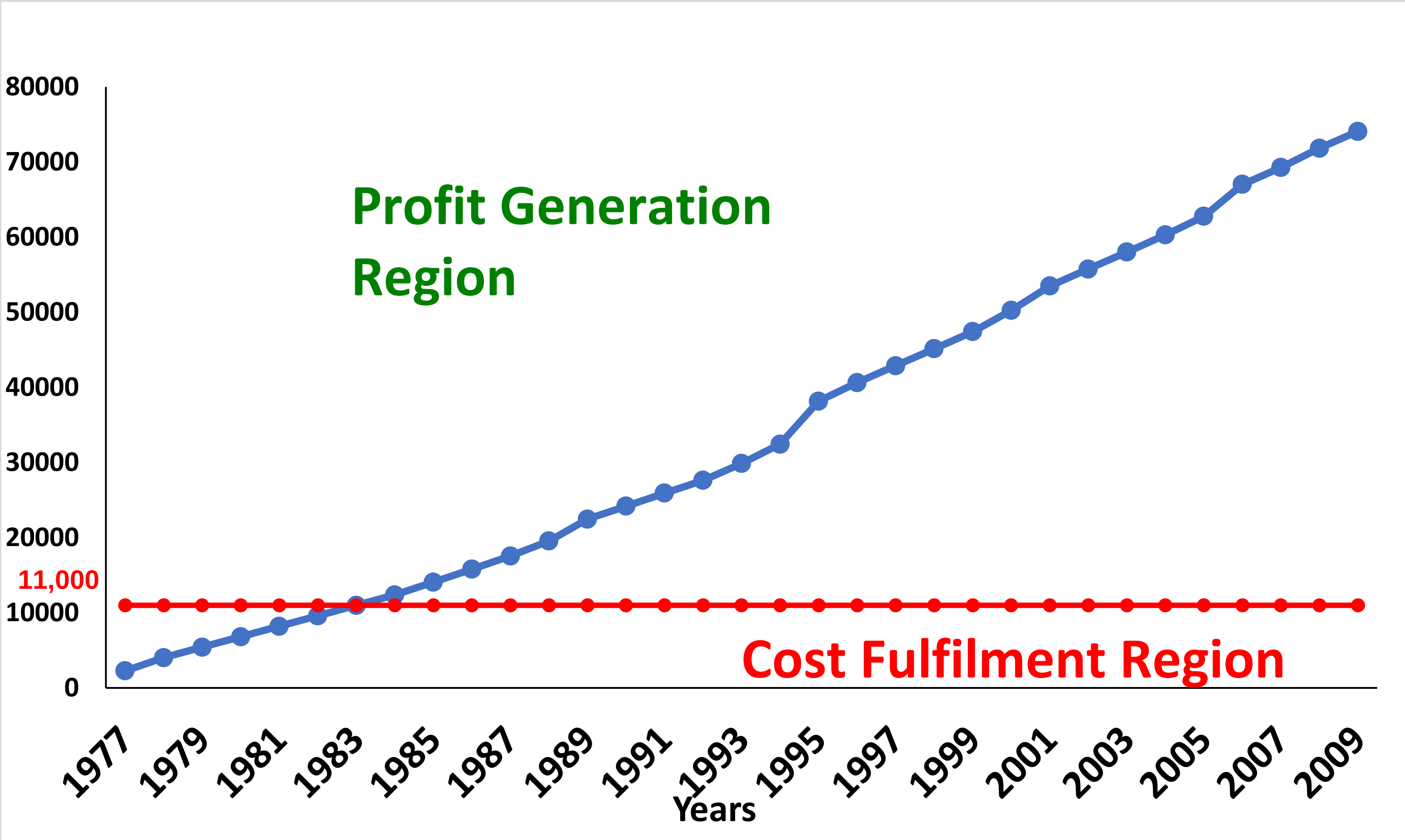


Figure 15 Overall Cost Recovery of Tarbela Combined

As shown in graph above, the combined benefits provided by Tarbela dam fulfil the present-day cost of the dam in almost 7.5 years. The dotted red line marks the present-day cost of US $11 Billion of Tarbela. Above the line is the profit region only while below it is the cost fulfilment region.

4.5 Diamer Bhasha Dam

Diamer Bhasha dam is under construction and its completion date is 2029. If we had built Diamer Bhasha in 2020 how we will be benefited from it, it has been analysed here.

For this purpose, operational cost on 1MW has been calculated and multiplied by the total number of MW produced in that particular year. To avoid the over estimation, we used half electricity production for calculation of revenue generated. All the analysed data has been arranged in table form and graphs have been plotted using table's data. Upon x-axis Years has been placed and on y-axis profit generated by production of electricity has been plotted.

Upon analysis we got more surprising results, that Diamer Bhasha has completed its Capital cost in just 9 years. The huge apparent amount of $14Billion can be recovered in no time only through its capacity of power generation. After 9 years we will be benefited by $1395Million every year and its pure profit.

Year	MW	Avg Production	Cost of One Year	Cumm. Cost in $Millions	Cumm. Cost in $Billions
2020	4500	2250	1395	1395	1.395
2021	4500	2250	1395	2790	2.79
2022	4500	2250	1395	4185	4.185
2023	4500	2250	1395	5580	5.58
2024	4500	2250	1395	6975	6.975
2025	4500	2250	1395	8370	8.37
2026	4500	2250	1395	9765	9.765
2027	4500	2250	1395	11160	11.16
2028	4500	2250	1395	12555	12.555
2029	**4500**	**2250**	**1395**	**13950**	**13.95**
2030	4500	2250	1395	15345	15.345
2031	4500	2250	1395	16740	16.74

2032	4500	2250	1395	18135	18.135
2033	4500	2250	1395	19530	19.53
2034	4500	2250	1395	20925	20.925
2035	4500	2250	1395	22320	22.32
2036	4500	2250	1395	23715	23.715
2037	4500	2250	1395	25110	25.11
2038	4500	2250	1395	26505	26.505
2039	4500	2250	1395	27900	27.9
2040	4500	2250	1395	29295	29.295

Table 18 Cost and Profit by Power Generation in Diamer Bhasha Dam

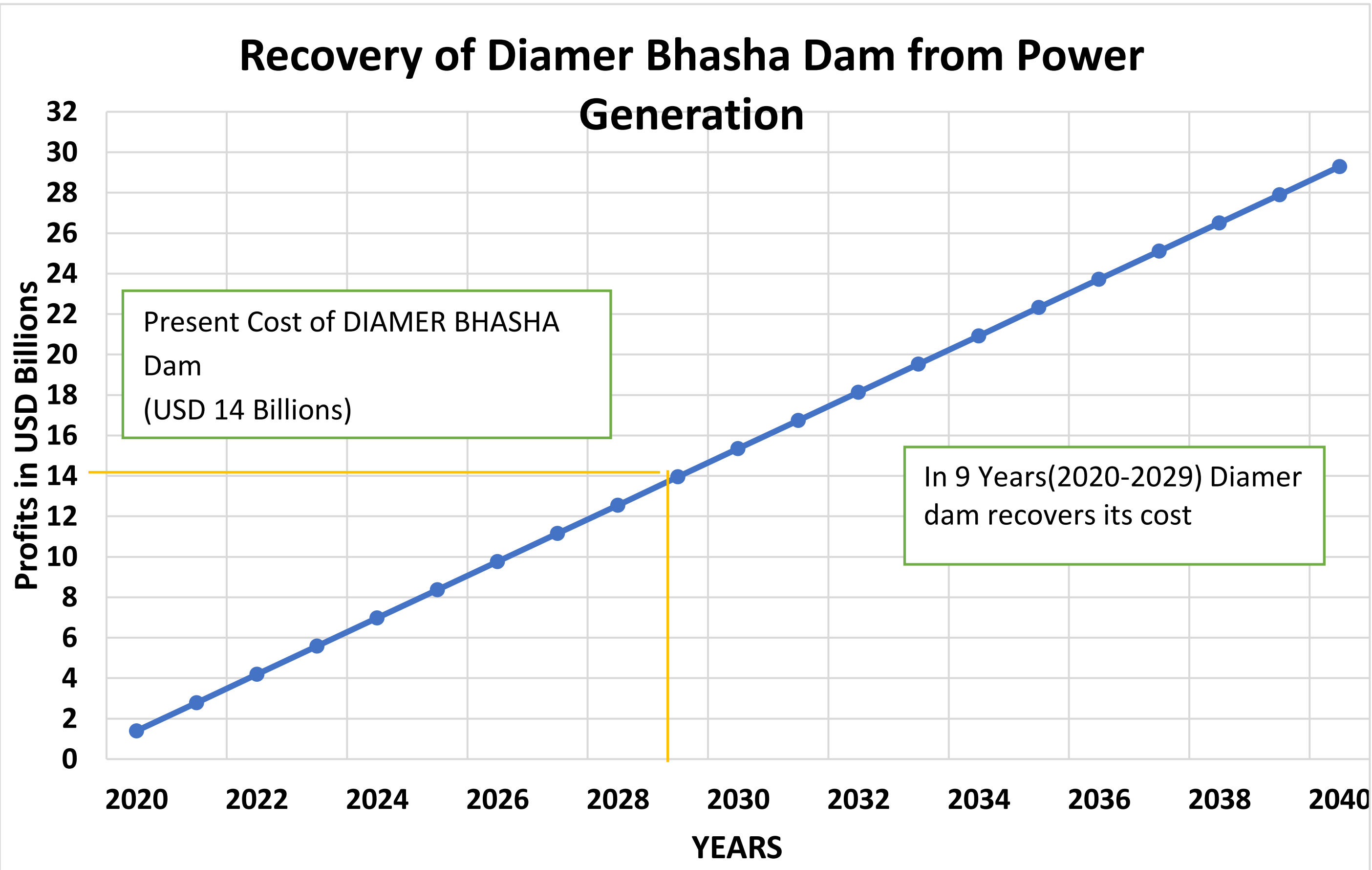


Figure 17 Cost Recovery of Diamer Bhasha from Power Generation

4.5.1 Effect of Diamer Bhasha on Tarbela

The construction of Diamer Bhasha dam does not only benefit the country directly but also adds to the beneficial impact of the dams and barrages downstream. The major advantage will be gained from its positive impact on Tarbela Dam which is currently the largest dam of Pakistan. In an interview with Dawn, the general manager of Tarbela dam provided the information that the live capacity of the reservoir of Tarbela is 6.43MAF as of 2015. This is after a 33.5% reduction from Tarbela's initial live capacity of 9.7MAF in 1976. The decrease in its capacity is due to the major problem of sedimentation but that will be relieved as the Diamer Bhasha dam will also act as a silt trap, reducing 69% of the incoming sediments to Tarbela (Roca, 2012).

Consequently, the potential life of Tarbela will be increased by 35 years (Muazzam Sabir, 2018). Recent studies have shown that the expected life of Tarbela Dam is till 2050. According to the above mentioned statistics, the Tarbela dam will then remain functional till 2085.

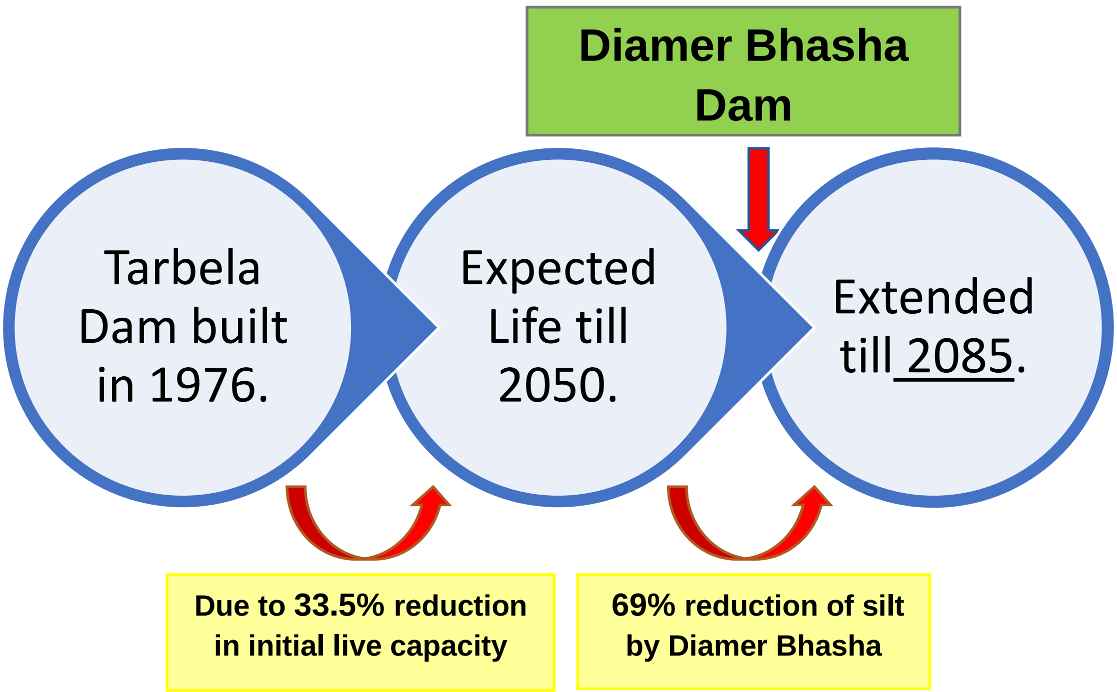


Figure 18 Diamer Bhasha and Tarbela Infographic

Power

Current power generation capacity of Tarbela Dam = 4888MW (2020)

Profit generated through average power production in 1 year = $1.5159 Billion

Profit generated from 2050 to 2085 = (35) x (1.5159)

= $53 Billion

Agriculture

Land irrigated by Tarbela Dam = 44.5 MA (Lieftinck Report, 1968)

Average profit per acre = $\frac{14.8 \text{ (Kharif)} + 16.8 \text{ (Rabi)}}{2}$

= $15.8 (2017)

= $ 16.53 (2020)

Total profit in 1 year = $16.53 x 44.5 MA

= $735 Million

Profit from 2050 to 2085 = 35 x $735 million

= $25 Billion

Flooding

Presence of large dams have alleviated flood levels and brought considerable reduction in floods each year. The graph above showed that the value of the damages secured in 11 years is US $5.652 billion. This value does not include the cataclysmic floods of 2010. Those alone wrecked damages of around US $122.5 billion.

As stated above, the construction and operation of Diamer Bhasha dam will reap many positive impacts on Tarbela. Most significant of which is the extension of Tarbela's life by 35 years. This will allow the dam to remain useful for 35 more years. The dam's life will increase from the previously calculated ending period of 2050 to 2085. This means that for additional 35 years, Tarbela will also play part in flood mitigation and damage protection besides other purposes.

Damages secured by Tarbela in 10 years ≈ US $5.625 Billion

Damages secured by Tarbela in additional 35 years ≈ US $20 billion

4.5.2 Added profit from Tarbela Dam (2050-2085) due to Bhasha Dam

	Profit per Year	Profit in 35 Years ($Billion)
Power Generation	1.5	53.06
Agriculture	0.736	25.75
Flooding	0.707	24.74
Total	2.94	103

Table 19 Added Profit from Tarbela to Diamer Bhasha

4.6 No Dams Scenario

Temporal Analysis

To see how much dams' alternatives are expensive, a temporal analysis is carried. Suppose a reservoir equal to that of Tarbela dam i.e. 9.68 MAF (421661x10^6 cft) is to be filled by an alternative 2 cusec diesel pump. Present worth of operating the mentioned pump for 1 hour is $4.6.

Now, the total time required for filling the reservoir with the pump is:

$$t = \frac{V}{Q}$$

$$= \frac{421661 \times 10^6}{2}$$

$$= 2.108x10^{11} \text{ sec}$$

$$= 5.856x10^{7} \text{ hours}$$

So, Total cost to fill reservoir once with pump is:

$$\text{Cost} = (\$4.6) \text{ x } (5.856x10^7)$$

≈ $270 Million

As a reservoir is filled approximately 1.25 times per year so, total cost per year for filling the reservoir is:

Total Cost Per Year = (1.25) x ($270 Million)

≈ $505 Million

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

5. Conclusions and Recommendations

5.1 Conclusions

The primary function in which the cost is fulfilled the earliest is of power generation which is responsible for doing this in a short period of 20 years. This is followed by agricultural profits that fulfil the dam’s cost in almost 11 years. Lastly, by securing the flooding damages, the dam will take almost 31 years to fulfil the cost of Tarbela Dam during which there were many years where there was no need to secure damages. This clearly shows that the accusations of large amounts of money being wasted in building dams as no considerable benefits are achieved are baseless.

A dam with a level of Tarbela always has the capacity to carry out all 3 functions; there isn’t any need for separate calculations. If all the three functions are all considered together then the cost of Tarbela is fulfilled in only 7.5 years. This is less than 10 years. After this all the money generated comes as profit. Therefore, the cost is covered as shown by the analysis above. The next 40-50 years of a dam’s life are used in profit generation completely. This is precisely put in the graph below.

If a dam as huge and functional as Tarbela has the potential to cover, it’s costs within 9 years then Diamer Bhasha would see no problem at all. Large dams are without any question the need of the time for Pakistan. It must build large dams to ensure a prospering economy.

5.2 Recommendations

- The dam projects for which the feasibility studies have been done need to be executed. There are more than a few dam projects that are not being able to enter the implementation phase due to political and social reasons overriding economic ones.
- The domain of flood control and mitigation must be given due consideration in the construction of dams. Besides power generation and water regulation, this purpose needs to be addressed also.
- It is pivotal to conduct thorough environmental and social studies and analysis before dam planning and construction in area. If these factors are overshadowing the benefits, then the plan needs to be reconsidered.

- The duration of the project life cycle of a dam should be controlled to such an extent that the project does not cease in its development or construction phase.

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