OPTIMIZATION, DESIGN AND RELIABILITY ANALYSIS OF A MINI HYDROPOWER PLANT IN KANJIRAPPALLY, KERALA

Submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology

In

Civil Engineering

by

ILA HARI

16BCL0017

SHASHANK GOSWAMI

16BCL0025

ADITI SAUMYA

16BCL0041

Under the guidance of

Dr. Pavan Kumar Kummamuru

SCE

VIT, Vellore

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DECLARATION

We hereby declare that the thesis entitled "Optimization, design and reliability analysis of a mini hydropower plant in Kanjirappally, Kerala" submitted by us, for the award of the degree of Bachelor of Technology in Civil Engineering to VIT is a record of bonafide work carried out by us under the supervision of Dr Pavan Kumar Kummamuru.

We further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

Place : Vellore

Date : 22-05-20

Signature of the candidates

16BCL0017

16BCL0025

16BCL0041

CERTIFICATE

This is to certify that the thesis entitled "Optimization, design and reliability analysis of a mini hydropower plant in Kanjirappally, Kerala" submitted by Ila Hari (16BCL0017), Shashank Goswami (16BCL0025) and Aditi Saumya (16BCL0041), SCE, VIT, for the award of the degree of Bachelor of Technology in Civil Engineering, is a record of bonafide work carried out by them under my supervision during the period 01.12.2019 to 15.05.2020, as per the VIT code of academic and research ethics.

The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university. The thesis fulfils the requirements and regulations of the University and in my opinion meets the necessary standards for submission.

Place : Vellore

Date : 22-05-2020

Signature of the Guide

Internal Examiner

External Examiner

Head of the Department

School of Civil Engineering

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Ila Hari

Shashank Goswami

Aditi Saumya

EXECUTIVE SUMMARY

This study focuses on the design of a mini hydro power plant in Kerala. The hydro power plant addresses the issue of sustainability so that the load on the conventional sources of energy is reduced. In this project, electricity is generated from water from two sources, rainfall and water from a nearby river named Manimala. The catchments study is done in detail through SWAT analysis in QGIS. A mathematical model to run turbine, decide storage and provide water for domestic purposes is made. The seasonal variation of data is observed. Daily optimization is done in MATLAB to see that the storage can store the water available from daily rainfall and also has enough water for running the turbine and the dimensions of the head pond are selected. The mechanical parts of the turbine are also discussed. The flow rate analysis of the river is done and an FDC is drawn. The cost benefit analysis is done keeping in mind the investments and the revenue of the power plant. The B/C ratio is calculated for 40 years to see the profitability of the plant. The reliability analysis is also done by calculating a reliability index, LOLE with the rainfall values from the years 2007-2016.

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List of abbreviations

WHO	World Health Organisation
W	Watt
kW	Kilo Watt
MW	Mega Watt
SWAT	Soil Water Analysis Tool
B/C	Benefit/Cost
SHP	Small Hydropower Plant
MNRE	Ministry of New and Renewable Energy
EIA	Environmental Impact Assessment
CN	Curve Number
SCS	Soil Conservation Service
FDC	Flow Duration Curve
TSS	Total Suspended Solids
DEM	Digital Elevation Model
O&M	Operation and Maintenance
AC	Alternating Current
CBA	Cost Benefit Analysis
UNIDO	United Nations Industrial Development Organization
LOLE	Loss Of Load Expectation

Symbols and Notations

Q	Runoff or Flowrate
P	Rainfall
S	Potential maximum soil moisture retention after runoff begins
I_a	Initial Abstraction
P	Power generated
η	Efficiency of the system (85%)
γ, g	Acceleration due to gravity
H	Head
D	Outer diameter
D	Hub diameter
φ	Flow ratio
μ	Flow velocity
K_u	Speed ratio
N	Specific speed

1. INTRODUCTION

1.1 Objectives

India is rich in minerals and energy related sources. Be it hydropower or solar energy India has been reaching out to newer domains with the world wide culture pressing on the fact of sustainable environment. India is gearing up for sustainable energy uses as directed and propagated by the WHO. The key aim to ensure sustainability methods is to see that the carbon intensity of the energy is overall reduced and hence the pollution capability will also reduce. Another big advantage of using renewable energy resources is to help make the rural areas capable of producing high output of electricity without the need of big transmission lines.

The objective of our project is to design a sustainable mini hydropower plant in the town of Kanjirappally, Kerala. Optimization and analysis of the power plant is also a part of our project. It also aims in providing a section of the water collected, to the population of the town for basic domestic water needs after a primary treatment.

1.2 Motivation

As energy is the building blocks of today's world, renewable energy is the widespread study material for the engineers now. Energy with the proper use of renewable sources and the proper optimization will be a better use in the next generation. India's renewable sources seem to be an unlikely fit with the shortage of new age technology in India's domain. The demand for new age technology is increasing day by day with micro small and medium industries in the village being dependent on electrification of rural villages for the growth of their industries. Another point which has been delivered upon is that renewable energy will progress the route of reducing the green house emission gases. The use of renewable energy is what scientists are propagating these days and hence an ample amount of studies is doing rounds with new inventions. In the world, around 2.8 billion people live without electricity and still depend on conventional use of energy such as coal, charcoal, dung, wood for cooking. [7] The clean energy is replacing renewable energy and is growing at 2.3% every year in the world. [1]

The fact that China has successfully implemented sustainability in renewable energy sources with huge building of small hydropower plants gives us ample boost to work towards this project. The technology used in these projects are local and takes us back to the age where flour was prepared by big grinding wheels that were powered by small streams in the villages. So that encourages us to bring small mini hydropower plants in rural areas where the rehabilitation and resettlement problems are less.

In India the situation is not very promising till now, only 55% of the households have access to electricity. Around 80,000 villages still need to be in the grasp of electricity. As per Indian research around 25% of the land of our country is inaccessible or poses difficult terrain. With high mast transmission lines and with that a huge amount of losses, laying of big electricity grids in remote places is difficult.

According to NITI Aayog, Kerala has potential of running hydro power plants 0f 6.6 GW. Kanjirappally is one of the places in Kerala having high annual rainfall. The main motive of this project is to harness this water from rainfall and a nearby river called Manimala and provide for the energy needs of the section of a society in Kanjirappally, Kerala. The energy made is renewable, thus making it a sustainable source. The electricity generation by renewable sources has increased from 5.6% of the total electricity generated by Indian utilities in 2016 to now at 8% during 2018. [2] We aim at contributing to the motive of the government to produce more renewable energy.

1.3 Background

Hydro power plants are a major backbone of any economy. It needs huge infrastructure but it clearly solidifies a country's investment. The glaciers of the Himalayan origin feed well to the rivers of India. They make sure that the rivers are perennial in many parts of India including the Gangetic Plain. Perennial rivers underscored with a big monsoon season, provides India with a unique opportunity to develop many hydropower projects. India occupies 6th position out of all the countries in the world in terms of installed hydropower capacity. [3] To keep the pace of growing into a developed economy India needs to let go of the brakes and go full gear into the sustainable power projects as it needs to fulfill the demands of the most populated country by 2050. However, many traditional businesses and even industries are using coal or any the fossil fuels to power it. With surging prices of coal, the world needs an alternate to nonrenewable source of energy. Hydropower projects are hence considered as an attractive area of investment and sustainable energy goals. Large hydropower projects are facing backlash due to an extensive amount of investment and less public private partnership to build more than 100MW in rural areas. The villagers also do not consent on building such large projects as they infer it as a threat to destroy their local environment. Environmentalists also have their own say in the building of large dams where they see it as deforestation and local flora and fauna getting disturbed.

Reading about these inspired us to think of a mini hydropower plant which can easily contribute to the energy demands of a small society like a village or town, without causing any harm to the surrounding environment. This lead to the optimization, design and analysis of a possible mini hydropower plant that can be built near the town of Kanjirappally, one of the places having highest annual rainfall in Kerala.

2. PROJECT DESCRIPTION AND GOALS

The project is a take on renewable energy with sustainable methods of optimization and reliability analysis. Our project will include designing of a mini hydropower plant in Kanjirapally, Kerela. The project used the concepts of choosing the preferred site using manual calculations and elevation analysis using Google maps. The delineation method option was used which is a preinstalled function in Q-GIS SWAT analysis (Soil Water Analysis Tool) to identify the catchments contributing to the storage tank or head pond and in due steps their outlet points were identified. A mathematical model for finding the optimal size of the head pond was generated. Making use of optimization function in MATLAB, the model was run and with this, the dimensions of the tank were fixed. The mechanical support of the hydropower plant was calculated manually, looking at the elevation and the desired output of the plant. The properties of the penstock, turbine has all been discussed vividly in this project. Later the reliability analysis of the power plant was done taking into account the rainfall in the area and the flowrate of the river for the last 10 years. The final output which concluded the project was the calculation of the B/C ratio, which helps us understand how profitable the project is.

Goals:

- Design of a mini hydro power plant with reliability and cost benefit analysis.
- Provide for the basic domestic water needs for a section of Kanjirappally.

3. TECHNICAL SPECIFICATION

Small hydro is the development of hydroelectric power on a scale serving a small community or industrial plant. The definition of a small hydro project varies but a generating capacity of up to 10 megawatts (MW) is generally accepted as the upper limit of what can be termed small hydro.

SHPs (Small Hydro power plants) can distribute power to local areas at a cheap cost and can emit a low amount of greenhouse gases. It has the most energy payback ratio when compared to electricity generation systems. [4] In India, the SHPs occupy a major place in the renewable sector of energy. They contribute as the second largest share to the energy sector after wind power. They don't require storage or backup systems with no or minimum ecological problems. The large hydropower plants create environmental hazards such as bad water quality, ecosystem destruction, biodiversity loss and inadequate environmental flow. [5]

SHPs are defined and classified in different categories in the world. The SHPs are classified in India as:

- 0-100kW – Micro hydropower plant
- 101-2000 kW – Mini hydropower plant
- 2001-25000 kW -- Small hydropower plant

The SHP is India are managed and constructed by the MNRE (Ministry of New and Renewable Energy). In India the SHP are exempted from getting all the environmental clearances and the process of EIA (Environmental Impact Assessment) with some conditions. However, research suggests that some conditions of environmental clearance is very much needed in the country to prevent unplanned and haphazard development of the projects sanctioned. Policies at the grass root level needs to be framed by the government so that consulting and contractors operate within a policy framework. [6]

This project deals with a mini hydropower plant. It is the type having a power range of 100kW to 1MW. The main components of it are:

3.1 Head pond or storage tank

It is a small-sized reservoir mainly for the purpose of storing the collected water. Another purpose of the headpond is to distribute evenly the water conveyed by the power canal among the penstocks and, at the same time, to regulate the power flow into the latter, as well as to ensure the disposal of excess water. The storage capacity of the headpond tends to drop of water level in case of sudden load increase. Headponds having a storage capacity may even provide daily storage for the plant. Water from here goes down to the turbine through penstock to generate electricity. The bottom of the headpond is governed primarily by topographic conditions, the geology of the site should be considered. The site of both the headpond and the powerhouse should be selected simultaneously with a view to ensure the shortest possible penstocks.

3.2 Penstock

A penstock is used to control the flow or level of a liquid and consists of a sliding door controlled by a mechanically operated spindle, which moves over an aperture in a frame, which in turn is secured onto a structure. 'Sluice gate' is more descriptive of the product, and this term is used widely in specifications outside the UK. The word 'penstock' originates from the days of water mills when it was not uncommon for a pond (stored or 'penned up' water), which was used to feed the water wheel or mill race to be referred to as the 'pen'. The timber stop logs used to control the flow onto the water wheel was called the 'stock'. Later, as the need to accurately control the velocity of the water wheel became more critical, a single sliding gate operated by a lifting mechanism replaced the stop logs with their individual sections. During the 17th century, the words 'pen' and 'stock' became combined into a single word – Penstock.

The great majority of penstocks at hydropower projects are steel. Older steel penstocks tend to be riveted plate; newer penstocks are typically spiral-wound welded plate. Woodstave penstocks are also used at hydropower projects to a lesser extent. These are typically constructed of creosote treated wooden strips called staves ringed with steel bands. The bands are typically spaced at about 1 ft. or less. Woodstave penstocks are limited to low internal pressures. [19]

3.3 Turbine

Turbines are devices used in hydroelectric generation plants that transfer the energy from moving water to a rotating shaft to generate electricity. These turbines rotate or spin as a response to water being introduced to their blades.

While there are only two basic types of turbines (impulse and reaction), there are many variations. The specific type of turbine to be used in a power plant is not selected until all operational studies and cost estimates are complete. The turbine selected depends largely on the site conditions.

A reaction turbine is a horizontal or vertical wheel that operates with the wheel completely submerged a feature which reduces turbulence. In theory, the reaction turbine works like a rotating lawn sprinkler where water at a central point is under pressure and escapes from the ends of the blades, causing rotation. Reaction turbines are the type most widely used.

An impulse turbine is a horizontal or vertical wheel that uses the kinetic energy of water striking its buckets or blades to cause rotation. The wheel is covered by a housing and the buckets or blades are shaped so they turn the flow of water about 170 degrees inside the housing. After turning the blades or buckets, the water falls to the bottom of the wheel housing and flows out.

Hydroelectric power works to harvest the inherent energy of moving water by directing the water through turbine converting the energy of the moving water into mechanical energy. The mechanical energy is then converted into electricity in the generator. In order to choose the appropriate turbine for a specific application, the flow rate and pressure head of water source must be known. Hydropower on a small-scale is one of the most cost-effective energy technologies to be considered for rural electrification in less developed countries. [20]

3.4 Power house

This serves as an Engine room. It protects the turbine, generator and other electrical/machinery equipment. It could also have a workshop/office/sanitary and other facilitates. Water after the generation of electricity is allowed to flow back into the river through a tail race from here.

4. DESIGN APPROACH AND DETAILS

4.1 Materials and methods

This project was carried out in 5 steps.

- Selection of site – A potential site for the mini hydropower plant was selected based on the following studies.

    - Rainfall Analysis: Rainfall data for the state of Kerala and a place with the highest annual rainfall was identified.
    - Flowrate analysis: Nearest river to the place was identified and its flowrate availability was checked.
    - Topographical Analysis: With the help of Google Earth and QGIS, different catchments in the area and their outlet points were identified. This helped in the selection of site of the headpond.
    - Population study: From a trustable source, the population of the site was collected.
    - Energy demand per household: Energy needed by each household per day is first calculated considering the average amount of time each of the devices will be used in a day. Considering 10% growth and 5% loss, the total energy was calculated.

- Optimization – This step was used to find the optimal size of the head pond that need to be used.

    - Generation of a mathematical model for input from the river and run-off: A mathematical model was made with an objective to minimize the cost of construction of the head pond with different constraints. The model was run with the help of optimization function in MATLAB and results were obtained.
    - Seasonal variation of input: The optimization model was based on daily rainfall and Flowrate data to account for the seasonal variation of water availability.

- Design – With the results obtained from the above steps, the components of the mini hydropower plant were designed.

    - Design of head, head pond and penstock: Head was calculated based on the topography data available. With the help of MATLAB Optimization results, dimensions of the headpond were calculated. Based on the potential location of the power house with turbine, the penstock lengths were determined.
    - Design of turbine: Considering the value of the head, a suitable type of turbine was selected and its design specifications were calculated manually.

- Cost Benefit Analysis: This step helped us determine how profitable the power plant is.

- Total cost estimation: With research, equations were obtained for cost functions of different types of turbines. These equations used two variables, head and power. With the help of this, total installation cost was calculated.
- Calculation of benefits: Different tangible and intangible benefits were identified. The tangible benefits were converted in terms of rupees to calculate the B/C ratio.
- Calculation of B/C ratio: Using appropriate equations, the B/C ratio, which gives how economically reliable our power plant is, determined.

* Reliability Analysis: With the help of Excel worksheet, the reliability of the mini hydropower plant was calculated over a period of 10 years. The rainfall and flowrate data were made use for this calculation.

5. SCHEDULE, TASKS AND MILESTONES

Table 5.1: Review 1 schedule

S No.	TASKS	Time taken	Milestone achieved on (date)
1.	Rainfall availability	2 days	06-12-2019
2.	Flowrate Analysis	6 days	12-12-2019
3.	Topographical analysis	One week	10-01-2020
4.	Population study	3 days	15-01-2020
5.	Energy demand per household	4 days	20-01-2020
6.	Preparation for review 1	1 day	21-01-2020

Table 5.2: Review 2 schedule

S No.	TASKS	Time taken	Milestone achieved on (date)
1.	Generation of a mathematical model for input from river and runoff	Two weeks	11-02-2020
2.	Seasonal variation of input	3 days	19-02-2020
3.	Design of head, headpond and penstock	4 days	25-02-2020
4.	Design of turbine	4 days	02-03-2020
5.	Preparation for review 2	2 days	04-03-2020

Table 5.3: Review 3 schedule

S No.	TASKS	Time taken	Milestone achieved on (date)
1.	Total cost estimation	4 days	12-03-2020
2.	Calculation of benefits	4 days	27-04-2020
3.	Calculation of B/C ratio	5 days	04-05-2020
4.	Reliability determination	5 days	08-05-2020
5.	Preparation for review 3	One week	16-05-2020

6. PROJECT DEMONSTRATION

6.1 Selection of site

6.1.1 Rainfall and flowrate availability

Kanjirappally is the site selected for our project. It is a town in Kottayam district situated about 38 km (24 mi) away from the district capital, in the state of Kerala. The place is also known as the Gateway of the Highrange as it is the entrance to the 'Malanad' or the Hill country of Kerala that extends to Idukki district and then to Tamil Nadu. Kanjirappally boasts the highest number of rainy days in Kerala. The place receives the highest amount of summer rains, winter rains and Northeast Monsoons (Thulaam Mazha) in Kerala, making it one of the very few places in India enjoying equatorial rainforest type climate, with no distinct dry season. The average annual rainfall is 4156 mm. It is bordered by the Western ghats in the east and the Vembanad lake in the west. The Kottayam district is located in the basin of the Meenachil River.

The mini hydropower plant is to be situated in Kanjirapally, Kerala. The place was chosen because it's a recipient of a high amount of rainfall in Kerala. The daily rainfall data in mm was collected from the government site from the last 50 years. The rainfall data of the last 50 years collected was used to produce a Flow duration Curve for the Manimala River. The discharge value of river was calculated for a period of 7 years, i.e, from 2010-2016 and the FDC curve was drawn for this data. For getting the flow rate of the river, first the catchments contributing to the flow of the river was found out using SWAT Analysis in QGIS. Then, the runoff for each day was calculated using SCS method. The CN value that we chose was 80 with due exploration of the soil type and the land use. This method made use of daily rainfall data. After getting the runoff, it was multiplied with the total area of catchments, which came out to be 84,00,40,000 m^2 and divide by the total time (in seconds) to find out the daily flowrate of the river. The SCS method was quite compatible with the research that we were doing. After getting the runoff from the SCS method, the FDC curve was plotted using Excel.

Most agricultural, hydrological and ecological models require long input of daily rainfall as the input. However, in reality the data series are too short in many sites in the recording stations to measure a good estimation of the probability of the extreme events. These types of data to map out the extreme data are simply unavailable. This has led to the formation of various stochastic models or weather generators. They are compared with the previous data of rainfall. [37]

In the stream gauges, we have to provide information for the management of water resources. However, the stream gauges cannot be applied at every location. Therefore, the storm management cannot be done very easily. Daily stream flow estimation can also be done at ungauged stations by using statistical approaches based on the available data at the gauged stations. Among the various statistical approaches FDC method is the best. [12]

One of the studies explicitly says that the SCS method is one of the most commonly and widely used method in the estimation of the watershed flood hydrograph ordinates. Also being widely used for its simplicity, the easy availability of the model's inputs with numerous outputs suggests that it can be easily used. It gives a number of outputs such as peak discharge of flood, time to peak, lag time and flood time. Many models derive the input data to their models from this method. The input to any SCS model includes the precipitation, time of concentration, watershed area and the CN number. [13]

The CN number is a parameter which is used in hydrology to predict the runoff and infiltration from the precipitation. The method was developed by Soil Conservation Service (SCS) and the CN number is also called SCS runoff curve number. The number is based on the soil conditions of the area, land use, treatment and hydrological condition.

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \qquad \text{...... (6.1)}$$

Where:

$S = \frac{1000}{CN} - 100$ And $I_a = 0.2S$

The study indicates that when the time of concentration is small, the infiltration has also less potential, loss of the precipitation is low, the slope angle is more and the peak discharge at the outlet increases. The parameter that has the largest influence on the peak discharge is the curve number (CN). When the curve number is increased, the peak discharge increases exponentially. This brings us to the conclusion that the soil type and the land use greatly influences the flow discharge. [13]

For analysis where the person designing the hydropower plant does not know the hydro potential of the river in question, FDC tells us about the potential of the river by ordering in a rank the maximum flow to the minimum. The area inside the FDC shows the measure of the energy potential of the river.

The FDC was drawn with the help of excel with arranging the data from the highest to the lowest and ranking them. The percentage exceedance was found with the appropriate formula. The FDC plotted was as follows.

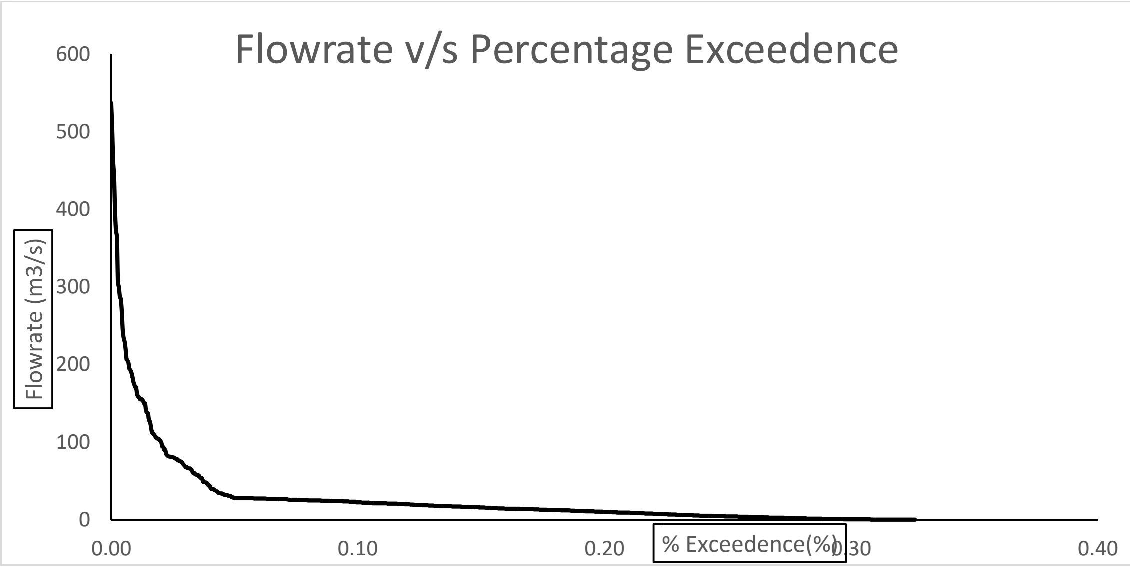


Fig 6.1: FDC of Manimala River

Manimala River: The Manimala River has a total length of about 90km. The river is devoid of any major reservoirs. It originates from the Thattarmala hill which has an elevation of about 1156m above sea level. The river exhibits a dendric drainage pattern. The river basin, the Precambrian crystallines are intruded at many places by acidic and basic rocks. The analysis of the river data tells us that 1941 m^3/s of water and 79545 tons of sediment (15137 tons sand and 64408 tons of mud) are discharged through Manimala River annually. About 65% of water discharge occurs during the monsoon period which is recorded during the months of May and June. The pH and the conductivity values of the water are high in the months of the monsoon. The TSS content was also five times higher during the months of south west monsoon season than the other months. [11]

6.1.2 Topographical analysis

With the help of Q-GIS and Google Earth different catchment areas and their outlet points were identified. Different characteristics of the Catchment areas were also identified.

Q-GIS and SWAT analysis

SWAT is a tool which is used in all major water resource projects. The major uses of the software are to assess the stream flow, agricultural chemical distributions, evaluating the non-point source pollution, impacts of climate change on the watershed management. The water balance equation is the primary driving force of the SWAT model analysis.

SWAT Analysis method:

- Prepare the data into the required formats to be put in the SWAT model. The WGS84 is used as the horizontal datum. The required data was realigned with WGS84 from whichever format we have.

- The land cover data and DEM (Digital Elevation Model) were drawn out into the ArcGIS.
- Delineation of the watershed was done using the inputs from the datasets.
- Write the input data tables into the database and then used for the entire SWAT modeling process.
- SWAT analysis was done daily from and to the require dates. In this project, the daily rainfall from the last 50 non leap years was taken into consideration.
- For better results, the calibration of the ArcGIS was done. The 11 parameters, adjusting the sensitivity analysis from the SWAT Calibration and Uncertainty Programs (SWAT-CUP) outputs were calibrated.
- After calibration, the validated DEM was used as the input file to create delineated areas and hence the results of the data set were obtained.

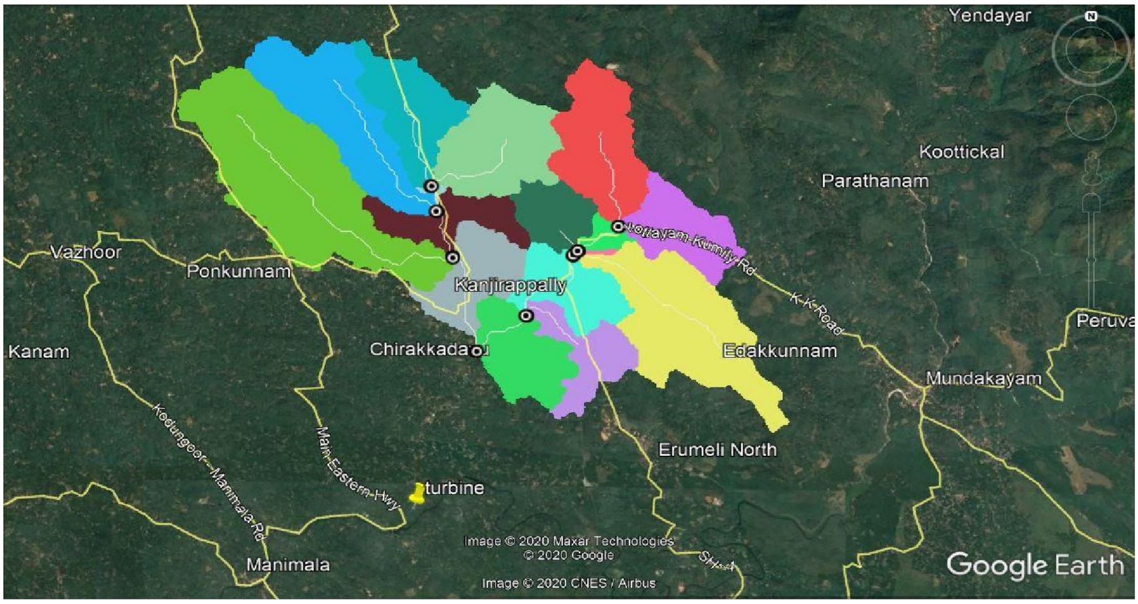


Fig 6.2: Catchments studied by SWAT Analysis

Geography, climate and land use of Kanjirappally: The average elevation of the area is 3 meters above sea level. Kottayam is classified as a mainland area. The general type of soil is alluvial soil. The vegetation found is mainly tropical evergreen and deciduous.

The area of Kanjirapally is subjected to two monsoon seasons, the south -west monsoon between June to August and the north-east monsoon between October and November. The dominant on is the South-west monsoon season which brings most amount of rainfall to the area. The average annual rainfall is 3,200 millimeters. The temperature in the area varies between 15.2° C and 25°C. The minimum temperature is at the time of November to January and the maximum temperature occurs during February to May. The level of humidity in the area is around 57%.[10]

More than 50% area in Kanjirappally is under mixed dense forests and the other major part of the area is utilized for human settlement. The major crops in the area are the cultivation of the rubber, cardamom, tapioca and coconut.[10]

6.1.3 Population Study

According to the census the total population of Kanjirapally is 32,680. The number of houses is more than 7000. The number of family member per house comes around 4-5. The literature findings guide us that the ideal number of households which can be provided electricity with the help of a single turbine in the district of Kerala is 1200. The number of houses is taken with due consideration of the land use, the economic activity and the population study of the area. The Google maps also indicate that the area is mainly rural area and hence provision of electricity will be given to them to further the idea of sustainable development and the aim of rural self-electrification.

Table 6.1: Population details of Kanjirappally Source: Google; Kanjirappally census 2011. [33]

PARTICULARS	TOTAL	MALE	FEMALE
Total No. of houses	7,668		
Population	32,680	16,073	16,607
Child (0-6)	3,425	1,785	1,640
Schedule Caste	1,420	695	725
Schedule Tribe	102	54	48
Literacy	96.97%	97.66%	96.31%
Total Workers	11,316	8,775	2,541
Main Worker	9,976	-	-
Marginal Worker	1,340	651	689

6.1.4 Energy demand per household

Coordinating from various sources the energy demand per household to be supplied was calculated in the following manner. The basic needs of any rural household were taken into consideration and the energy calculations were done as follows:

- 4 CFL of 11W each
- 2 tube lights of 40 W each
- 2 fans of 50 W each
- Miscellaneous demand of 40 W.

The total energy demand per household is 264 W

After considering 10% growth and 5% loss, the total demand of 1200 houses were calculated to be **370 kW**.

Hence the power needed from the turbine is **370kW** per day.

Load management: The maximum load on the hydroelectric power plant can be reduced. The energy can be used wisely using the electricity using only for extremely important activities such as cooking. These practices come under the umbrella of load management. Some engineered devices can be used to control the excessive electricity on non-essential activities. One such device is the electronic load controller. They manage the maximum load by using the energy available to the maximum. In these the non-essential activities power can be cut-off when the mini hydro power plant reaches load more than the maximum.

6.2 Optimization

Mathematical modeling turns real life abstract problems with variables of different unit in a syntax where we can find our maximization or a minimization result. The variables and the output can be generally captured by a strong mathematical model. These not only tell us the dimensions of the optimized result but various other characteristics about the model and in directly the real-world problem.

6.2.1 Generation of a mathematical model for input from river and run-off

In a research we studied, the author addressed the optimal design of hydroelectric power systems. The interaction between the sizing and sequencing decisions were investigated. Design rules were also determined for choosing the optimal size and hence the marginal cost for the project and showed the interdependence of them on each other. [14]

In this project, we are making use of this method. The motive of drawing an optimization model is to determine design decision variables.

The objective function

$$Min\ Z = 480 * S_n + 437.13 * sqrt\left(V_{S,n}^{HEP}\right) + 48.4 * sqrt(V_{R,n}^{HEP})$$

The decision variables are:

$V_{S,n}^{HEP} - Volume\ of\ water\ needed\ from\ head\ pond\ on\ nth\ day$

$V_{R,n}^{HEP} - Volume\ of\ water\ needed\ from\ river\ on\ nth\ day$

$V_{S,n}^{DWD} -\ Volume\ of\ water\ taken\ from\ head\ pond\ for\ domestic\ purposes\ on\ nth\ day$

$S_n - Storage\ of\ head\ pond\ needed\ on\ nth\ day$

$V_{R,n} - Runoff\ volume\ on\ nth\ day$

$V_{available} - Volume\ of\ water\ available\ in\ the\ river\ on\ nth\ day$

The constraints are:

$V_{S,n}^{HEP} + V_{R,n}^{HEP}$ - $C_0 \leq 0$ (1)

$S_n - S_{n-1} - V_{R,n} + V_{S,n}^{HEP} + V_{S,n}^{DWD} \leq 0$ (2)

$V_{S,n}^{DWD} + V_{S,n}^{HEP} - S_n \leq 0$ (3)

$V_{R,n}^{HEP} - V_{available} \leq 0;$ (4)

The constraint (1) entails that the total volume of water needed from river and from head pond should be always less than the total volume of water needed to produce the required amount of electricity, ie, 370Kw. For easy estimations, the volume of water is given as C_o. The constraint sees to it that the peak production capacity of the hydro power plant is binding with a clause that the volume of water does not exceed the peak capacity produced by a volume of water C_0.

The second constraint (2) says that the storage volume difference in the head pond on any two consecutive days ie S_n-S_{n-1} will be equal to the total runoff volume that day minus the volume of water taken from headpond for electricity generation and also for domestic purposes. Here a less than or equal to sign is given for the sake of MATLAB calculations. $V_{R,n}$ is calculated using the equation Q = CiA ; C- Runoff coefficient (0.3), i – rainfall intensity (cm/hr) and A – area in hectares (6827). Multiplying the Q value with time, we get the volume. Thing that we need to keep in mind is that the optimization is done on a daily basis and hence the daily storages are also calculated. The other thing that we can derive from the constraint is that the storage of water can also be zero if required in case the runoff value that day is zero

The third constraint (3) is on the same lines as the second constraint. It simply ensures that the head pond each day has enough volume to provide water for the turbine and domestic water use. It implies that the total storage of the headpond will always be greater than the total volume of water needed for turbine and domestic purposes.

The fourth constraint (4) was added if in the condition where the runoff from the precipitation is not enough to run the turbine. Those days we will have to derive water from the river. But the river has its own discharge. The water flowing in the river should sufficient for the minimum water requirement for running the turbine. So, we will need to have a constraint where the river discharge should be limiting. The fourth constraint simply says that the water required to run the turbine from the river should be less than the water discharge in the river that day.

A sample of MATLAB code used for the daily optimization model:

Objective function:

```
z = -(480*(x(1,960)))-(sqrt(x(1,229))*437.13)-(sqrt(x(1,396))*48.4)
```

Constraints:

(1) `c(1,1)=x(1,1)+x(1,366)-159741;`
(2) `c(1,366)=x(1,1)+x(1,731)+x(1,1096)-co(1,1)`
(3) `c(1,731)=x(1,1)-x(1,731)+x(1,1096)`
(4) `c(1,1096)=x(1,366)-do(1,1)`

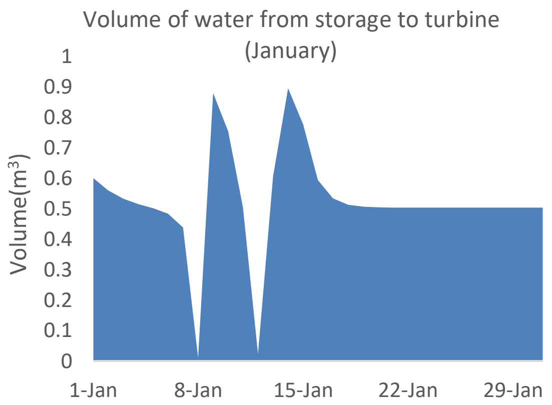
This is the code for day 1 and these 4 constraints are changed for all of the 365 days and the daily optimization results were obtained.

The maximum storage value obtained was 669.89 m^2. Since the height of the headpond was assumed to be 5 m, the other two dimensions were calculated as 12 m and 12 m. This makes the headpond of dimensions **12*12*5 m**.

6.2.2 Seasonal variation of input

Since the rainfall and flowrate values each day are different, there is a daily variation of input data which reflects in the optimization results. Daily optimization was done in MATLAB and the variation was observed as follows:

Results of Volume of water from storage to turbine:



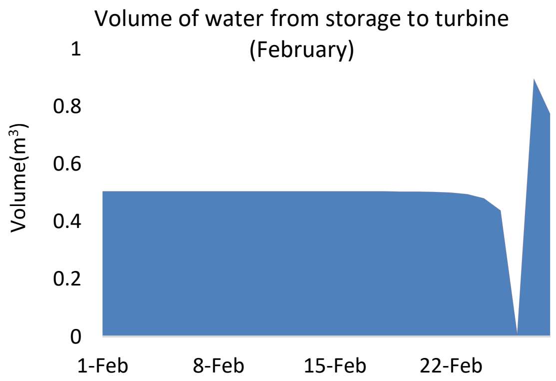
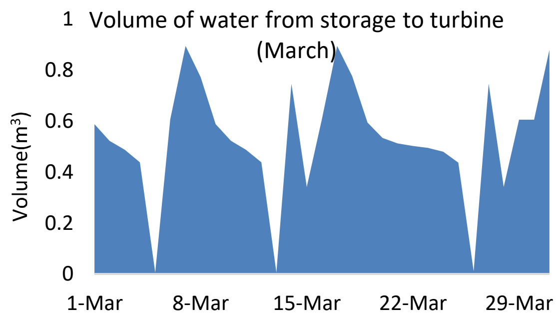


Fig.6.3- 6.4: Graph showing the trend of volume of water diverted from storage to turbine in January(6.3) and February(6.4)



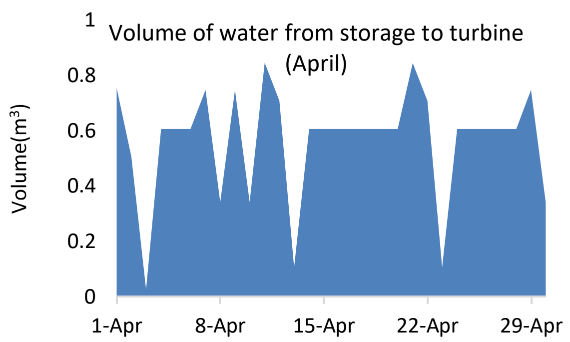


Fig. 6.5- 6.6: Graph showing the trend of volume of water diverted from storage to turbine in March(6.5) and April(6.6)

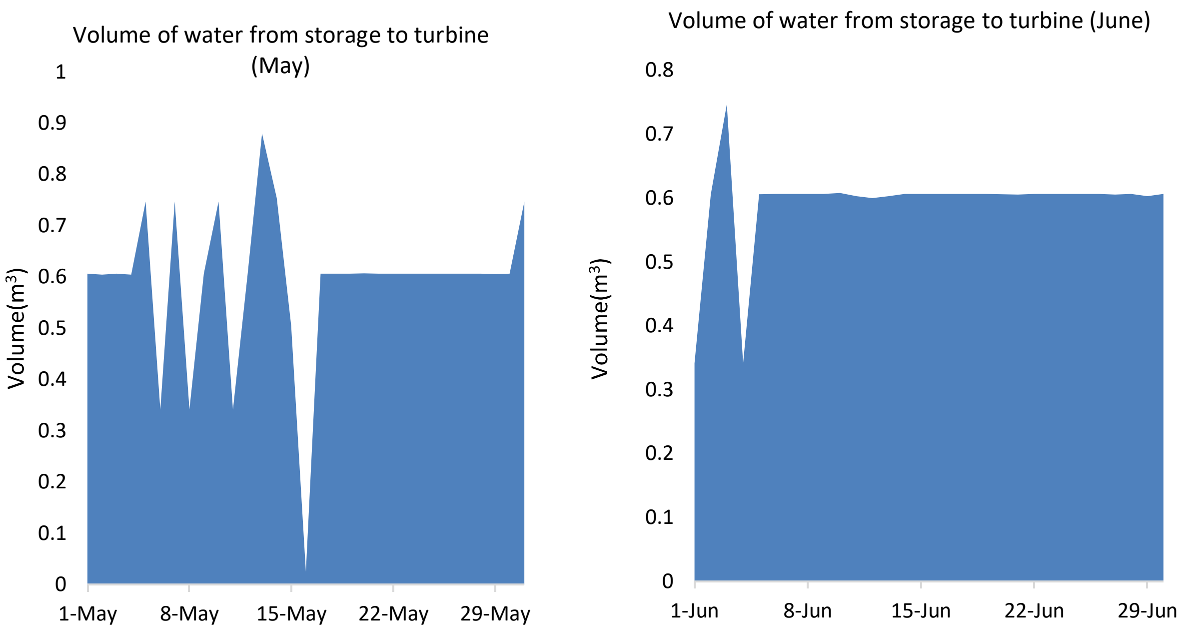


Fig. 6.7- 6.8: Graph showing the trend of volume of water diverted from storage to turbine in May(6.7) and June(6.8)

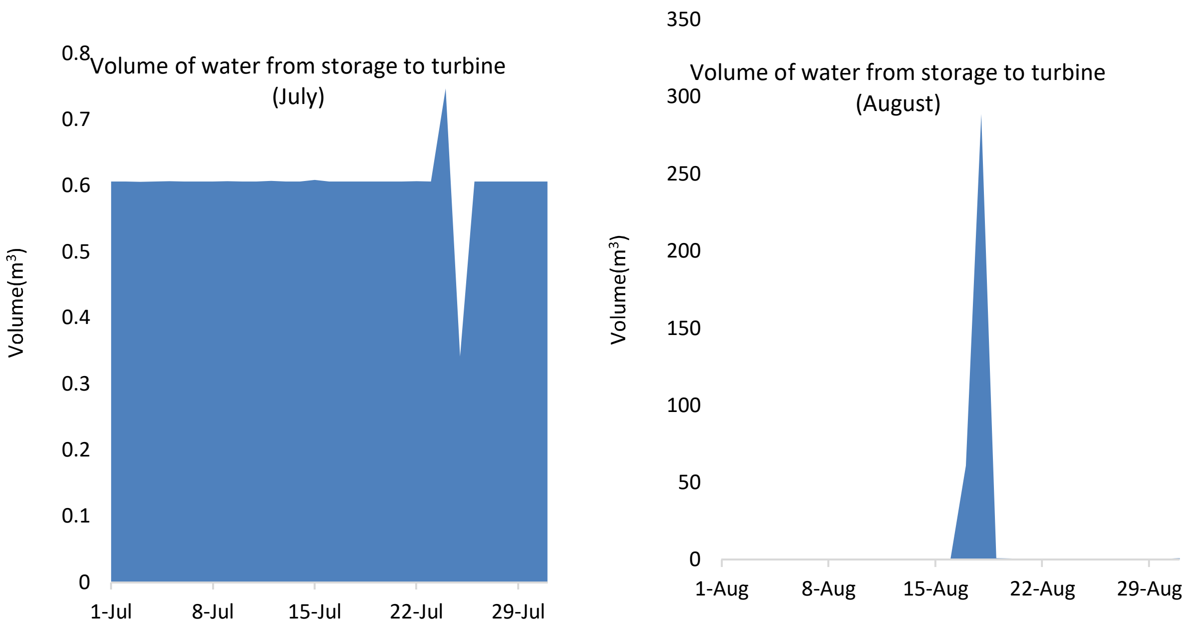
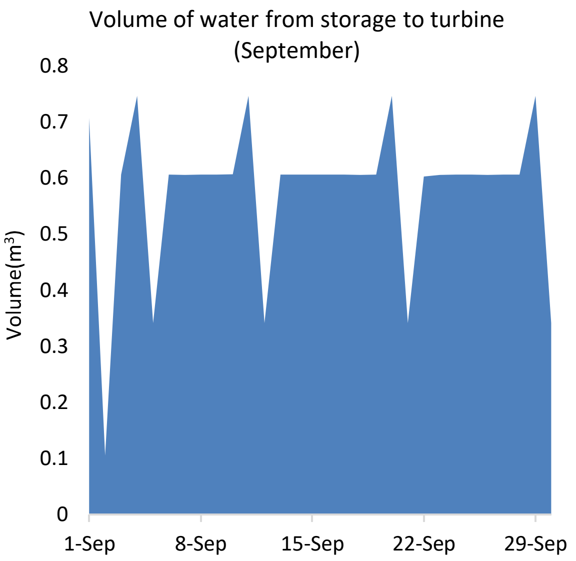


Fig. 6.9- 6.10: Graph showing the trend of volume of water diverted from storage to turbine in July(6.9) and August(6.10)



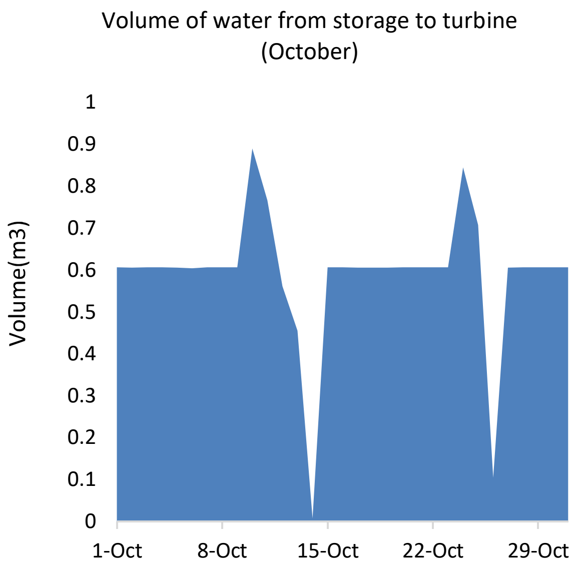
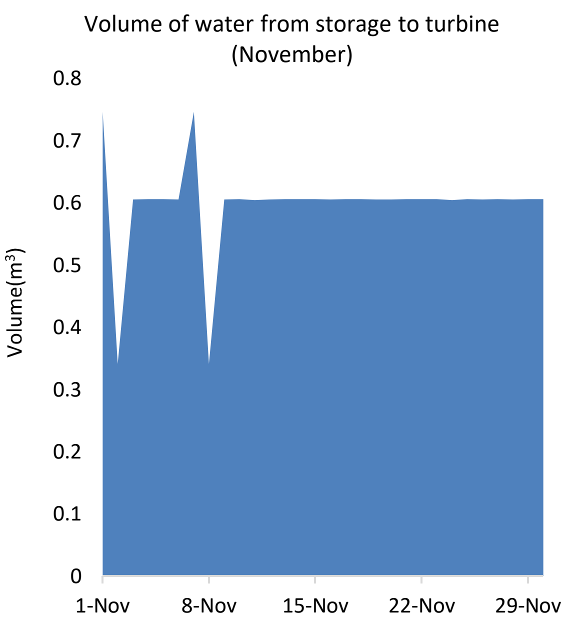


Fig. 6.11- 6.12: Graph showing the trend of volume of water diverted from storage to turbine in September(6.11) and October (6.12)



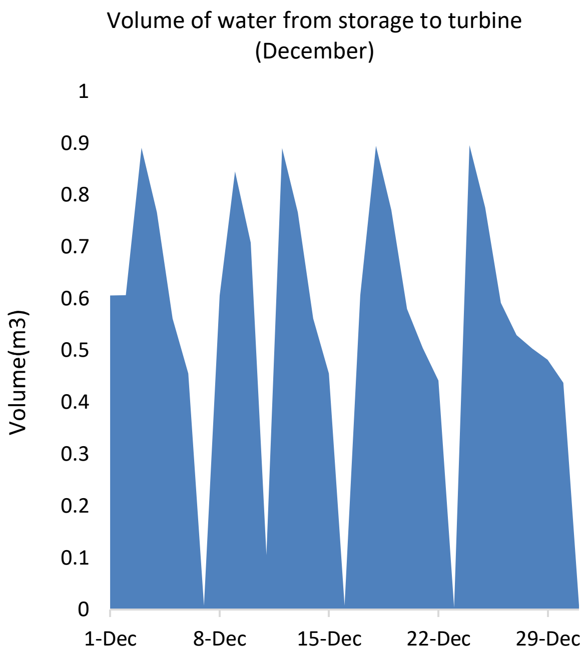
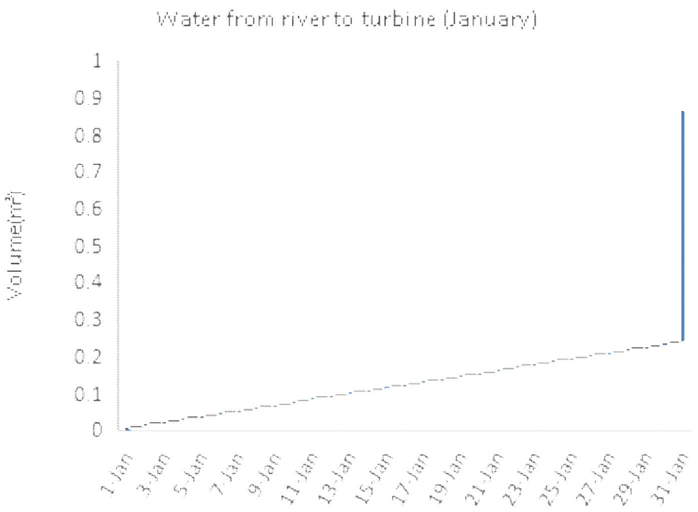


Fig. 6.13- 6.14: Graph showing the trend of volume of water diverted from storage to turbine in November(6.3) and December(6.14)

Results of Water from river to turbine:



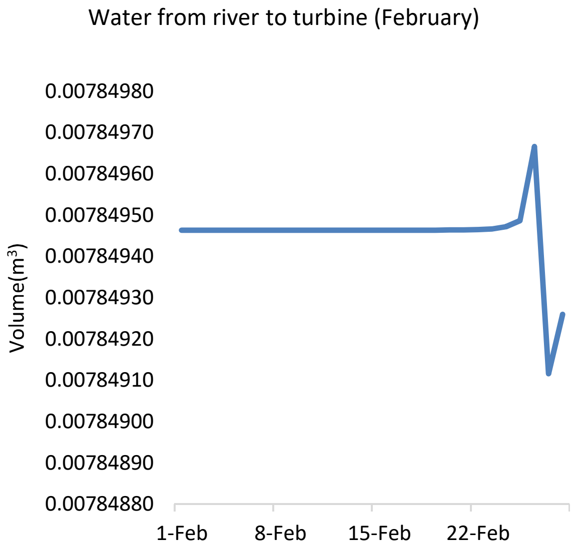
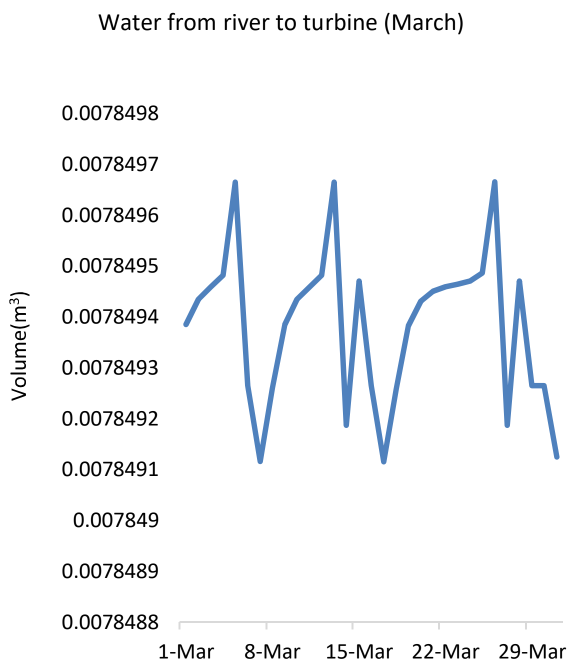


Fig. 6.15- 6.16: Graph showing the trend of volume of water diverted from river to turbine in January(6.15) and February(6.16)



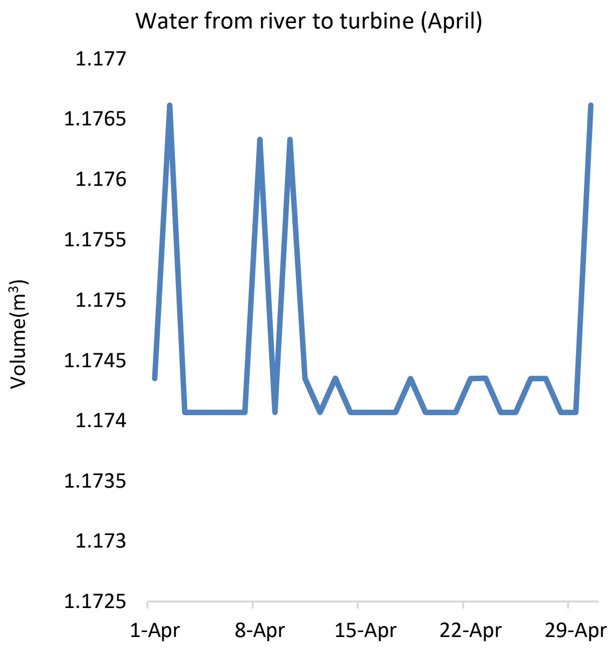
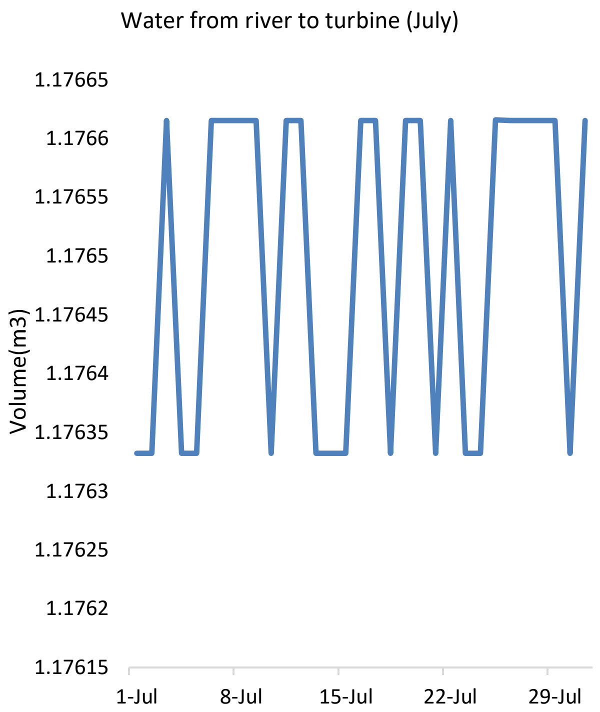


Fig. 6.17- 6.18: Graph showing the trend of volume of water diverted from river to turbine in March(6.17) and April(6.18).



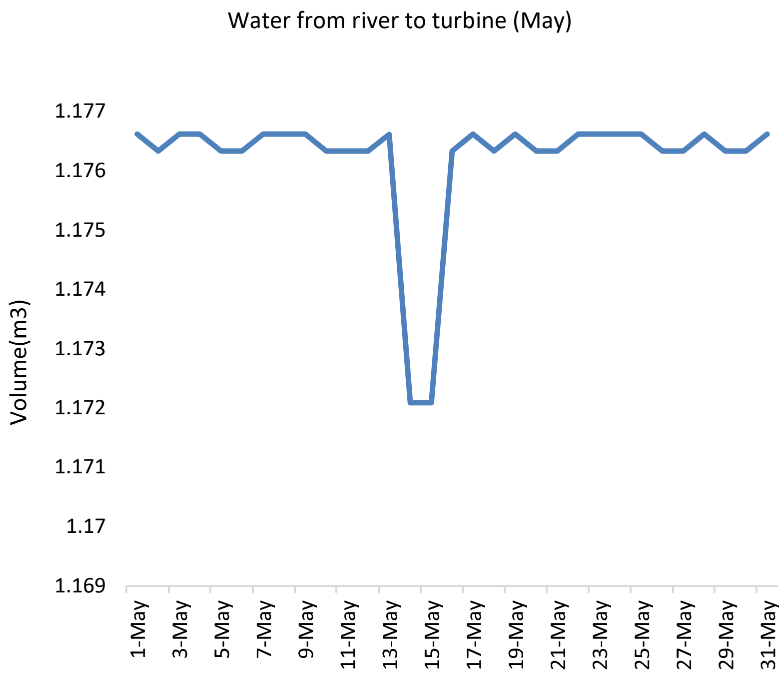
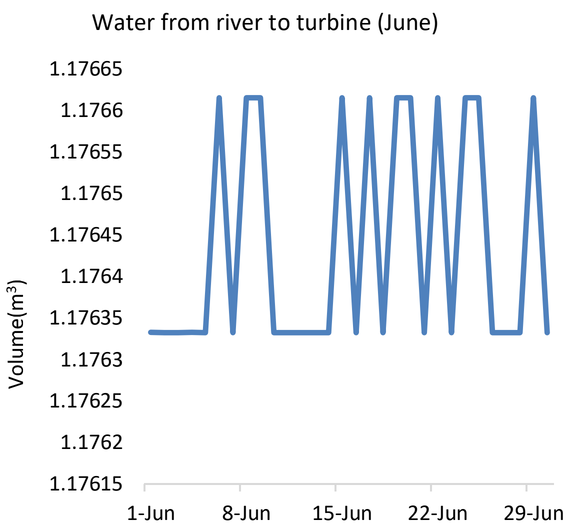


Fig. 6.19- 6.20: Graph showing the trend of volume of water diverted from river to turbine in July(6.19) and May(6.20).



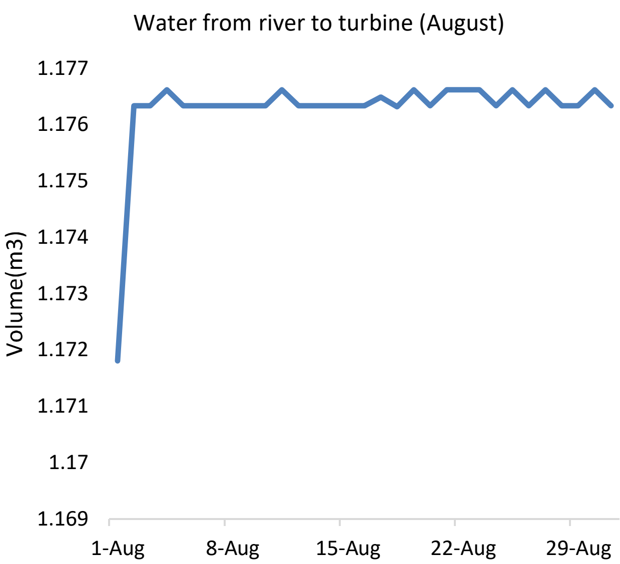
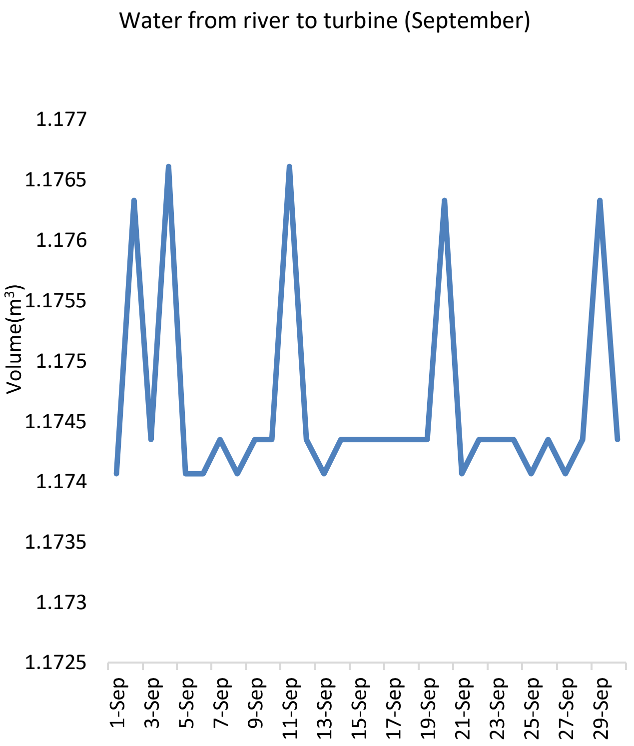


Fig. 6.21- 6.22: Graph showing the trend of volume of water diverted from river to turbine in June(6.21) and August(6.22).



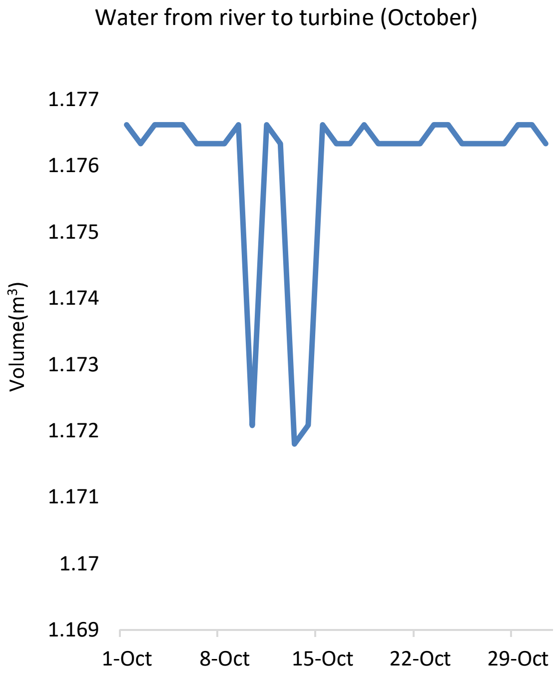
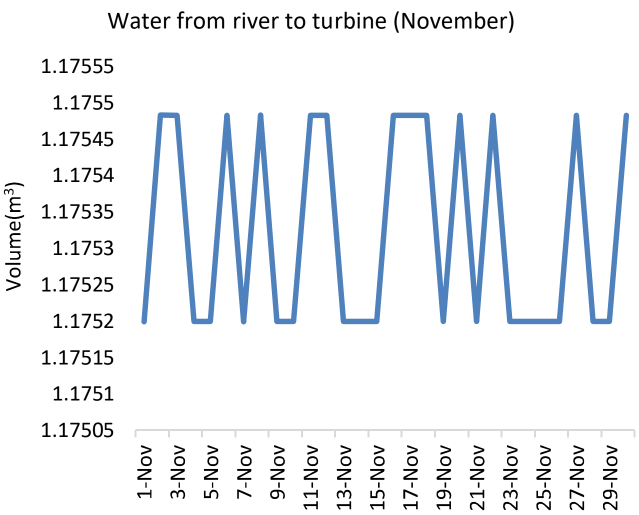


Fig. 6.23- 6.24: Graph showing the trend of volume of water diverted from river to turbine in September(6.23) and October(6.24).



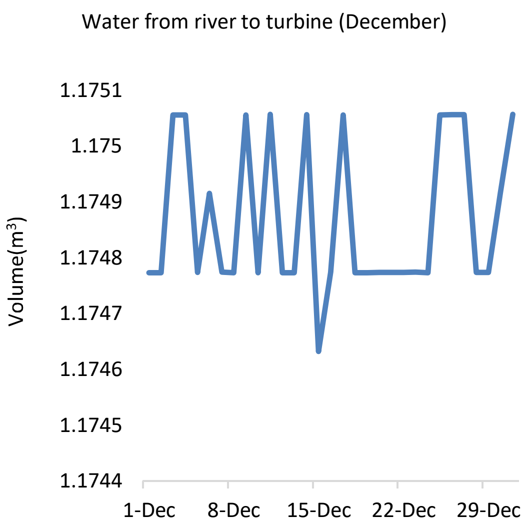
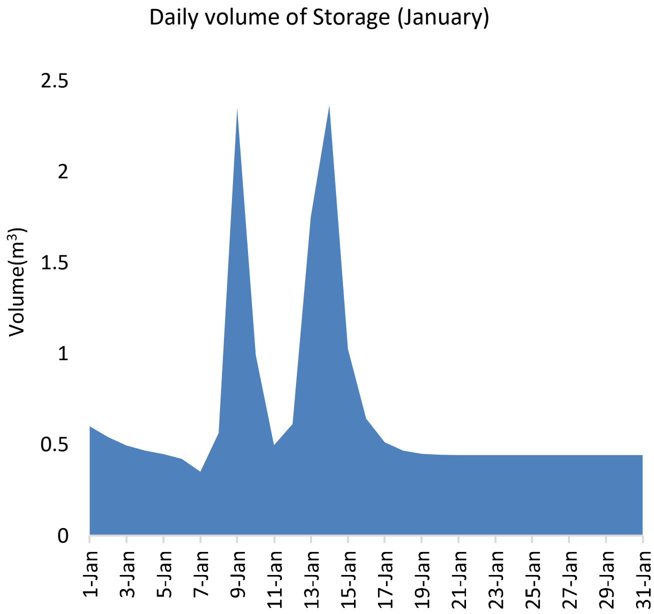


Fig. 6.25- 6.26: Graph showing the trend of volume of water diverted from river to turbine in November(6.25) and December (6.26)

Results of Daily volume of Storage:



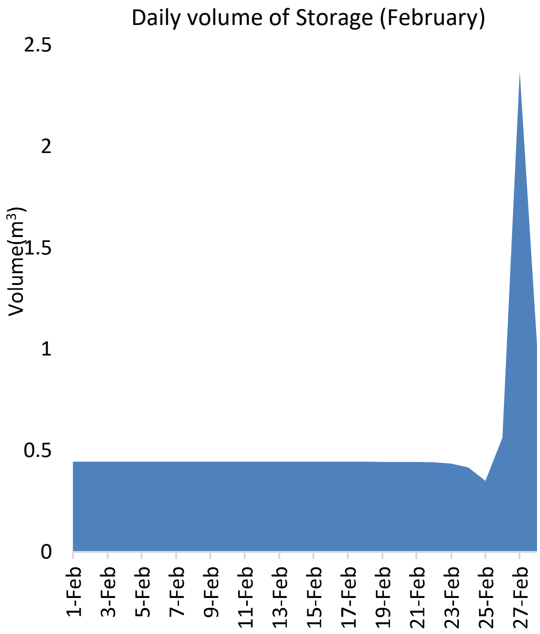
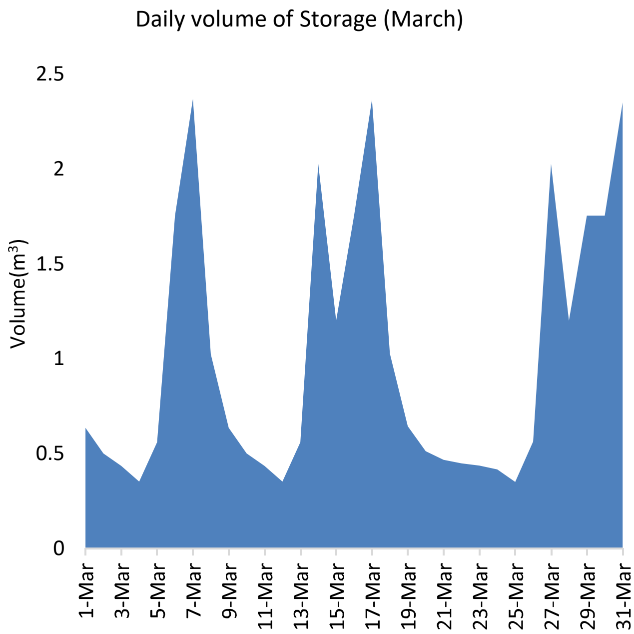


Fig. 6.27- 6.28: Graph showing the trend of volume of water storage in the head pond in January(6.27) and February(6.28)



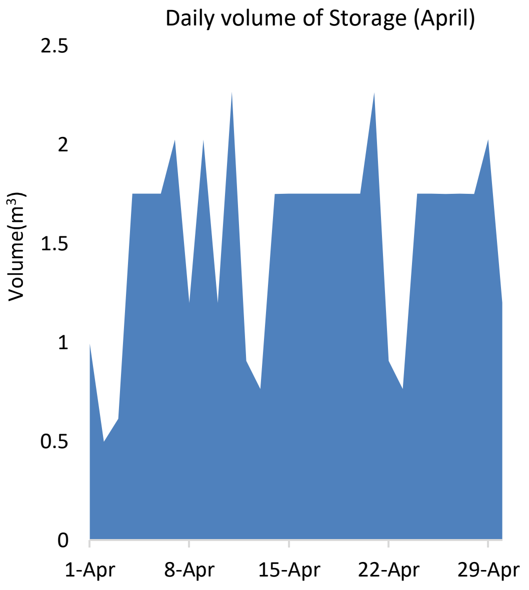
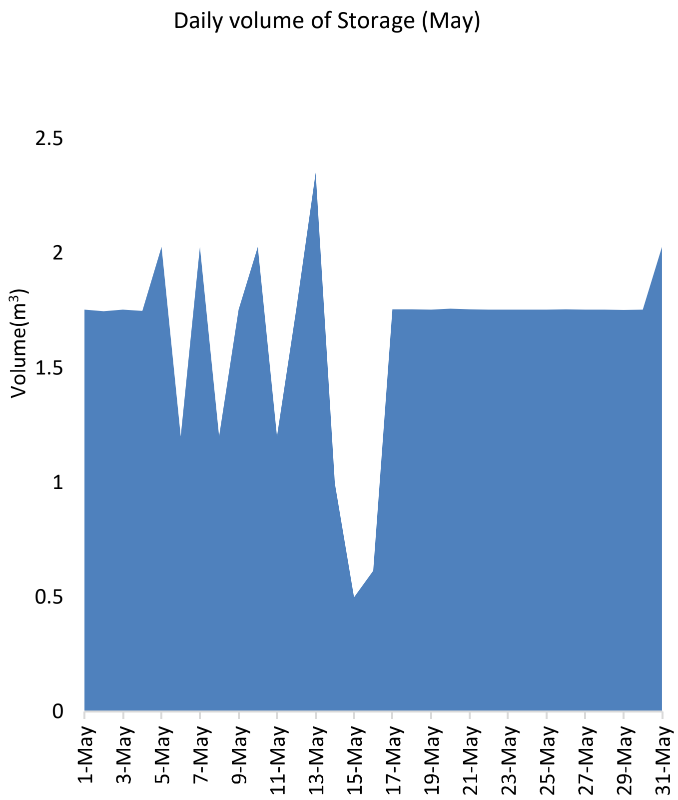


Fig. 6.29- 6.30: Graph showing the trend of volume of water storage in the head pond in March(6.29) and April(6.30)



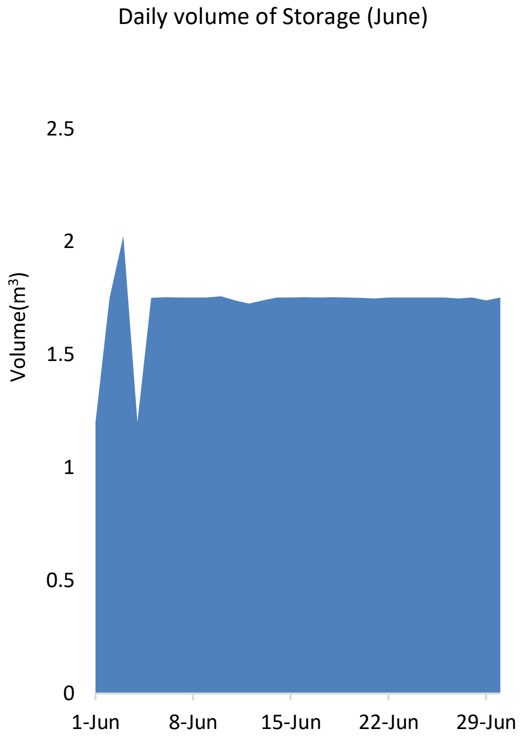
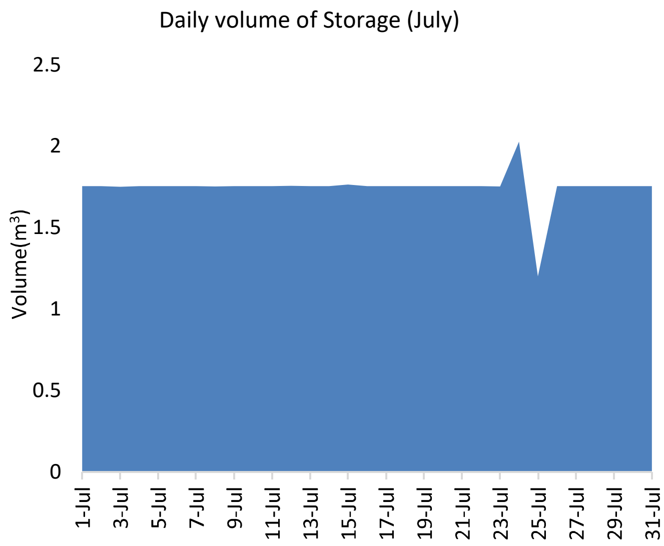


Fig. 6.31- 6.32: Graph showing the trend of volume of water storage in the head pond in May(6.31) and June(6.32).



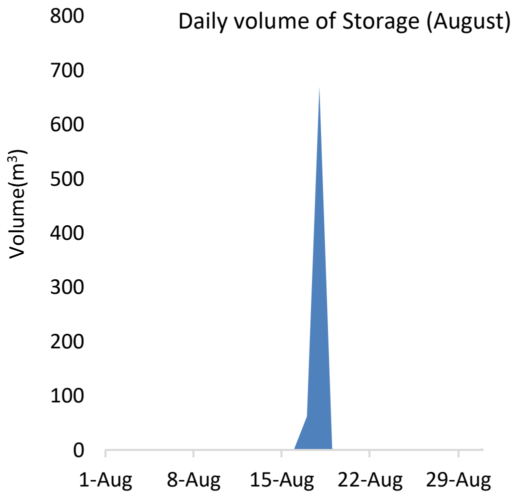
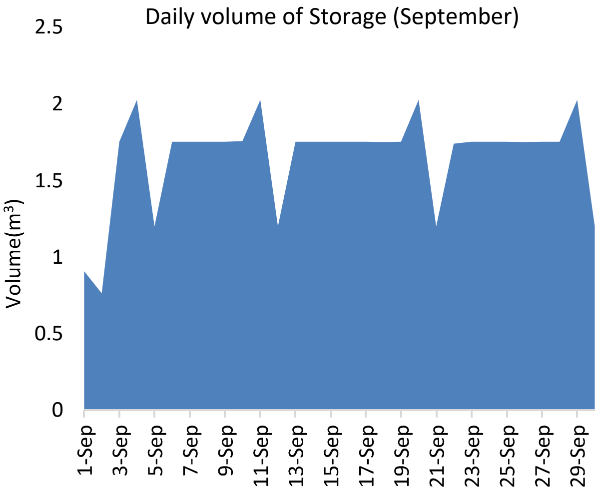


Fig. 6.33- 6.34: Graph showing the trend of volume of water storage in the head pond in July(6.33) and August(6.34).



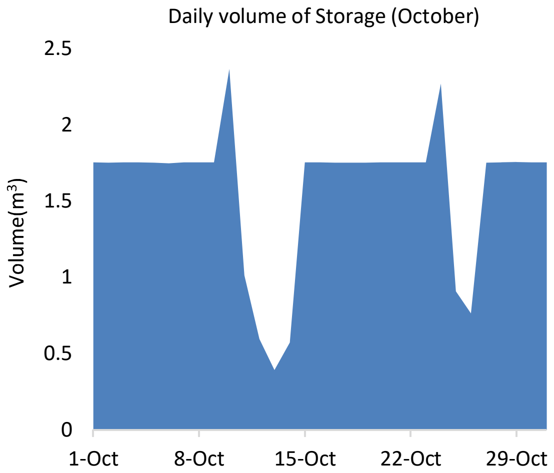
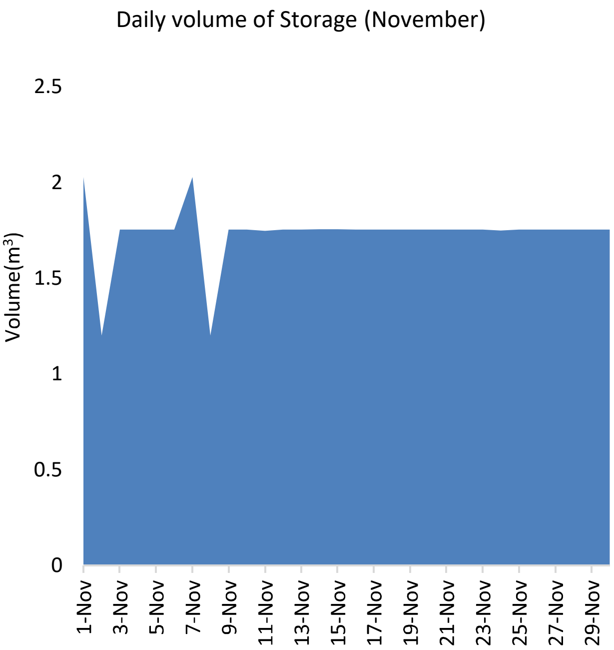


Fig. 6.35- 6.36: Graph showing the trend of volume of water storage in the head pond in September(6.35) and October(6.36).



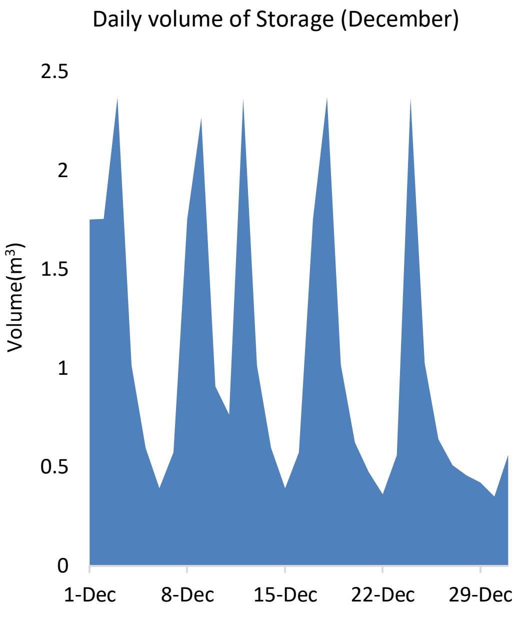
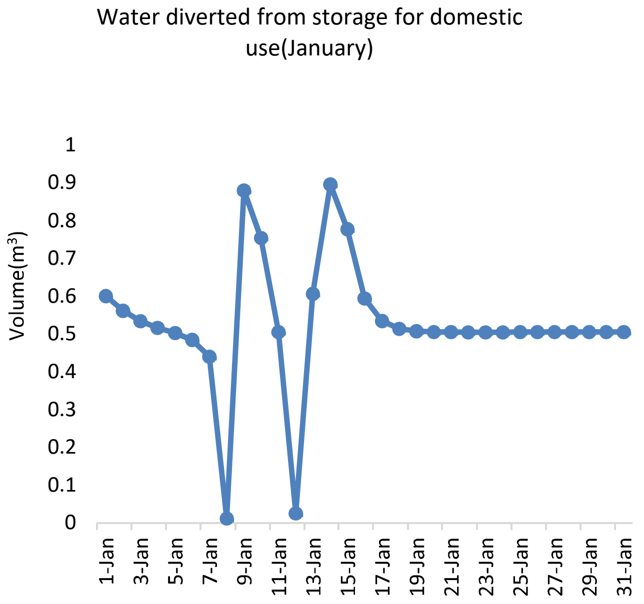


Fig. 6.37- 6.38: Graph showing the trend of volume of water storage in the head pond in November(6.37) and December(6.38).

Results of Water diverted from storage for domestic use:



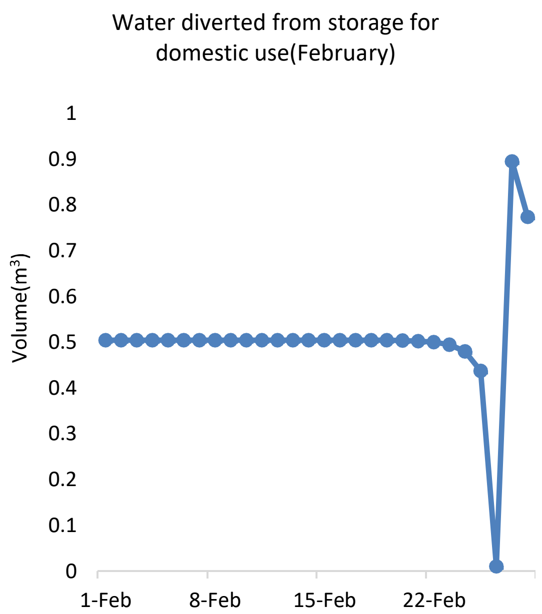
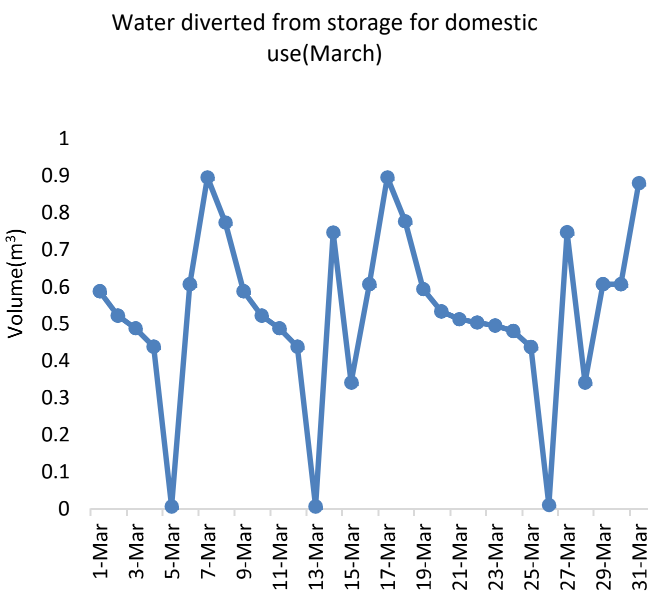


Fig. 6.39- 6.40: Graph showing the trend of volume of water diverted from storage for domestic purposes in January(6.39) and February(6.40).



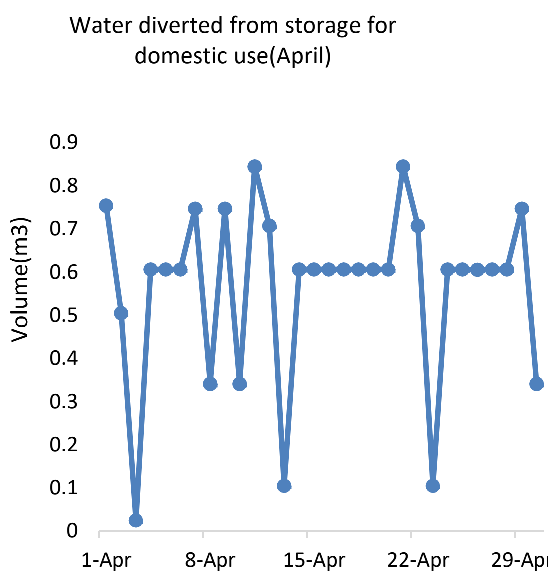
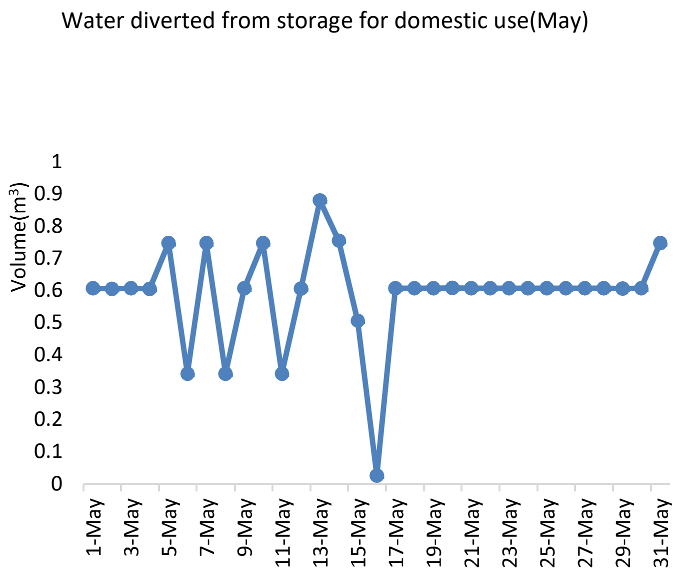


Fig. 6.41- 6.42: Graph showing the trend of volume of water diverted from storage for domestic purposes in March(6.41) and April(6.42).



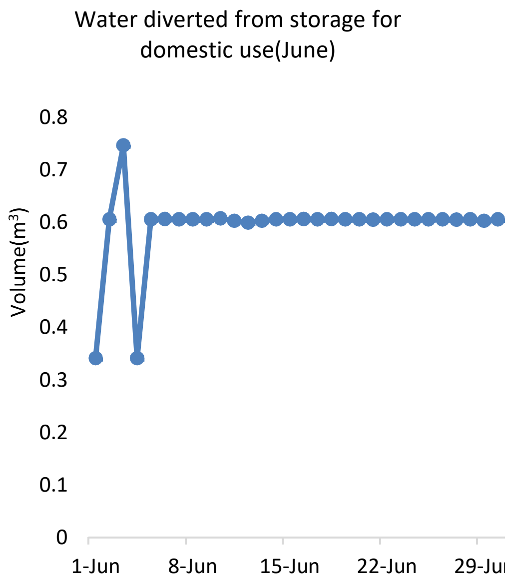
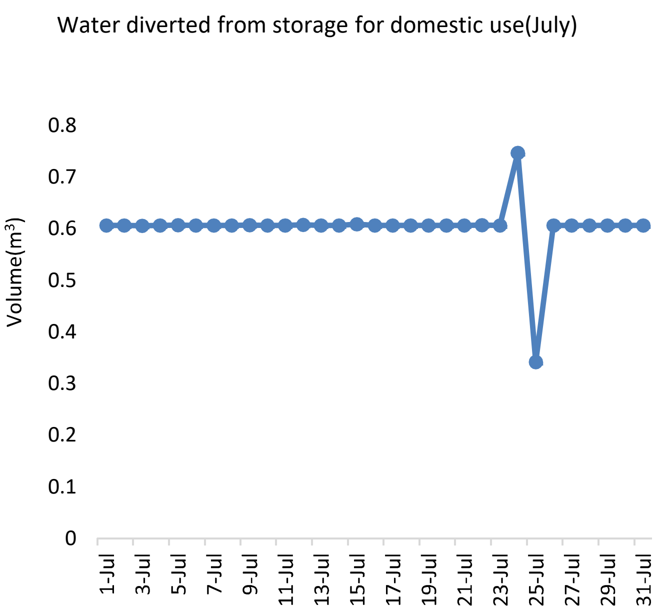


Fig. 6.43- 6.44: Graph showing the trend of volume of water diverted from storage for domestic purposes in May(6.43) and June(6.44).



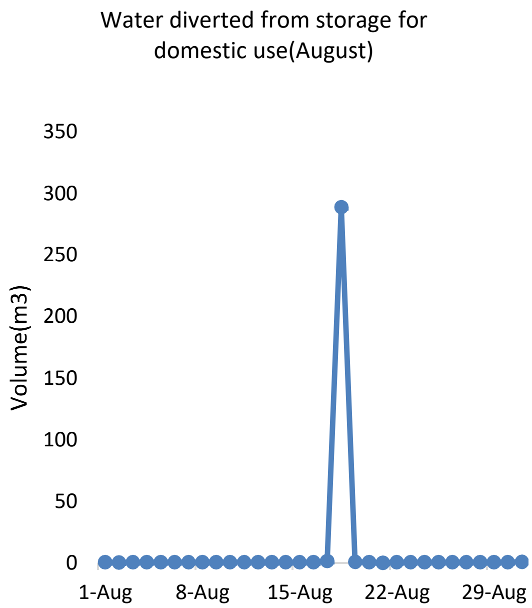


Fig. 6.45- 6.46: Graph showing the trend of volume of water diverted from storage for domestic purposes in July(6.45) and August(6.46).

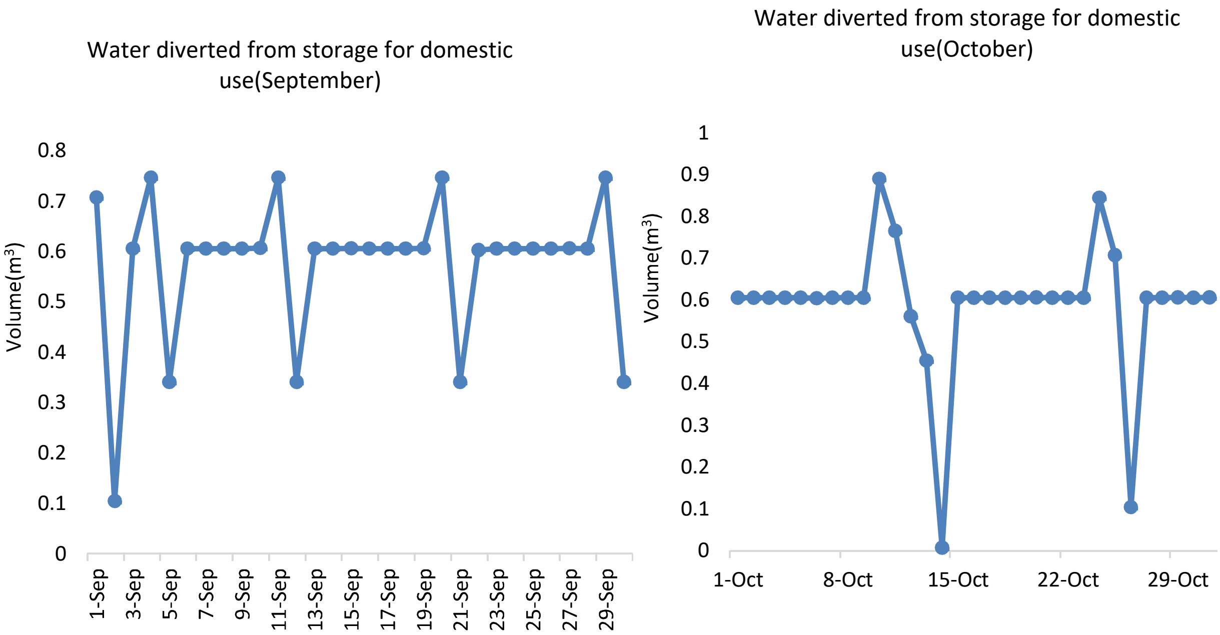


Fig. 6.47- 6.48: Graph showing the trend of volume of water diverted from storage for domestic purposes in September(6.47) and October(6.48).

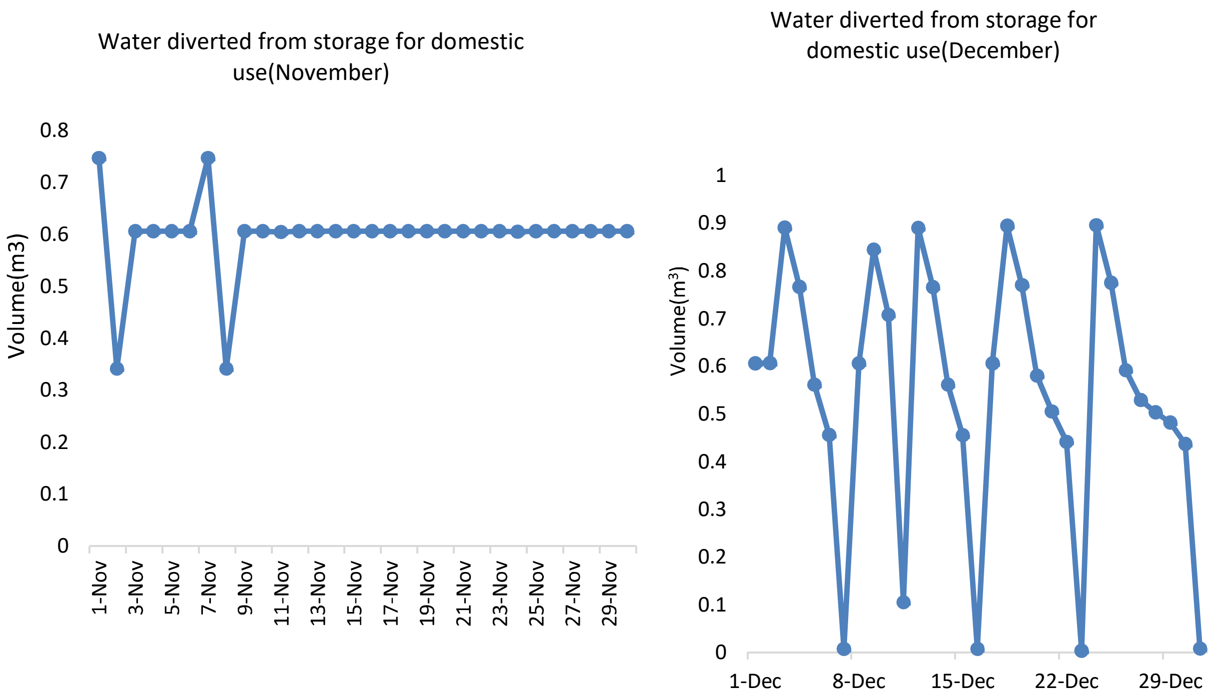


Fig. 6.49- 6.50: Graph showing the trend of volume of water diverted from storage for domestic purposes in November(6.49) and December(6.50).

From these results, we can analyse that the maximum storage is during the month of August with a value of 669.89 m^2. The headpond is made with dimensions 12*12*5 m.

6.3 Design

The design of the hydropower system will include the estimation of head, penstock and the turbine.

6.3.1 Design of head, headpond and penstock

With the help of literature and the general elevation of the land the maximum elevation that can be provided without much effort in excavation would be **10m**. The dimensions of headpond were already calculated as **12*12*5 m**. After research, the penstock was calculated to be 1 m and their lengths are:

- From headpond to turbine – 4500 m
- From river to turbine – 500 m

These values of penstock length were calculated based on the position of headpond and turbine and the topography.

6.3.2 Design of turbine

The head provided for the headpond is set as 10m. 10m would generally classify as low head. The choice for a specific type of turbine depends on the design flow criteria, choice of the specific speed to be installed. Part flow is the condition where the water flow is less than the design flow. The choice of type of turbine also depends on the part flow. According to the literature on turbines, the most suitable type of turbine that can be provided is the Kaplan Turbine. The choice of turbine also is very greatly influenced by the head provided. The maximum level of efficiency and speed is provided when the turbine is designed according to the following criteria: [24]

Table 6.2: Different types of turbines

Turbine runner	High head (more than 100m)	Medium head (20 to 100 m)	Low head (5 to 20 m)	Ultra -low head (less than 5m)
Impulse	Pelton	Multi-jet pelton	Cross-flow multi-jet turgo	Water wheel
Reaction	--	Francis turbine	Propeller kaplan	Propeller kaplan

From the table, we can observe that the suitable turbine for this hydropower plant is Kaplan turbine.

Kaplan turbine: This is a type of propeller type of turbine which has the property of adjustable blades. The Kaplan turbine has one characteristic that it can be installed in places which have a rich bio-diversity. The low to medium head of the turbine ensures that the fishes and the fauna do not get hampered. The one disadvantage of this type of turbine is that if installed in rivers, the oil from the blades may go into the water and pollute it. It was developed by Austrian professor in 1913 who combined automatically adjusted blades with automatically adjustable wicket gates to achieve efficiency over a wide range of flow level [14]. Kaplan turbines can go up to the efficiency of 95%. This type of turbine can be implemented in low-head conditions with varying size of turbine. The cost of setting up a Kaplan turbine is also low and low maintenance cost.

The equations used in the design of turbine are:

$$P = \eta \gamma Q H \qquad \text{....... (6.2)}$$

$$Q = \frac{\pi}{4}(D^2 - d^2)\varphi\sqrt{2gH} \qquad \text{....... (6.3)}$$

$$\mu = K_u\sqrt{2gH} \qquad \text{....... (6.4)}$$

$$\mu = \frac{\pi D N}{60} \qquad \text{....... (6.5)}$$

The design of the turbine was done manually. Assumed values are $\eta = 85\%$; $\varphi = 0.5$; K_u – 1.6; and the ratio of hub diameter to outer diameter – 0.35.

First, the flowrate was calculated using equation (6.2). This value of Q was put in equation (6.3) to find the value of D. Using equation (6.4) value of μ was found. This value was put in equation (6.5) to find the specific speed.

The design specifications of the turbine were calculated to be:

- Flow rate = 4.437 m^3/sec
- Outer Diameter = 0.958 m
- Flow Velocity = 22.411 m/sec
- Specific Speed = 446.7 rpm.

6.4 Cost Benefit Analysis

6.4.1 Total cost estimation

Basic Components of a SHP are as follows:

- Civil works component- intake, penstock, powerhouse building, tailrace.
- Power house components- turbines, generators, drive systems and controllers.
- Transmission or distribution network.

In this project, we are designing only the civil and electrical components. Transmission or distribution network can be studied, designed and their cost can be included in the project as an extension. For the time being, only civil and electrical works are included while calculating the cost.

Civil works control the water flow into the hydropower system. It is required that the civil structures are located at suitable sites. The structures should be reliable and sustainable. The estimation and the cost of the structures can be reduced by optimization and sustainable use. The use of technology and local materials should also be looked at while designing the civil works. The parts of civil works are:

- Intake: It is designed and located in such a way to ensure that the full flow goes into the turbine. Many site considerations can also be put while designing the intake. A low head dam could be used to provide a steadier flow.
- Penstock pipe: The structure that transports the water from headpond to the turbine where the energy is generated. It is the most expensive structure in the civil works which needs use of durable material and optimization to minimize the cost. The penstock should be chosen in such a way that the length of the penstock should be minimum and the head loss due to friction also targets a specific value, not more than that. In SHP the head loss can be taken up to 35%. The choice of penstock also depends on factors such as pressure rating of the pipe and maintenance of the pipe. Expansion joints should also be provided in humid cases such as our place.
- Powerhouse building: It is the house for the turbine and generators. Water after generation of electricity goes out from here to the tailrace.
- Tailrace: It is a structure which allows the water after hitting the turbine back to the river. Power house components house the following structures:

The electrical components of the hydropower plant are:

- Turbine: A turbine consists of a runner which is supported by a shaft. Shaft is responsible for converting the potential energy of the falling water into mechanical energy which causes the turbine to move.
- Generators: They convert the mechanical energy to electrical energy. Generators work on the simple principle of magnetic field induced by alternating current. When a coil of wire is moved in presence of a magnetic field, an electrical voltage is induced. AC is known for generate varying voltage in an alternating manner. The voltage produces the electricity. There are two types of generators synchronous and asynchronous. Synchronous generators are used in all types of power plants of all capacity. Asynchronous generators are used as induction generators. There are used in single phase or three phases. The type of hydropower project determines the type of phase of the generator. In this project we will use the asynchronous generators because of its usage in small power projects. They are also cheaper than synchronous generators.

According to the study and research, the cost depended on two variables, head and power. The cost in the study includes the market price of the component which helps determine the cost of the starting capital that the power plant needs. The results are shown in the table below: [8]

Table 6.3: Cost function of turbine (Source: Ogayar B, Vidal PG. Cost determination of the electro-mechanical equipment of a small hydro-power plant. Renewable Energy 2009; 34(1):6-13)

Type of turbine	Cost function(€/kW)
Pelton	$17.693P^{-0.3644725}H^{-0.281735}$
Francis	$25.698P^{-0.560135}H^{-0.127243}$
Kaplan	$33.236P^{-0.58338}H^{-0.113901}$
Semikaplan	$19.498P^{-0.560135}H^{-0.127243}$

The units of the turbine also have an impact on the initial investment of the hydro power plant. One study included the use of regression analysis on the actual analysis on each elements of the hydro power plant. The study also included the use of the prevailing rates to make a correlation under a low head. They were taken to determine the cost of the whole hydro power plant with each additional unit if applied. Further the results change depending on the type of turbine, number of units, type of generator and sol condition at the site. The cost was broadly divided into civil works and electro-mechanical equipment. [9]

Table 6.4: Total cost of turbine (Source: Singal SK, Saini RP. Cost analysis of low-head dam -toe small hydropower plants based on number of generating units. Energy for Sustainable Development 2008;12(3);55-60.)

S no	Components of work/equipment	Formula	Total cost
1	Intake	$14382\, p^{-0.2368}H^{-0.0596}$	3,090.72
2	Penstock	$4906p^{-0.3722}H^{-0.3866}$	222.968
3	Power house building	$62246p^{-0.2354}H^{-0.0587}$	2,828.96
4	Tail race channel	$28164p^{-0.376}H^{-0.624}$	724.52
5	Turbine with governing system	$39485p^{-0.1902}H^{-0.2167}$	1,015.75
6	Generator with excitation system	$48568p^{-0.1867}H^{-0.2090}$	9,951
7	Mechanical and electrical auxiliaries	$31712p^{-0.19}H^{-0.2122}$	6,325
8	Main transformer and switchyard equipment	$14062p^{-0.1817}H^{-0.2082}$	2,973

- Cost/ kW of civil work (C_c) = 6,867.17
- Cost/ kW of civil work (C_{em}) =20,264.75
- Total cost/kW= 1.13(C_c+C_{em}) = 35,271.5
- Total cost = ₹ 1, 30, 50, 453.52

The above cost implies the installation cost. The installation cost is only one side of the total cost structure. The two types of costs are initial cost or the installation cost and the annual cost. The above one crore thirty lakhs is the initial cost which is the cost incurred when there is no production of electricity. The above does not include permit costs which can be adjusted in the addition of the 13%.

The other type of cost is the annual cost. The annual costs include the operation and maintenance cost. The hydroelectric maintenance cost is not very high as compared to all the renewable energies. These costs include labour and materials to clean the trash rack, equipment maintaining. A small proportion of the costs include land leases, property taxes and genera administration. The average life time of a battery is 5 to 10 years. Weekly maintenance of the turbine is apt for a small hydro-power plant. One more type of maintenance includes adjusting the intake valve, nozzle and the guide vane to see that the water flow is not disturbed [48] . Greasing of machinery and bearings, tightening of belts and checking the water level in the batteries for every month also include in the maintenance. The process of welding should also be done regularly. The leaks should be monitored to make the turbine well maintained.

6.4.2 Calculation of benefits

Environmental benefits: Renewable energy reduces the effect of the conventional sources of energy which is the main source of pollution. They reduce the greenhouse emission into the atmosphere. The governments around the world in order to promote these energy sources provide various subsidies to small hydro power plants. Hydro power energy also results in a lower carbon footprint than the conventional sources of energy. [15]

Intangible benefits: The intangible benefits of any hydro power plant include increase in agriculture production, local employment, saving of non-renewable energy, reduction in the load to the fossil fuels. [16] To increase the intangible benefits from the power plant, we will divert some units of water on a daily basis to provide for the domestic needs of the people. The water will not be purified and not really fit for drinking purposes but it will cater to some household demands of washing, bathing, watering the garden etc. The cost to divert the water to these houses is not included in the costs and is overall a different project. The water for domestic purpose will further our goal to provide rural benefit. The basic idea behind this is to make a simple desilting tank and then provide connections to each household and provide them with water.

Tangible benefits: In this project, the only tangible benefit is the revenue collected from generation of electricity. The price of electricity is ₹ 6.45/unit. With this value, the total amount earned from revenue is calculated. While calculating the benefits over the years, it is kept in mind that there is a 5% increase in the tariff after every 5 years.

6.4.3 Calculation of B/C ratio

The ratio of the benefits and costs of the present value and with the lifetime of the income throughout the project is known as the B/C ratio. It can also be called as the comparison of the present value of the return on the present investments. It is a major process of identifying a profitable business during their whole lifetime of the project. The ratio also tells us about the further investments we might need during the project.

$$B/C = \frac{\sum_{i=0}^{n} B_t(1+r)^{-t}}{\sum_{i=0}^{n} C_t(1+r)^{-t}} \qquad \text{....... (6.6)}$$

Operation and Maintenance Cost:

These costs are often expressed as the percentage of the investment cost per kW. The IEA assumes that the cost of O&M is 2.2 % for large hydropower plants and 2.2 – 3 % for smaller projects [25]. The O&M costs are higher in small hydropower plants than in large hydropower plants. The O&M costs represent 4% of the total capital cost of the project [26].

Net Present Value:

Using this method, we calculate the costs that could be incurred to us in the life time analysis of the hydro power plant. The NPV discounts the future revenues that the plant might generate. This counts for the real time change in money. The time value of money is not the same. The currency might see inflation effects or might lose the value. We cannot foresee the changes in the currency but looking at the growth of the Indian currency, appropriate interest rates are chosen. The value of money consists of the money value for present and future when the event is paid and the money value for present revenue or expense that occur each year. [30]

$$P_m = \frac{F}{(1+i)^n} \qquad \text{....... (6.7)}$$

Where,

P_m= present value of the money

F= future value of the money or the money getting in the future

I= interest rate

n= number of years

Payback period

Payback period refers to the time in which the investment is recovered by the revenue of the project. It measures the return on the investment and how will it pay back it few years. It also is a key factor to determine the profitability of any project. The formula for calculating the payback time period is as follows:

$$payback\ time\ period = \frac{Initial\ investment}{the\ average\ annual\ net\ return} \qquad \text{........(6.8)}$$

The detailed cost benefit analysis is done in Excel with the following assumptions:

- Initial investment = 1,30,75,000
- Total number of units per hour = 370
- Electricity produced in a day= 10 hours or 3700 units (1 unit = 1kWh)
- Price of 1 unit of electricity = 6.45/unit (As stated by the Kerala State Electricity Board) [60]
- Saleable energy= 1,350,500 kWh
- #Operation and maintenance = 10% of the total capital
- Annual depreciation = 3% of capital
- Transmission loss = 1% of capital
- The economic life of the turbine is considered as 35 years excluding construction period.[17]
- Interest rate is considered as 8%
- 3% tariff escalation is considered in present posted rate for 5 years after commercial operation date.[18]

Operation and maintenance include the provision of domestic water supply and includes battery costs also which is why it is higher (10%).

The results of the financial evaluation are given and discussed below:

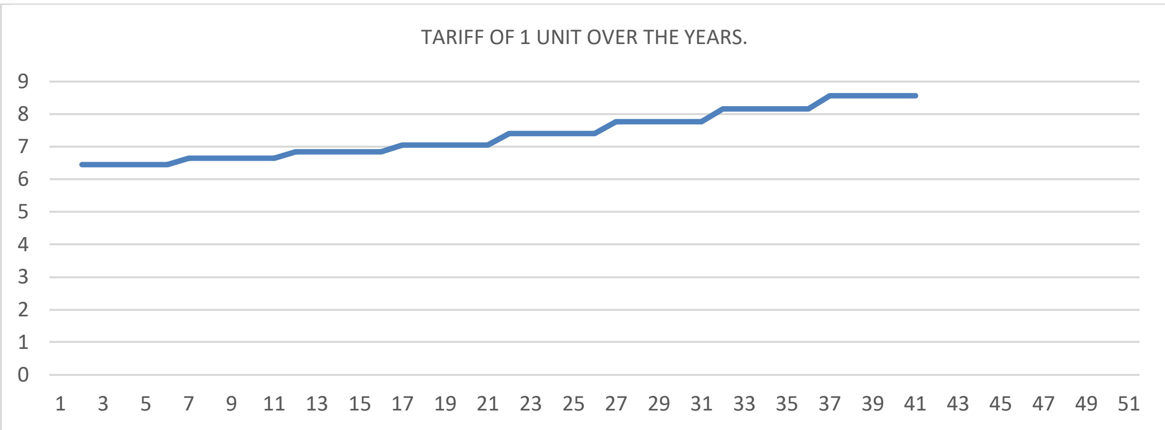


Fig 6.51 Change in tariff of 1 unit over the years

Figure 6.15 shows implicitly that the tariff of the cost of one unit of electricity will increase over the given time period of 40 years. The change however will be very gradual and keeping in mind the growth of earning capacity of the consumers and increasing value of the money.

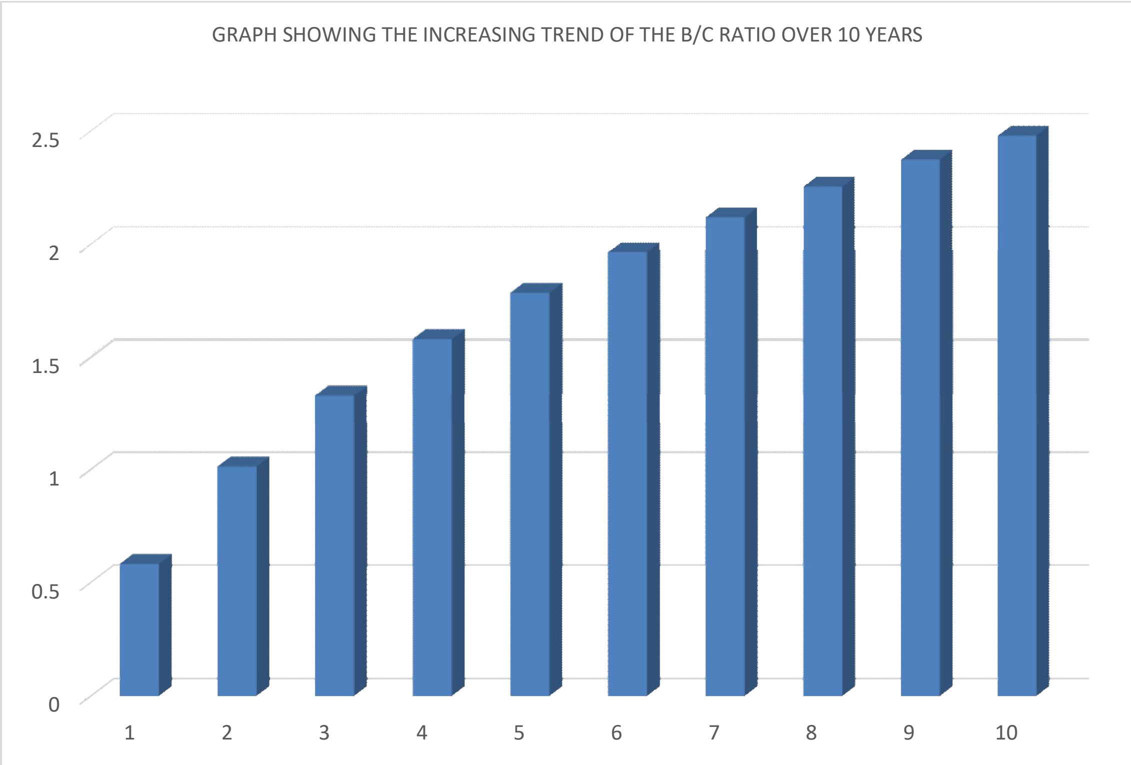


Fig 6.52: Trend of B/C ratio over 10 years

Figure 6.16 shows the trend of the B/C ratio over the starting 10 years. The B/C ratio of the first year is less around 0.58 and it increases in the years to come. Hydropower plant is one unique area where the units of produce can be increased without changing the variable cost. Variable cost is the cost incurred to the producer with each additional unit of production. In electricity production due to hydropower plant, the variable unit is not there. The cost of producing each unit is same. However, while producing extra unit units during peak times, the battery storage of each unit will increase which is added in the O&M costs. 10% is relatively higher than the normal O&M costs in the literature surveyed for a mini hydropower plant but that cost includes the retained profits and also to ensure that the extra units if can be produced will be stored in the battery. The storage costs are hence added in the O&M costs which we have roughly assumed to be 10%. The B/C ratio increases however after the second year due to low variable cost as stated and hence according to the analysis the project is very profitable.

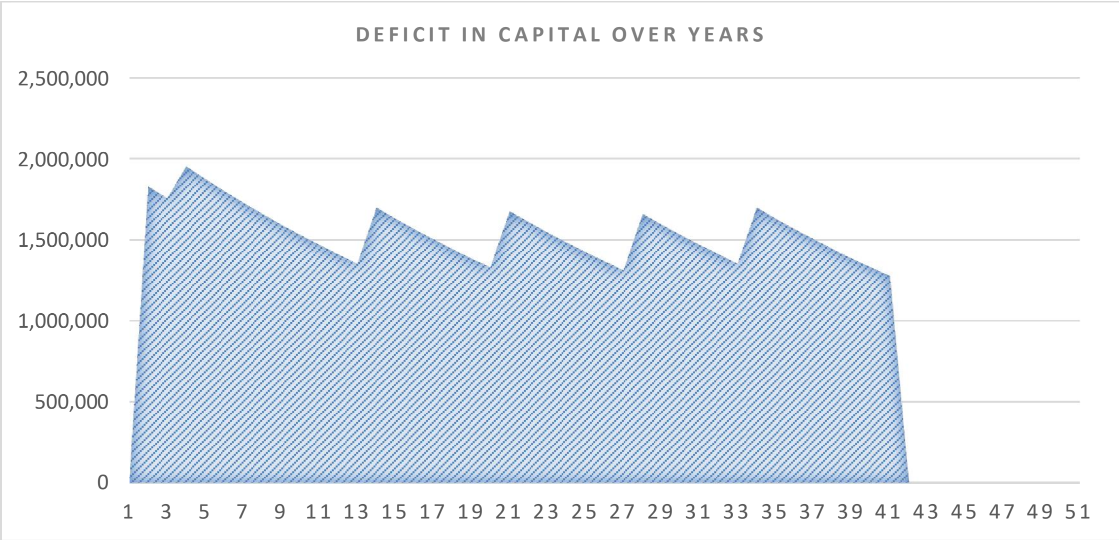


Fig 6.53: Deficit in capital over years

Figure 6.17 shows the deficit of capital over the years. The capital assumed at the start of the timeline is around 1crore 50 lakhs. However due to annual depreciation and the O&M costs, the capital decreases. The deficit in the capital also accounts for transmission loss. The deficit in capital is balanced by revenue generated by the hydro power plant. The deficit however shrinks in the next 12 years due to the machinery being depreciated so much as the O&M costs can also not be procured by the revenue generation. By the end of 12 years certain civil and electro mechanical parts will be so outdated that the production capacity of the power plant will suffer. As previously stated, it is always better to change the outdated parts which will increase the capacity by around 3%. The revenue however goes to balance out the deficit in capital and hence we will require an investment of 1 crore at the end of the 12th year and more years which happens due to the same scenario. The above figure will change if the investment is procured in steps of 10 lakhs every year. Different scenarios will require different evaluations.

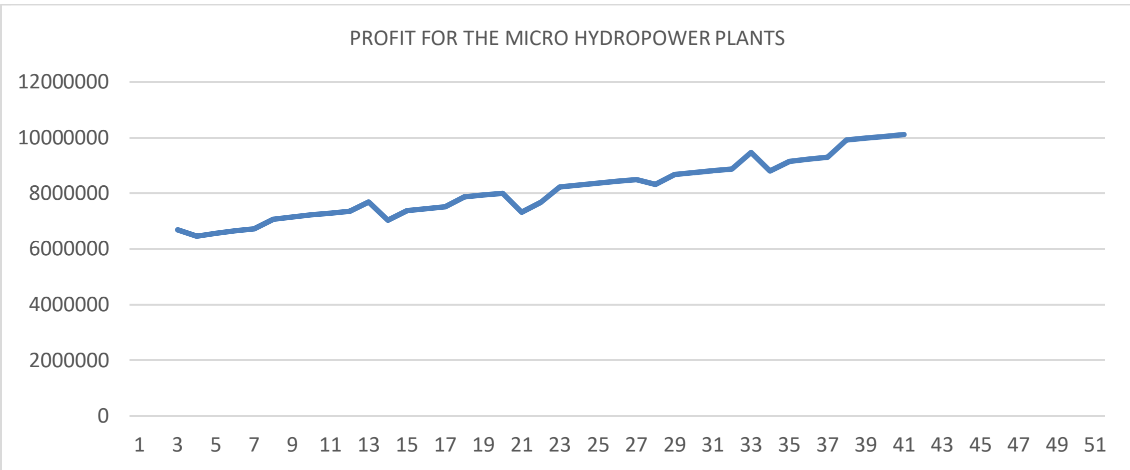


Fig 6.54: Profit trend over years

Figure 6.18 shows the profit trend for the next 40 years of the functioning of the hydropower plant. The profit generated is increasing due to the increased tariff and hence it makes a great input to decide whether to invest in the project. The trend shows that if proper interest is shown, small hydro power plants are a very good investment.

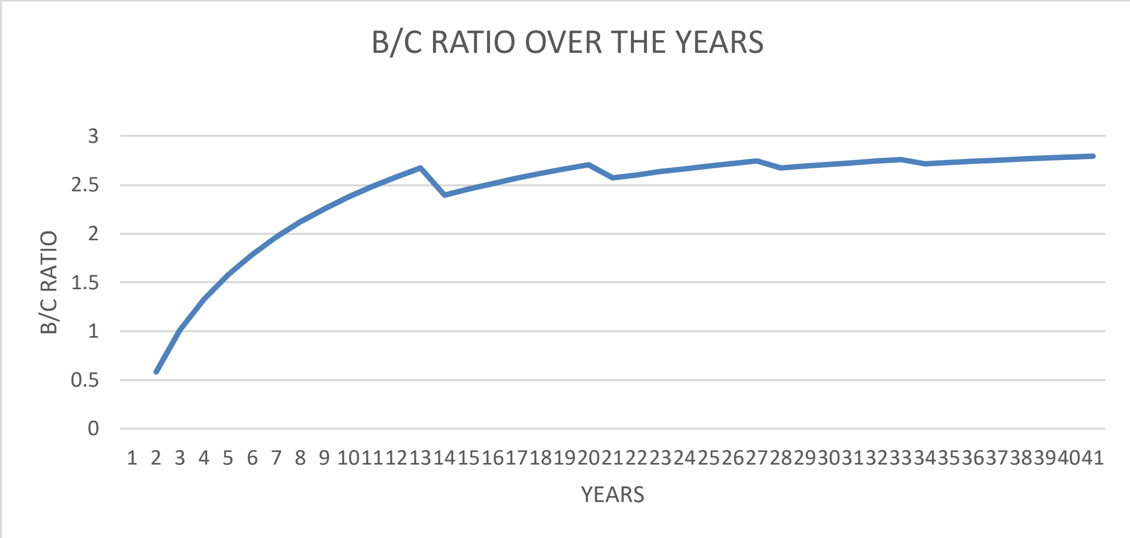


Fig 6.55: Trend of B/C ratio

Figure 6.19 shows the trend of B/C ratio over forty years. The ratio increases at a steady manner and decreases rather steeply. The scenario depicts that the ratio will decrease if there is no investment and will increase sharply if it is provided with yearly investments. This proves that the hydro power plant need not have just the primary investment into it, it should also acquire money from time to time when required to keep the power plant profitable.

6.5 Reliability Analysis

The probability that a system, including all hardware, firmware, and software, will satisfactorily perform the task for which it was designed or intended, for a specified time and in a specified environment is known as the reliability of a system. The power systems main emphasis is to provide a reliable and economic supply of electrical energy to the customers. A real power system is complex, highly integrated and almost very large. It can be divided into appropriate subsystems in order to be analyzed separately. In general, a study of the reliability of the three sections of generation, transmission and distribution of power systems should be done. In this project, only generation reliability is being considered to meet the load demands. The transmission and distribution ability are assumed to be perfect (reliability = 100%).

Hydropower is more efficient than many other energy sources and can run consistently with little maintenance, making it an ideal source of base load power. Most hydropower plants can quickly change the level of water flowing through their turbines to adjust electrical output. This output flexibility allows hydropower to meet changes in electricity demand better than many other energy sources.

There are two main categories of reliability evaluation techniques: analytical and simulation. Analytical techniques represent the system by a mathematical model and evaluate reliability indices by mathematical solutions. Simulation on the other hand, like Monte Carlo simulation methods, estimates the reliability indices by simulating the actual process and random behaviour of the system.

In this project, analytical techniques were used. In finding the reliability of the mini hydropower plant that is being designed, a reliability index is calculated which gives the percentage of days the electricity generated from the power plant will be able to meet the demand of 370Kw. For this study, a period of 10 years is taken (2007 – 2016). Daily runoff from rainfall to the headpond and the flowrate of the river is calculated for 10 years and from this, the total flowrate available per day to generate electricity is calculated. The total amount of energy that can be generated each day is calculated.

A reliability index known as LOLE was used for the calculation of reliability of the hydropower plant. It is given by,

$$LOLE = \frac{days}{years} \qquad \text{……. (6.9)}$$

Where, days – no. of days in which the plant is not able to meet the demand,

Years – total no. of days over the period of consideration

This is a probabilistic approach – that is, the actual amount will vary depending on the circumstances in a particular year, for example how much rainfall the place receives, whether or not the runoffs from different catchments flow efficiently to the river and all the other factors that affect the balance of electricity supply and demand.

However, it is important to note when interpreting this metric that a certain level of load is not equivalent to the same amount of blackouts; in most cases, loss of load would be managed without impacts on consumers.

It was found that on 1342 days out of a total of 3653, the supply was not able to meet the demand. This gives an LOLE of 36.74%. From this, the reliability is calculated to be 100 – 36.74, ie, 63.26%. All these calculations were done using Excel.

The reliability of the system was found out to be **63.26%**, which means that out of 100 days, the plant will be able to generate electricity for the entire population of 1200 households, on 63 days. In this calculation, the storage of excess electricity produced on the previous day and providing this to meet the demand of the present day is not considered because the design of storage is not included in this project. So, in actual conditions, this reliability value can be more.

7. COST ANALYSIS

Cost Analysis refers to the measure of the cost – output relationship. This project has made use of B/C ratio for the analysis. A benefit-cost ratio (B/C ratio) is an indicator showing the relationship between the relative costs and benefits of a proposed project, expressed in monetary or qualitative terms. If a project has a ratio greater than 1.0, the project is expected to deliver a positive net present value to a firm and its investors.

Cost-Benefit Analysis (CBA) estimates and totals up the equivalent money value of the benefits and costs to the community of projects to establish whether they are worthwhile. In order to reach a conclusion as to the desirability of a project all aspects of the project, positive and negative, must be expressed in terms of a common unit; i.e., there must be a "bottom line." The most convenient common unit is money. This means that all benefits and costs of a project should be measured in terms of their equivalent money value. A program may provide benefits which are not directly expressed in terms of rupees but there is some amount of money the recipients of the benefits would consider just as good as the project's benefits. These are intangible benefits.

The calculations for cost analysis were already done in the previous section. The observations are as follows:

The capital at the start of every month will decline until the 12 year is completed, hence we shall need the investment of 1 crore. To ensure that the capital at the start of every year is positive we will need an investment of 1 crore for the 20th, 27th and the 33rd year.

The payback period comes to around 2 years which is a good value because the whole 1 crore 50 lakhs investment is procured at the beginning of the project. Had the money being taken on loan, the payback period will definitely increase.

The B/C ratio shows promising results. The difference in the financial evaluation of a hydro power plant with respect to any commodity being sold is that hydropower production does not involve any variable costs. The cost of production of electricity will not increase with each additional unit. The only cost that we incur is the operation and maintenance, which is not very much. The B/C ratio is also a little higher due to the increase of the tariff rates in the years to come.

Average annual profit= ₹ 7,151,570

Payback time period = 1.82 years

Small hydropower can be a reliable, cost effective, and environmentally friendly way to increase renewable energy production in the country.

8. SUMMARY

Energy is the golden thread that connects economic growth, increases social equity and an environment that allows the world to thrive. Development is not possible without energy and sustainable development is not possible without sustainable energy. This project focused on developing such a source of energy, hydroelectric energy. We designed a mini hydropower plant with an installed capacity of 370 that will provide electricity to a population of 1200 households in the town of Kanjirappally in Kerala. Optimization was done before designing and this paved way to the development of an economically feasible, technically viable, reliable and profitable system with minimum environmental impact.

According to the United Nations Industrial Development Organization (UNIDO), the technology applied in small hydropower of renewable form allows the development of rural areas and the access to electricity by a portion of the population living in these regions and they contribute to sustainable development and social inclusion. These factors are positive in the evaluation of governments and their public policies. Kerala has many untapped potential locations for micro and mini hydropower plants. Kanjirappally is just one of them. This project, with slight adaptations, can be made use for the development of SHPs anywhere in the world with similar geographic conditions.

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