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Feasibility Assessment of Medium-Scale Hydro-Power Plant – Case Study in Kerala, India

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Abstract: The power of the hydrological cycle is enormous, sometimes devastating, but when it is utilised wisely, its negative impacts on humankind can be mitigated. Catastrophic floods and droughts are boosted by the world climate change. Hence, water management programs came into effect. On the other hand, energy production plays a major role in the country's economic development. So, studies have come up with many ideas to ameliorate disasters especially floods through building mini, small, and large hydro-power plants against the rivers. This study presents a feasibility analysis of flood management and energy production in the Madupetty River, Kerala, India. Even though there are other dams in the Madupetty River, Mudirappuzha basin, the old Headwork built for a hydroelectric project, needs capacity augmentation. This study looks at ways to optimise the Maduppetty River's water distribution system by building a dam-toe powerhouse where flood water can be stored and utilised when needed. Detailed analysis and design of the hydro-power station is presented. Rainfall runoff equations are used to assess the inflow for power potential studies. During flooding, the projected dam can hold 20.42 MCM of water. From this study, the dam toe powerhouse and cascade powerhouses will create 7.12 Mu and 90 Mu.

Key words: Dam toe powerhouse, feasibility analysis, hydropower plant, hydropower potential analysis, Kerala hydro power, Madupatti Reservoir, reservoir storage augmentation, site suitability analysis.

Introduction

The economic development of a country is firmly linked to energy with a positive correlation between gross domestic product and energy utilisation. As the sprawling of urbanisation and industrialisation is escalating, there will be always more demand for energy (Wadanambi et al., 2020). This economic development using electricity need not be solely relayed on conventional sources but also with energy diversification incorporating renewable resources. But, fossil fuels are being burned without any restrictions to cope with the ever-increasing energy demand significantly impacting the environment. Also, the potential of water is mostly not utilised as Kerala has only used about 1/3 of the hydropower resources found. Though much work has been done to develop ideas for hydroelectric projects, many have become caught up in environmental and forest-related problems (John Paul et al., 2021). The projected future climate change despite having risks due to the extreme conditions, has a potential to increase hydropower production (Chuphal and Mishra, 2023) due to the average increase in inflow. On the other hand, Global energy demand is rising exponentially, especially in developing nations (Kishore et al., 2021). According to India's Central Electricity Authority, by 2020 and 2021 there will be a need for 6093 MW of power generation and 34691 Mu of annual energy from Kerala state. For more

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energy, projects to increase the amount of energy made and extend hydroelectric projects are looked at. For this important decision-making, a feasibility study is needed (Ozigis et al., 2019). For the successful output generation through the hydropower plant, the technically and economically optimised turbine, which will produce the best energy with less cost must be considered (Bitar et al., 2015). This paper presents the feasibility of hydro energy production and mitigation of flood in the Maduppetty River of Munnar, Idukki district of Kerala, India. The feasibility of a hydro power plant in terms of site suitability, power generation, and economic and environmental acceptability is studied.

Study Area

There are 41 west-flowing rivers and three east-flowing rivers in Kerala. The Maduppetty River falls under Mudirapuzha Sub-Basin (Latitude 10°01'55''N – 10°11'31''N and Longitude 76°59'45''E - 77°14'52''E), Periyar basin, Kerala, India. The study area majorly has a forest cover, the soil is classified under forest soil with granitic and gneissic rock formation. The climate of this region is a tropical humid climate with southwest and northeast monsoons. The annual average precipitation of this basin is 3700 mm and the elevation ranges from 740 to 2690 m above mean sea level (MSL). The basin experiences a maximum temperature of 25°C in summer and a mean temperature of 17°C (Thomas et al., 2018). The Madupatti River in the Mudirapuzha sub-basin, Kerala is shown in Figure 1.

Pallivasal Hydroelectric Project (1940) in the Mudirapuzha sub-basin, Periyar basin was Kerala's first hydropower development. The Ramaswamy Aiyer Headworks (R A headworks), Munnar commissioned in 1944 has a storage capacity of 0.223 Mm^3 only. The powerhouse was initiated with the potential of 32.5 MW which was renovated and upgraded to 37.5 MW. Due to the impossibility of increasing the storage capacity of RA headworks, two storage dams were constructed in the Maduppetty River, a tributary of the Mudirapuzha basin. One of them is a Setuparvathipuram masonry gravity-type dam (Kundala Dam) (7.65 MCM) and the second one, is the Maduppetty concrete gravity dam

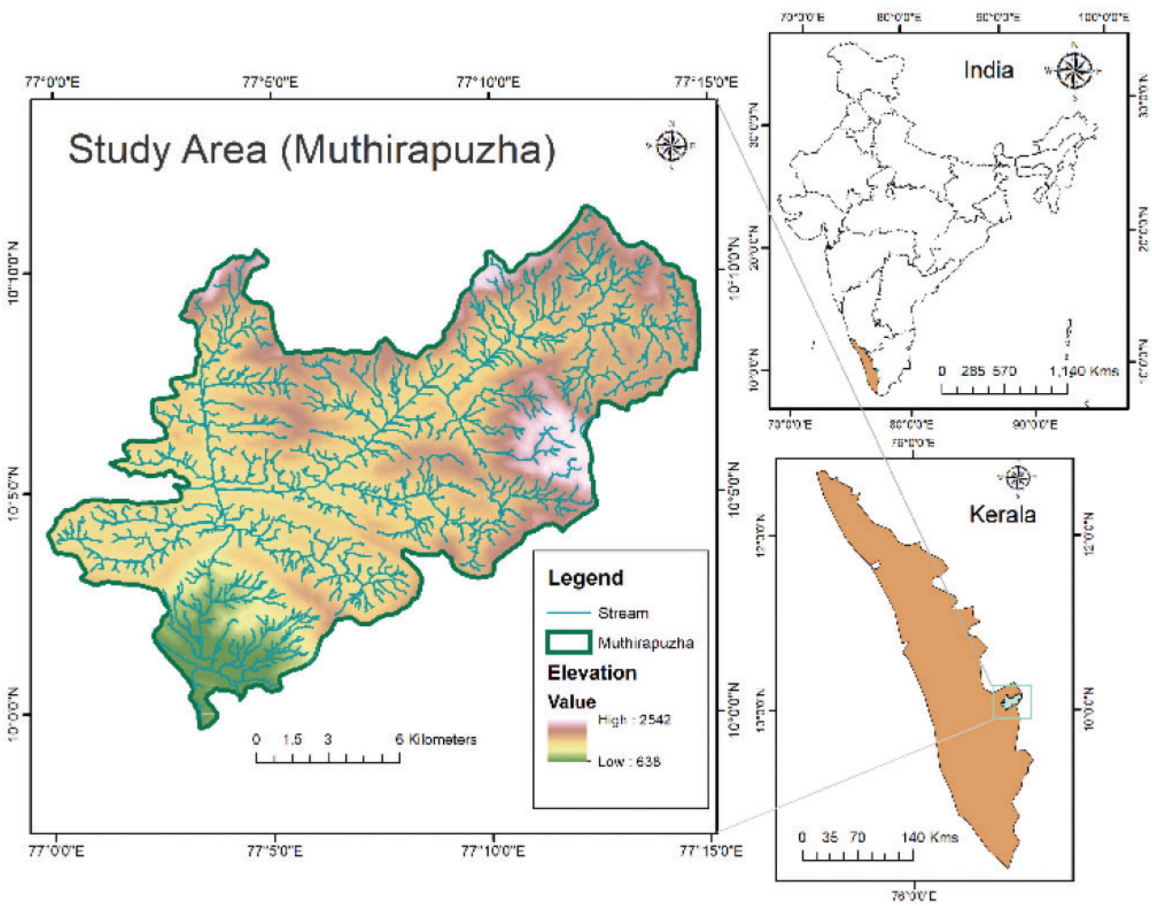

Figure 1: Study Area- Muthirapuzha Basin.

(55.4 MCM). Even with two storage dams, the RA headworks will spill for most of the year due to two additional tributaries at Munnar, namely Nallathanni and Lakshmi rivers. Therefore, if a dam is built in the Maduppetty River, spillage of R A head works can be avoided and the dam to Power House could be utilised for additional power generation along with Mudirapuzha and Periyar power projects.

Methodology

The feasibility analysis includes the site suitability analysis, design flow and maximum flood estimation, power potential studies, economic analysis, environmental impact assessment, etc. Also, the power which the dam-toe powerhouse can generate from the released water is investigated and the number of machines it can accommodate is obtained. The flow chart showing the methodology is shown in Figure 2.

Site Suitability Analysis

Environmental aspects, geographical properties such as downstream conditions, lakes, and geological hazards are critical considerations in the site suitability analysis for constructing the multipurpose dam (Kishore et al., 2021). As this study entails the construction of a dam to effectively use the Maduppetty River's waters for flood control and power generation, a site reconnaissance survey was done to select a suitable location that serves the objective. The topography of the study area

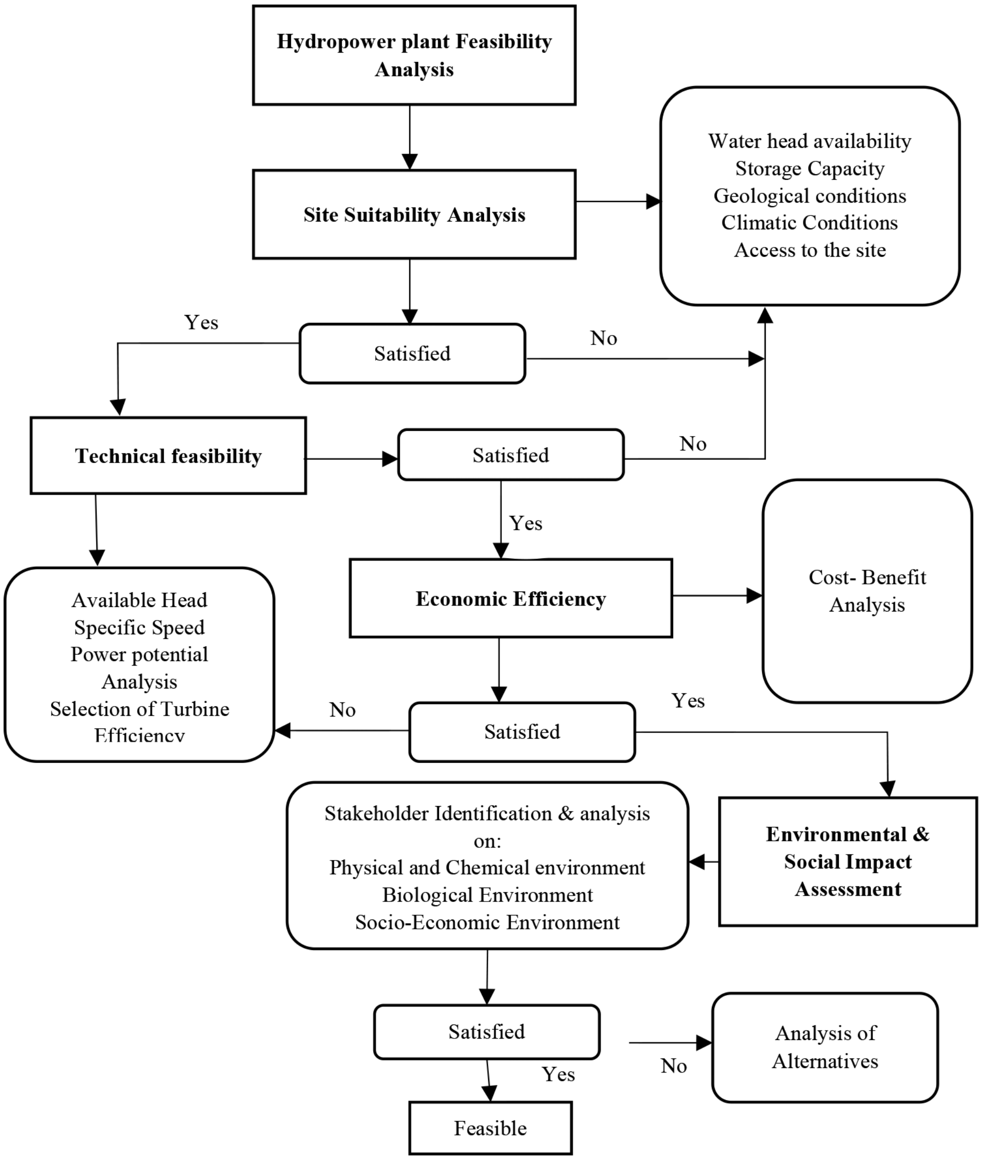

Figure 2: Methodology flow chart.

is studied using the Digital Elevation Model (DEM) obtained from the Bhuvan website.

Modelling Hydropower Plant

Hydrological Data Analysis

Researchers have proposed many methods to calculate the discharge in ungauged stations (Tian et al., 2020; Tuna, 2013). There is no gauging weir at the proposed location. Rainfall data collected from ten rain gauge stations owned by private tea estates in the catchment over nine years, from 2011 to 2020 were obtained. Equation (1) corresponds to the runoff depth estimation using the SCS-CN method (Bhagat, 2017).

$$\mathrm{Q} = \frac{(P-I_a)^2}{p-I_a+S} \tag{1}$$

where Q is the Runoff depth, P is the precipitation in mm, I_a is the initial abstraction and S is the potential maximum retention of water by the soil (mm) which is given by Eq. (2) for Indian soil conditions.

$$S = \frac{25400-254}{CN} \tag{2}$$

The monthly rainfall-runoff relations were obtained from the Central Water Commission (CWC) for the Kunjithanny River, a tributary of the Mudirappuzha basin which is best fit for the proposed site used for the study. The relationships with their correlation coefficient are shown in Table 1.

Table 1: Rainfall-runoff relation approved by CWC

Month	*Relationship*	*Correlation coefficient*
June	Y=0.349 X + (-0.0435)	0.9
July	Y= 0.779 X + 0.0369	0.94
August	Y = 0.676 X +0.017	0.968
September	Y = 0.866 X + (0.0416)	0.901
October	Y= 0.40 X + 0.0599	0.91
November	Y = 0.695 X + 0.066	0.861

75% dependable flow to ensure water availability and the corresponding year was calculated based on the Weibull plotting position formula given in Eq. (3).

$$\mathrm{P_p} = \frac{m}{N+1} \times 100\% \tag{3}$$

where, P_p= percentage probability of the flow magnitude being equalled or exceeded, m = order number/rank of the inflow, N= number of data points. Also, there are two dams upstream from the proposed location. Total Inflow = Catchment Rainfall Inflow + Release from upstream dam/powerhouse. The inflow details are shown in Table 2.

Table 2: Inflow details

Year	*Rainfall [mm]*	*Inflow from own catchment [MCM]*	*Release from Maduppetty dam/dam toe PH [MCM]*	*Total Inflow [MCM]*
2011-12	1888.50	55.94	41.23	97.17
2012-13	1350.23	39.64	38.06	77.70
2013-14	2146.20	66.78	62.99	129.77
2014-15	2340.63	76.69	65.98	142.67
2015-16	1870.36	54.78	52.35	107.12
2016-17	1482.61	42.11	40.96	83.07
2017-18	2071.55	65.80	43.33	109.13
2018-19	3187.80	102.47	71.26	173.72
2019-20	2255.16	72.68	68.32	141.00
Total	18593.07	576.89	484.47	1061.36
Average	**2065.90**	**64.10**	**53.83**	**117.93**

Power Potential Analysis

The power potential studies were conducted for this dam toe power house based on the discharge and the available head worked out. For calculating the power, Equation (4) is used (Alshami and Hussein, 2021).

$$P_w = \gamma Q H \eta \tag{4}$$

where P_w = power in KW, γ = weight density in kN/m^3, Q = discharge in m^3/s, H = operating head in m, η= efficiency. The specific speed of the turbine is calculated using the Eq. (5),

$$n_s = \frac{n\sqrt{1.358P}}{H^{5/4}} \tag{5}$$

where, n_s = Specific speed of turbine (r.p.m.), n = Rated speed of turbine rpm, P = turbine output in kW, and H = Rated head in meters at the start of the water year, which is on June 1, it was assumed that the water level was at minimum draw down level (MDDL). In June, the inflow was proposed to keep until 30% of the total storage space reached, after 30% storage, the influx will be released. If the amount of water available each day is not enough to run a machine at half load, the water will be released through the river sluice in the dam body. Likewise, storage will be raised to 50%, 70%, 90%, and 100 % during July, August, September, and

October, respectively. In November, the total inflow will be either utilised for power generation as per availability as mentioned above or released through the spillway. During the dry periods, it is proposed to run the dam toe powerhouse as per the requirement in the downstream Pallivasal Powerhouse, and in such a way, the storage in the dam will be depleted to MDDL in the morning of 1st June of the next water year. Energy in Mu = Power output in KW × Working Hours /10^6. The installed capacity which gives maximum energy was selected for the proposed dam toe powerhouse.

Hydraulic Design of Components

The selection of suitable turbines for power generation is based on qualitative and quantitative conditions. The quantitative conditions include the head, specific speed, power cost, efficiency and size. The technical components should be selected considering the local constraints from social, environmental, cultural, technical and economic perceptions. Hydraulic design of components was carried out using standard codes and Manuals (2011; Hydro and Centre 2012; Central Electricity Authority, 2015). The design and analysis of the dam is based on the IS 6512:1984, USBR, US Army Corps of Engineers, IS 1893: 1984, Guidelines by AHEC. The preliminary design of the power house was done as per the provisions of IS 12800 part 1, 2 &3.

Economic Analysis

Cost-Benefit Analysis

Economic investigation and evaluation are considered as one of the main factors of industrial projects. The financial viability of the proposed project was ascertained by cost-benefit analysis. An estimate of cost was prepared based on the guidelines for the preparation of Project estimates for hydroelectric projects issued by the Central Electricity Authority / State Government (2011). The quantities of various components as per the Hydraulic design were ascertained as well as the cost of equipment and requirement of land were considered. The rates adopted for the estimation are based on the Delhi Schedule of Rates 2018 with cost index for the Idukki district and prevailing rates obtained from Kerala State Electricity Board Limited. The total cost of the project was estimated. Ministry of New and Renewable Energy (MNRE) subsidy at Rs.35000 per kW is provided by the Government of India.

Environmental and Social Impact Assessment

Environmental Impact Assessment is a tool to find out ways to the best solution having the least negative impacts on the environment due to the project among the different proposed alternatives. The detailed environmentally feasible assessment includes presenting environmental constraints and quantifying the impacts. This study investigates the social and environmental conditions around the proposed site and reconnaissance survey to find the possible impacts that may occur due to the proposed hydropower plant.

Result and Discussion

Proposed Site

The proposed site's location is Graham Land [11°15'25" N and 72°80'90" E (left bank) and 11°54'87" N and 72°80'89" E (right bank)], a village in Kerala's Idukki District. Having the smallest possible width, this site has been chosen as at this point, the maximum inflow will tap. Also, exposed rock, is available for abutting the dam, particularly in the banks. The dam toe powerhouse will be built on the site. The details of the site selected are presented in Table 3.

Table 3: Description of selected site

Criteria	*Details*
Left bank	$11^0$15'25" N and $72^0$80'90" E
Right Bank	$11^0$54'87" N and $72^0$80'89" E
Catchment area	50 Sq. Km
Climate	Tropical
Temperature	35.60 to 84 deg. Fahrenheit

Other than June to rainy October, all other months are mostly dry. The tea estates area mainly covers the proposed site. The site has elevations ranging from +1600.00 m to +1460.00 m above mean sea level.

The contour map of the area and proposed reservoir capacity is shown in Figures 3 and 4, respectively. The Full Reservoir Level (FRL) was fixed at +1520.00 m. The storage capacity and submergence area at FRL are 20.42 MCM and 1.5921 Sq Km.

Modelling of Hydropower Plant

The average annual inflow calculated from catchment runoff was 64.10 MCM. The release from Maduppetty Dam / Dam toe Power House has an average value of 53.83 MCM. The total inflow to the reservoir is represented in Figure 5.

For the selection of a suitable turbine, the Gross head is determined as 45 m which is the difference between the Full Reservoir Level (FRL = 1520 m) and

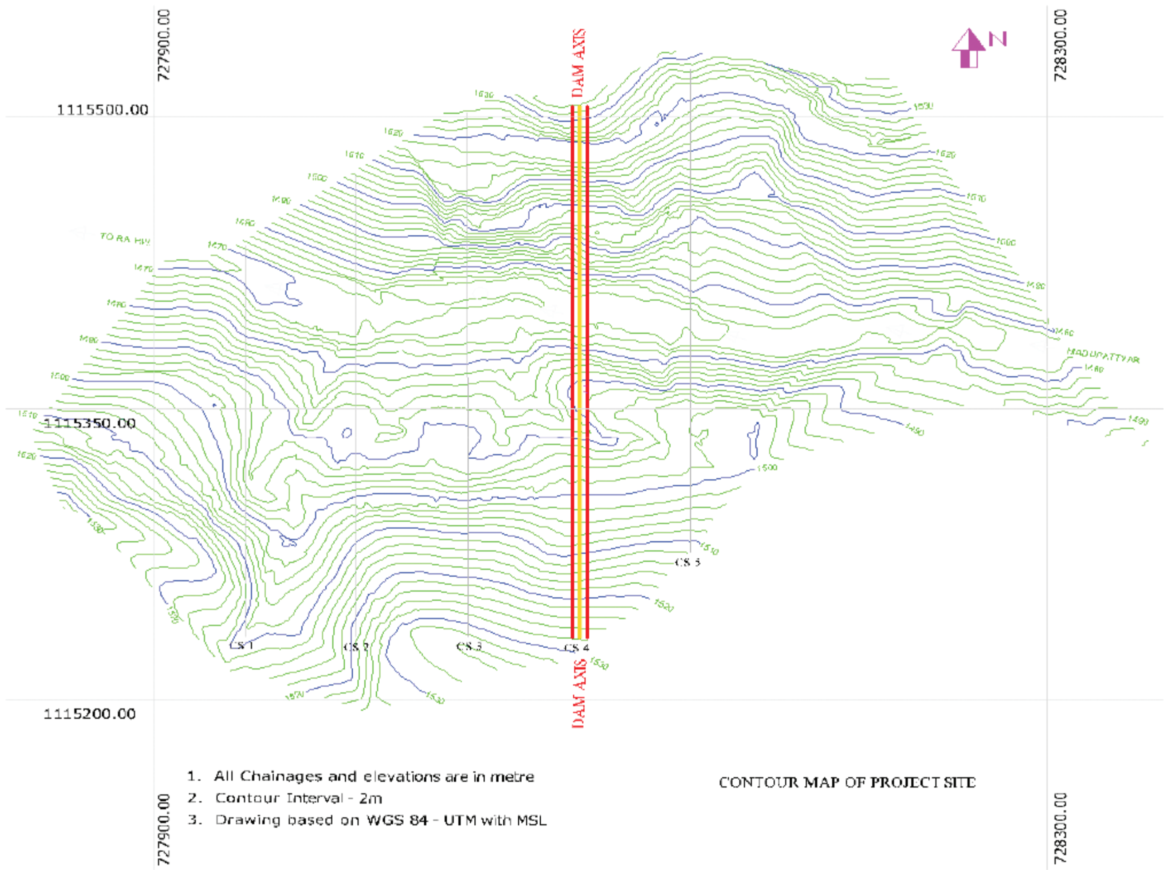

Figure 3: Contour map of proposed site.

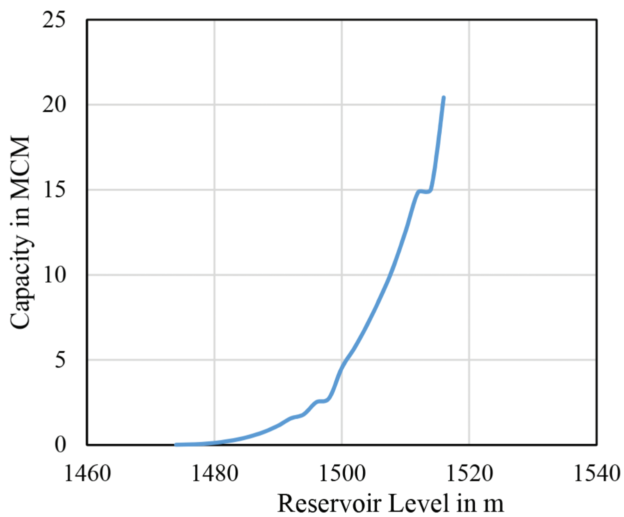

Figure 4: Capacity vs reservoir level.

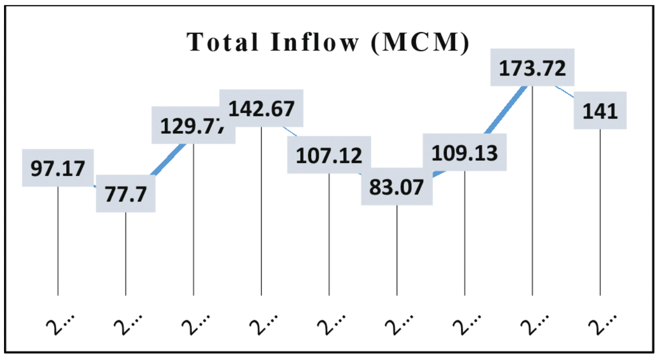

Figure 5: Total Inflow to the reservoir.

the Tailrace crest level. As the Maximum Flood Level is +1475.00 m, the tailrace crest level of the dam toe power house was fixed as +1475.00 m. As per Indian Standard (IS) 12800 coal specifications, the Francis design was selected (head ranging from 3 to 600 metres). These turbines can be operated effectively for medium heads with their features of controllable vanes are constant blades. Modern Francis turbines achieve peak efficiencies of between 80% and 95%; however, these efficiencies can be increased to between 90% and 95% with proper design. As per Table 1 of IS 12800 Part 3, the design head for the Horizontal Francis turbine is calculated as 37 m. Capacities used for power potential studies are 3 MW (2 × 1.5), 4 MW (2 × 2), 5 MW (2 × 2.5) having design discharge 10.14 m^3/sec, 13.51 m^3/sec, 16.89 m^3/sec, respectively.

The 75 % dependable year was found using the Weibull method and the flow duration curve is shown in Figure 6. The year 2011-12 is the 75% dependable year and the corresponding inflow is 97.17 MCM. Energy generation for various installed capacities mentioned above is worked out in Table 4.

Table 4: Energy vs installed capacity

Sl No	*Installed Capacity (MW)*	*Energy (Mu)*
1	3 (2 × 1.5)	6.89
2	4 (2 × 2)	7.12
3	5 (2 × 2.5)	6.70

The capacity is optimised after conducting potential power evaluations for various installation capacities. The power optimisation graph is shown in Figure 7.

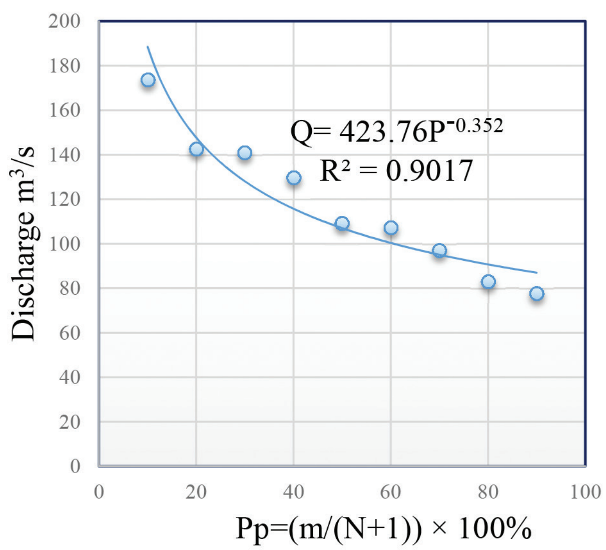

Figure 6: Flow duration curve.

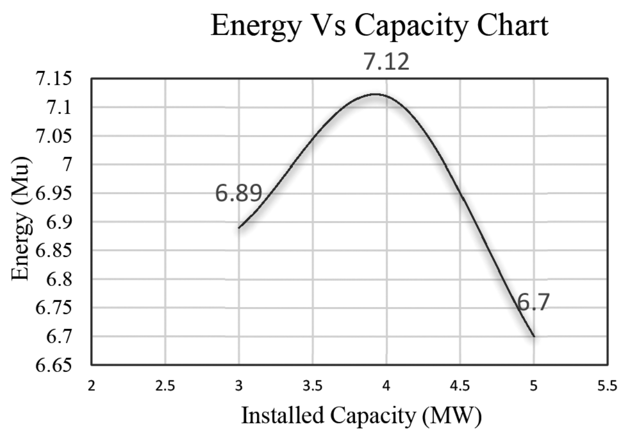

Figure 7: Energy vs installed capacity chart.

The optimum energy and corresponding installed capacity were chosen from the power optimisation graph. 2 number of each turbine are considered to tap the lean flow. Optimally, two 2MW Horizontal Francis turbines will be constructed at the dam's toe powerhouse producing an average of 7.12 Mu energy per year which is an additional benefit.

Profile of Dam and Power House

As per the hydraulic design of the dam, the features of the dam that should be kept into consideration are listed, as shown in Table 5. The dam is safe against overturning, sliding and shear sliding friction. The salient features of the dam toe power house and appurtenant structures are given in Table 6.

Table 5: Summary of dam features

Sl. No	*Component*	*Design value*	*Unit*
1.	Height of dam	48.3	meters
2.	Base width	39.3	meters
3.	Free board	2.30	meters
4.	Downstream slope	1 in 0.84	
5.	Length of Dam at top	245	meters
6.	Top width	6.78	meters
7.	Spillway crest level	+1512.00	meters
8.	Spillway type	Ogee with upstream vertical	
9.	Spillway gates	3 Nos radial gates of size 6 m × 8.5 m	meters
10.	Spillway discharge capacity	860	m^3/sec

Economic Analysis

The estimated cost of the project based on the Delhi Schedule of Rates 2018 is Rs. 229 crores. The project is financially viable as per the guidelines stipulated by the Kerala State Electricity Regulatory Commission. The financial study was done with an annual average energy of 97.12 Mu both from the dam toe scheme and downstream projects. The payback period is 12 years. The payback period can be defined as the total time period for paying back or recovering all the costs invested in the project. For a project investment to be successful, the payback period should be less than the investment period (Vyas et al., 2015). The project has an Internal Rate of Return of 43.48 %. The Net Present Value of the Project is 53.59 crores, Levelised Tariff at a discounting rate of 10% for the project is Rs. 2.73/unit.

Table 6: Summary of dam toe power house features

Sl. No	*Component*	*Design value*
1.	Installed capacity	2 × 2 MW
2.	Design Head	37 m
3.	Design discharge	13.51 m^3/sec.
4.	Diameter of main penstock	2.6 m
5.	Number and dia of feeder pipes	2 no's of 1.84 m each
6.	Type of intake	Rectangular Bellmouth
7.	Thickness of penstock pipe	12 mm
8.	Sill level at intake	+1492.70 m.
9.	Control gates at intake	Two vertical lift gates to suit clear size of 2.15 × 2.6 m
10.	Gross Area of trash rack opening	100 m^2
11.	C/L of machine	+1477.220 m
12.	Runner diameter	1.23 m
13.	Tailrace crest level	+1475.00 m
14.	Size of Power House	25 m × 10 m × 13 m
15.	Length of tail race	8.64 m

Environmental and Social Analysis

This project necessitates the construction of a reservoir, where there are no such environmentally sensitive areas nearby, so there will be no environmental impact. After power generation, the tailwater will be discharged into the Maduppetty, which will flow to R A headworks. Except for some colonies known as Kuttiar Valley, there is no human habitation in the proposed project area. There are approximately 40 houses that need to be rehabilitated. There are a few revenue lands nearby where these houses could relocate. There will be no cultural, religious, or heritage areas of historical significance lost or relocated due to the project's implementation.

Conclusion

The dams built for other purposes give the possibility for additional energy generation. If the power generation can be integrated while planning the construction of hydraulic structures it is well and good. According to the findings of this study, constructing a dam in the Maduppetty River for flood control and electricity generation is technically feasible. The dam site was initially recognised through a reconnaissance survey and using the concerned Global Telecommunication System (GTS) map 58 F/4. The detailed survey was conducted using Leica to make TS11 total station to fix the profile of the dam and reservoir such as maximum height, Full Reservoir level, storage capacity, etc. A dam with 48.3 m in height and 245 m at the top can store 20.42 MCM water during monsoon. Water overflowing during the monsoon season and release for power generation throughout the summer can be effectively employed in the proposed dam-toe powerhouse to harness the energy, which is an extra benefit of this investigation. The project will benefit 97.12 Mu energy annually. The project is financially viable based on the Kerala State Electricity Regulatory Commission.

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