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Research Article

Exploring the Hydroelectric Potential of Thulagi Glacial Lake for Risk Reduction and Sustainable Energy in the Himalayas

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Abstract
Glacial Lake Outburst Floods (GLOFs) represent one of the most devastating natural hazards in the Himalayas, with their unpredictable nature leading to significant infrastructure and economic damage in Nepal. While this resource has the potential to benefit society, it poses a risk to communities located downstream. This research primarily aims to investigate the hydroelectric potential of the Thulagi Glacial Lake in Manang district of Nepal, focusing on risk reduction and sustainable energy solutions in the Nepali Himalayas. The study is confined to the context of Nepal and serves as a preliminary investigation rather than a detailed technical evaluation. Data was gathered using a conductivity meter, revealing a maximum discharge rate of 6155.22 L/s on 23 August 2018. The lake's area, glacier, and volume were assessed through satellite imagery, which indicated significant expansion of the lake and substantial retreat of the Thulagi glacier from 2005. Despite the glacier's rapid recession, it is estimated that it will continue to supply water to the Thulagi Lake for over a thousand years. The lake contains approximately 35.7 million cubic meters of water, with an annual discharge of about 93.4 million cubic meters. Even with the minimal required gross head and turbine efficiency for micro-hydropower, the lake's maximum discharge rate could generate 102 kW of energy. By harnessing the lake's water for energy production, the risks associated with the lake can be transformed into economic benefits.

Keywords: *Glacial lake, glacial lake outburst flood, Thulagi Glacier, hydropower*

Introduction
Nepal Himalayas span 800 kilometers of the central section of the Himalayan range, which extends for approximately 2,400 kilometers and encompasses about 33,000 square kilometers of glaciated area (ICIMOD, 2011). The thinning and retreat of glaciers in this region are increasing the number of glacial lakes while also adding volume to the existing ones. These lakes serve as both a resource and a potential hazard for communities living downstream. The sudden release of water from a glacial lake is known as a Glacial Lake Outburst Flood (GLOF) and they have catastrophic consequences to the infrastructure, people and property in the valleys downstream.

International Centre for Integrated Mountain Development (ICIMOD) identified 47 potentially dangerous glacial lakes in November 2020. Among these, 25 glacial lakes inventory were in Tibetan Autonomous Region (TAR) China, 21 in Nepal and 1 in India. Koshi basin was declared at highest risk as 42 out of the 47 dangerous lakes lie at its boundaries, while Gandaki and Karnali basins contain three and two such lakes, respectively (ICIMOD, 2020). In March 2021, two under-construction hydroelectric plants in Uttarakhand, India, were washed away due to flash floods (Khanduri, 2021). This serves as a warning for any construction or infrastructure projects in the identified dangerous basins. Nepal has been developing numerous projects in the basins of the Bhote Koshi, Marsyangdi, Tama Koshi, and Arun rivers. In particular, the Gandaki basin, which includes the Thulagi Glacial Lake, poses a threat to three major hydropower plants along the Marsyangdi River. Historical events, such as the flash flood caused by a glacial lake outburst in TAR, China, in 1934, which resulted in significant destruction along the Bhote Koshi basin, indicate the potential danger of transboundary glacial lake outburst floods (GLOFs) (Khanal et al., 2015a). However, glacial lakes are not only a potential threat; they also represent valuable natural resources. The mountain dwellers in the Nanga Parbat region, Hunza-Karakoram, and Ladakh have developed techniques to utilize meltwater from glaciers, snow, and permafrost, which have helped them cope with recurrent water scarcity (Nusser et al., 2019). This demonstrates that glaciers and glacial lakes can be a boon to society if utilized effectively.

The energy generation potential of glacial lakes presents both opportunities and challenges with broad environmental, geopolitical, and socio-economic implications. As climate change accelerates glacial melt, these lakes expand, offering a new and abundant source of hydropower. Harnessing this energy could provide sustainable electricity to remote and underserved regions, reducing reliance on fossil fuels and lowering carbon emissions. Hydroelectricity generation from glacial lakes is an emerging topic in Nepal's hydropower sector. Currently, only one glacial lake, the Langtang Lirung glacial lake, has been utilized for power generation through the Langtang Microhydro Electricity Project, which produces 100 kW of energy (Dixit, 2021).

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While numerous studies have explored Nepal's potential for generating hydroelectricity, very few have investigated the feasibility of harnessing energy from glacial lakes. Generating hydroelectricity from these lakes could mitigate the risks associated with glacial lake outburst floods (GLOFs) by transforming them into economic assets. Therefore, this research aims to provide insights into the potential of glacial lakes for hydroelectricity generation. This paper may serve as a valuable resource for other researchers interested in this field.

Materials and Methods

Study Area

The study area lies in Ward Number 2 of Nasongh Rural Municipality located in the Manang District of Gandaki Province, Nepal (Fig. 1). The Thulagi Glacier of Mount Manaslu feeds Thulagi Lake and is locally popular as Dona Lake. Geographically, the study area is situated at 28^0 29’ 9.80" N latitude and 84^0 29’ 14.85" E longitude. The end moraine of the lake is at an elevation of 4029 masl while glacier terminus lies at 4140 masl.

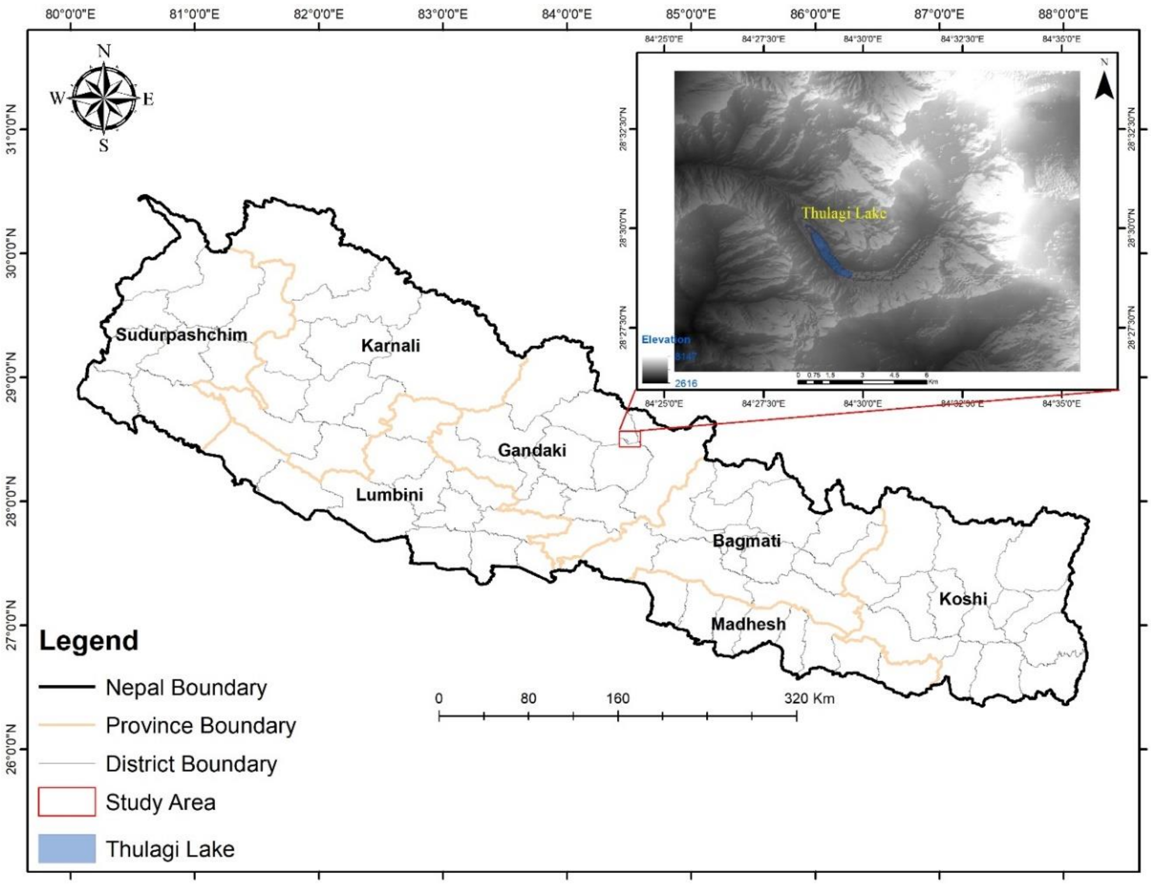

Figure 1. Location map of the study area. The map in the upper right box shows Thulagi Lake (enlarged in Fig. 3).

Topography

The highlands surrounding the lake are marked by stable lateral moraines. There is a significant increase in elevation from the end moraine to the glacier terminus, indicating that the lake lies on a slope. Additionally, the surrounding area exhibits substantial altitude variation, further contributing to the area's instability. The steep slope of the glacier and the lake bed increases the potential energy of the water stored in the lake. In the event of a breach in the end moraine—caused by factors such as melting ice, seismic activity, or heavy rainfall, this slope would amplify the rapid drainage of water, triggering a GLOF. The sudden release of water down a steep gradient can result in catastrophic downstream impacts, including flash flooding, debris flows, and widespread damage to infrastructure and ecosystems. The roughness of the land can be seen in Fig. 2 where the contour line represents an interval of 100m. The watershed or catchment area of the Thulagi Lake is 56 km^2 and is presented substantially covered by snow and ice (Fig. 3). However, from time to time rain and snowfall also add up water in the lake.

Socio-Economy

Apart from one-two seasonal tents there are no settlements near the lake. During the monsoon, land around the lake is lush with alpine pasture, thus villagers from Nachai and Karte leave their yaks in the region for grazing. To look after the yaks, on their mutual agreement, few people set tents around the area and live there until pastures dries or yaks need to be taken down for any events. Figure 4 depicts the scenario of the area.

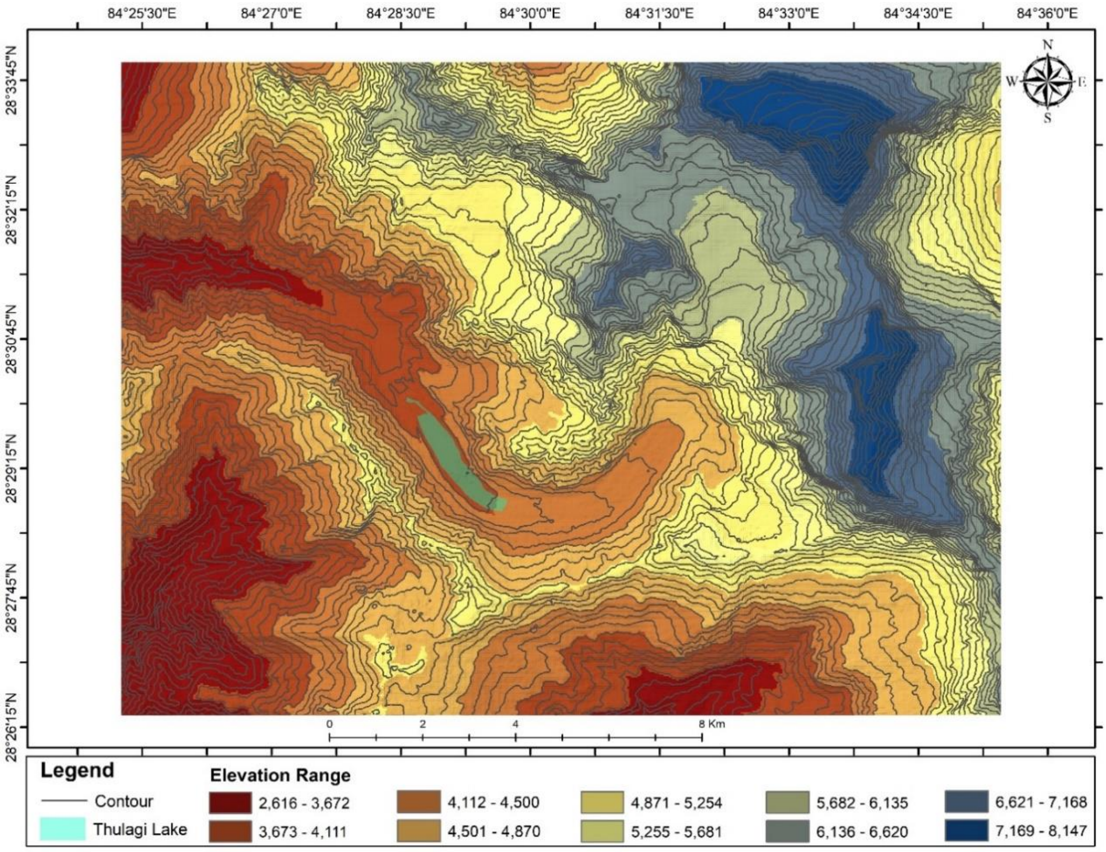

Figure 2. Topography map of study area.

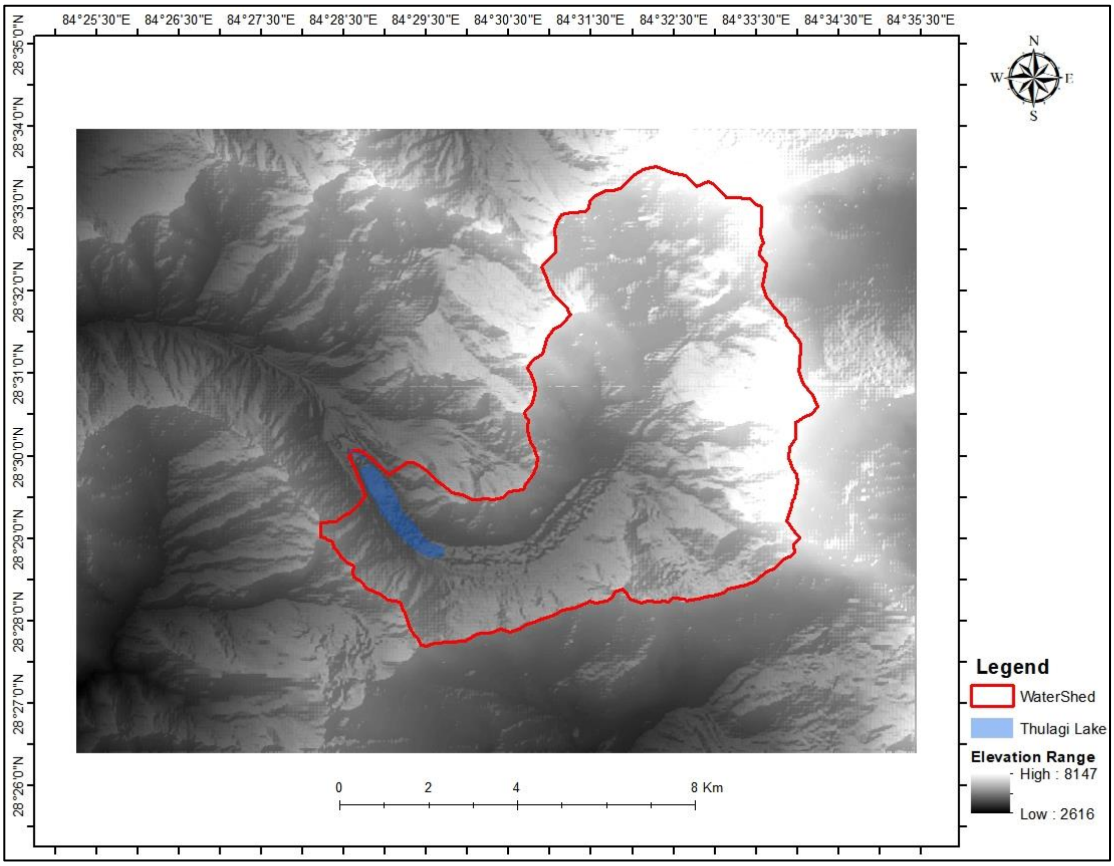

Figure 3. Watershed of Thulagi Lake.

Figure 4. Tent of shepherd along with yaks.

Materials and Methods

Research Design

In this research, both qualitative and quantitative methods of data collection and analysis are used. Quantitative data collected through conductivity meters are analyzed with qualitative approach along with the possible generation of electricity. Possible investment and return are also analyzed with the reference of governmental scheme.

Tools and Techniques for data collection

Various literatures were studied before the field visit along with analysis of Google Earth Pro's images of 2005, 2012, 2015 and 2019 to calculate the differences in size of glacial lake. For lake's volume calculation, 2019 Google Earth Pro's image was used. To calculate the area of glacier Landsat-8-9 OLI/TIRS images from 2019/03/31 were downloaded from the website of USGS (https://earthexplorer.usgs.gov/), then image of all bands was analyzed on ArcMap 10.3 (GIS). First using Normalized Difference Snow Index (NDSI), snow and glacier area was selected from the area which then was further studied by creating the False Color Composite (FCC) to create the boundary of the glacier. Different band combinations were tried and finally, the band combination 6 (R), 5(G) and 2 (B) were used as the glacier information was clearer distinguishable from the snow and clouds.

In Landsat 8-9, NDSI = (Band 3 – Band 6) / (Band 3 + Band 6) ……………………………(1)

Furthermore, field data were collected using different tools and techniques such as field observation and conductivity meter.

Field Observation

Changes in the volume of the lake in different seasons along with the retreat of the glacier were observed. In months like January and February when the surface layer of the lake was frozen, water kept on flowing from the end of the moraine. During the monsoon season the downstream river path expands which eventually shrinks in dry season. The change is also seen in Fig. 5. These observations during the field visit coincided with Google Earth Pro's image, making the images more reliable for analyzing.

Conductivity Meter

The conductivity meter was used to measure the discharge of the lake using salt dilution method. In this method, a tracer solution is injected into the river to be diluted by the stream discharge. Downstream of the injection point, when vertical and lateral dispersion throughout the flow is complete, the discharge is calculated by the measurement of the electrical conductivity as a function of time. Once the measurements are complete, the integral of the area under the curve of the time-conductivity diagram needs to be calculated (Sentlinger, 2015). Data being collected in the field is shown in Fig. 6.

The formula for the calculation of the discharge is

$$Q = \frac{S}{Cal*(\sum Ct-(N*C0))*T} \quad \ldots\ldots(2)$$

where,
Q is discharge
S is the amount of salt injected
Cal is Calibration Factor
$\sum Ct$ is the sum of all the conductivity values
N is the number of conductivity values
C_0 is the background conductivity
T is the measurement interval

Figure 5. Thulagi Lake in different time frames.

Data processing and analysis
Discharge data measured from a conductivity meter were processed and analyzed both quantitatively and qualitatively. Geographic Information Systems (GIS) were utilized for spatial data analysis to input, process, analyze, and map the spatial and attribute data. Spatial data layers, including catchment area, lake area, and glacier area, were created in GIS using ArcMap 10.3 software. The estimation of the power potential from the power plant was calculated using the specified formula.

$\mathbf{P = m \times g \times H_{net} \times \eta}$ (AHEC, 2008). ………….(3)
where:
P is power, measured in Watts (W).
m is quantity of water flowing through the hydraulic turbine in litre per second.
g is the gravitational constant, which is 9.81 m/s^2
H_{net} is the net head. This is the gross head physically measured at the site, less any head losses.
η is the product of all of the component efficiencies, which are normally the turbine drive system and generator.

RESULTS AND DISCUSSION
Risk analysis
In 2011, ICIMOD classified Thulagi as critical lake for GLOF. Since there are settlements and other human activities going downstream of the lake, the outburst becomes more dangerous, and the risk possessed must be studied.

Past events
Nepal has witnessed 10 GLOF events originated from TAR, China. Since the first case recorded in 1935 from Lake Tara-Cho to the last outburst from Lake Zanaco in 1995. Nepal has lost more than 66,700 sq.m. of cultivatable land, a hydropower and numerous highways, roads and bridges (ICIMOD, 2011).

Along with the GLOFs originated in TAR, China, there have been numerous outburst incident that originated in Nepal, among which, outburst of Dig Tsho and Tam Pokhari glacial lake in 1985 and 1988 respectively are regarded as most catastrophic events. GLOF of Dig Tsho washed the almost completed Namche Small Hydel facility which was 11 km distant from the GLOF originated point. Loss of five lives was recorded and infrastructures in tens of kilometers downstream were obliterated. The long section of the main trekking route leading to the Mount Everest base camp was destroyed. Event happened in August when the numbers of tourists were at the lowest, if the timing had been different, numerous lives could have been at risk (ICIMOD, 2011). Tam Pokhari GLOF of 1998 is also often mentioned as most catastrophic outburst event occurred in Nepal as it is estimated that several lives along with more than NRs. 156 million was lost in the incident (ICIMOD, 2011).

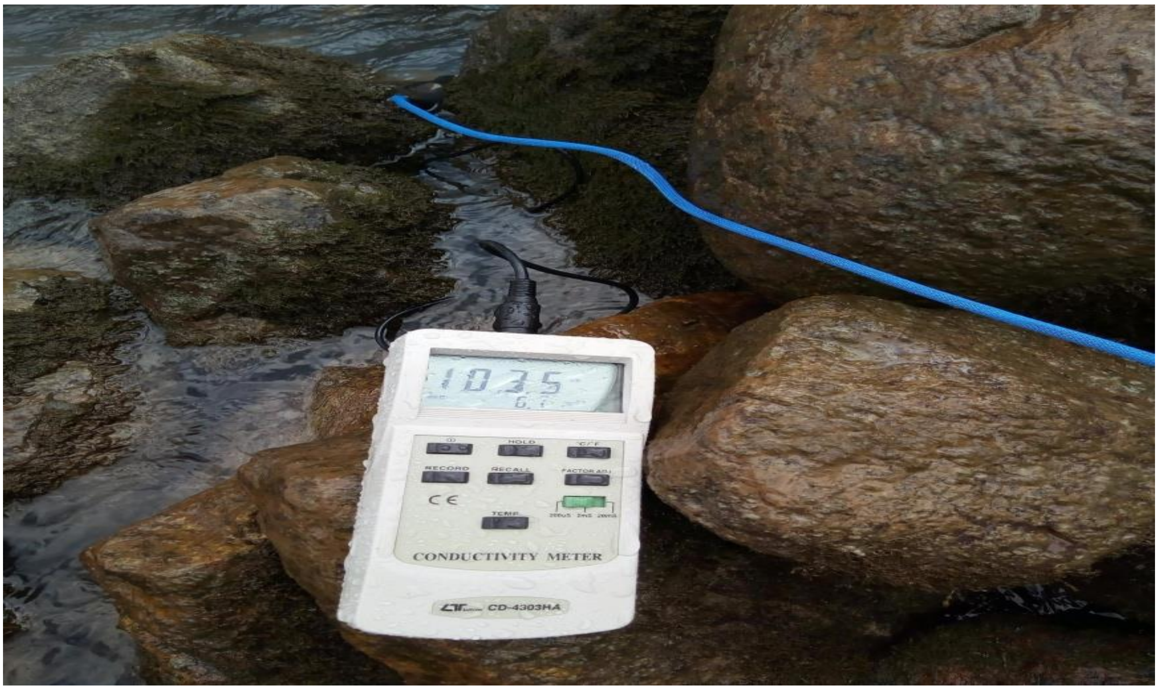

Figure 6. Discharge data being collected through conductivity meter in field.

From the past incidents it can be concluded that, Nepal is vulnerable to the GLOF event and has already bared huge losses due to the unpleasant event. However, there has not been any outburst event from Thulagi Lake and also not any other GLOF incident has happened in Marsyangdi river basin till date.

Future probability

The Paris Agreement on 12 December 2015 in Paris adopted a target to limit the temperature rise to well below 2^{0}C, compared to pre-industrial levels. If there is rise of 1.5^{0}C in global temperature, due to the 'altitude effect' phenomenon, the average temperature in the Himalaya will go up by 1.8 degrees (Krishnan, 2019). This indicates that there will be rapid meltdown of the glaciers and even it has been estimated that one-third of all remaining Himalayan glaciers may melt during this century (Preiss, 2019).

This scenario suggests there will be rapid meltdown of Thulagi Glacier too which will eventually add up in the probability of GLOF from Thulagi Lake. Day by day new infrastructures are being added in the downstream of the Thulagi River, also as being in the popular tourist region, the flow of tourists in exposed regions is also increasing. Many new hydropower plants are being constructed while there are also the plants which have got license for survey from Nepal Electricity Authority (NEA), in the risk region of GLOF from Thulagi.

Table 1 shows the major hydropower projects in the construction phase, which have got construction license from the government and lie in the downstream of the Thulagi River. These projects will be affected if Thulagi GLOF happens.

There are two more hydropower projects which are applying for construction downstream of Thulagi Khola, one is applying for survey license, and one has already got a license for survey (Table 2).

Khanal et al. (2015b) presented US $415,351 million, monetary value of elements are potentially exposed to Thulagi GLOF risk, where estimated maximum flow was 4,736 m^3/second. This estimation at the time did not calculate the value of Hydropower plants from Table 1, as they were in the process of getting license for the construction, thus the new monetary value exposed crosses way over US $415,351 million.

Table 1. Hydropower projects in the construction phase

Project	Capacity (MW)	River	Date of Issue	Validity	Promoter	Latitude N		Longitude E		VDC/District
Super Nyadi Hydropower Project	40.27	Nyadi	6/01/2074	5/13/2109	Siuri Nyadi Power Ltd.	28° 21’ 09”	28°24’ 23”	84° 26’ 57”	84° 30’ 18”	Bahundada, Bhulbhule (Lamjung)
Marsyangdi Besi	50	Marsyangdi	6/01/2074	5/31/2109	Divyajyoti Hydropower Pvt. Ltd.	28° 12’ 00”	28° 16’ 00”	84° 21’ 15”	84° 24’ 40”	Besisahar, Chandisthan,Bhulbhule, Gaunsahar, Bajhakhet, Hiletaxar (Lamjung)
Lower Manang Marsyangdi	140	Marsyangdi	7/18/2075	7/17/2110	Butawal Power Company	28° 29’ 35”	28 32’ 30”	84° 20’ 00”	84° 21’ 55”	Tachi Bagarchhap, Dharapani, Thoche (Manang)
Upper Marsyangdi 1	138	Marsyangdi	9/10/2075	9/09/2110	Upper Marsyangdi Hydropower	28° 19’ 28”	28°22’ 25”	84° 23’ 51”	84° 25’ 00”	Taghring, Khudi, Ghermu, Bahundada (Lamjung)
Nyadi-Phidi HPP	21.4	Nyadi, Phidi	11/27/2075	11/26/2110	North Summit Hydro Pvt. Ltd.	28° 24’ 27”	28°26’ 12”	84° 30’ 10”	84° 31’ 43”	Bahundada, Bhulbhule (Lamjung)

Source: Department of Electricity Development (DoED, 2022)

Pre-Feasibility analysis
For the pre-feasibility of lake as source of electricity generator, series of different primary data were taken for the analysis.

Hydrology
The major source of the Thulagi Lake is the Thulagi Glacier, once the glacier is gone, lake can’t sustain by the rainwater only. Along with the source, discharge of the water from the end terminal is important for the study of feasibility analysis.

Thulagi Glacier and lake analysis
As whole world is suffering “Global Warming”, so does Nepal. The process of melting down glaciers has increased in the Himalayas too, forming the glacier lakes in process along with adding the volume of water in already existing ones. The same case can be viewed in Thulagi Glacier and Thulagi Lake.

Thulagi Lake, which was 0.86 sq km in 2005, has expanded and reached the area of 0.94 sq km in 219. Figure 7 shows the expansion of the lake in a different time frame.

Recession of glaciers in different years is clearly visible in Fig. 7, thus for the calculation of rate of glacier recession and for the estimation of how long glaciers can survive in the rate, Thulagi Glacier from 2005 and 2019 were mapped.

After observing images from 2005 to 2019, it was concluded that the recession of glaciers was only happening at end terminus (Fig. 8), thus True Color Composite (Fig. 8a) and False Color Composite (Fig. 8b) were compared and analyzed to create the Thulagi Glacier boundary. FCC was further studied with Google Earth Pro images to create precise boundaries as much as possible. After the boundary of 2019 was created, for the Glacier map of 2005, the boundary was further extended observing the satellite image with the help of Google Earth Pro.

Table 2. Hydropower license applicants

Project	Capacity (MW)	River	Date of Issue	Validity	Promoter	Latitude N	Longitude E	VDC/ District
Application for Survey License								
Super Thulagi Khola HEP	4.95	Thulagi Khola	8/23/ 2078		Sunder Basnet	28° 30' 40" 28° 32' 15"	84° 25' 51" 84° 28' 10"	Dharapani, Thoche /Manang
Dana Khola HEP	49.95	Dana Khola	7/26/ 2074	7/25/ 2079	Lalupate Hydropower Company Pvt. Ltd.	28° 30' 00" 28° 31' 18"	84° 21' 39" 84° 24' 20"	Dharapani, Thoche /Manang
Application for Construction License								
Lower Nyadi HEP	12.6	Nyadi	11/15/ 2078		Hub Power Pvt. Ltd.	28° 18' 30" 28° 19' 45"	84° 24' 10" 84° 25' 25"	Bahundada, Bhulbhule/ Lamjung
Upper Marsyangdi-2	600	Marsyangdi	6/25/ 2068		Himtal Hydropower Company Pvt. Ltd.	28° 22 04" 28° 30' 00"	84° 21' 30" 84° 25' 03"	Ghermu, Taghring/ Lamjung, Manang

Source: Department of Electricity Development (DoED, 2022)

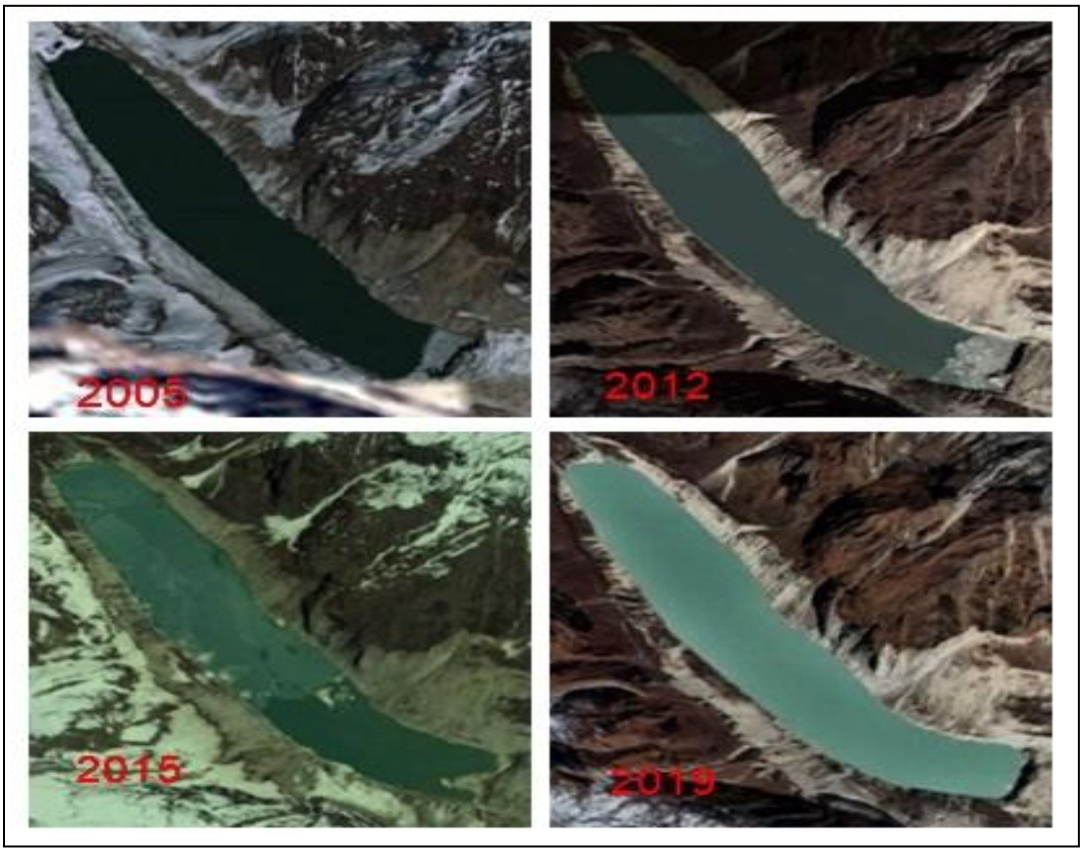

Figure 7. Expansion of Thulagi Lake in different time periods.

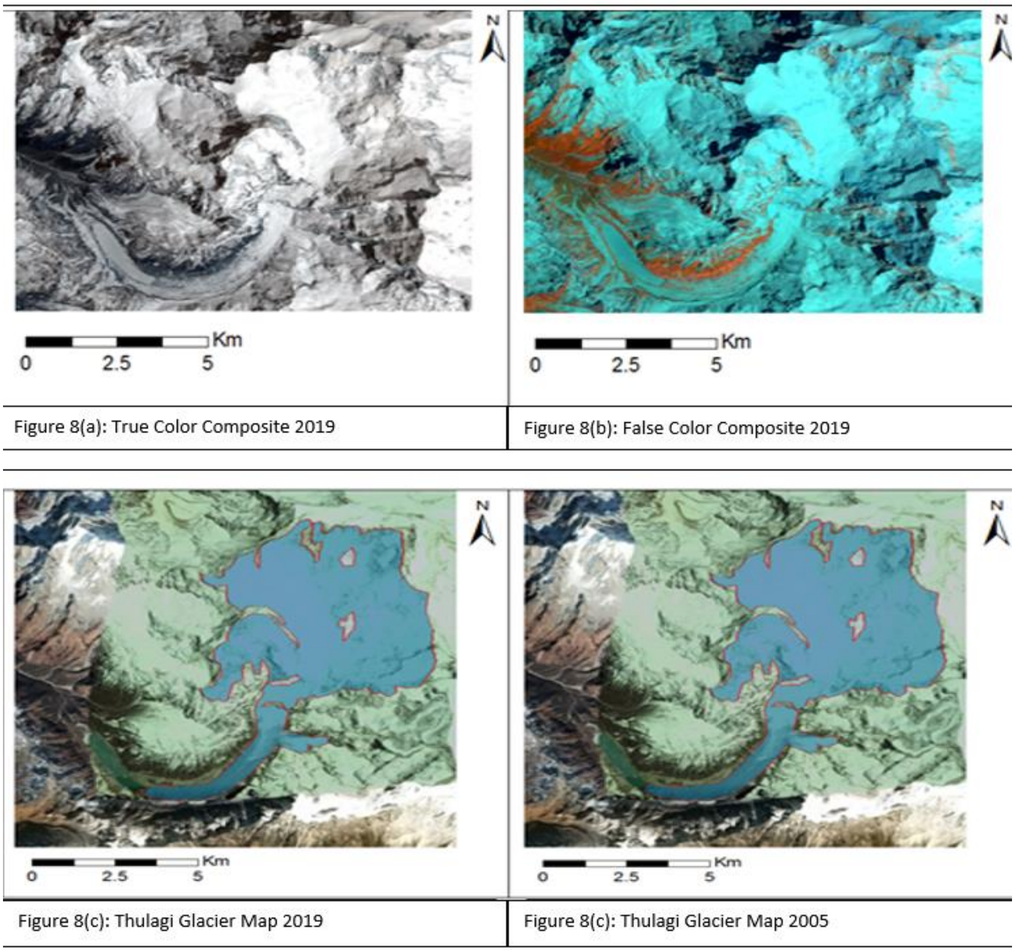

Figure 8(a): True Color Composite 2019

Figure 8(b): False Color Composite 2019

Figure 8(c): Thulagi Glacier Map 2019

Figure 8(c): Thulagi Glacier Map 2005

Figure 8. Glacier Analysis.

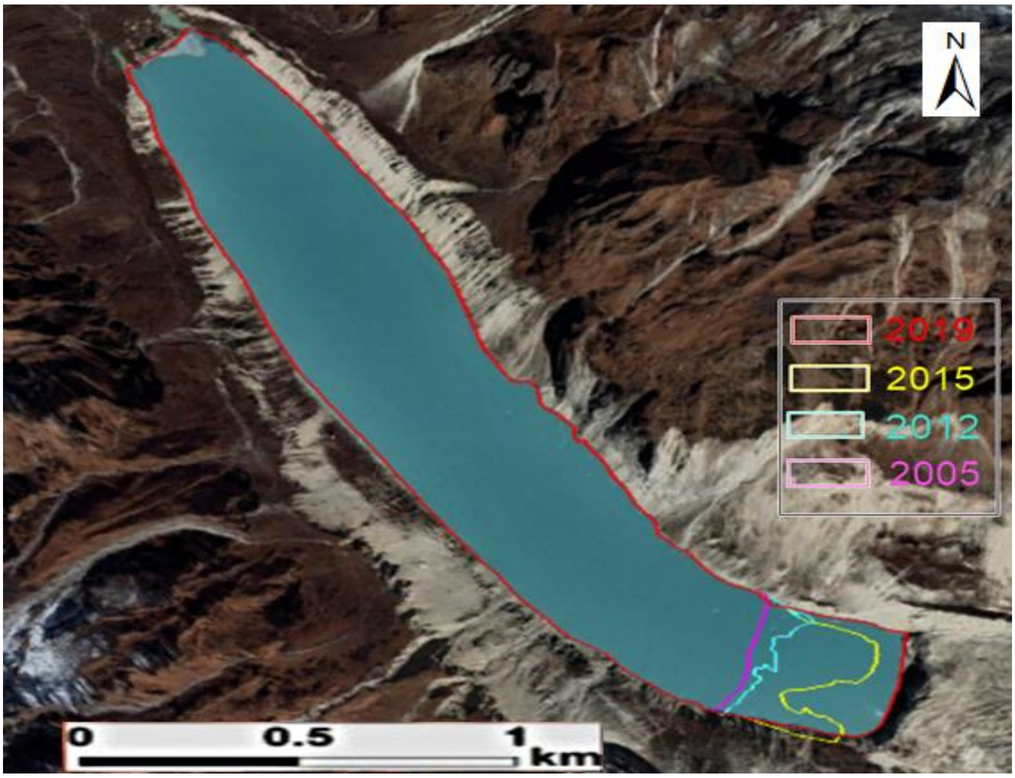

Figure 9. Glacier recession in different time frames.

The area of glacier feeding to the lake was calculated to be 26.41 sq km from 2019 image (Fig. 8c) while it was calculated as 26.50 sq km from 2005 image (Fig. 8d). As was observed the recession of glaciers was only happening at end terminus, Fig. 9 visualizes the recession of glaciers in different time period. The maximum loss of glaciers happened from 2012 to 2015 when 0.0433 sq km of glaciers had melted. The detailed information about the recession has been presented in Table 3.

From 2012-2015 Thulagi Glacier faced the maximum recession, and it was happening at an alarming rate of 0.0144 sq km/year but however it seems to have been slowed down little as rate dropped to 0.0083 sq km/year afterward. The maximum recorded recession rate was 0.0144 sq km/ year and the average rate of recession was calculated as 0.0082 sq km/year. At the calculated average recession rate, 26.41 sq km of Thulagi Glacier from 2019 can last for 3,225.50 years while at the maximum recorded recession rate the glacier has a life span of 1,831.68 years. From 2005 to 2019 the total area of 0.0895 sq km of glacier has already melted.

From 2005 to 2019 Thulagi Lake expanded by 0.08 sq km. As glaciers are melting, the size of the Thulagi Lake is also increasing (Table 4).

Table 3. Recession analysis

Year-Year	Loss of Glacier (sq km)	Rate of Recession (sq km/year)
2005-2012	0.0132	0.0019
2012-2015	0.0433	0.0144
2015-2019	0.0330	0.0083
Total	0.0895	
Average		0.0082

Table 4. Area of Lake

Year	Area of Lake (sq km)
2005	0.86
2012	0.87
2015	0.91
2019	0.94

Volume of Lake

The maximum depth of the lake was 76 m (Maskey et al., 2020). To calculate the volume of the lake, the polygon of Thulagi Lake was created from Google Earth Pro (2019), which with the help of GPS Visualizer was converted to gpx file which had information about the elevation of the lake ground surface. gpx file then with the help of ArcMap 10.3 was converted to triangular irregular networks (TIN) file which then was changed into raster file. The raster file was processed using surface volume tool where reference plane was selected as "Below". This calculated the volume of the lake as 35.7 X 10^6 m^3.

Water discharge

Either for Run of River (RoR) powerplants or for storage powerplants, the key factor for the generation of electricity is water discharge. Discharge from the lake is required to be measured for the calculation of potential electric power generation as well as it also helps to figure out the volume of water that will be stored in period of time if lake is dammed either by natural or human process.

Monthly discharge data were collected from 31st May 2018 to 1st August 2019 (Fig. 10).

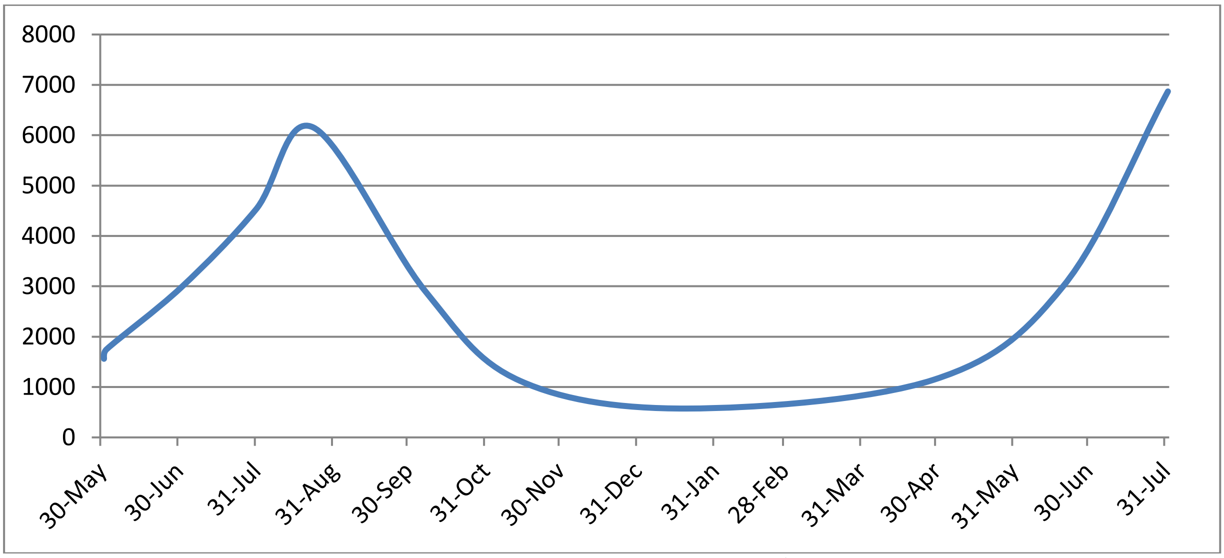

Figure 10. Field data of discharge (L/s).

From the collected data, it is seen that maximum discharge from lake happens in August as highest recorded discharge 6870 L/s happened on August 1st, 2019, followed by second highest discharge of 6155.22 L/s on 23rd August 2018. The lowest recorded discharge was 572.89 L/s on 20th January 2019. Average discharge from the taken data has been calculated as 2961.84 L/s. The graph shows that the discharge peaks in August and starts to fall and reach lowest in January, from where it then starts to rise. This is due to the monsoon season in August and winter season in January when the surface of the lake freezes.

Power that can be generated from (storage) power plant can be calculated by using the formula

$P = m \times g \times H_{net} \times \eta$

where:
H_{net}, Head losses here is assumed to be 10%, so $H_{net} = H_{gross} \times 0.9$

For a typical small hydropower system, the turbine efficiency would be 85%, drive efficiency 95% and generator efficiency 93%, so the overall system efficiency would be:

0.85 x 0.95 x 0.93 = 0.751 (75.1%)

A low-head micro hydropower system needs at least 2 meters of gross head (Hydropower fundamentals, 2020).

So, Lets assume that we have relatively low gross head of 2.5 meters.

Then,
Hnet = H gross x 0.9 = 2.5 x 0.9 = 2.25 m

We have,
Maximum discharge rate of 6155.22 L/s
Average discharge rate of 2961.84 L/s
Lowest discharge rate of 572. 89 L/s

Now,
$P = m \times g \times H_{net} \times \eta$

At the Maximum discharge rate,
P = 6155.22 x 9.81 x 2.25 x 0.751 = 102,031.68 W = 102 kW

At Average discharge rate,
P = 2961.841 x 9.81 x 2.25 x 0.751 = 49,096.80 W = 49.1 kW

At Lowest discharge rate,
P = 572.89 x 9.81 x 2.25 x 0.751 = 9496.48 W = 9.5 kW
From the calculation it can be concluded that, if Hydropower project is installed with corresponding to its discharge rate, then, yearly energy from 9.5 Kw to 102 kW can be generated from the system.

For Storage of water per year,
Conversion base: 1 L/s = 31536 m^3/year (SI unit converting method)

Taking the average discharge rate, 2961.841 L/s as base,
Storage per year = 2961.84 X 31536 = 9.34 X 10^7 m^3

By taking the average discharge rate, it can be calculated that 9.34 X 10^7 m^3 of water can stored in a storage facility yearly, which then further can be run through penstock for generating electricity in panned manner.

Budget analysis
The cost of constructing Hydropower plants differs from different variables, from effectiveness of the equipment to the remoteness of the site plays a key role. However, power purchase rate (PPR) remains constant according to the various situations. Renewable Energy Subsidy Policy (2012) of Nepal Government plays vital role in determining the cost. According to the policy, the subsidy amount is expected to cover 40% of the total costs with around 30% coming from credit and 30% from private sector investment and/or community or households contribution.

Power Purchase Rate (PPR) analysis
Power Purchase Agreement (PPA), the agreement by which Nepal Electricity Authority (NEA) sets the rate of the electricity as it buys from hydropower companies is known as Power Purchase Rate (PPR). The latest rate and associated rules for PPA have been effective from 2074/01/14 (April 27, 2017). Water needs to be pumped out from the lake, so the Run of River (ROR) and Peaking Run of River (PROR) is not suitable as they only utilize the discharge water and do not throw water directly from the lake. ROR or PROR installment would just be like adding new powerplant in the path of Thulagi River. Storage facilities on the other hand can reserve the water and can discharge more water than the lake receives from its source. Thus, a storage scheme needs to be installed in the lake to reduce the water. Blocking the lake's end moraine and connecting penstock seems very feasible way. Table 6 shows the PPR for storage facility.

Table 6. PPR of Storage

Season	Rate Rs/KWh	Min. Dry season Energy required
Dry (Mangsir 16 – Jestha 15)	12.40	35%
Wet (Jestha 16 – Mangsir 15)	7.10 (If wet season energy is more than 50%, this rate shall be decreased by the excess %)	

Source: Nepal Electricity Authority

Table 7 calculates the hypothetical income, taking the ideal situation as it produces a minimum 35% of electricity in the dry season and 50% in wet season.

Table 7. Hypothetical income scenario

Month	Generation	Rs./kWh
Jan	35%	12.40
Feb	35%	12.40
Mar	35%	12.40
Apr	35%	12.40
May	35%	12.40
Jun	50%	7.10
Jul	50%	7.10
Aug	50%	7.10
Sep	50%	7.10
Oct	50%	7.10
Nov	50%	7.10
Dec	35%	12.40
Ave. Price, Rs/kWh		**9.75**

It is calculated that in an ideal scenario of Thulagi Storage Project, the average income of Rs.9.75/kwh can be generated all year around.

We have to reduce the water from the lake thus, if calculated maximum discharge is 6155.22 L/s, if same amount of water is let to run through penstock, hydropower plant of 102 kW seems feasible in Thulagi Lake.

So, 102 kWh x 24 x 365 = 893,520kWh energy can be generated yearly.

From Table 5.3.2(d), we have average earning per year as Rs. 9.75

Thus, earning per year can be calculated as,
893,520 x 9.75 = Rs. 8,711,820

With average USD price as, 1 USD = 125.73 in 2022,
Rs. 8,711,820 = $69,290.

Subsidy policy

Subsidy is provided by Alternative Energy Promotion Centre (AEPC) to motivate the investors to invest in renewable sources of energy. AEPC prepares and implements the subsidy delivery mechanism once it gets the approval from the Ministry. The following list shows the way the subsidy is provided however the remote areas may be subjected to higher subsidy (Sources: IRENA, 2021; Renewables First, 2024).

Mini/micro hydropower

- Generation – Equipment. (per kW): NPR 125,000 to 80,000/kWp (USD 1175 to 750).
- Generation – Civil. (per kW): NPR 80,000 to 20,000/kWp (USD 300 to 190).
- Distribution (per household): NPR 35,500 to 28,000/household (USD 333 to 260).

Cost analysis

Budget is required in power plants from construction of infrastructure to maintenance of the plant, to construct the distribution lines and to pay the salary to the staffs. For each component the required cost is different in every power plant. According to the report published by International Renewable Energy Agency (IRENA) in 2020, average cost for construction of small hydropower projects is $2459/ kW.

By taking it as reference, to generate 102kW of energy:
$2459 x 102 = $250,818

So, if we take $250,818 as the estimated construction price then without any subsidy, the annual earnings of $69,290 take the investment return period as 3.61 years.

But this project can get a subsidy of USD 119,850 to 76,500 for equipment, USD 30,600 to 19,380) for civil components and also subsidy for distribution can be claimed. The subsidy can also increase as the project lies in a remote area of the country. Moreover, the main objective of the policy is to provide 40% of total cost as subsidy.

In the case of 40% subsidy to total cost of $250,818 = $100,327
,
The cost for investors becomes $250,818 - $100,327 = $ 150,491

So, if we take $150,491 as the estimated construction price for investors, then with the annual earnings of $69,290, the investment return period will be 2.17 years.

Possible benefits and Socioeconomic impacts

Latest studies have showed that the man-made reservoirs for hydropower generation are not global warming gas emission free as thought earlier. They also impact on marine life negatively. Unnatural and stagnant lakes are subjected to rotting of vegetation which generates carbon dioxide and methane- a greenhouse gas 86 times more potent than CO_2 (Foley, 2016). Global reservoirs account for just under a gigaton of annual CO_2 equivalents- about 1.3% of all global emissions and dams disrupt free flowing of water causing harm to fish, freshwater mussels and other animals (Lohan, 2022).

Thulagi Lake may not emit methane as it lies in high elevation with very low vegetation in surrounding. Even if Thulagi has been emitting greenhouse gas, damming it may not increase the emission rate in contrast generating energy from it will compensate if any emission had been happening. Hydroelectricity from Thulagi or any other glacial lakes could be the greenhouse gas free energy. Along with energy there is no presence of aquatic animals in the lake so there is no context for hurting marine animals.

Thulagi receives more meltwater during summer when energy demand is often high, this could ensure energy availability during peak period. The Manaslu glacier ensures the long lifespan of the lake and the energy potential. Hydropower facilities can also provide secondary benefits, such as controlled water release for downstream irrigation, drinking water supply, and flood management, enhancing regional water security. It would also act as a defense mechanism for the people, their properties and infrastructure like hydropowers and other assets exposed to the potential GLOF.

People in the surrounding villages are dependent on animal husbandry due to the lack of job opportunities in the area. Construction of hydropower in Thulagi would provide them with long-term economic benefits by creating jobs during construction, operation, and maintenance. Furthermore, it can stimulate local economic growth by supplying affordable energy to industries and households. It would also aid the communities around by providing a reliable source of electricity, reducing dependence on imported fuel or centralized power grids.

Future Studies

Future studies on glacial lakes should focus on a multidisciplinary approach to understanding their evolution, risks, and potential benefits. Advanced remote sensing and AI-driven modeling should be used to predict glacial lake expansion, monitor stability, and assess the likelihood of GLOFs. Hydrological and geophysical research should explore the feasibility of sustainable energy generation while minimizing ecological disruptions. Additionally, climate impact studies should evaluate how changing temperatures and precipitation patterns influence glacial lake formation and downstream water availability. Socioeconomic research should investigate the effects of glacial lake dynamics on local communities, infrastructure, and water-sharing policies. Furthermore, international collaboration is needed to develop early warning systems, risk mitigation strategies, and adaptive management frameworks for regions vulnerable to glacial lake hazards. These future studies will be essential for balancing conservation, disaster prevention, and the responsible use of glacial water resources. While this paper only studies preliminary feasibility of Thulagi Glacial Lake, future studies should also incorporate technical analysis such as geological factors, engineering challenges and solutions, infrastructure requirements, stakeholder identification and legal frameworks.

Conclusions

The growing size of the Thulagi Lake is a national threat. Catastrophic events that can be triggered need to be checked before it unfolds itself. The viable solution for mitigating the risk is to drain the water from the lake. Since the lake has every pre-feasible component for hydropower generation; it is recommended that the water is utilized for hydro-electricity generation. Subsequently, more water than the lake gets from its source needs to be drained to decrease the volume of the lake, so ROR and PROR method of electricity generation are not adequate, and the storage method is recommended where lake itself acts as the reservoir.

Main source of the lake is Thulagi Glacier which has the life span of more than thousands of years. Annually about 93.4 million cubic meters of water can be stored by damming the terminal moraine of the lake. With just a gross head of 2.5 meters and discharge rate of 6870 L/s, lake can generate 102 kW of energy. The investment return period is also calculated as just 3.61 years to 2.17 years. This concludes that generating power from Thulagi Lake is feasible, profitable and also reduces the risks of the community living downstream.

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