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Using GIS to Assess the Hydropower Potential of a Run-of-River Small Hydropower Plant in Chamkhar River, Bhutan

Dorji Letho, Leki Dorji, PhuntshoTashi, Jamyang Seldon
Department of Civil Engineering,
College of Science and Technology,
Royal University of Bhutan
ldorjee6722@gmail.com

***Abstract*-Bhutan is a considered as a carbon negative country as forested sequestered more amount of CO2 as compared to the CO2 emission through variety of activities. Being the world's only carbon negative economy, hydropower development continues to play a major role in Bhutan's sustainable economic development.Clean energy sources such as hydropower, are crucial in combating global warming and the effects of it. Bhutan is blessed with one of the highest per capita hydropower potentials in the world and has only harnessed around 6.3% of its total hydropower potential so far. It also has numerous potential sites for small scale run-of-river hydropower, which have minimal adverse environmental impacts, in contrast to large scale hydropower plants. The limitations fostered to such development have been imposed by the inaccessibility physically to these locations, owing to the rugged terrain making a difficult to select an appropriate location, thus it could be partially solved and boosted by the use of GIS technology of ArcGIS tools. In using such tools, enable us to explore hydropower potentials in faster, cost effective and precise ways. This paper studies the location of the run-of-river small scale hydropower potential along the Chamkhar River in Bhutan. Ninety-eight potential locations were found under the criteria of the head, discharge and slope criteria out of which twenty-seven locations lied outside protected bounds. Of these only ten of them are further taken to get the most optimized location and this result can be refined by field studies to select the most optimized location among the potential ones.**

***Keywords*- Run-of-River Small hydropower, clean energy, GIS tool, Chamkharchhu Basin, Bhutan.**

I.INTRODUCTION

The increasing awareness of global warming and the need to conserve our environment has shifted the global focus to more eco-friendly energy sources. Bhutan's hydropower generation is considered as renewable and environment friendly whereby every hydroelectric plant in the country contributes towards mitigation of global warming and climate change.The glacier of Himalayas in Bhutan are storing a fresh sources of water with huge volume (Khare D, Dorji L, et al 2016). Although Bhutan is a small in size, yet it is a global environmental leader, as recognized as only carbon-negative economy.

This is because forested sequestered more CO_2 than the emission. So hydropower development is the one the method in maintaining this status. Given Bhutan's mountainous terrain and perennial rivers vis-à-vis the enormous demand for clean energy in South-Asia, hydropower development continues to play a crucial role in Bhutan's sustainable economic development.

As hydropower generation is the "backbone" of Bhutan's economy, it contributes about 27% of the RGoB's revenues and over 14% of Bhutan's GDP, as in the PSMP 2040 (JICA, 2019). Bhutan has a total hydropower generation potential of around 36888MW, approximately 2330 MW have been realized as of September 2020 (JICA, 2019).

While hydropower is regarded as a clean form of energy, large-scale hydropower schemes can have massive repercussions on the environment. Small-scale run-of-river schemes have minimal environmental impacts and also require lesser investments.

It has been noticed that Bhutan is blessed with numerous potential run-of-river small, mini/micro hydropower sites, the viability of these resources can be assessed spatially based on the topographical, hydrological and geological data of the selected project. The hydropower sector will continue to play a major role in Bhutan's economy, thus it is righttime to study, research, and build adequate local expertise to enable Bhutan to accelerate the pace of hydropower development.

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Small hydropower plants are commonly installed as Run-off-River-schemes. A low dam or a weir directs water into the headrace, where it passes through the fore-bay tank or the desilting tank before being released down a penstock to the powerhouse, where electricity is generated and water is routed back to the river network via the tailrace (Sammartano, Liuzzo, & Freni, 2019).

There is no storage of water and hence, the power generation is subject to variation with the seasonal variation of the river flow. The potentiality of hydropower for a specific location is determined by the head and discharge, which further dependon the topography and the various hydrological processes occurring in the watershed area, in-depth study of the region and an appropriate river flow modeling are also required for effective hydropower system planning (Sammartano et al., 2019).

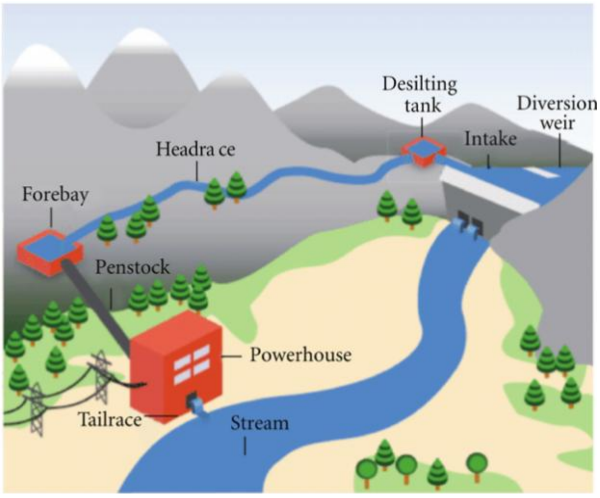

Fig 1. Schematic diagram of a Run-off-River Hydropower Plant (IPPC, 2012).

Accurate assessments contribute significantly to the success of the project. Prospects of hydropower development can be limited by the inaccessibility of sites, especially in developing countries. Hydrological modeling in conjunction with Geospatial technologies has been employed to assess the viability of these resources spatially.

The use of satellite imagery data as well the computational GIS platforms for data processing, has incredibly led to the development of several approaches for obtaining terrain features such as the length, location of drainage networks and slope of a watershed area (Digital Elevation Models)(Larentis, Collischonn, Olivera, & Tucci, 2010).

Such technologies have been increasingly using in places around the globe in hydropower potential assessment and in exploring hydropower prospects of different scales. While the use of hydrological models has been found suitable for evaluating river flow in ungauged sites, the model of the flow has to be consistentand accurate, where the river flow rate and the head drop generate the electricity (Sammartano et al., 2019).
These methods facilitate initial screening and the results obtained are suitable for in-depth feasibility studies of the hydropower potential of the basin (Kayastha, Singh, & Dulal, 2018).

A study was conducted by Kusre, Baruah, Bordoloi, & Patra (2010) in the Kopili River in Assam, India to evaluate the hydropower potential used GIS and SWAT hydrological modeling software). The search criteria were set as: - streams of fifth-order or greater, to ensure sufficient flow is available; minimum distance specified between two sites as 500 m and the general gradient steeper than 2%, i.e. a 1:50 slope, to ensure sufficient head is obtained. It stated that the limitations posed by traditional methods of using discharge data at the outlet could be lifted by the use of the latest modeling tools (Kusre et al., 2010).

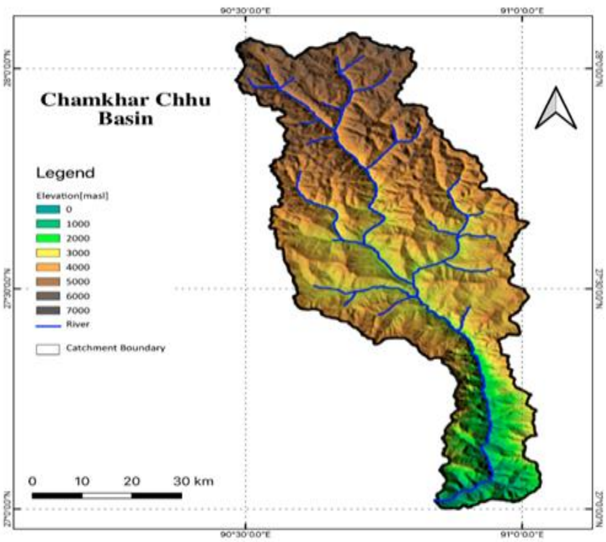

Fig 2. Study Area.

Kayastha et al. (2018), as a case study of the BhoteKoshi Basin in Nepal, used GIS and hydrological modeling software, SWAT in their research for hydropower location analysis, where it was concluded that the search algorithm employed would be useful for prompt identification of hydropower schemes, essential for the development of hydropower sectors(Kayastha et al., 2018).

The studies which were carried out in Indonesia (Rospriandana & Fujii, 2017), Pakistan (Zaidi & Khan, 2018), Iran (Tian, Zhang et al., 2020) and Korea (Yi et al., 2010) to identify hydropower potential, enabling the processing of large amounts of data using geospatial computations and hydrological models.

The findings proved how a lack of hydrometeorological records (discharge data from gauged discharge station and daily precipitation data from rainfall stations) could pose as a significant obstacle to assessing hydropower potentials. (Rospriandana & Fujii, 2017).

II. MATERIALS AND METHODS

1. Study Area:

The study area is the Chamkhar Chu Basin, ranging roughly from 90°30'00" E to 91°00'00" E and 27°00'00" N to 28°07'30" N and extends to two Dzongkhags(Districts), Bumthang and Zhemgang. The altitude of the study area ranges from 300 masl in the south to >6500 masl in the north as indicated in Figure 2. The areal extent of this basin is about 3172.8 m2.

Chamkharchhu is a glacial-fed perennial river originating from MonlaKarchung glaciers in Bumthang. Other tributaries join the river as it flows, which then converges with the MangdeChhu and the Manas, reach the Brahmaputra, and eventually, the Bay of Bengal. The river passes through steep narrow gorges; the slopes are gentler in some parts where settlements are located.

2. Methodology:

The framework of the methodology employed in this study has been presented in Figure 3. The following sections explain the details of the methodology.

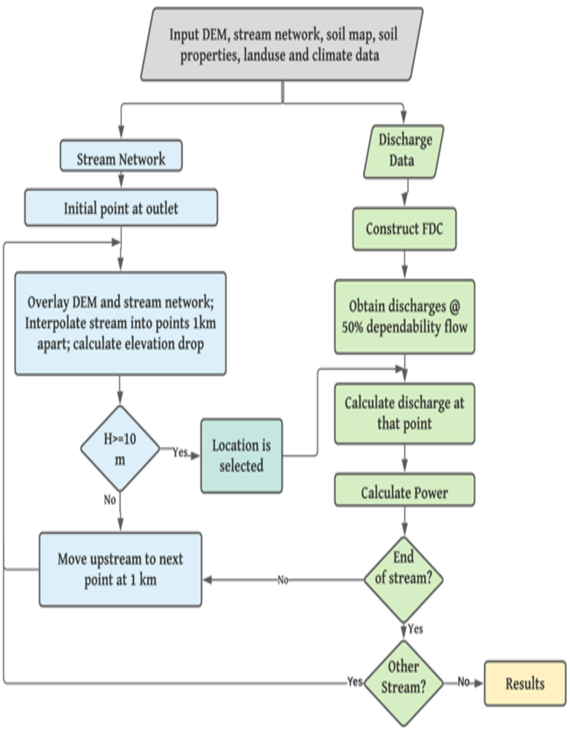

Fig 3. Framework of Methodology in this study

3. Data Collection:

Discharge data For Chamkharchhu at the discharge gauging stations Kurjey (1992-2020) and Shingkhar (2009-2020) were obtained from National Centre for Hydrology and Meteorology (NCHM). The DEM of the study area was obtained from SRTM of USGS, which provides void-filled data with a 30m resolution.

This study also requires data on elevation, slope (topography), and geometric data of the river system, coordinates, areal extent, and data on the hydrological processes occurring in the basin, which were retrieved from the Digital Elevated Model using GIS software (QGIS). The SRTM of 30m resolution was used in this study.

4. Catchment Delineation:

To find the area contributing to the run-off at an outlet point, the catchment delineation is done by defining the boundary of the catchment and the stream network. The DEM was re-projected to the project coordinate system, which were WGS 84/ UTM zone 46N for Bhutan.

The DEM was then corrected by filling voids and sinks. The purpose of filling any DEM grid cell flaws is to generate a hydrologically accurate DEM since it is susceptible to errors in data processing, spatial resolution and interpolation methods used. (Purinton & Bookhagen (2017), Kayastha et al. (2018)). By Setting a threshold Strahler order to ensure flow sufficiency, it generates the stream network containing streams of that Strahler order and lesser. For this study, a Strahler order of 5 was adopted.

III. DISCHARGE EVALUATION

The discharge values for different points along the stream network need to be acquired, either from interpolation from recorded discharge data of discharge gauges or through flow modeling and simulation;

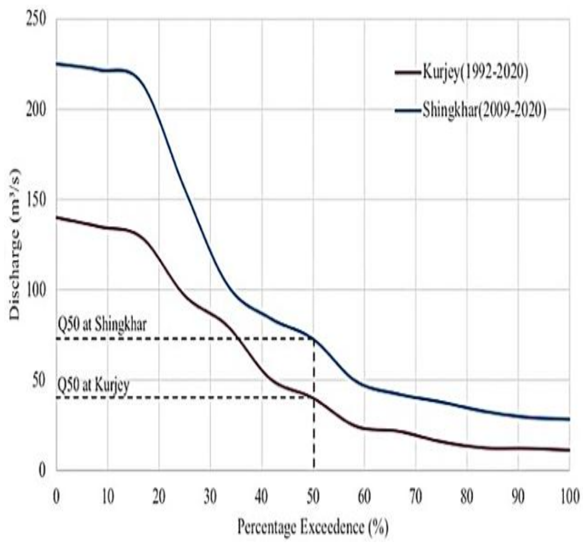

Fig 4. Flow Duration Curves.

Discharge data from two gauges in the basin (Kurjey and Shingkhar) were used to interpolate the discharge at any point in the stream network. The Q50 (50% chance of exceedance) values from each FDC were considered as the discharge to account for lean and wet season flows.

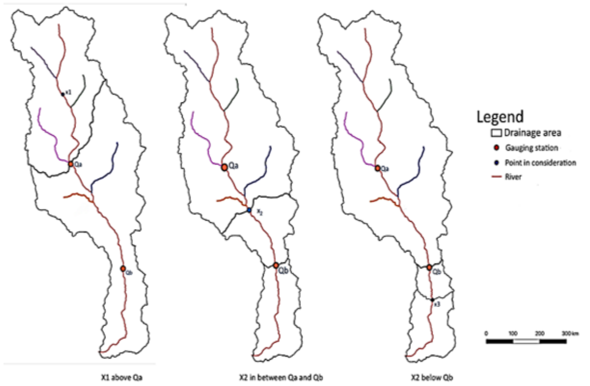

Fig 5. Relative Estimation of Discharge.

Table 1. Dependability flows at different percent and drainage area at stations (m3/s).

Discharge (m3/s)	Kurjey Chhu (River)	Shingkhar Chhu (River)
Q10	132.41	219.44
Q50	40.79	72.84
Q90	12.93	31.48
Drainage Area (km2)	1343.36	2721.14

1. Measuring Discharge at Ungauged Sites:
The discharges at the ungauged location were calculated from the discharge data of two discharge gauges, at Kurjey and Shingkhar. The Drainage-to-Area Ratio method (Zaidi & Khan, 2018) based on continuity equations has been used.

Estimating Flow Qx1 at 'x1'

$$\mathbf{Q_{x1} = \left(\frac{A_{x1}}{A_a}\right) * Q_a \ (1)}$$

Estimating Flow Q_{x2} at 'x2'

$$\mathbf{Q_{x2} = Q_a + \left(\frac{A_{x2}-A_a}{A_b-A_a}\right) * (Q_b - Q_a)(2)}$$

Estimating Flow Qx3 at 'x3'

$$\mathbf{Q_{x3} = \left(\frac{A_{x3}}{A_b}\right) * Q_b(3)}$$

2. Interpolation of head:
The data on the head gained between two points was extracted from the DEM in QGIS. The entire stream network was interpolated into points 1km apart starting at the outlet. The attribute table of this point file in QGIS shows the elevation of each point along the River.

3. Identification of sites:
The criteria set for the selection of sites, referring to past literature (Kayastha et al. (2018), Rospriandana & Fujii (2017), Kusre et al. (2010)) and considering basin characteristics was set as:

- Stream order >= 5
- Distance between two locations = 1km
- Head between the prospective intake and power house>= 10m

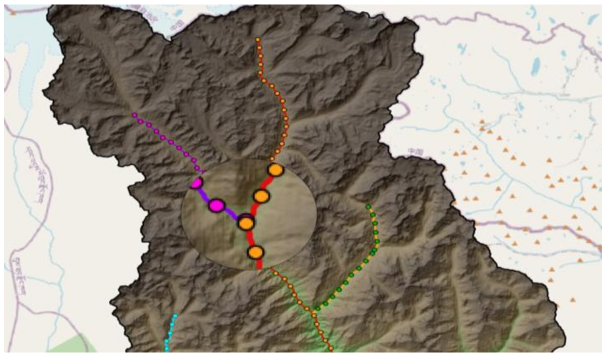

Fig 6. Entire stream network marked by points 1km apart.

Based on these criteria, a search algorithm was developed and executed in a GIS environment.There are restrictions on any form of development in protected areas.

Some parts of the study area fall under two wildlife sanctuaries (Thrumsengla National Park and Wangchuk Centennial Park) and a biological corridor linking them. The prospective locations in these areas were filtered out.

4. Power Calculation:
Power generation is a function of the head gained and the discharge available. Power is generated when the flow drops from the head availed to turn the turbine, hence harnessing hydropower.

The function is given as:

$$\mathbf{P = \rho * g * Q * h * \eta \ (4)}$$

Where,
P = Power generated (W),
ρ = density of water (1000 kg/m3),
g = acceleration due to gravity (9.81 m/s2),
Q = discharge available for power generation (m3/s)
h = head/ difference in elevation (m)
η = system efficiency of the turbine, generator, gearbox.

IV. RESULTS

In total, 182 locations were found to meet the head criteria (head >=10m) in the entire stream network as shown in figure 6. However, the average bed slope for only stream 1 is greater than 2%. Therefore, 98 locations met the set criteria (Table 2) for the location analysis. However, excluding the locations which are within the protected areas whereby 27 locations remained for further analysis.

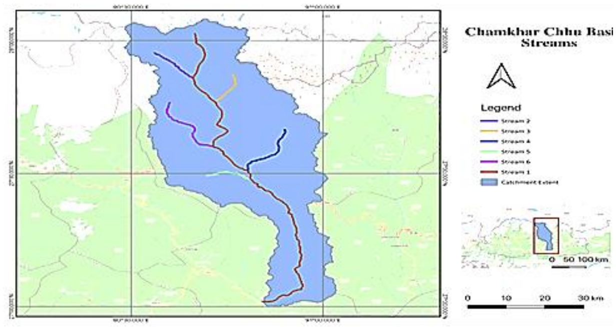

Fig 7. Major streams considered for the analysis.

Table 2. Number of potential sites and average bed slope of each stream.

Stream No.	Stream length (km)	Max. El. (m)	Min.El. (m)	Sites (H>=10m)	Av.bed Slope (%)
1	158.841	4664	298.05	98	2.749
2	16.689	4456	3688	18	0.484
3	14.188	3984	3183	13	0.504
4	24.415	2892	2589	13	0.191
5	14.556	2832	2514	12	0.201
6	28.73	4118	2648	28	0.926

Table 3. Details of ten locations with the highest power potentials.

Prospective Location	El. at intake (m)	El. at powerhouse,m.	El.diff. (H-m)	Drainage Area (m^2)	Discharge (Q_{50}) (cum)	Power (MW)
1	2675.0	2655.06	20.67	1034.67	31.42	5.097
2	2504.0	2465.38	38.64	2263.72	68.74	20.841
3	1009.0	952.00	57.10	2731.23	75.33	33.756
4	904.0	878.03	25.97	2845.23	76.16	15.524
5	752.0	732.24	19.58	2895.01	76.80	11.798
6	732.0	688.01	44.04	2944.56	78.80	27.232
7	620.0	595.21	24.87	2983.23	79.86	15.589
8	507.0	425.08	81.99	3001.31	80.34	51.697
9	377.0	344.13	31.97	3096.55	82.88	20.795
10	318.0	298.05	20.01	3168.80	84.83	13.322

V. DISCUSSION

The study was conducted using past discharge data recorded by gauging stations and elevation data extracted from a 30m resolution DEM. The accuracy of the results obtained depends on the data quality. The precision of the elevation data depends on the resolution of the DEM. As for the discharge, as compared to short-term data, data for longer periods lead to better accounting of the flow fluctuation.

It is seen that the stream network downstream had more potential sites where the discharge is larger and the power potential would be higher. Location analysis was done based on only two factors, head, and discharge. There are, however, other factors that need to be considered in the location analysis, such as the site geology and seismicity, availability of access roads and infrastructure, power evacuation, and the distance of the nearest transmission line. Since hydropower development is multifaceted and the effect of one aspect influences the others. Environmental and socio-economic aspects also need to be considered in the location selection of SHP.

VI. CONCLUSION

Conventional methods of hydropower potential spotting are laborious and subject to errors. In rugged terrains, such as in Bhutan, inaccessibility to high potential locations poses a barrier to hydropower development. Using GIS to explore the Run-of-River Small Hydropower potentials lifts the limitations of orthodox methods and location analysis can be conducted in more cost-effective and quicker ways that are more accurate.

In this study, the following are made some conclusion:

- The search algorithm is used as a tool for rapid identification of potential locations; however, it does not optimize the selection.
- Further optimization studies may be opted for, in order to calculate the optimum power potential.
- The methodology used to is suitable for similar basin to explore the potentials of run-of-river small-scale hydropower projects especially in a Himalayan basin.
- The most suitable location is concluded around 6 locations based on head difference conditions and gradient requirement but ten of the locations are qualified based on power generation.

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