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Development of a python-based tool for hydropower potential estimation and temporal change detection of run-of-river projects in hilly regions of Nepal

Shiva Aryal and Bhumika Sharma

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Abstract
Run-off-the-river (RoR) hydropower project are the key component for sustainable energy development in context of Nepal, more specifically in hilly and mountainous regions. But due to constraints like limited resources and harsh topography, preliminary assessment of hydropower potential is challenging. This study majorly deals with the development of Python-based tool (Potential Estimator) to detect temporal change for Rehabilitation, Upgradation and Modernization (RUM) of existing project and to compute hydropower potential of RoR projects using hydrological data and Digital Elevation Models (DEMs). This tool takes flow data (long-term daily, long-term monthly or monthly) and computes mean monthly flow to generate Flow Duration Curve and design discharge. It integrates DEM based elevation analysis to calculate gross head between the provided upstream and downstream section coordinates. This model also takes head loss percentage with respect to gross head into consideration for determining net head and overall efficiency to estimate installed capacity of proposed hydropower in megawatts. Flow duration curve and calculations that have been carried out by model can be extracted in image and CSV file format respectively for documentation and validation. Potential Estimator uplifts the transparency, reproducibility and accessibility in initial stage of hydropower planning and can serve a benchmark for future improvement.

Keywords: Run of river hydropower, flow duration curve, digital elevation model, pre-feasibility analysis, temporal change detection, hydropower potential estimation, python based model, river flow analysis

Introduction

Hydropower plays a vital role in producing sustainable energy in context of Nepal. Nepal's total theoretical hydroelectric capacity is 83 GW, with 43 GW being technically and economically achievable [1]. However, a study by Water and Energy Commission Secretariat (WECS) in 2019 revealed a gross hydropower potential of 72.5 GW, with a techno-economical potential of 32.7 GW, and total installed capacity of reservoir projects of 48.1 GW [2]. Among different type of hydropower plant, RoR hydropower plants are more favorable for the countries like Nepal due to the presence of hilly and mountainous terrain.

Regardless of immense potential, the assessment of hydropower potential in pre-feasibility stage remains a major challenge due to limited resources, difficult geographical condition, and irreproducibility. Computation of potential of hydropower often rely on conventional approach like manual calculations, assumptions or use of expensive software package that might not be accessible for junior designer, students or local researchers. There is need of open source software that is user friendly and accessible to all which facilitates hydropower analysis using commonly available inputs like discharge data from DHM and Digital Elevation Models (DEMs) from USGS EarthExplorer website for the context of Nepal.

The Flow Duration Curve (FDC) of the hydropower project provides a frequency distribution of discharge and energy occurrences from the project. It serves as a representation of the power generation characteristics concerning installed capacity, firm and secondary power, and energy of the project [3]. Similarly, DEM-based Terrain Analysis is a suite of Digital Elevation Model (DEM) tools for the extraction and analysis of hydrologic information from topography as represented by a DEM, especially when ground survey data is unavailable [4].

This paper focuses on development of Python-based tool (Potential Estimator) that uses hydrological data and DEM data to detect the temporal change and determine potential of proposed RoR hydropower projects in hilly terrain of Nepal. This tool processes raw long-term monthly or long-term daily or monthly discharge data and computes mean monthly flow in extractable form and generates Flow Duration Curve and estimates design discharge based on user's probability of exceedance. Further, DEM elevation data is used to determine gross and net head between user-defined upstream, downstream section coordinates and percentage head loss with respect to gross head respectively. All these process sums up in providing installed capacity of proposed hydropower project. Potential Estimator is designed for pre-feasibility studies and educational purposes which promotes accessibility, reproducibility, and ease in initial stage of hydropower planning and detection of temporal change for Rehabilitation, Upgradation and Modernization (RUM) of existing project.

Literature Review

Digital Elevation Models (DEM) can be utilized to derive river slopes, elevation drops, and to identify potential head sites [5]. *L.P.* Devkota and D.R. Gyawali (2015) also stated, if DEMs are combined with hydrological data, one can estimate gross energy potential [5]. Their study reflects that the use of DEM-based head computation can be used as a baseline method and also justify the integration of Python and GIS tools to enhance accessibility and efficiency.

On the other hand, Rocky Talchabhadel (2020) analyzed stream flow changes across 27 hydrologic monitoring stations in Nepal over two distinctive periods that were 1986-1999 and 2000-2015 and developed flow duration curves for both periods [6]. They found out approximately 60% of the stations showed increases in peak daily flows during the latter period which was seen due to variation in FDCs [6]. This study validates precisely the use of FDC on our Python-based tool to estimate design discharge. FDCs can be used to analyze the temporal change in the flow over time, is also a key finding of their study. R. Karki (2018) found out, the shape and reliability of FDCs directly influence the estimation of firm capacity, which ensures continuous energy output across seasons [7]. Further his study highlights that accurate selection of exceedance-based discharge is crucial [7]. This study validates the integration of FDC-based Python tool to determine design discharge. B. Thapa (2021) present a comprehensive open source platform that integrates DEM-based terrain analysis with hydrological inputs (such as measured discharge) to estimate run-of-river hydropower potential [8]. As part of their workflow, they automate head computation, discharge analysis. And power estimation - providing a multi module GIS-based software framework [8]. The main advantage over his tool is simplicity. In other words, our Python-based model uses minimum variables which are suitable for the users who do not have any experience in complex GIS software platforms. Marahatta, Devkota and Aryal (2021) analyzed the effect of streamflow variability on the energy generation of run of river (RoR) hydropower projects in the Budhigandaki River Basin [9]. Their study highlighted that the seasonal and inter-annual variation in discharge significantly affects the power generation, specifically during dry season [9]. The use of flow duration curves (FDCs) in this context highlighted the importance of proper design discharge for ensuring consistent energy output. Joshi and Mishra (2024) used the Soil and Water Assessment Tool (SWAT) hydrological model linked with GIS to assess RoR hydropower potential in the Marsyangdi River Basin [10]. They generated long term discharge data and estimated a hydropower potential of 1,569 MW at Q_{40} exceedance [10]. Their approach was technically intensive and used heavy data. Jha (2011) performed an assessment of RoR hydropower potential in Nepal using GIS and FDC approaches [11]. His study estimated around 53,836 MW of potential exists at Q_{40} exceedance, assuming 80% efficiency and discharge data [11].

Compared to these studies, Potential Estimator developed within this study provides a more accessible, lightweight alternative that incorporates hydrological and Digital Elevation Model without requiring specialized GIS software or complex hydrological modeling. It empowers local researchers and engineers to conduct pre-feasibility studies using available discharge data and DEMs, especially in limited resource availability.

Methodology

This Python-based tool is automated using Python programming in Visual Studio Code in order to estimate hydropower potential and temporal change detection of run of river sites using discharge data and elevation data from DEMs.

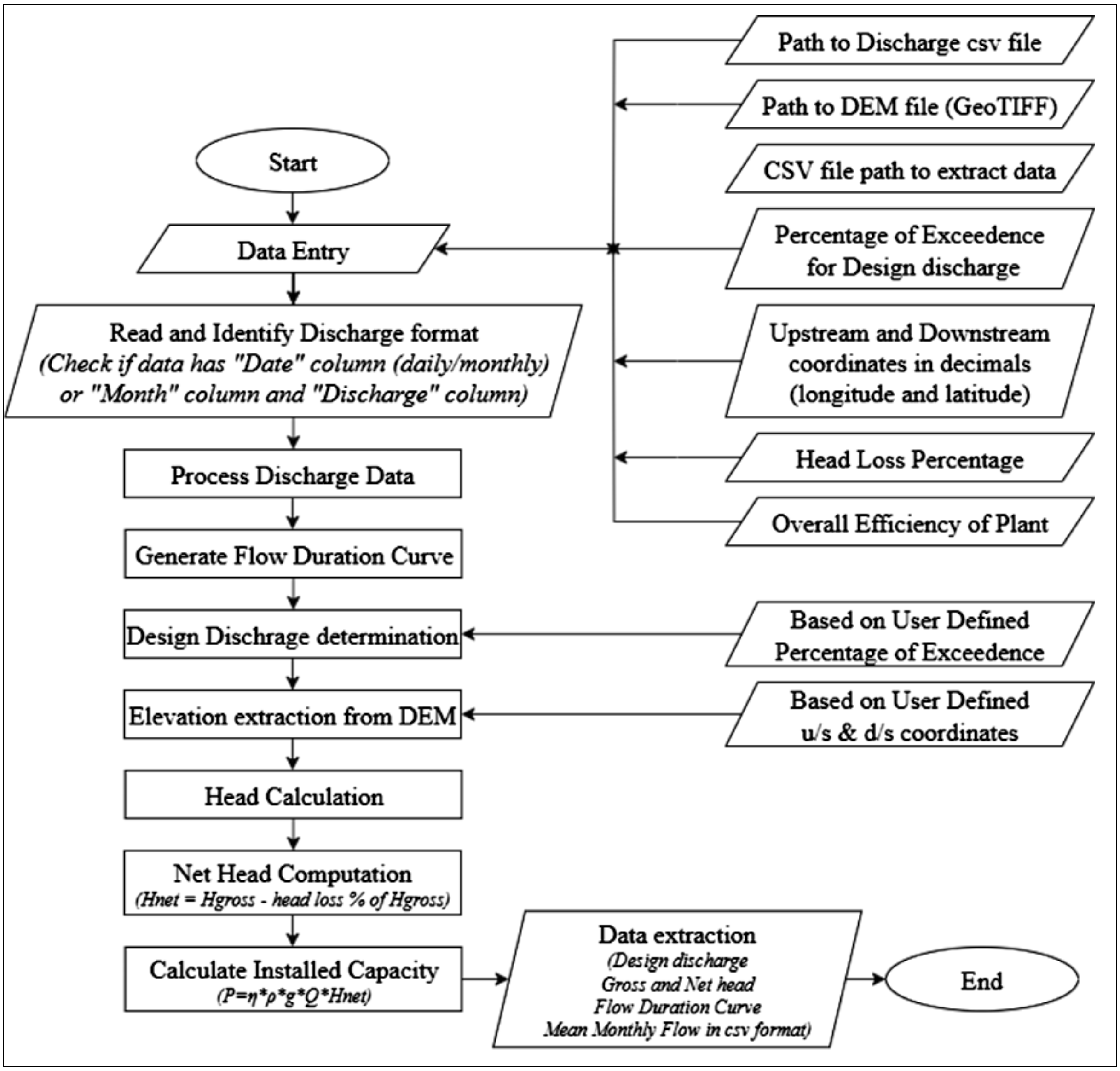


Fig 1: Methodology Flowchart

Figure 1 shows the methodology which is followed for potential estimation and temporal change detection for run of river hydropower in hilly regions of Nepal.

Data Acquisition and Pre-processing

Two primary datasets are used:

- **Discharge data** in CSV format consisting of "Date" either daily or monthly or long-term daily or long-term monthly only in column and "Discharge" in m^3/s in another column. Discharge data of required river basin can be obtained from Department of Hydrology and Meteorology (DHM) in the context of Nepal.
- **Digital Elevation Model (DEM)**, preferably SRTM in GeoTIFF format, is used to extract elevation data at intake and tailrace locations.

These discharge data are processed and segregated based on date in order to determine mean monthly flow of each year. Then these mean monthly flows of each year are averaged to determine long-term mean monthly flow.

3.2 Flow Duration Curve (FDC) Generation

Our Python-based tool arranges the obtained long-term mean monthly flow in descending order and then calculates the percentage of exceedence. Then Flow Duration Curve is drawn which shows the variation of flow in m^3/s with respect to probability of exceedence in extractable form. Further, required percentage of exceedence for design discharge is asked to user, based on which design discharge is obtained by interpolation. This method ensures a repeatable and reproducible approach to design flow selection.

Gross Head and Net Head Calculation

The tool accepts latitude and longitude inputs for upstream (intake) section and downstream (powerhouse) section in decimals. Elevations are extracted using the *rasterio* library from provided DEM file, and the gross head is computed as the difference between two elevations. A head loss percentage is input by the user, and the net head is calculated as:

$$Hnet = Hgross \times (1 - \frac{head\ loss\ \%}{100})$$

Power Output Estimation

The installed capacity is calculated using hydropower equation as:

$$P = \eta \times \rho \times g \times Q \times Hnet$$

Where,
P is power in watts,
η is efficiency (user-defined),
ρ is the density of water (1000 kg/m^3),
g is acceleration due to gravity (9.81 m/s^2),
Q is the design discharge in m^3/s, and
Hnet is the net head in meters.
The final power is reported in Megawatts (MW) and displayed alongside intermediate values as head loss and river distance.

Tool Implementation

- Language used: *Python (version 3.13)*. The reason behind using this programming language is that, it is easy to learn, versatile and free language with high number of libraries for data analysis and scientific computing.
- **Application used:** Visual Studio Code (version 1.101)
- **Key libraries used:** *Pandas, NumPy, Rasterio, Matplotlib, GeoPy*
- **Pandas:** Pandas is a very popular library for working with data. Pandas has helpful functions for handling missing data, performing operations on columns and rows, and transforming data [12].
- **NumPy:** NumPy is an open-source Python library that facilitates efficient numerical operations on large quantities of data [12].
- **Rasterio:** Rasterio library is used to access geospatial raster data [13].
- **Matplotlib:** Matplotlib is a comprehensive library for creating static, animated, and interactive visualizations in Python. Matplotlib makes easy things easy and hard things possible [14].
- **GeoPy:** GeoPy makes it easy for Python developers to locate the coordinates of addresses, cities, countries, and landmarks across the globe using third-party geocoders and other data sources [15].

The Python code developed for the Potential Estimation and Temporal Change Detection of Run-of-River hydropower plants in hilly regions of Nepal is hosted on a private GitHub repository: https://github.com/shiva-aryal/Potential_Estimator.git. Access to this code will be provided upon request.

Output Generation and Export

The tool generates a plot of Flow Duration Curve in exportable form and the provision of extraction of calculations carried out by Python tool itself in CSV file format to the path of file user has entered. The output includes:

- Year-wise monthly discharge means,
- Long-term monthly discharge values,
- Flow Duration Curve (FDC),
- FDC table (probability of exceedence value versus discharge), and
- Selected design discharge

The lightweight structure and modular Python code make it easy to manipulate and use, especially during initial stage of hydropower design and to detect temporal change in flow for RUM of existing hydropower projects. It is particularly helpful in area with limited resources and complex terrain which is not accessible.

Results

Potential Estimation Validation using Sunkoshi Small Hydropower (SSH)

Its salient features are [16]:

Project Starting Year	2003	Project Completion Year	2005
Installed Capacity	2.6 MW	Hydropower Type	Run of River
Design Discharge	2.7 m^3/s	Percentage of Exceedence	40%
Gross Head	124.50 m	Net Head	117.50 m
Head loss percentage	5.62%	Overall Efficiency	85%

The intake of Sunkoshi hydropower is an ungauged station. So, the nearest river gauge station, which is located at Khurkot Bazar (Station no. 652), was taken into consideration for flow data. It has a catchment area of 10,000km^2. The monthly flow data is taken from 1993 to 2002 which was available in Department of Hydrology and Meteorology (DHM), in order to estimate the design discharge and installed capacity. The catchment area of the Sunkoshi Hydropower (Small) is 81km^2. Hence, we used the Catchment Area Ratio (CAR) method to determine the flow data for the project's intake site [17].

$$CAR = \frac{Area\ of\ Catchment\ of\ desired\ site}{Area\ of\ Catchment\ of\ river\ gauging\ station} = \frac{81}{10000} = 0.0081$$

The mean monthly discharge which was obtained from gauge station is then multiplied with CAR factor to transpose the flow to the intake of Sunkoshi Hydropower (Small). Then this ten year data and SRTM DEM file obtained from USGS Earth Explorer site is fed to the tool to compare the result with actual data.

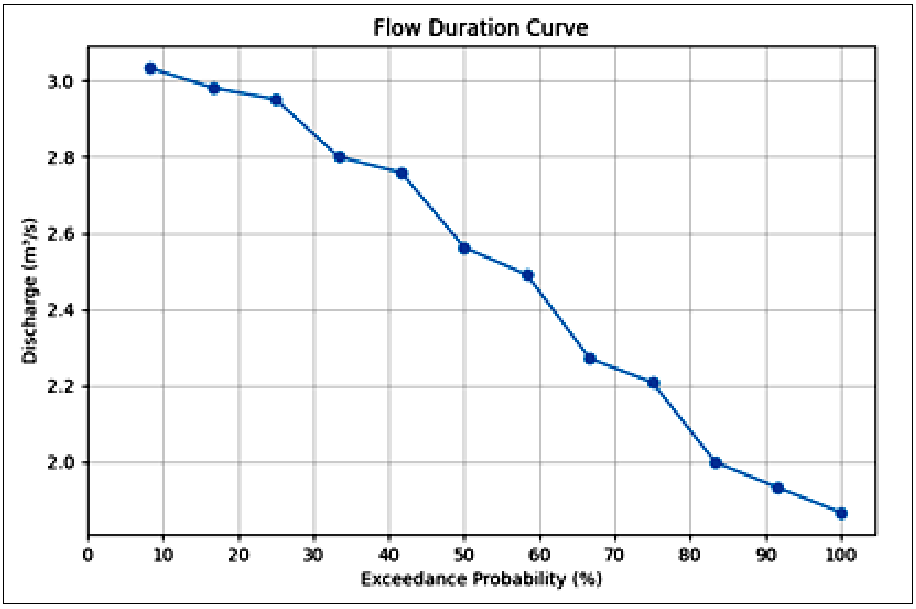


Fig 2: Flow Duration Curve of Sunkoshi (Small) Hydropower from Potential Estimator

```
PS C:\Users\shiva\OneDrive\Desktop\Python trial> & D:/Python/python.exe "c:/Users/shiva/OneDrive/Desktop/Python trial/trail.py"

--- HYDROPOWER ESTIMATION TOOL WITH FULL FDC ANALYSIS EXPORT ---


FOLLOW THESE GUIDELINES BEFORE YOU RUN THE PYTHON CODES
1. NEVER USE ANY SPACES IN ANY FILE OR FOLDER NAME WITHIN THE PATH YOU PROVIDE
2. YOU CAN DRAG AND DROP YOUR FILE FOR PROVIDING FILE LOCATION
3. THE FORMAT OF RAW DISCHARGE DATA SHOULD BE .csv WITH 'Date' AND 'Discharge' OR 'Month' AND 'Discharge'
4. THIS TOOL ACCEPTS DAILY, MONTHLY OR LONG-TERM AVERAGE MONTHLY DISCHARGE
5. ENTER LATITUDE AND LONGITUDE IN DECIMAL FORMAT
6. THIS IS FOR PRE-FEASIBILITY PURPOSE ONLY

Enter path to discharge CSV file: c:\Users\shiva\OneDrive\Desktop\PYTHON_for_installed_capacity\SSH_monthly_flow_1993_2002.csv
Enter path to SRTM DEM file (.tif): c:\Users\shiva\OneDrive\Desktop\PYTHON_for_installed_capacity\DEM_file1.tif
Enter path to save FDC analysis CSV: c:\Users\shiva\OneDrive\Desktop\PYTHON_for_installed_capacity\output.csv

Monthly Long-Term Mean Flows (for FDC):
[3.03 2.98 2.95 2.8  2.76 2.56 2.49 2.27 2.21 2.   1.93 1.87]

✅ FDC analysis exported to: c:\Users\shiva\OneDrive\Desktop\PYTHON_for_installed_capacity\output.csv
Enter design exceedance percentage (e.g. 40 for Q40): 40
Design Discharge (Q40): 2.76 m³/s
```

Fig 3: Determination of Design Discharge using Potential Estimator

Figure 2 shows the Flow Duration Curve of Sunkoshi Small Hydropower generated from Potential Estimator and *figure 3* is the screenshot showcasing the design discharge corresponding to 40% of percentage of time equaled or exceeded. The FDC is obtained in .png format as an output.

```
Enter upstream coordinates:
  Latitude (decimal): 27.781839
  Longitude (decimal): 85.919519

Enter downstream coordinates:
  Latitude (decimal): 27.776481
  Longitude (decimal): 85.890650

--- Elevation Information ---
Upstream Elevation: 966.00 m
Downstream Elevation: 823.00 m
Gross Head: 143.00 m
River Distance (approx.): 2906.67 m
```

Fig 4: Gross Head of SSH from Potential Estimator

```
Enter head loss percentage (e.g. 10): 5.62
Head Loss: 8.04 m
Net Head: 134.96 m
```

Fig 5: Net Head of SSH from Potential Estimator

```
Enter plant efficiency (e.g. 0.85): 0.85

--- HYDROPOWER OUTPUT ---
Installed Capacity: 3.10 MW
```

Fig 6: Installed Capacity of SSH from Potential Estimator

```
SELECTION CRITERIA AS PER AVAILABLE HEAD
High Heads (250m and above): Pelton Turbine
Medium Heads (60m to 250m): Francis Turbine
Low Heads (Below 60m): Kaplan Turbine


Selected Turbine Type: Francis Turbine
```

Fig 7: Turbine Selection of SSH from Potential Estimator

Figure 4, is the screenshot obtained after running the model, shows the gross head obtained after entering upstream and downstream coordinates in degree. Similarly, figure 5, 6, and 7 showcases net head considering 5.62% head loss, installed capacity of 3.10 MW and selected turbine respectively.

Hence, the results of pre-established Sunkoshi Small Hydropower (SSH) obtained from the Potential Estimator are:

Parameter	Obtained Value	True Value	Relative Error
Design Discharge	2.76 m^3/s	2.7 m^3/s	2.22%
Gross Head	143m	124.5m	14.86%
Net Head	134.96m	117.5m	14.86%
Installed Capacity	3.10 MW	2.6 MW	19.23%

The error in the gross head is seen high due to the use of 30m resolution DEM file. And other errors are due to propagation of error of gross head. So, we recommend using lower resolution (tile) DEM file.

4.2 Potential Estimation Validation using Upper Tadi Hydropower Project (UTHP)

Its salient features are [18]:

Project Starting Year	2012	Project Completion Year	2025
Installed Capacity	11 MW	Hydropower Type	Run of River
Design Discharge	6.3 m^3/s	Percentage of Exceedence	40%
Gross Head	216.80 m	Net Head	208.08 m
Head loss percentage	4.02%	Overall Efficiency	88.27%

The intake of Upper Tadi hydropower is an ungauged station. So, the nearest river gauge station is Tadi Khola (Station no. 448), was taken into consideration for flow data. It has a catchment area of 651km^2. The monthly flow data is taken from 1990 to 2012 which was available in Department of Hydrology and Meteorology (DHM), in order to estimate the design discharge and installed capacity. The catchment area of the Upper Tadi Hydropower Project is 88.95km^2. Hence, we used the Catchment Area Ratio (CAR) method to determine the flow data for the project's intake site [17].

$$CAR = \frac{\textit{Area of Catchment of desired site}}{\textit{Area of Catchment of river gauging station}} = \frac{88.95}{651.00} = 0.137$$

The mean monthly discharge which was obtained from gauge station is then multiplied with CAR factor to transpose the flow to the intake of Upper Tadi Hydropower Project. Then this 23 year data and SRTM DEM file obtained from USGS EarthExplorer site is fed to the tool to compare the result with actual data.

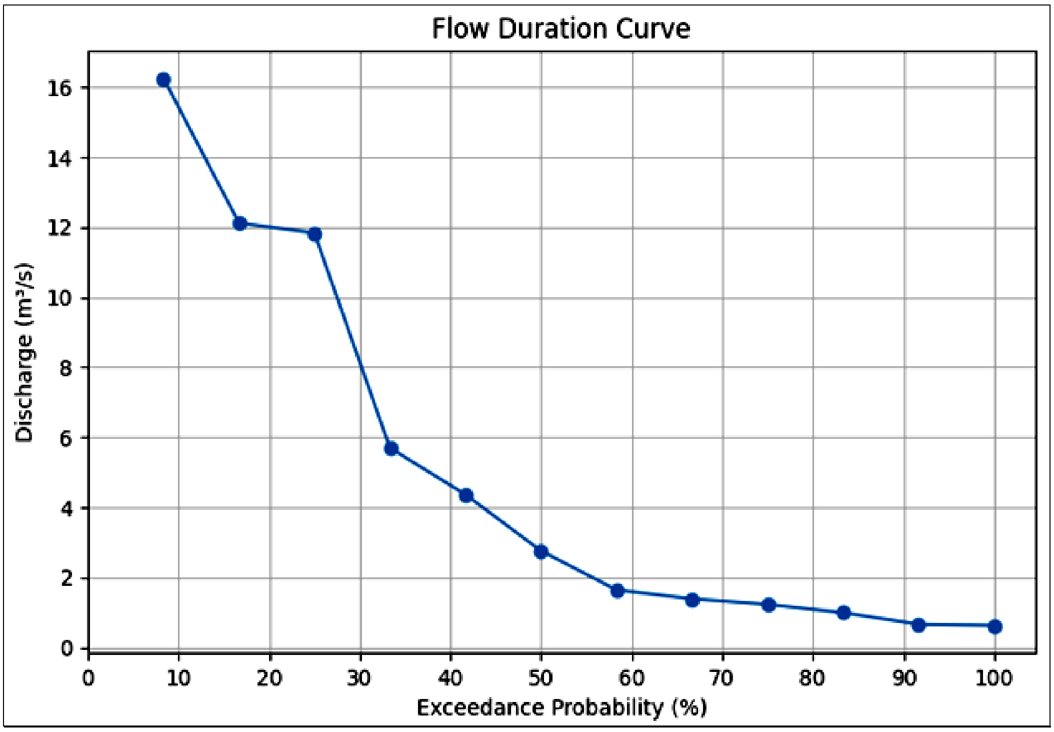


Fig 8: Flow Duration Curve of Upper Tadi Hydropower from Potential Estimator

```
PS C:\Users\shiva> & D:/Python/python.exe d:/1.PROJECTS/POTENTIAL_ESTIMATOR/Python_trial/Potential_Estimato
ial_Estimator.py

--- HYDROPOWER ESTIMATION TOOL WITH FULL FDC ANALYSIS EXPORT ---


FOLLOW THESE GUIDELINES BEFORE YOU RUN THE PYTHON CODES
1. NEVER USE ANY SPACES IN ANY FILE OR FOLDER NAME WITHIN THE PATH YOU PROVIDE
2. YOU CAN DRAG AND DROP YOUR FILE FOR PROVIDING FILE LOCATION
3. THE FORMAT OF RAW DISCHARGE DATA SHOULD BE .csv WITH 'Date' AND 'Discharge' OR 'Month' AND '
Discharge'
4. THIS TOOL ACCEPTS DAILY, MONTHLY OR LONG-TERM AVERAGE MONTHLY DISCHARGE
5. ENTER LATITUDE AND LONGITUDE IN DECIMAL FORMAT
6. THIS IS FOR PRE-FEASIBILITY PURPOSE ONLY

Enter path to discharge CSV file: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\UTHP_daily_flow_1990_2
012.csv
Enter path to SRTM DEM file (.tif): d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\DEM_UTHP.tif
Enter path to save FDC analysis CSV: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\output.csv
d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Python_trial\Potential_Estimator.py:21: UserWarning: Could no
t infer format, so each element will be parsed individually, falling back to `dateutil`. To ens
ure parsing is consistent and as-expected, please specify a format.
  df['Date'] = pd.to_datetime(df['Date'], errors='coerce')

Monthly Long-Term Mean Flows (for FDC):
[16.25 12.12 11.83  5.7   4.37  2.76  1.65  1.39  1.24  1.    0.67  0.64]

✅ FDC analysis exported to: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\output.csv
Enter design exceedance percentage (e.g. 40 for Q40): 40
Design Discharge (Q40): 4.37 m³/s
```

Fig 9: Determination of Design Discharge of UTHP using Potential Estimator

Figure 8 shows the Flow Duration Curve of Upper Tadi Hydropower generated from Potential Estimator and *figure 9* is the screenshot showcasing the design discharge corresponding to 40% of percentage of time equaled or exceeded. However, the design discharge obtained from potential estimator is low as compared to the one used in design because the data that was obtained from DHM had temporal gaps, meaning the observations of data in between several months were missing.

```
Enter upstream coordinates:
  Latitude (In decimal): 27.9736
  Longitude (In decimal): 85.4405

Enter downstream coordinates:
  Latitude (In decimal): 27.9639
  Longitude (In decimal): 85.4192

--- Elevation Information ---
Upstream Elevation: 1562.00 m
Downstream Elevation: 1312.00 m
Gross Head: 250.00 m
River Distance (approx.): 2355.32 m
```

Fig 10: Gross Head of UTHP from Potential Estimator

```
Enter head loss percentage (e.g. 10): 4.02
Head Loss: 10.05 m
Net Head: 239.95 m
```

Fig 11: Net Head of UTHP from Potential Estimator

```
Enter plant efficiency (e.g. 0.85): 0.8827

--- HYDROPOWER OUTPUT ---
Installed Capacity: 9.08 MW
```

Fig 12: Installed Capacity of UTHP from Potential Estimator

```
SELECTION CRITERIA AS PER AVAILABLE HEAD
High Heads (250m and above): Pelton Turbine
Medium Heads (60m to 250m): Francis Turbine
Low Heads (Below 60m): Kaplan Turbine


Selected Turbine Type: Francis Turbine
```

Fig 13: Turbine Selection of UTHP from Potential Estimator

Figure 10, is the screenshot obtained after running the model, shows the gross head obtained after entering upstream and downstream coordinates in degree. Similarly, figure 11, 12, and 13 showcases net head considering 4.02% head loss, installed capacity of 9.08 MW and selected turbine respectively.
Hence, the results of pre-established Upper Tadi Hydropower Project (UTHP) obtained from the Potential Estimator are:

Parameter	Obtained Value	True Value	Relative Error
Design Discharge	4.37 m^3/s	6.3 m^3/s	30.63%
Gross Head	250 m	216.80 m	15.31%
Net Head	239.95 m	208.08 m	15.31%
Installed Capacity	9.08 MW	11 MW	17.45%

As mentioned earlier the relative error in design discharge is high because of temporal gaps in observations of flow data. Whereas, the error in the gross head is seen high due to the use of 30m resolution DEM file. And other errors are due to propagation of error of gross head. So, we recommend using lower resolution (tile) DEM file.

Temporal Change Detection Validation using Sunkoshi Small Hydropower (SSHP)

For the validation of temporal change detection using Potential Estimator, we took flow data of Sunkoshi Small

Hydropower project (1993 to 2013) from Department of Hydrology and Meteorology (DHM).

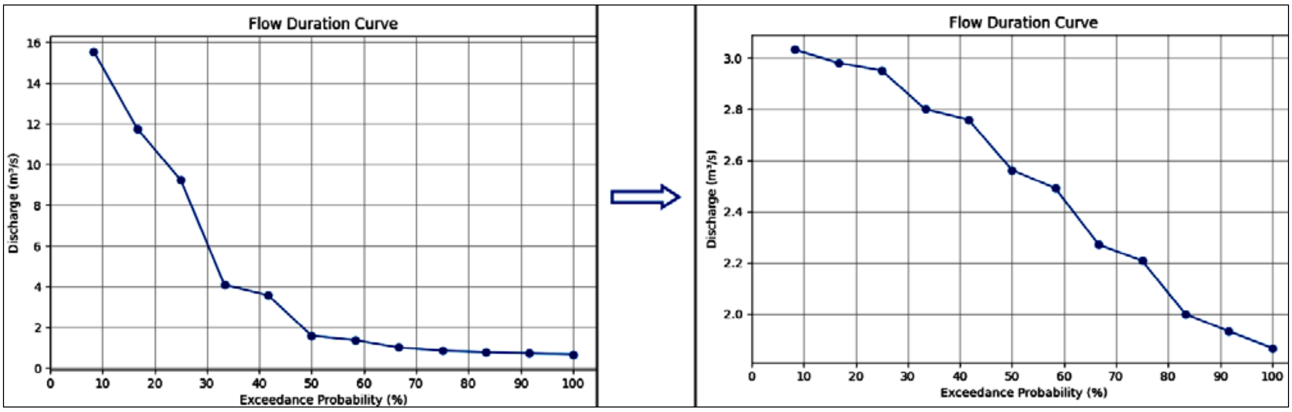
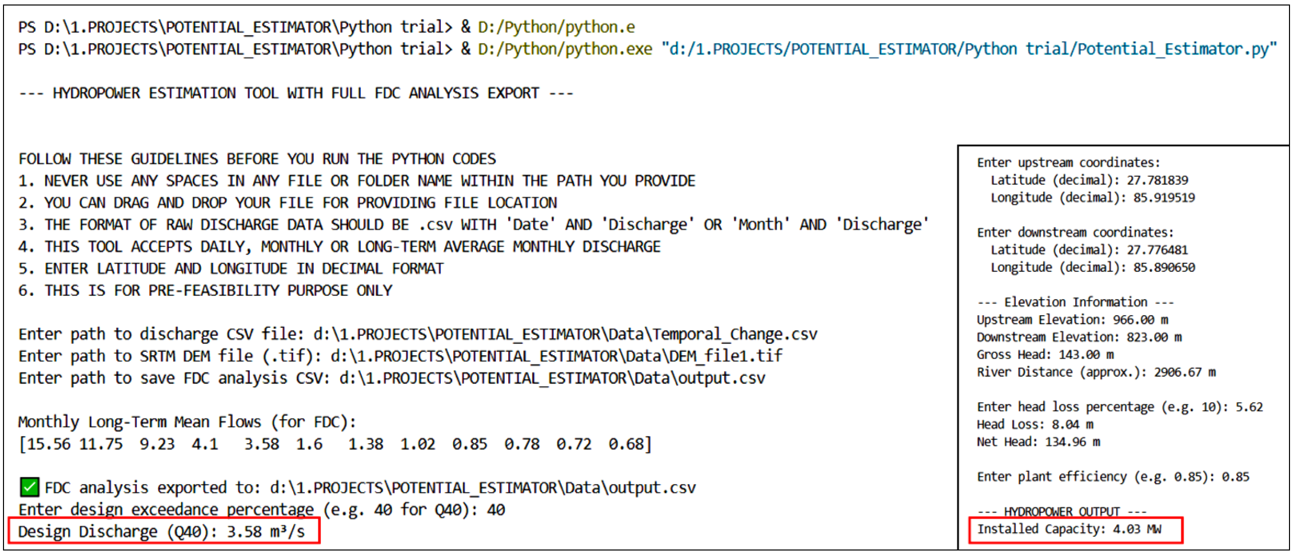


Fig 14: Temporal Change in FDC by 2013 of SSHP



```
PS D:\1.PROJECTS\POTENTIAL_ESTIMATOR\Python trial> & D:/Python/python.e
PS D:\1.PROJECTS\POTENTIAL_ESTIMATOR\Python trial> & D:/Python/python.exe "d:/1.PROJECTS/POTENTIAL_ESTIMATOR/Python trial/Potential_Estimator.py"

--- HYDROPOWER ESTIMATION TOOL WITH FULL FDC ANALYSIS EXPORT ---

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1. NEVER USE ANY SPACES IN ANY FILE OR FOLDER NAME WITHIN THE PATH YOU PROVIDE
2. YOU CAN DRAG AND DROP YOUR FILE FOR PROVIDING FILE LOCATION
3. THE FORMAT OF RAW DISCHARGE DATA SHOULD BE .csv WITH 'Date' AND 'Discharge' OR 'Month' AND 'Discharge'
4. THIS TOOL ACCEPTS DAILY, MONTHLY OR LONG-TERM AVERAGE MONTHLY DISCHARGE
5. ENTER LATITUDE AND LONGITUDE IN DECIMAL FORMAT
6. THIS IS FOR PRE-FEASIBILITY PURPOSE ONLY

Enter path to discharge CSV file: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\Temporal_Change.csv
Enter path to SRTM DEM file (.tif): d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\DEM_file1.tif
Enter path to save FDC analysis CSV: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\output.csv

Monthly Long-Term Mean Flows (for FDC):
[15.56 11.75  9.23  4.1   3.58  1.6   1.38  1.02  0.85  0.78  0.72  0.68]

✅ FDC analysis exported to: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\output.csv
Enter design exceedance percentage (e.g. 40 for Q40): 40
Design Discharge (Q40): 3.58 m³/s

Enter upstream coordinates:
  Latitude (decimal): 27.781839
  Longitude (decimal): 85.919519

Enter downstream coordinates:
  Latitude (decimal): 27.776481
  Longitude (decimal): 85.890650

--- Elevation Information ---
Upstream Elevation: 966.00 m
Downstream Elevation: 823.00 m
Gross Head: 143.00 m
River Distance (approx.): 2906.67 m

Enter head loss percentage (e.g. 10): 5.62
Head Loss: 8.04 m
Net Head: 134.96 m

Enter plant efficiency (e.g. 0.85): 0.85

--- HYDROPOWER OUTPUT ---
Installed Capacity: 4.03 MW
```

Fig 15: Temporal Change in Design Discharge and Installed Capacity by 2013 of SSHP

Figure 14 shows the change in nature of Flow Duration Curve within 12 years of operation of SSHP. It indicates higher electricity production capacity of SSHP. Similarly, figure 15 indicates higher design discharge corresponding to 40% of time than that of one at design phase of SSHP in 2002. Higher the design discharge higher is the installed capacity.

We found the following Temporal Change in Sunkoshi Small Hydropower project by 2013:

Parameter	Designed Value	New Value	Percentage Increase
Design Discharge	2.70 m^3/s	3.58 m^3/s	32.59%
Installed Capacity	2.60 MW	4.03 MW	55.00%

Temporal Change Detection Validation using Upper Tadi Hydropower Project (UTHP)

We took flow data of Upper Tadi Hydropower project (1990 to 2019) from Department of Hydrology and Meteorology (DHM).

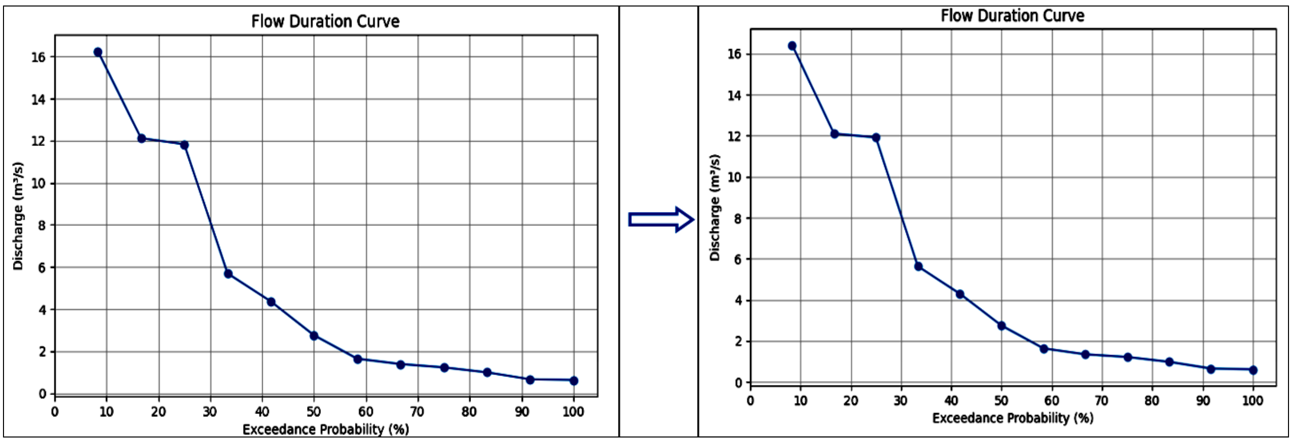

Fig 16: Temporal Change in FDC by 2019 of UTHP

Figure 14 shows the change in nature of Flow Duration Curve within 7 years of operation of UTHP. Due to not so long time difference, the nature of the flow duration curve is identical. However, the difference in design discharge is seen. Similarly, figure 15 indicates lower design discharge corresponding to 40% of time than one at design phase of UTHP in 2012. Lower the design discharge lower is the installed capacity. This creates a possibility that the minimum discharge required for power production might not be available which might create a huge problem in future. This also implies the Rehabilitation, Upgradation and Modernization of the project.

```
PS C:\Users\shiva> & D:/Python/python.exe d:/1.PROJECTS/POTENTIAL_ESTIMATOR/Python_trial/Potentia
l_Estimator.py

--- HYDROPOWER ESTIMATION TOOL WITH FULL FDC ANALYSIS EXPORT ---


FOLLOW THESE GUIDELINES BEFORE YOU RUN THE PYTHON CODES
1. NEVER USE ANY SPACES IN ANY FILE OR FOLDER NAME WITHIN THE PATH YOU PROVIDE
2. YOU CAN DRAG AND DROP YOUR FILE FOR PROVIDING FILE LOCATION
3. THE FORMAT OF RAW DISCHARGE DATA SHOULD BE .csv WITH 'Date' AND 'Discharge' OR 'Month' AND 'Di
scharge'
4. THIS TOOL ACCEPTS DAILY, MONTHLY OR LONG-TERM AVERAGE MONTHLY DISCHARGE
5. ENTER LATITUDE AND LONGITUDE IN DECIMAL FORMAT
6. THIS IS FOR PRE-FEASIBILITY PURPOSE ONLY

Enter path to discharge CSV file: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\Temporal_Change_UTHP.csv

Enter path to SRTM DEM file (.tif): d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\DEM_UTHP.tif
Enter path to save FDC analysis CSV: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\output.csv
d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Python_trial\Potential_Estimator.py:21: UserWarning: Could not
infer format, so each element will be parsed individually, falling back to `dateutil`. To ensure
parsing is consistent and as-expected, please specify a format.
  df['Date'] = pd.to_datetime(df['Date'], errors='coerce')

Monthly Long-Term Mean Flows (for FDC):
[16.42 12.1  11.92  5.64  4.31  2.75  1.64  1.35  1.22  0.99  0.66  0.62]

✅ FDC analysis exported to: d:\1.PROJECTS\POTENTIAL_ESTIMATOR\Data\output.csv
Enter design exceedance percentage (e.g. 40 for Q40): 40
Design Discharge (Q40): 4.31 m³/s

Enter upstream coordinates:
  Latitude (In decimal): 27.9736
  Longitude (In decimal): 85.4405

Enter downstream coordinates:
  Latitude (In decimal): 27.9639
  Longitude (In decimal): 85.4192

--- Elevation Information ---
Upstream Elevation: 1562.00 m
Downstream Elevation: 1312.00 m
Gross Head: 250.00 m
River Distance (approx.): 2355.32 m

Enter head loss percentage (e.g. 10): 4.02
Head Loss: 10.05 m
Net Head: 239.95 m

Enter plant efficiency (e.g. 0.85): 0.8827

--- HYDROPOWER OUTPUT ---
Installed Capacity: 8.96 MW
```

Fig 17: Temporal Change in Design Discharge and Installed Capacity by 2019 of UTHP

We found the following Temporal Change in *Upper Tadi Hydropower Project* by 2019:

Parameter	Designed Value	New Value	Percentage Decrease
Design Discharge	6.3 m^3/s	4.31 m^3/s	31.58%
Installed Capacity	11.00 MW	8.96 MW	18.55%

Discussion

This study shows that the Potential Estimator and Temporal Change Detector tool can give useful predictions for small hydropower projects, but it's not perfect. When we tested it on Sunkoshi and Upper Tadi projects, the tool gave results close to the actual values for things like discharge and installed capacity. However, there were noticeable errors in estimating the head, mostly because we used 30m resolution elevation data (DEM files). Using better-quality data could improve accuracy.

We also looked at how things changed over time. For Sunkoshi, the water flow and power capacity increased, which means the project might now produce more electricity than before. But for Upper Tadi, both values dropped, which could be a problem in the future. If the water flow keeps decreasing, the plant might not work as well, and upgrades may be needed.

In short, the tool is helpful for early planning and checking changes over time, but it depends a lot on the quality of the input data. Better flow records and higher-resolution maps would make the tool more reliable and useful for hydropower planning in Nepal.

Conclusion

This study successfully developed a lightweight Python-based tool, also called Potential Estimator, to estimate the potential of hydropower of Run of River (RoR) projects using long term discharge data and Digital Elevation Models (DEMs). By using these inputs, Estimator can perform flow duration curve (FDC) analysis, DEM-based head calculation, and capacity estimation. This tool provides a time-reducing, efficient, reproducible, and open-source alternative to commercial GIS platforms.

Potential Estimator was validated using real discharge data obtained from DHM and analyzed by taking Sunkoshi Small Hydropower (SSH) plant and Upper Tadi Hydropower Project (UTHP) as a case study. It showed the accuracy of the estimation. It is flexible in data extraction in CSV format which enhances transparency and usability, especially for early-stage feasibility assessments.

This tool is particularly suited for use in remote or limited resource regions like hilly or mountainous terrain of Nepal, where access to commercial software is limited. It supports junior engineers, students and planners in making decisions during preliminary hydropower project assessment. This tool can further be improved by integrating energy calculations, sediment analysis and real-time data automation to further enhance its application in the sustainable hydropower development.

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