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ROR POTENTIAL HYDROPOWER OF NEPAL AT DIFFERENT DISCHARGES

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ABSTRACT

The total hydropower potential of Nepal was assessed as 83,500 MW by Dr. Hari Man Shrestha during his Ph. D. research work in USSR in 1966. Since then, no further study has, so far, been done in this field. The 1966 Power potential estimate has been used by NEA, WECS and DOED for power development, licensing and policy making. However keeping in view the recent advancements in computer technology which have offered many benefits to the field of water resources and the importance of power estimation in Nepal Dr. Shrestha's estimate needs further review and updating. The hydro-meteorological data of DHM for hydrological analysis of all the rivers in Nepal incorporating GIS and the Hydropower Model that has specifically been developed by the author, the power potential and annual energy estimate on an ROR basis of the entire country has been estimated. The result shows that the total hydropower potential and corresponding annual energy capacity of Nepal on run off the river basis at Q40 and 80% efficiency is 53,836 MW and 346534 GWh respectively [3]. In this study $Q_{30}$is used with 80% efficiency and estimates the total power potential of Nepal as 88,306 MW. The total dry energy is 53,021GWh and total wet energy is 421,430 GWH, totaling 474,451 GWH energy. This research also conclude that comparing Q_{30} and Q_{40}, the installed power increased from 53,836MW to 88,306MW which is around 64% and the wet energy only increased by 36.9%.

Keywords -Hydropower Model, Gis, Potential Hydropower, Srtm Dem

Introduction

Dr. Hari Man Shrestha assessed the total hydropower potential in Nepal as 83500 MW in 1966 in his Ph. D. research in USSR. Since then, no further study has, so far, been done in this field covering the entire nation. Dr Shrestha's work was more manual and he did his job with limited available tools. The study was done with the few hydrological, meteorological, and topographical data and the quality of data was very poor.

According to him only four discharge gauging stations were available in Nepal. However, the availability of precipitation data was more than discharge data. He plotted the curve of rainfall and elevation band. From the analysis of the curve, he calculated the discharge using the regression equation developed using limited discharge gauging stations and rain gauge stations.

Manual delineation of catchment area of about 300 sq km was done with the old topographical maps. The available heads along the rivers were calculated using contour interval and the discharge were calculated by means of contour interval and Elevation-Rainfall curve. According to him, each drop of water was used to calculate the power potential and considered efficiency as 100 %.

Later the government institutions like NEA, WECS and DOED also attempted to estimate the hydropower potential. But the estimates were influenced under the policy of the government with priority to small, medium and large hydroelectric and multipurpose projects at different facet of time. It is realized that the past efforts of identifying undeveloped hydropower capacity by the different government agencies were more project-oriented and the methodologies for undeveloped hydropower resources assessment werenot well defined. Also it should be important to note that apart from Dr. Shrestha's estimate, no agency had previously attempted to estimate the undeveloped hydropower capacity of the basins based on the site characteristics, stream flow data and available hydrologic head. In a country of huge hydropower potential like Nepal, this issue has to be properly addressed and the suitable methodology has to be developed.

Recent advances in computer technology have offered many benefits to the field of water resources especially due to the development of Geographic Information Systems (GIS)[1],[2]. GIS in conjunction with Hydropower Model can be used in a variety of hydrologic applications like delineating the drainage pattern, catchment area and to assess the hydropower potential of the river reaches.

Keeping this in view, the objective of this study is to calculate the theoretical hydropower potential of Nepal by using GIS and Hydropower Model.

Methodology

Flow chart of the methodology for the research is shown in **Error! Reference source not found.**. It can be divided into three components:

Hydrological Analysis

The monthly discharge of more than 100 river gauging stations from the year 1997 to 2006 were collected from Department of Hydrology and Meteorology. Flow duration curve of each station was developed and Q_{30}, Q_{40}, Q_{50} and Q_{60} were calculated for all 12 months. Here Q_{40} represent the flow magnitude in an average year that can be expected to be equaled or exceeded 40 percentile of time. If the average monthly discharge were less that Q_{40} then average discharge of the month were considered for power production otherwise Q40 discharge were considered. This consideration is valid for all Q_{30}, Q_{40}, Q_{50} and Q_{60} discharges respectively. Then the specific discharge (discharge divided by catchment area) of each gauging station were calculated and used for calculating the discharges above and below the gauging station by multiplying the average catchment area of upstream and downstream. Following example shows methodology for calculation of discharge at a point on the stream using specific discharge method.

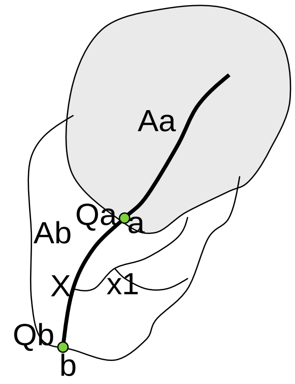

Figure 1: Discharge Calculation

Let the catchment area and discharge at gauging stations *a* and *b* are A_a, Q_a and A_b, Q_b respectively. The discharge upto*a* gauging stations can be calculated using specific discharge at gauging station *a*, i.e specific discharge multiplied by catchment area The specific discharge at *b* is calculated as $(Q_b - Q_a)/(A_b - A_a)$. The discharge along the main river at *x*, Q_x is calculated as $Q_x = Q_a + (Q_b - Q_a)/(A_b - A_a) * (A_x - A_a)$

Where, A_x is catchment area at x. The discharge at x_1 (on a distributary line), Q_{x1} is calculated as $Q_{x1} = (Q_b - Q_a)/(A_b - A_a) * A_{x1}$

ii) **GIS Analysis**

The freely available SRTM dataset of 3" second resolution in WGS84 datum is downloaded from seamless SRTM dataset site. The SRTM Decimal Degree format dataset is transformed to MUTM (Modified Universal Transverse Mercator) and Everest datum and resampled to 100m resolution. The available DEM is processed using GIS software and flow direction, flow accumulation, river network, stream order, stream link and elevation along the generated rivers are calculated. GIS Grid output of flow accumulation, stream order, stream link and river elevation are converted into the ASCII format and fed to the Hydropower model.

iii) **Hydropower model**

Hydropower model is developed by the author and written in FORTRAN program. This model reads the ASCII data processed in GIS software and calculates head from the river elevation. It reads discharge data processed in Hydrological analysis and calculates the installed capacity, wet energy and dry energy in all generated rivers and for all discharge percentiles. The flowchart of the model is given in the Figure 3.

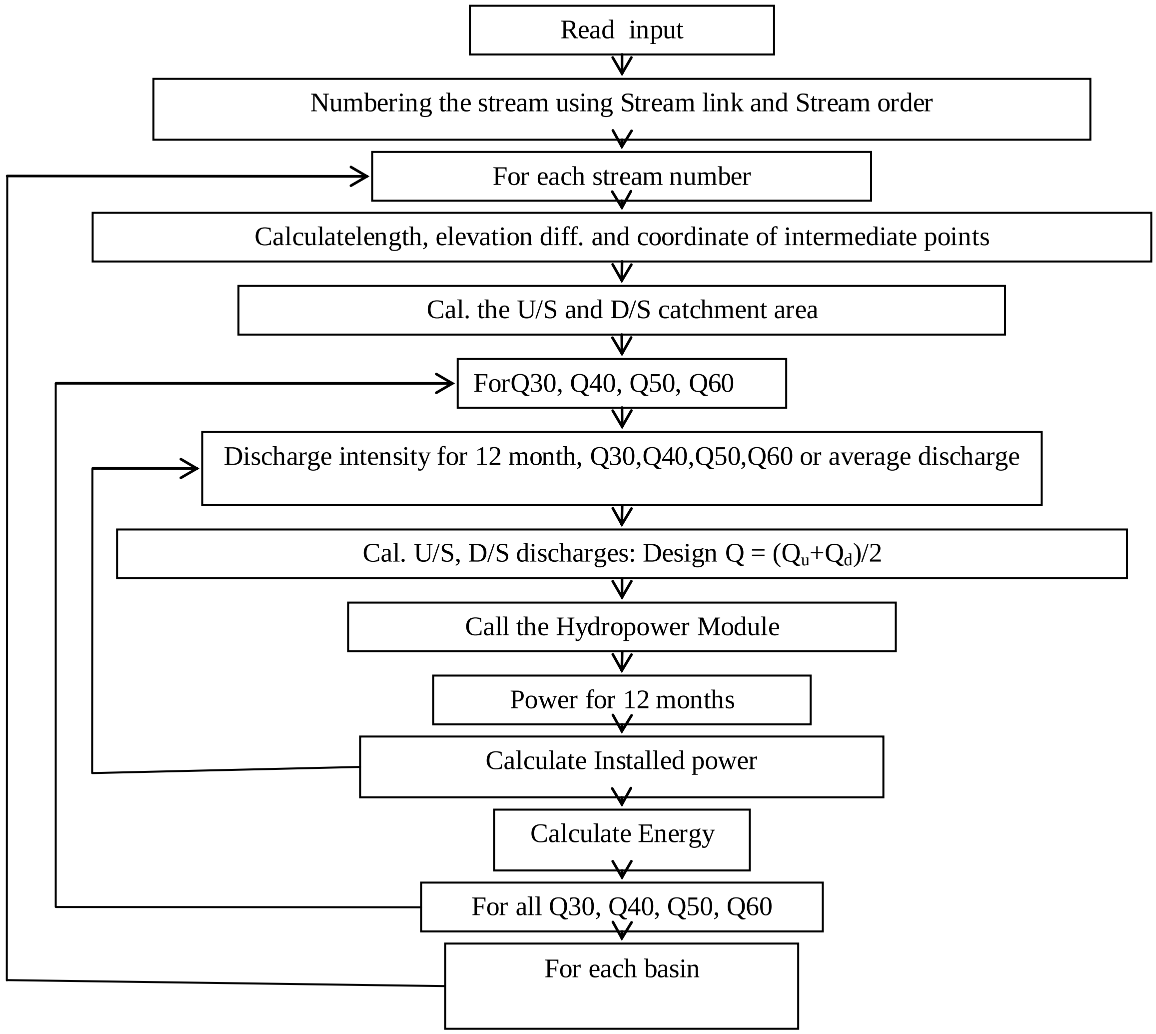

Figure 2: Flowchart of the Hydropower Calculation

Study Area

Most of the surface water in Nepal drains through four major rivers; Koshi (Saptakoshi), Gandaki (Gandaki), Kanali and Mahakali and their tributaries. These all rivers originate from the Himalayan Mountains or Tibet Plateau, forge through varied mountain ranges and are perennial.

Other major rivers originate from the Mahabharata ranges. They are the Mechi, Kankai, Kamala, Bagmati, Tinau, Rapti, and Babai. The Mahakali and Mechi rivers mark the international boundaries between Nepal and India

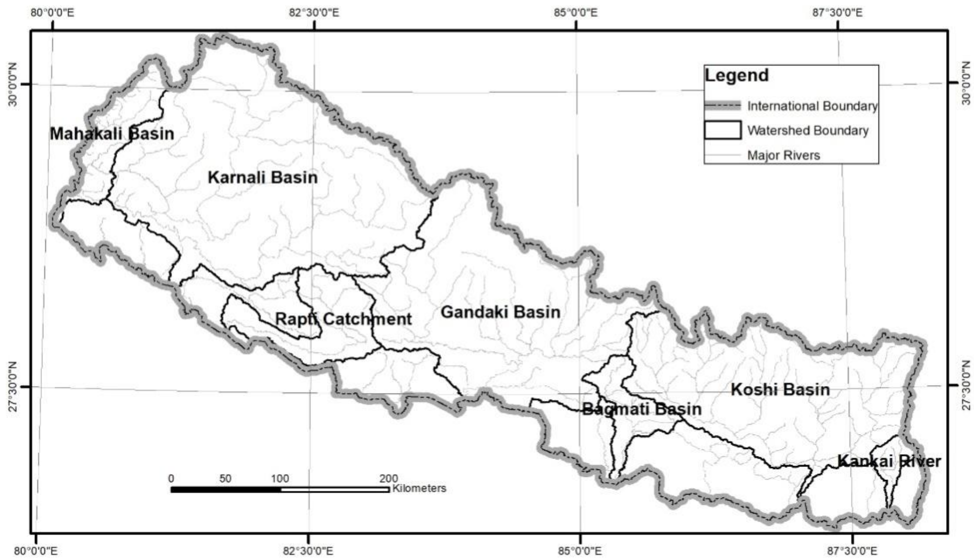

Figure 3: Major Watershed Boundary in Nepal

3.1 Koshi River Basin

The Koshi basin is the largest basin of Nepal. It lies in the eastern development region of Nepal between latitudes 27°06'23" to 28°09'23"N and longitude 88°22'36" to 88°23'37"E. It comprises an area of about 61,000 sq.km Out of the total catchment area, 27,816 sq. km (45.6%) lies in Nepal and the remaining 33,184 sq.km. lies in Tibet, China. The river Koshi, also commonly known as Sapta Koshi, comprises of seven rivers namely (from west to east); Indrawati, Sunkoshi, Tamakoshi, Likhu, Dudhkoshi, Arun and Tamur. Out of these rivers, three major rivers or tributaries originate in Tibet. They are Sunkoshi, Tamakoshiand Arun. The Koshi River basin can be divided into three major river sub-basins: the Sunkoshi, Arun and Tamor. The Sunkoshi River comprises of the Indrawati, Sunkoshi, Tamakoshi, Likhu and Dudhkoshi rivers.

There are altogether thirty-four discharge gauging stations in different rivers: Majhimtar and Mulghat in Tamor river; Uwagaon and Tudkeghat in Arun river; Rabuwaght in Dudhkoshi; Sangutar in Likhu; Rasnalo in Khimti; Busti in Tamakoshi; Pachawarghat in Sunkoshi; Jalbire in Balpeni and Chatra in Saptakoshi are some of the major gauging stations.

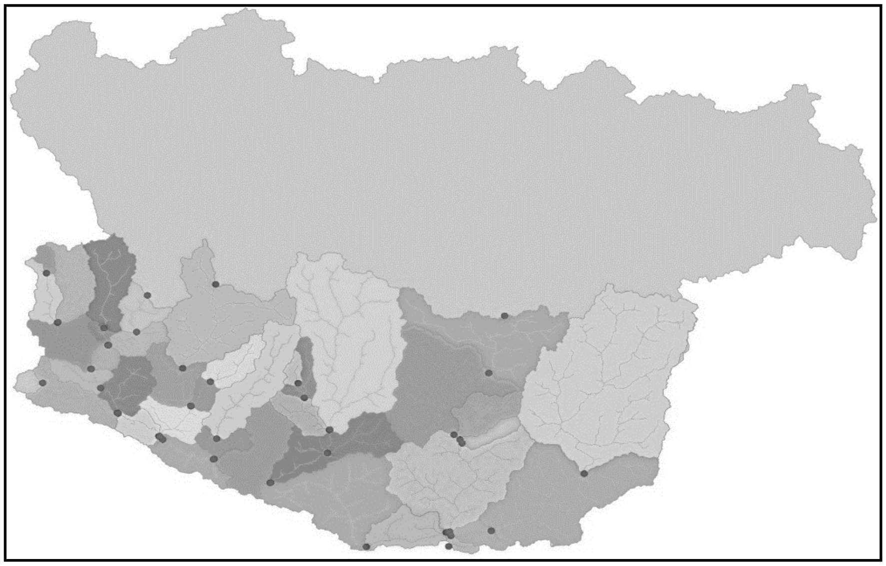

Figure 4: The Koshi River Basin

3.2 Gandaki River Basin

The gandaki basin is the second largest basin of Nepal. It lies in the western development region of Nepal between latitudes 27°21'00" to 29°20'00"N and longitude 82°53'00" to 86°13'00"E. It covers an area of 31,890 sq. km. It is situated in Nawalparasi, Baglung, Chitwan, Makawanpur, Mustang, Parbat, Palpa, Gorkha, Lumjung, Myagdi, Gulmi, Syangja, Dhading, Rasuwa, Kaski, Arghakhanchi, Tanahu, and Nuwakot districts, lying within the higher Himalayas to the Terai. The highest elevation in this basin is 7163m at Ganesh Himal to 73m at the Nepal-India Border.

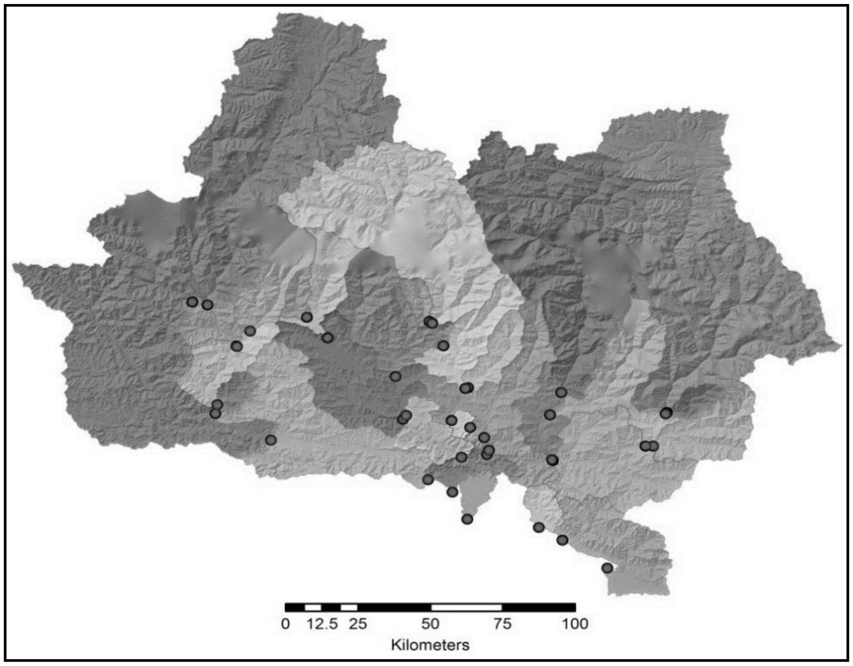

Figure 5: The Gandaki River Basin

3.3 Kankai River Basin

The Kankai River drains out from Ilam. It firstly flows towards the south-west and then makes typical easterly bend from there to Bhatbat and finally turns towards south. The Kankai basin has approximately 1,150 km2 as drainage area and approximately 110km in length. The average discharge is 60m3/sec. In the eastern Nepal, the Terai Rivers have a gradient of 10-12 m per km in the upper reaches, whereas, 5-6 m in the middle part and 1 m near indo-Nepal border. The Kankai River is a little steeper than the others. The source of the Kankai Mai River is Chhintapu hill in the Mahabharat range. Puwa Kholo, Jogmaikhola, Deomaikhola and Mai khola are its main tributaries.

3.4 Bagmati River Basin

The Bagmati River with the drainage area of 3, 600km2 and the length of 160km starts from the southern slopes of Sheopurilekh, north of Kathmandu valleyand flows straight to south-west cutting through the Mahabharat range. It appears that the present nature of river came into existence in Pleistocene times when the Kathmandu Lake disappeared. The Bagmati first flows towards south west from Kathmandu upto Jhanalkot, from there to Gangate in south and later on south east and makes a U bend at Betehaniup to Hariharpurgarhi, thereafter to south easterly direction and finally to the south. The average discharge is reported to be approximately 210. 6m3/s.

3.5 Rapti River Basin

The West Rapti River has in its upper basin, two major tributaries, namely Jhimruk Khola and Mari Khola. Both Rivers originate from Mahabharata range and flow south until they join at Airawati from which location it is named West Rapti . About 25 km below the confluence of Mari and Jhimruk Khola, the West Rapti River meets the Siwalik range from where it meanders into Terai belt. The Rapti River, of approximately 257 km length, has an estimated yearly mean runoff of about 125 cum/sec with a total drainage area of about to 6500 sq.km.

3.6 Karnali River Basin

The Kamali River, one of the three major rivers in Nepal originates from the south of Mansarovar and Rokas lakes located in China (Tibet) and enter in Nepal near Khojarnath flowing in southern direction as shown in Figure **6**5.

The drainage area in China is approximately 2500 km2 and that inNepal is approximately 41500km2. Therefore, the total drainage area is approximately 44000 km2. In Nepal it becomes Humla Karnali. It makes a sharp bend at Naralagna Himal. From there, it flows towards the east and to south west at Nima-pipalang. There it is joined by Mugu Karnali and Kharte Khola meets at Sukhadik. In between these two tributaries the Raradaha (lake) is situated.

The length of Mugu Karnali is 160 km and Humla Karnali is100 km.

In Terai, it flows a distance of 30 km inside Nepal before entering the Nepal India border.

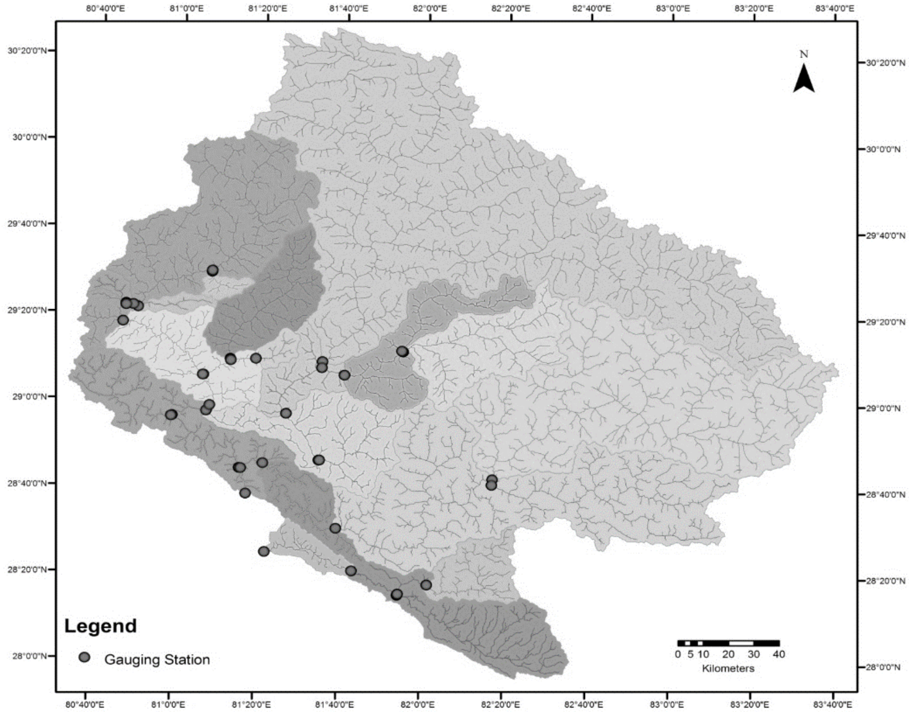

Figure 6: The Karnali River Basin

3.7 Mahakali River Basin

The Mahakali River as shown in Figure 7, is 223 km long, having its origin in ApiHimal of the Himalaya range It is an international river located on the western border of Nepal with India. The total catchment area is approximately 15260 km2 and about 5400 km2 (35%) lies in Nepal. The river starts from Milan glacier of India and from the Lipulekh of Nepal. It flows southwest making numerous oxbow lakes in the Indian Territory. The main tributaries in the Nepal side are Surnaga driver and Chamelia river. The Mahakali I irrigation project is under operation and execution in the Terai plains. Mahakali is in dolomite up to Jhulaghat, whereas, in the south, it is in gneiss and dolomite and near Rang unkhola it is in the Churia formation. Mahakali River divides into two channels near Lamsari which again join together at Suklapur. The Mahakali River meets the Karnali River in India Its estimated mean yearly runoff is 557 m3/sec.

Atthe Nepal-India border area, but officially located in Indian Territory at present, there is Sharada Barrage crossing the Mahakali River. As an international river, the water right of the Mahakaliriver causes long-termdispute between both the countries

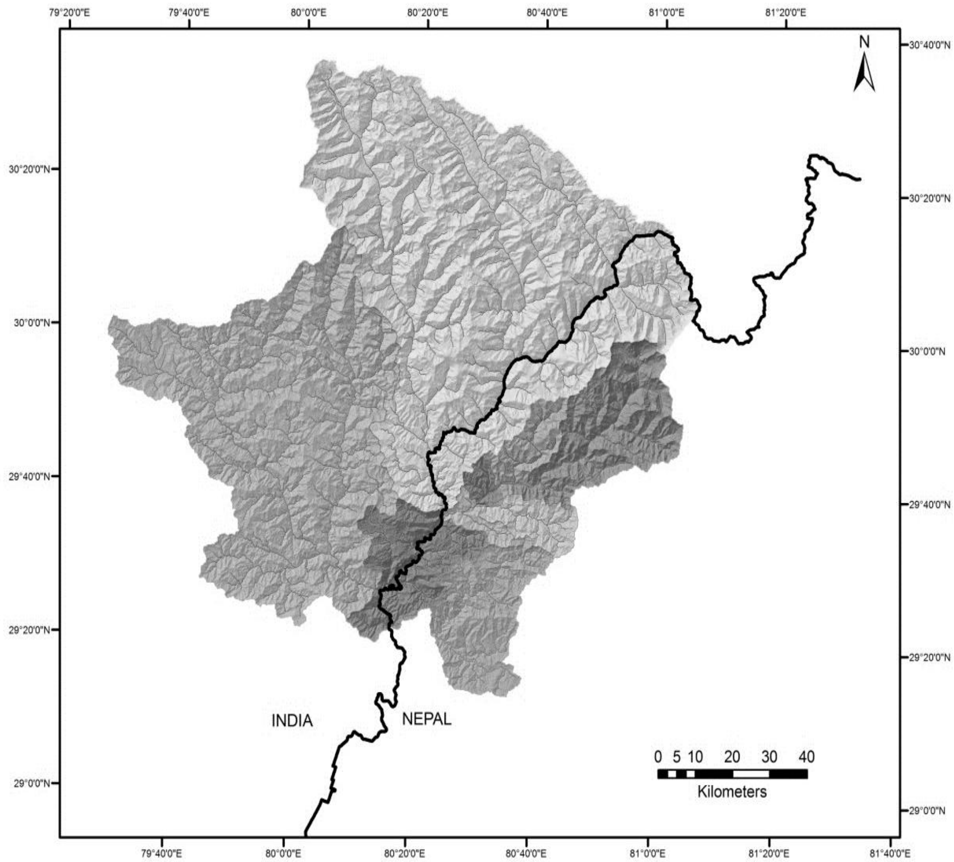

Figure 7: The Mahakali River Basin

Results

The installed capacity, dry energy, wet energy and total energy at different discharges for all major rivers in Nepal excluding the small Churia Range rivers are shown here.

4.1 Kankai

The total installed power and total annual energy at 30%, 40%,50%, and 60% flow exceedence has been calculated as385MW, 241.3MW, 147.5 MW,103.4 MW and 2033GWh, 1517.2GWh,1035.4 GWh,809 GWh respectively. The result is shown in Table 1.

Table 1: Installed Power, Dry Energy, Wet Energy and Total Energy of Kankai River

Discharge	Installed Power, MW	Dry Energy, GWh	Wet Energy, GWh	Total Energy, GWh
Q_{30}	385	213	1,820	2,033
Q_{40}	241.3	213	1304	1,517
Q_{50}	147.5	213	822	1,035
Q_{60}	103.4	213	595	808

4.2 Koshi River Basin

The total installed power of the Koshi river basin at Q30, Q40, Q50, and Q60 flow exceedence is 29,362 MW, 17008 MW, 10826 MW and 7807 respectively and total energy from this basin is 155,905 GWh, 108,817 GWh, 77,064 GWh and 61,557 GWh respectively.

Table 2: Installed Power, Dry Energy, Wet Energy and Total Energy of Koshi River

Discharge	Installed Power, MW	Dry Energy, GWh	Wet Energy, GWh	Total Energy, GWh
Q_{30}	29,362	16,488	139,420	155,908
Q_{40}	17008	16,488	92329	108,817
Q_{50}	10826	16,488	60576	77,064
Q_{60}	7807	16,488	45069	61,557

4.3 Gandaki River

The individual installed power and annual energy of Gandaki river at 30%, 40%, 50%, and 60% of flow exceedence is shown in Table 3.

Table 3: Installed Power, Dry Energy, Wet Energy and Total Energy of Gandaki River

Discharge	Installed Power, MW	Dry Energy, GWh	Wet Energy, GWh	Total Energy, GWh
Q_{30}	28,980	16,260	138,520	154,780
Q_{40}	17800	16,260	97113	113,373
Q_{50}	12344	16,260	68550	84,810
Q_{60}	9648	16,260	54705	70,965

4.4 Bagmati River

The total installed power and total annual energy at 30%, 40%,50%,60% of flow exceedence has been calculated as 679MW, 424.4MW,236 MW, 152.2 MW and 3452GWh, 2574.4 GWh,1607 GWh, l 176.8GWh respectively as shown in Table 4.

Table 4: Installed Power, Dry Energy, Wet Energy and Total Energy of Bagmati River

Discharge	Installed Power, MW	Dry Energy, GWh	Wet Energy, GWh	Total Energy, GWh
Q_{30}	679	302	3,150	3,452
Q_{40}	424	302	2271	2,573
Q_{50}	236	302	1304	1,606
Q_{60}	152	302	874	1,176

4.5 East Rapti Basins

The total potential energy at 30th, 40th, 50th and 60th percentiles of flow are 3760GWh, 2951.17GWh, 2094.12GWh, 1820.16 GWh and the installed powers are 670MW, 438.89 MW**,** 272.02 MW, 218.68 MW for the above respective cases. This is shown in Table 5.

Table 5: Installed Power, Dry Energy, Wet Energy and Total Energy of West Rapti River

Discharge	Installed Power, MW	Dry Energy, GWh	Wet Energy, GWh	Total Energy, GWh
Q_{30}	670	550	3,210	3,760
Q_{40}	438	550	2400	2,950
Q_{50}	272	550	1543	2,093
Q_{60}	218	550	1269	1,819

4.6 Karnali Basin

The total energy at 30th, 40th, 50th and 60th percentiles of flows are 134928GWh, 102324.03 GWh, 76189.69 GWU 64024.44 GWh and the installed powers are 24700MW, 15661.16 MW, 10572.70 MW, 8204.08 MW for the above respective cases. This is shown in Table 6.

Table 6: Installed Power, Dry Energy, Wet Energy and Total Energy of Karnali River

Discharge	Installed Power, MW	Dry Energy, GWh	Wet Energy, GWh	Total Energy, GWh
Q_{30}	24,700	16658	118,270	134,928
Q_{40}	15661	16658	85666.1	102,324
Q_{50}	10573	16658	59531.8	76,190
Q_{60}	8204	16658	47366.5	64,025

4.7 Mahakali Basin

The total potential energy at Q30, Q40, Q50, and Q60percentiles of flow for Mahakali River are19590GWh, 14980.90 GWh, 12860.16 GWh, 10614.21 GWhand installed powers are 3530MW, 2262 MW, 1849MW, 1411 MW for the above respective cases. This is shown in Table 7.

Table 7: Installed Power, Dry Energy, Wet Energy and Total Energy of Mahakali River.

Discharge	Installed Power, MW	Dry Energy, GWh	Wet Energy, GWh	Total Energy, GWh
Q_{30}	3,530	2,550	17,040	19,590
Q_{40}	2262	2550	12430	14,980
Q_{50}	1849	2550	10309	12,859
Q_{60}	1411	2550	8063	10,613

Discussion and recommendation

Table 8: Installed Power, Dry Energy, Wet Energy and Total Energy of whole Nepal

Discharge	Installed Power, MW	Dry Energy, GWh	Wet Energy, GWh	Total Energy, GWh
Q_{30}	88,306	53,021	421,430	474,451
Q_{40}	53,835	53,021	293,513	346,534
Q_{50}	36,247	53,021	202,636	255,657
Q_{60}	27,543	53,021	157,942	210,963

The total hydropower potential of Nepal for Q_{30}, Q_{40}, Q_{50}, and Q_{60} are 88306 M, 53836 MW, 36247 MW and 27543 MW respectively. The total potential dry energy for Q_{30}, Q_{40}, Q_{50}, and Q_{60}discharges are 474,451 GWh, 346,534 GWh, 255,657 GWh and 210,963 GWh respectively. The dry energy in each case is same as 53021GWH because the discharge during the low flow is very less and only few turbines will be operated. The three major river basins viz. Koshi, Gandaki and Karnali contribute 29362 MW, 28980 MW, 24700MW of power and 155908GWh, 154780 GWh, 134928GWh of energy respectively thus contributing about 94% of total hydropower and hydroelectric energy potentials at Q30 discharge.

If Q30 is considered in comparison to Q40, then the installed power increases from 53,835MW to 88,306MW which is around 64% and the wet energy increased only by 346,534GWh to 474,451 GWh which corresponds 36.9%increase. It can be interpreted from this statistics that the cost will be increased by 64% however the benefit will be increased only by 36.9%. This can be easily seen in Figure 8.

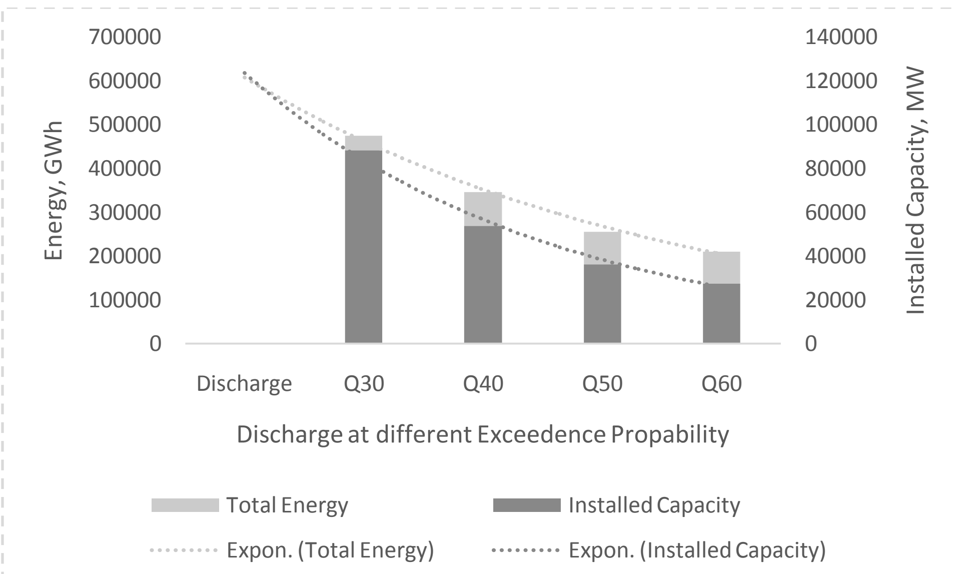

Figure 8: The Variation between the installed capacity and total Energy at different Discharges.

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