**Hydro Potential and Present Status of Hydropower Development in Nepal: A Review**

**Abstract**

Nepal has enormous hydro potential that can be tapped for power generation. The hydro potential of Nepal was assessed 83000 MW by Dr Ram Man Shrestha during his Phd study in 1966. Since then No further study were carried out in this field. The advancement in computer technology offers many benefits for the study of water resources. Dr. Raghunath Jha carried out the energy mapping of river basins of Nepal using GIS and remote sensing developing Hydrological model in 2011. His studies revealed that Nepal pegs 53836 MW on ROR basis at Q40% flow exceedances, and 80% overall efficiency. In 2019 Water Energy commissions of Nepal government revealed 72000 MW hydro potential of three major basins Saptakoshi, Gandaki and Karnali. There are different figures of hydro potential however 83000 MW is considered as approximate potential for Nepal. First hydropower plant was Pharping of installed capacity 500 KW constructed in 1911. Before 1990 development was sluggish. After 1990 the development pace are encouraging. Hydropower development is challenging itself in Nepal. Political instability, poor economic condition of the country, vulnerable geology hinders the development. Poor institutional set up, weak policy, technical constraints and local people’s interest affects the development work. Still Nepal is importing more than 1000MW energy from neighboring country India and there is huge economic loss for power purchase. Up to 2025 the gross installed capacity of Nepal is 3255.806 MW which is 7.5% of total economically feasible hydro potential 43000MW. Strategic action and dedication of the Nepal government can bring the socioeconomic transformation in next level through the development of energy sector. For this the acknowledgement of major challenges for hydropower development, formulation of friendly policy, robust institutional set up are needed.

**Key words:** Hydro potential, Hydropower Development, Challenges, opportunities, Nepal

**1. Introduction**

Nepal is a rich Country in per capita hydro potential in the world. In short reach Nepal has more than six thousands rivers originated from high Himalayan range that flows from steep terrain to plain region(Sharma and Awal 2013). Snow fed rivers are perennial in nature with sufficient head and high kinetic energy that can be tapped for hydropower generation in sustainable way(Shrestha and Dixit 2020). For the development of hydropower project in a river a complete hydrological and meteorological study is needed. Dr Ram man Shrestha was the first researcher who carried out finding the total hydro potential of Nepalese river in an authorized documented form as a thesis work of his Phd research work in 1966 and revealed the total potential of 83000 MW calculated at overall efficiency of 100% considering Q40 as best utilization discharge for all rivers(Shrestha 2016) . He carried out the study with the very limited tools and insufficient data at that time especially in context of Nepal. There were no sufficient hydrological and meteorological stations in river basin)(Adhikari. dipak.). The technology like GIS and remote sensing were not introduced. Most of the stu dy and calculation were manual. The studies were inconvenient however the result given by Dr. Shrestha is accepted worldwide for Nepal(Bohara and Shrestha 2017; Huang & Yan, 2009). After him there are not much study carried out on this issues. Manual calculation of the catchment area, discharge of the rivers and 100% overall efficiency taken for power estimation are ideal case (Mishra et al., 2015). For the quality data execution further study was needed. There is a large gap on the review of the study on this topic. With the advancement of technology and stations built up study became easier (Li et al., 2018; Li et al., 2015). The hydro potential mapping was carried out by the institution water energy commission (WECS) of Nepal government itself. Many studies have been carried out to find the hydro potential of Nepalese Rivers for small, medium and large power plant separately in personal level (Panić et al., 2013; Koç, 2014; Panić et al., 2013). In 2011 Dr. Raghunath Jha reviewed the study using GIS and remote sensing developing hydrological model. River geometry, its geology, hydrology and morphology changes with time(Chandra, Basnet, and Sherchan 2019; Sun et al., 2019). So its continuous study is necessary for reliable water project development. Environmental change scenario has become a serious issue for climate change and its adverse impact globally(Delhi 2012). Hydrological cycle is mostly affected in rivers due to the impact on snow layer high Himalayan from where our Rivers originates(Dhakal 2013; Aroonrat & Wongwises, 2015). Hydrological analysis with environmental assessment is necessary so that certain forecast can be made(Parajuli et al. 2015). We design and develop water project considering at least hundred years return period in any river so that possible water induced hazards can be prevented and most vulnerable regions can be identified before site selection(Parmelee 2001). Robust geological investigation is important in case of underground structures like tunneling(Singh and Nachtnebel 2014). Considering all these this study is aimed to review the river systems of Nepal, its hydro potential and status of hydro power projects which helps for future planning and implementation of new construction in energy sector .

**2. Aim of the study**

Nepal started hydropower development from the year 1911 with the construction of Pharping Hydropower plant of installed capacity 500KW. The power generated was for the capital city Kathmandu valley. Starting time of hydropower development was same in India, china and Nepal. Today there is huge difference in power generation and consumption among the three countries. China has the biggest source of power developed today. India is following to china parallel in energy generation. But Nepal is still importing substantial amount of energy around 1000 MW from India for the mitigation of power demand. Huge amount of money is invested for energy purchase. It is economic loss for nation. A data based review study is realized on the development history of hydropower plant from Nepalese river basins from the beginning of first hydropower development to till now so that an information can be documented which will be useful for future development planning and policy making in energy sector

 **3. Methodology of the Study**

The study is based on both qualitative and quantitative information. For the study the data required are secondary types collected from the literature review, and the data collected from the office of Nepal electricity authority.

**4. River system of Nepal and Streams flow trend**

Most of the surface water of Nepal drains through the four major river basins ie.Mahakali, Karnali, Gandaki/Narayani and Saptakoshi which are originated from snow layered Himalayans. They are perennial in nature. Some of the rivers are originated from mahabharat range which is major rivers in Nepal like Bagmati, kamala, Mai and Mechi Rivers. Mahakali and Mechi river mark the international border between Nepal and india (Khadka 2021). A brief description on river basins of Nepal is as:

**4.1 Mahankali River Basin**

The Mahakali River Basin is located in the western part of Nepal and Indian state of Uttarakhanda. The basin’s total catchment is approximately 15260 square kilometer, with a significant portion in Uttarakhanda (65%) and remaining area in Nepal. It encompasses diverse ecosystems, including the Terai, outer Himalayas and middle higher Trans Himalaya. The basin is drained the Kali or Sarada River, which is also known as Mahakali in Nepal. Other rivers that contribute to the basin include the Dhauliganga, Goriganga and Lodhiya. On Nepal side the Mahakali River Basin covers Darchula, Bardia, Dadeldhura and Kanchanpur Districts of far western Province. Mahakali River originates from the Milan Glacier and is crucial for water resources and hydro potential.

* 1. **Karnali River Basin**

The Karnali river basin is the largest in Nepal, covering an area of approximately 46,000 square Kilometers. It is located in the mid and far western development of Nepal. The Karnali River is a transboundary river and originates in china (Tibet) and flows through Nepal before joining the Ghaghara River in India. The basin’s elevation ranges from 163 meters in the southern lowlands to 7747meter in the higher mountains to the north. The highlands are dominated by snow /glaciers and grasslands while the lowlands feature forests and agricultural lands. Forest occupies 33% of the basin followed by agricultural land at 16%. The basin is largely rain-fed with the monsoon season. The major tributaries include the west seti, Bheri, Kawari and Tila Rivers. The basin comprises 1459 glacier and 742 glacial lakes. The Karnali basin is considered as the most vulnerable areas in Nepal to climate change. The Karnali River basin is at the headwater of the Ganga Basin.

* 1. **Narayani River Basin**

The Gandaki River Basin (GRB), a transboundary basin in the central Himalayan region, originates in the Tibetan plateau flows through Nepal, and drains into the Ganges. It is a transboundary basin, spans across international boarder including Nepal, India and a portion of china. The basin total drainage area is 46300 square kilometer with 72% in Nepal , 18% in india and 10% in china. The Gandaki river also known as Narayani in Nepal and Gandak is the main river with tributaries like Kali gandaki, Trishuli, Budhi gandaki, Marsyandi, Madi and Seti Gandaki. The GRB encompasses all of Nepal’s agro- ecological zones from the Terai plains in the south to the high mountains and Trans- Himalayan regions in the north. The basin features a wide range of elevations from 185 meters in the south to over 8000 meters in north. Where the Dhaulagiri and Annapurna peaks are located. The basin experiences significant climate variation due to its diverse topography with the contrasting climates across the different agro ecological zones. The basin is crucial for agriculture water resources, hydropower and livelihoods of millions of people in the region. The GRB is vulnerable to the impact of climate change including drought, late monsoon rains, flash floods and landslides. The basin is known for the black stone, Shaligram which is revered in Hinduism.

* 1. **Saptakoshi River Basin**

The Saptakoshi River Basin, also known as the Koshi River basin is a transboundary river system that drains the eastern third of Nepal and part of the Tibet, flowing through china, Nepal and India before joining the Ganges. It is formed by seven major tributaries giving it name Saptakoshi. The river originates in the Tibetan plateau, crosses the Himalayas, and flows through the Mahabharat range and Siwalic hills. The seven major tributaries that form the Saptakoshi are : Sunkoshi, Tamakoshi, Dudh koshi, Indrawati, Arun, and Tamor. The koshi basin is the largest basin in Nepal draining 45% of the country area. The Koshi River is known for its unstable nature and prone to devastating floods, often referred to as the sorrow of Bihar. The basin is rich in natural resources and has potential to harvest multiple uses and contributes to sustainable development(Khatiwada 2014). Figure 1 and 2 are the River basins and its systems in Nepal.



Figure 1.River Basins in Nepal



Figure 2 River systems in Nepal (Picture developed in Arc GIS)

The monsoon precipitation is the main source of stream flow in Nepal. 70 to 90% of annual flow occurring during the monsoon (April to September) and post monsoon (October to November) seasons. Although most of the peak flow occurs during July and August. Some gauge stations show late peaks during August and September. Snowmelts contributes pre monsoon streamflow (March to May) and is not significant in other months. Distributions of precipitation in Nepal are uneven and mainly governed by topography and location. Climate is mostly affected by monsoon and westerly circulation systems. The highest annual rainfall is observed in the central Gandak basin and the lowest in the western Karnali basin. Snowmelt is the primary source of pre monsoon flow in the basins above the snowline .The monsoon contributes about 80% of the annual precipitation in Nepal(Gautam and Acharya 2012).

**5. Literature Review of Hydropower Potential Estimation in Nepal**

Dr. Ramman Shrestha was the first who carried out the energy mapping on the river basins of Nepal. He found hydro potential of Nepal is of 83000 MW in 1966. The estimation were manual calculation as there were no modern technology like of today that we can estimate using satellite technology. The Artificial intelligence has made the calculation so fast with the high accuracy today. AfterShrestha Dr. Raghunath Jha carried out the energy mapping in river basin using GIS technique developing hydrological model. The mapping carried out by Dr. Jha was based on the sufficient data recorded. He carried out the study at 2011 with the financial support of Department of water energy commission (WECS) of Nepal government. In small scale various studies has been carried out as research work from different researcher considering factors affecting. The basin potential estimated by Dr. Jha looks more realistic after Dr. Shrestha. The hydro potential of basins estimated by Dr. Jha is tabulated as below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Basin | Power Potential(MW) | Dry Energy(GWH) | Wet Energy(GWH) | Total Energy(GWH) |
| Tamor Basin | 3643.5 | 2950.3 | 19694.1 | 22644.4 |
| Arun Basin | 4065.1 | 5780.2 | 27178.8 | 32959.0 |
| Dudhkoshi | 2741.5 | 2533.0 | 14872.2 | 17405.1 |
| Likhu | 607.5 | 527.8 | 3288.9 | 3826.7 |
| Tamakoshi | 2087.9 | 1611.1 | 11194.4 | 12805.4 |
| Sunkoshi | 2548.4 | 2593.9 | 13830.8 | 16424.7 |
| Indrawati | 414.4 | 481.9 | 2269.6 | 2751.5 |
| Saptakoshi(Total) | 17008.3 | 16488.2 | 922328.6 | 1088816.9 |

Table 1 power and energy estimates of Saptakoshi basin at Q40

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Basin | Power Potential(MW) | Dry Energy(GWH) | Wet Energy(GWH) | Total Energy(GWH) |
| Kaligandaki | 4338.8 | 4027.3 | 23658.5 | 27685.8 |
| Seti | 7880.0 | 698.3 | 4258.5 | 4957.1 |
| Madi | 477.5 | 460.4 | 2613.5 | 3073.9 |
| Marsyandi | 3251.8 | 2823.5 | 176881.7 | 20505.2 |
| Budhi Gandak | 3286.0 | 2747.2 | 17797.0 | 20544.2 |
| Trishuli | 5569.8 | 5365.0 | 30559.6 | 35924.6 |
| East Rapti | 96.3 | 139.0 | 543.6 | 682.5 |
| Narayani (Total) | 17800.2 | 16260.7 | 97112.8 | 113373.3 |

Table 2 Power and Energy Estimates of Narayani Basin at Q40

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Basin | Power Potential (MW) | Dry Energy(GWH) | Wet Energy(GWH) |  Total Energy(GWH) |
| Seti River | 2060.08 | 2421.04 | 11346.98 | 13768.02 |
| Karnali River | 8328.48 | 80088.29 | 45378.28 | 53386.57 |
| Budghi Ganage  | 402.79 | 545.76 | 2213.50 | 2759.26 |
| Bheri River | 4140.75 | 4678.97 | 22683.37 | 27362.34 |
| Babai River | 106.6 | 143.98 | 585.26 | 729.24 |
| Tila River | 622.48 | 859.87 | 3458.74 | 4318.61 |
| Karnali (Totai) | 15661.16 | 16657.90 | 85666.13 | 102324.03 |

Table 3.Power and Energy estimates of Karnali Basin at Q40

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Basin | Power Potential (MW) | Dry Energy(GWH) | Wet Energy(GWH) | Total Energy(GWH) |
| Chamelia River | 601.78 | 890.27 | 3351.75 | 4242.02 |
| Surnadad River | 16.84 | 25.39 | 93.04 | 118.43 |
| Mahakali River | 1643.21 | 1635.29 | 8985.16 | 10620.45 |
| Mahakali (Total)  | 2261.83 | 2550.94 | 12429.96 | 1490.90 |

Table 4. Power and Energy estimates of Mahankali Basin at Q40

From the study report the total hydropower potential estimated is 53523.33 MW. In 2023 a research group published the hydropower potential of Sunkoshi river basin estimated by using integrated GIS and SWAT hydrological modeling. According to the paper the Sunkoshi River Basin pegs hydropower potential of 371.3 MW at 40% probability of flows exceedance(Bhattarai et al. 2024). The new study carried out by water energy commission (WECS) in the year 2023 concluded that 72000 MW could be generated for four month in a year. As much as 72000 MW-73000MW can potentially be generated under Q40. The estimated potential is in the line with the commission’s 2019 study put the gross hydropower potential of Nepal at 72544 MW with the three major river basins- Koshi, Gandaki and Karnali accounting for 94% of the total gross potential. Earlier, different studies had put the different figures on Nepal‘s hydropower potential. ADB report published on 2020 on hydropower development and economic growth cites the hydropower potential as:

|  |  |
| --- | --- |
| Basins | Hydropower Potential (MW) |
| Saptakoshi River Basin | 22350 |
| Sapta Gandaki River Basin | 20650 |
| Karnali and Mahakali River Basin | 36180 |
| Southern River  | 4220 |
| Total  | 83290 |

Table 5 Major River system of Nepal and their Hydro potential (ADB report 2020)

**6. Hydropower Development Scenario in Nepal**

There are various studies that has revealed different figures on Nepal’s hydropower potential .However 83000 MW is considered as approximated theoretical power out of which 43000 MW is economically feasible. After the establishment of first hydropower plant Pharping (500KW) at 1911, second hydropower plant was established in Sundarijal at 1996 of capacity 640 KW(Anon n.d.). The development of hydropower plant was institutionalized after the initiation of development planning process. The first five year plan was from 1956 to 1961 that had target to develop 20 MW. Till 1962 the Electricity Department of HMG had full responsibility to develop hydropower plant and was responsible for generation, transmission and distribution of the electricity. In 1962 Nepal electricity corporation NEC was established and later in 1985 all department of electricity were merged and Nepal Electricity Authority NEA was formed that has been responsible for the management, planning and development of all hydropower development in the country. In 2001 NEA made its acting policy that motivated to the private developer from public level. Today independent power producers IPPs have been ongoing institutional innovations in power sectors. The decadal hydropower development status of Nepal is tabulated below. Due to the completion of the Kaligadaki A of 144 MW the power generation in the decade 2001 to 2010 increased significantly. In 2011 to 2020 the power generation is increased more in which the production of upper Tamakoshi is not added as it was not officially inaugurated. Later Upper Tamakoshi started power production which is the largest capacity in Nepal. With the addition of this generation total installed capacity of Nepal became 1852 MW(Bhatt and Joshi 2024). Up to 2025 the total installed capacity is 3255.806MW contributed by hydropower. Figure 3 and figure 4 are the decade wise power generation and cumulative power generation up to the year 2021.

Figure 3.Decade wise Hydropower Development in Nepal

Figure 4 Decade wise Cumulative Hydropower development in Nepal

**7. Hydropower Development plan and Policy**

By 2002 to 2007 government made a plan to electrify rural areas to enhance the economic standard of rural people by the expansion of hydropower development in a sustainable and environmental friendly manner at low tariff to improve the living standard of people. Its aim was also to help in agriculture production through proper irrigation management using electricity in Terai region. Water resources strategy 2002 was formulated with strategic plan of cost effective hydropower development in sustainable manner. The short term (5 years), medium term (15 years) and long term (25 years) strategies are prescribed. The strategic plan and policy are made to promote private sector to invest in hydropower development. International investors are encouraged to invest in hydropower development sector by providing well facilities and security. Nepal has adopted the BOOT policy in hydropower development with the neighboring countries India and China. At the end of 2035 government has made a plan to develop hydropower plant of installed capacity 28000 MW.

**8. Challenges for Hydropower Development in Nepal**

More than 80% people are living in rural areas of Nepal where conventional sources of energy like fuel and wood are more significant. These sources of energy are constrained from environmental impact consideration. Forests are depleting due to its consumptions for energy. In contrast the country’s enormous hydropower potential is virtually untapped to meet its energy needs. The rapid and large increase in population resulting in the huge loss of per capita land and poor state of development in other renewable sources of energy have left Nepal no space except to rely on hydropower Development. To replace the use of traditional/conventional energy resources large hydropower plant is to be constructed which is more capital intensive. There are numerous challenges for hydropower development in Nepal. Major challenges are described as:

* 1. **Financial Constraint and investment**

Hydropower project require substantial upfront investment making them capital intensive and posing a challenge for securing financing from both domestic and international sources. Political instability and currency risk can deter investors and make it difficult to secure long term financing. Inconsistent policy framework, bureaucratic delays and regulatory hurdles delays long term financing. Risk mitigation strategies are poor. In the absence of clear risk mitigation policy to the private and foreign investors can hinders the development.

 **8.2 Technical Challenges**

Nepal’s mountainous terrain and fragile geology present significant technical challenges for civil construction and project design. The steep slopes and rugged terrain are susceptible to landslides and slope failures requiring careful geotechnical engineering. Diverse weather and climatic condition has impact on the hydropower such as flood, land slide due to extreme weather events and glacial lake outburst that disrupts hydropower operation. Sedimentation in river is problematic. High concentrations of sediment deplete the reservoir life and reduce the efficiency and life of electromechanical component especially for turbine.

* 1. **Environmental and Social Concern**

The degradation in environmental condition has global impact. Extreme rainfall, long drought conditions has severe impact on hydropower project. Extreme flood in river damage the infrastructures and water deficit due to drought leads to the project with poor power generation and load shedding are compulsory to manage the power demand. Social issues like displacement of communities, loss of livelihoods and potential conflicts over water resources also important social considerations.

* 1. **Policy and Regulatory Issues**

Political instability, frequent change in government can hinder project development. Inadequate policy interventions can deter investment. High level personal interest on investment makes complication to the project investment and development.

* 1. **Infrastructure Limitations**

Lack of access road transportation and transmission network can increases the project cost and make it difficult to evacuate power to load center. Inaccessible market for electricity can also make hinder the viability of hydropower projects.

* 1. **Political and institutional challenges**

Political instability can create an uncertain environment for long term investments in hydropower projects. Weak institutional capacity to manage hydropower project and enforce regulation can also be a challenge to hydropower development. Local people’s behavior, their disagreement and agitations are big problems for construction work of hydropower projects in Nepal.

**9. Ways of Overcoming Challenges/ Barriers to Hydropower Development**

Despite all above problems/challenges mentioned above there are lot of opportunities if we develop hydro power in substantial number. For this it is important to focus on creating conducive environment for developers and investors. Political turmoil has long been blamed a major barrier for hydropower development. Political Leader must be able to give a stable government of full majority for full tenure of five years. Political system should be on track at first. Likewise in order to address the issue raised by local people hydropower project should be constructed by involving the local people in different ways. A coordination committee can work with investors. The committee also works towards simplifying administrative procedures. Requirement of huge capital investment and financing can be addressed with the concept of project financing and increasing interest of foreign investors. Government should make the opportunities for international investors to come and feel the sense of optimism. For this the security and risk mitigations strategies should be made in policy level. A smart institutional set up can resolve all intervenes that hinders the hydropower development and overcomes the problems.

**10. Conclusion**

Nepal is rich in water resources and has enormous potential that can be tapped for hydropower development which is predominant energy sources for Nepal. The hydro potential estimations of river basins are carried out by different researcher personally and at an institutional level earlier. There are different figures of hydro potential of Nepal. However the total potential is considered approximately 83000 MW out of which 43000 MW is economically feasible. For economic growth of nation hydropower is a key that make the nation brighter, improves the living standard of people by eliminating the poverty as it can create large number of job employment during construction and operation stage. It is inflation proof, environmentally free, technology based plant that offers reliable and flexible operations works at high efficiency above 80% making the most reliable energy conversion technology. However the hydropower development in Nepal is very sluggish. Only after 1990 its development seems in some encouraging pace. At present the total installed capacity of the country is 3255.806 MW which is about 7.5 % of the economically feasible hydro potential. Nepal electricity Authority is playing major role for power production, transmission and distribution. Some private organizations are engaged too. Most of the hydropower plants are ROR type and few are PROR and only one is reservoir type i.e. Kulekhani hydropower plant used for peak time period. Still Nepal is importing energy from neighboring country India in substantial quantity to meet the demand and load shedding is reduced. Replacement of all fossil fuel and end of the energy import will be achieved only after the hydropower development in adequate quantity so that we can export the energy in international market that helps national economic budget significantly. The hydropower developments in Nepal are challenging itself. Political instability, economic conditions of nation, geological condition, environmental condition, and weak policy is major hindrance for hydropower development. Strategic action and dedication of the government can bring the nation in next level of socioeconomic transformation through hydropower energy sector.

**DISCLAIMER (ARTIFICIAL INTELLIGENC)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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