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Research Article

IMPACT OF FLOW VARIATION ON HYDROPOWER PROJECTS IN BUDHIGANDAKI RIVER BASIN OF NEPAL

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ABSTRACT

Daily flow data from 1964 to 2015 of Budhigandaki River at Arughat were analyzed to assess the impact of flow variation at different time scales to the run of the river (RoR) type of hydropower projects. The data show very high inter-annual variation in daily, monthly and seasonal flows. The long term annual average flow at Arughat was 160 m^3/s and varies from 120 to 210 m^3/s. The long-term averages of loss in flow for both dry and wet seasons based on daily flows for three design discharges (Q_{90}, Q_{60} and Q_{40}) were found to be respectively -0.72, -1.76 and -1.54 m^3/s for dry season and 0.0, -0.27 and -2.26 m^3/s for wet season. Although long-term average loss is small, uncertainty increases with the increase in design discharge. The long-term dry season power loss is about 3 % for the RoR projects of the basin however, its annual variation is large. There is a probability of losing the quantum of energy generation by nearly 40% in some years and gaining by about 30 % in some other years in dry season. The impact of flow variation on power production was negative in both dry and wet seasons for RoR projects of Budhigandaki basin. This study concludes that uncertainty arising from daily flow variation should be assessed while estimating energy generation in hydropower projects. Intra-annual flow variation is, thus, to be taken into consideration while calculating the power generated by the RoR plants; and it should be reflected in power purchase agreement.

Keywords: Design discharges, Energy, Fractional difference, Monthly flows, Runoff the river

INTRODUCTION

Nepal is one of the 47 least developed countries in the world at present (United Nations, 2020). The government of Nepal has put priority on the hydropower generation as the backbone of economic development in its endeavor to advance from its Least Developed Country status to Developing Country by 2022 and to reach to the middle income country level by 2030 has put its endeavor to graduate from its Least Developed Country status to Developing Country in 2022 and to upgrade middle income country level by 2030 (NPC, 2020). In order to realize these goals, Nepal has to achieve high growth in all sectors of economic development.

Electricity is one of the key drivers among these factors for overall development of the country. Number of past studies showed that economic development of a country was strongly correlated with the access of electricity and its consumption (Aslan, 2014; Devkota, 2020; Kamaludin, 2013; Lorde *et al.*, 2010; Stern *et al.*, 2019). It is because electricity brings higher agricultural productivity through powering irrigation, food and seed preservations, and contributes to effective running of industrial and service sectors. Similarly, it enhances productivity of education efforts and health services, and helps to improve clean water supply and sanitation. It also helps to create opportunities in the application of new technologies and ease access to information (Satpathy, 2015). Previous empirical studies have revealed the bidirectional causality between economic growth and electricity consumption, i.e., greater electricity consumption brings about higher economic growth and higher economic growth creates demands for greater electricity consumption (Ogundipe & Apata, 2013). However, this relationship was not linear and depends on the stages of development (Hirsh & Koomey, 2015). Some of the other studies found unidirectional causality between economic growth and electricity consumption, i.e., electricity consumption leads to economic growth or vice versa, depending on the stage of development (Bayar & Özel, 2014; Zhang *et al.*, 2017).

Per capita energy consumption in Nepal is low, i.e., 434 kg oil equivalent for the year 2014 when the world average was 1,922 kg oil equivalent (World Bank, 2020). More than 77 % of the energy consumed comes from traditional and inefficient sources, e.g., wood, cow dung and agricultural residue, and about 17 % from petroleum product and coal. The share of electricity in total energy use is only 3.4 % (WECS, 2013). The per capita electricity consumption of Nepal was 146 KWh in 2014, less than 5 % of the world average of 3,132 KWh. Nepal's electricity consumption is less than 4 % and 18 % compared to China and India, respectively (World Bank, 2020).

Recognizing the importance of energy for socio-economic development, the Government of Nepal plans to increase per capita energy consumption in its finer form, i.e., electricity. Nepal has set hydropower development as a priority (WECS, 2013) using its annual available water of 225 km^3 (WECS, 2005) and its unique topography, vast abundance of rivers and streams for hydropower development. Hydropower development can contribute to national development through reduced imports of fossil fuels, expand the area of land under irrigation and diversify the economy in which poor households are more integrated in the economy. Increase in greater electricity generation is expected to promote industrialization, generate foreign currency reserves through export of electricity to reduce Nepal's trade deficit (Alam et al., 2017; MoWR, 2009; Thapa & Basnett, 2015).

Hydropower development in Nepal started in 1911 with a 500 KW plant in Pharping near Kathmandu (Dixit, 2002). At present, total hydropower production in Nepal is around 1,278 MW (NEA, 2020), of which storage plant produces 104 MW (DOED, 2020). After the People's Movement of 2006 that transformed the country's political structure into federal republic, the Government of Nepal (GoN) has taken new policy and project level initiatives for hydropower development. A task force was formed in December 2008 to formulate programs for developing 10,000 MW in 10 years for overcoming the energy crisis (MoWR, 2009).

This task force has provided the list of storage and run-off the river projects with a time-line for development. Similarly, GoN has also proposed a plan of development of 25,000 MW in 20 years in 2009 (MoWR, 2010). The government has announced plans for developing 3,000 MW of hydropower in three years, 5,000 in five years and 15,000 MW in ten years, raising per capita energy consumption of 245 KWh to 700 KWh in 2022 (NEA, 2019). It includes both storage projects: (16, Total Capacity: 9,000 MW) and peaking run-of the river (PRoR) projects (16, Total Capacity: 6,000 MW) (MoWR, 2010).

The above shows a shift in the government's priority to hydropower development and focus on storage projects. This shift is useful because a storage project addresses the seasonal variation of river hydrology by storing water during high flow period (monsoon season) for power generation during lean flow period when the demand of electricity is higher in Nepal. Further they can act as a multipurpose water resources projects by having provisions for water supplies for drinking, irrigation and industrial uses; recreation; navigation and flood control. To have year-round irrigation mainly in the Terai region (Indo-Gangetic plain), the irrigation policy of Nepal foresees the need of reservoir projects. Reservoir projects are not only beneficial to Nepal but also to India in terms of irrigation and flood control (Pun, 2017; Upadhyay & Gaudel, 2018). Although stored water of a reservoir can be used for various purposes, in Nepal they are meant for hydropower generation.

Production of electricity (hydropower) is a function of flow and head. The capacity of a power plant depends on the river discharge in RoR types of projects. In a storage hydropower plant, the operation is based on the reservoir volume, inflow characteristics and purpose of its use, such as if a plant is operated for generating electricity to meet the daily demand or to meet peak hours' demand (Liu *et al.*, 2016). Whatever the cases, river hydrology plays an important role in hydropower generation.

Rivers supply water for drinking, industries, irrigation, hydropower generation, transport and sustaining ecosystems services to the people in downstream (Akhtar *et al.*, 2008; Miller *et al.*, 2012; Molden *et al.*, 2011; Viviroli *et al.*, 2011), however climate change is impacting river hydrology (Devkota & Gyawali, 2015; Pandey *et al.*, 2020). Variation in flow in rivers is high (BGHEP, 2015; DHM, 2018) and the impact of variation in meeting daily, monthly or seasonal water requirements is seldom studied. This understanding of river hydrology is important from a technical point of view of generation and operation of hydropower plants and from an investment portfolio as investment is substantial. The knowledge of the magnitude of such variations is crucial to the private investors because the developer has to pay penalty if the project cannot supply the agreed amount of energy to NEA (NEA, 2017). In 2020, private producers contribute almost 55 % of power to Nepal's integrated power system (NEA: 582 MW, IPPs: 696 MW) (NEA, 2020).

Energy generation by a hydropower project is calculated on the basis of the long-term monthly average flow (Q_{LTMA}) of the river (DOED, 2018). However, the flow of a given month of a particular year varies significantly from Q_{LTMA}. Such variations have implications on power production of the plant but the developer has to pay penalty if the project cannot supply the agreed amount of energy to NEA (NEA, 2017). The main objective of this study was to assess the impact of flow variation in the Budhigandaki river basin on power production of RoR type of hydropower projects. The specific objectives of the study were (i) to estimate the flow available for power production of each month based on long term monthly flow and design discharge, and (ii) to calculate the change in power production due to monthly variation in flows.

MATERIALS AND METHODS

Study area

The location map of the Budhigandaki river basin is given in Fig. 1. It is a part of the Narayani river basin, bordered in the north by the Tibetan Plateau, in the south and east by the Trishuli river basin, and in the west by the Marsyangdi river basin. The flow gauging station of this basin is located at Arughat (#445) of which the catchment area is 3,863 km^2. The total catchment area at the confluence of the river with the Trishuli river is 4,988 km^2 (Marahatta *et al.*, 2021).

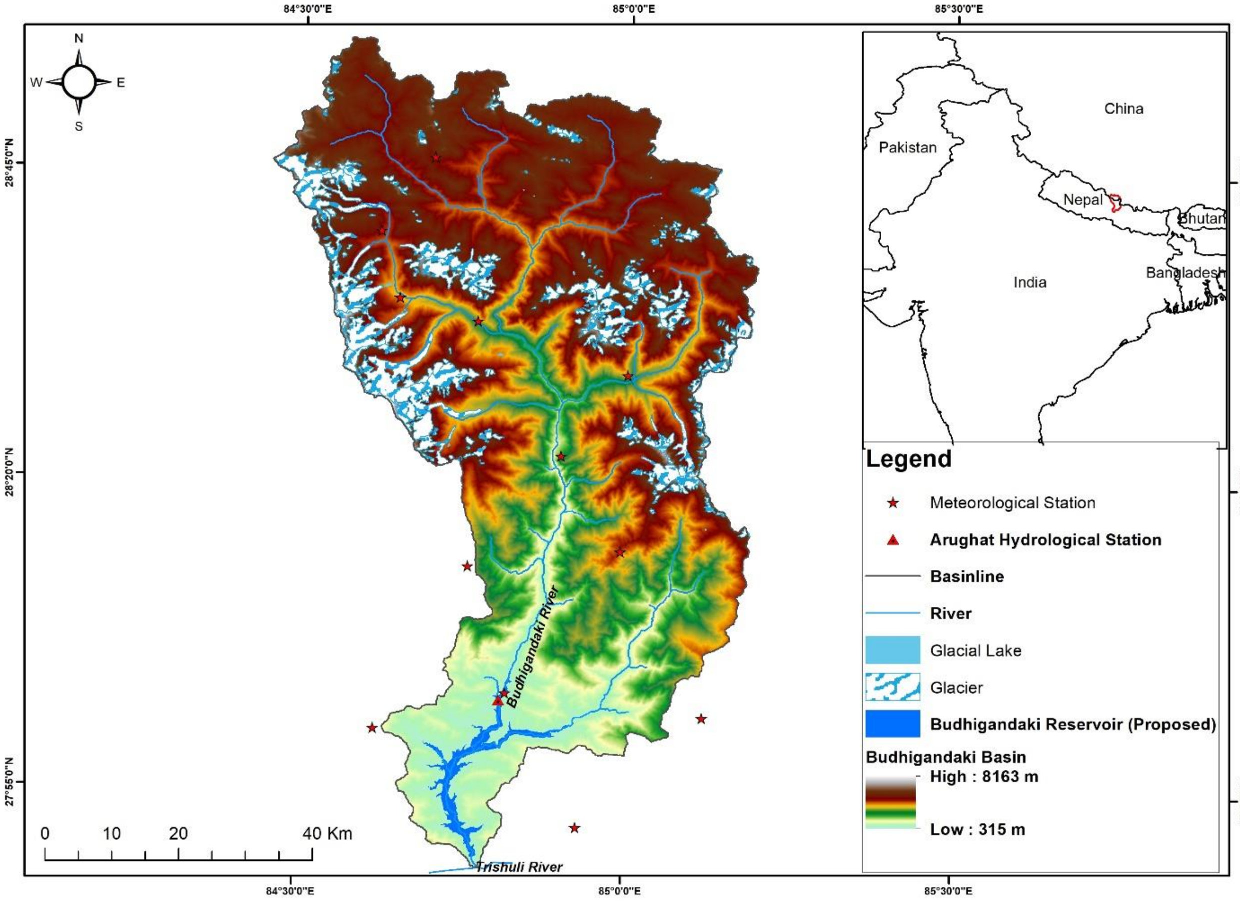

Fig. 1. Location map of Budhigandaki basin

The database of the Department of Electricity Development (http://www.doed.gov.np) shows that 35 hydropower projects (total capacity ~ 3000 MW) are ranging from 0.5 to 1200 MW at various stages of development in the Budhigandaki basin. Budhigandaki storage hydro-electric project (1200 MW) is one proposed.

Theoretical background; the impact of flow variation in power generation

The power that can be generated in a hydroelectric power plant is given as in equation (1)

$$P = \eta \gamma Q H \tag{1}$$

Where, P represents the power (KW), η is the efficiency of the plant, γ is the unit weight of water (9.8 KN/m^3), Q flows through the turbine (m^3/s), and H is the net head (m).

A power plant is either storage or the run of the river (RoR) type depending on the availability of storage reservoir in a river and the generation system. The RoR type of project uses the instantaneous flow of the river which governs the capacity of the RoR plant. In Nepal, the RoR plants are generally designed for Q_{40} (Q_x: the flow having x percent exceedance probability) using historic daily flow data (DOED, 2018). Energy generated by such plants is estimated based on the long-term monthly average flows. Department of Electricity Development, of the Government of Nepal, grants survey and generation license to the private/public developers (DOED, 2018) based on the calculated energy. A power purchase agreement (PPA) is signed between the developers and the Nepal Electricity Authority (NEA), the sole buyer of electric energy in the country. The price of electricity depends on the season of the year (dry or wet). It is more for dry season energy than for wet one. If a producer cannot supply a committed amount of electricity to NEA in the dry period of a given year, a penalty is imposed on the producer. The flow variation in the river (daily, monthly, annual) affects the power generation by a power plant affecting the price. The variation besides affecting power planning for NEA brings in uncertainty for the producers in terms of revenue and the danger of a penalty.

Using equation (1), the change in power (*dP*) generated can be expressed as equation (2). In RoR projects, change in head, *dH* of equation (2) is negligible. Thus, the change in power generation by RoR plants for a given day or month is dependent on the change in the flow (*dQ*) of the river entering into the system as given by equation (3).

$$dP = \eta\gamma[QdH + HdQ] \tag{2}$$

$$dP = \eta\gamma HdQ \tag{3}$$

Possible case of flow and implication of flow variation in RoR project

The flow in a river at a particular month can be divided into 6 types with respect to the long-term mean monthly (Q_{LTMA}) and design flows (Q_{design}) as given in Table 1. These flows are clustered into two cases. Case 1 can be taken as a flow in the wet season (June-November) in which Q_{LTMA} is, generally, higher than the design discharge. Case 2 resembles dry season (December -May) flow in which season Q_{LTMA} is generally lower than Q_{design}. The flow at a particular day can be higher or lower than both Q_{design} and Q_{LTMA} or in between them. Such deviation of flow ($\pm dQ$)) from Q_{LTMA} can be advantageous, disadvantageous or neutral for the project as shown in Table 1.

Daily flow data at Arughat gauging station (#445) from January 1, 1964 to December 31, 2015 were collected from the Department of Hydrology and Meteorology (DHM) of Nepal (DHM, 2018). An exceptionally high flood of July 5, 1968 washed away the gauging station (Shankar, 1969), and DHM could not collect the data for the remaining days of that year. The flow data of 1968 was, therefore, not included in the analysis. The methodology followed to assess the impact of flow variation on power production is as follows:

Table 1. The implication of flow variation for a run of the river power plant

Case/Flow	Condition	Loss/gain amount inflow (***dQ***)	Power loss or gain to design value	Remarks Spill: resource loss
Case 1: Q1-1	$Q > Q_{LTMA}$ & $Q > Q_{design}$	0	No	Water Spill ($Q - Q_{design}$)
Case 1: Q1-2	$Q < Q_{LTMA}$ & $Q > Q_{design}$	0	No	Water Spill ($Q - Q_{design}$)
Case 1: Q1-3	$Q < Q_{LTMA}$ & $Q < Q_{design}$	$Q-Q_{design}$	Loss (-)	No Spill
Case 2: Q2-1	$Q > Q_{LTMA}$ & $Q > Q_{design}$	$Q_{design}-Q_{LTMA}$	Gain (+)	Water Spill ($Q - Q_{design}$)
Case 2: Q2-2	$Q > Q_{LTMA}$ & $Q < Q_{design}$	$Q-Q_{LTMA}$	Gain (+)	No Spill
Case 2: 2-3	$Q < Q_{LTMA}$ & $Q < Q_{design}$	$Q-Q_{LTMA}$	Loss (-)	No Spill

Annual and monthly flow estimation: The annual average flow, monthly average flow for each year, and long-term monthly flows were calculated from daily data.

Seasonal flow estimation: Average flows for the monsoon season (June-September), post-monsoon season (October and November), winter season (December-February), Pre-monsoon season (March-May) flows, and dry season (December-May) and wet season (June-November) flows for each year from monthly flows were calculated.

Design discharge estimation: Three design discharges viz. Q_{90}, Q_{60}, and Q_{40} were estimated from the flow duration curve.

Estimation of change in available flow (dQ) for power production: Based on long-term mean monthly flow (Q_{LTMA}) and design flows (Q_x) as discussed in the theoretical section, the change in available flow for power production in a particular month was calculated.

Estimation of change in power production (dP): Change in power production for each month was calculated using equation (3).

RESULTS AND DISCUSSION

Annual flow characteristics

Annual average, an average of the upper 20 % and lower 20 % of the flows, and their mean values are plotted in Fig. 2 to examine if there is any trend in those flows. A few ups and downs can, noticeably, be seen in an interval of certain years, mainly on high and average flow. However, they were found decreasing since 2000 for about 15 years.

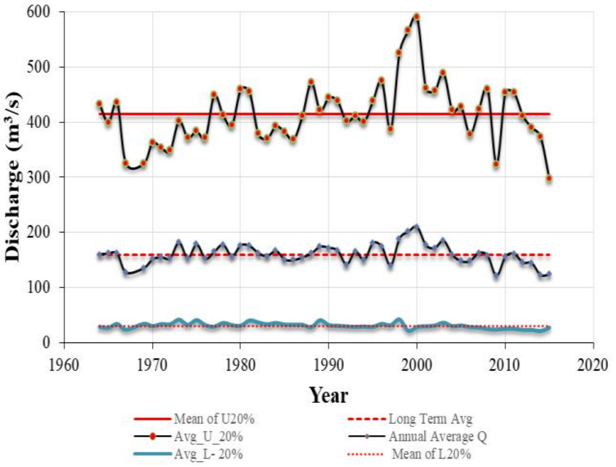

Fig. 2. Annual average, mean of upper 20 % and lower 20 % flow at Arughat

To cross-check if the observed flow data of this period at Arughat are correct, the annual average flow of this station was plotted along with annual total rainfall at Arughat rain-gauge station and annual average flow observed at nearby gauging station (Betrawati of Trishuli river) in Fig. 3. Similar variability and decreasing trend after the year 2000 both inflows and rainfall can be seen in this figure. It depicts that the observed flow data used in the analysis can be safely said to be reliable and the decrease in flow after 2000 is mainly attributed to rainfall decrease in this period. However, it is too early to say that the flow at Arughat station has started to decrease as a result of climate change.

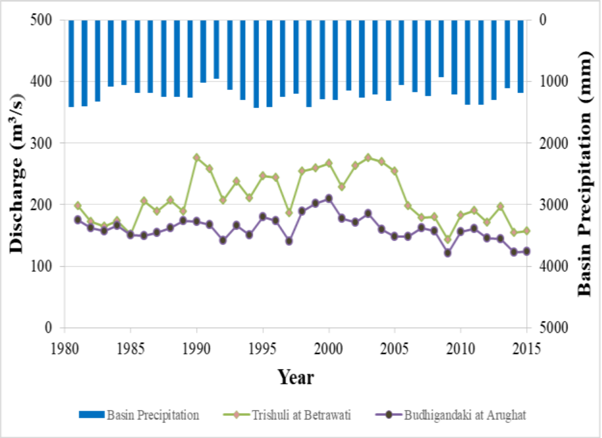

Fig. 3. Comparison of annual average flow at Arughat with the rainfall and flow at nearby Gauging station, Betrawati

Long term average of annual, upper 20 %, and lower 20 % flows are given in Table 2. It shows that the long-term average flow at Arughat was 160 m^3/s with an annual variation between 121 and 210 m^3/s. Similarly, long-term averages of the highest 20 % and lowest 20 % flows were respectively 416 and 31 m^3/s. Data showed that the annual variation was more in higher flows (298-591 m^3/s) and less for low flows (21-42 m^3/s). The fractional difference between upper 20 % and lower 20 % flows is about 14 for the study period. However, in some years this fractional difference was quite above 20 (26 in 1999 and 21 in 2000). It showed a great variation between high and low flows that occur in this river.

Table 2. Flow characteristics of Budhigandaki River at Arughat

Particulars	No. of data	Average flow (m^3/s)	Standard deviation (m^3/s)	Minimum flow (m^3/s)	Maximum flow (m^3/s)
Annual flow	51	160	18	121	210
Monthly flow	612	160	148	20	597
Daily flow	18,627	160	157	18	1,457
Upper 20 %	51	416	57	298	591
Lower 20 %	51	31	5	21	42

Daily and monthly flow characteristics

Data presented in Table 2 show that the observed daily flow varied from 18 m^3/s to 1,457 m^3/s whereas monthly averages vary from 20 to 597 m^3/s in the study period (1964-2015). It shows that the fractional difference between maximum to minimum of daily and monthly flows were 80 and 30 respectively. A higher fractional difference of maximum to minimum flow with decreasing period reveals the need for a storage facility in this river to utilize its water to the maximum extent possible, in the present case for hydropower generation. At the same time, it indicates high uncertainty on the availability of water for the run of the river schemes proposed in this basin.

Seasonal variation

In Nepal southwest monsoon becomes active from June to September when rainfall is heavy. The river flow is, consequently, high during these months (monsoon season). In the next two months, October and November (post-monsoon season), the flow is less than monsoon season but substantially high. The months of December, January, and February are called the winter season in which river flow is low. During the remaining three months (March, April, and May) called pre-monsoon season temperature starts to rise and the snow starts to melt. The flow in Nepalese rivers during monsoon and post-monsoon (considered wet) seasons is high and enough to meet various needs including hydropower generation.

The remaining two seasons categorized as dry season (NEA, 2019) flow in the rivers is not sufficient to meet the required water demand, for hydropower generation. The long-term average, minimum and maximum flows calculated for these seasons at the Arughat Gauging station are depicted in Fig. 4. The flow during monsoon, post-monsoon, winter, and pre-monsoon seasons were respectively 72 %, 12 %, 6 %, and 10 % of the total annual flow. These figures show the six months of the dry season has only 16 % of the annual total whereas the wet season has as high as 84 % of the total flow. The fractional difference between seasonal maximum to minimum flows lies between 2 and 3 (Fig. 4).

Monthly variation

Month-wise long-term average flows and their variation are given in Table 3. In hydropower projects, these long-term monthly average flows are used to calculate the energy generation for the RoR plants. We can see from Table 3 that the highest value of long-term monthly average flow occurs in August (436 m^3/s) and the lowest (30 m^3/s) in February.

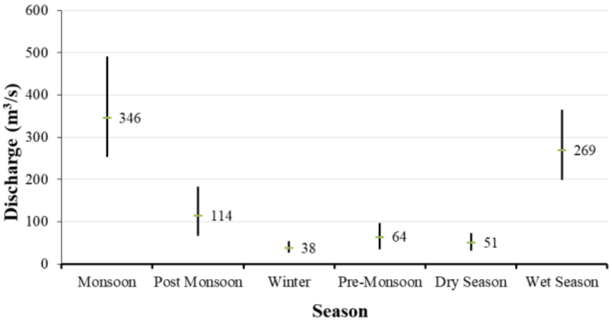

Fig. 4. Seasonal variation of flow at Arughat station

The intra-month variation in those 51 years' data is high, i.e., more than three times in four months (April, May, June, and October) and not that much high (less than two) in August while in other months it is in between 2 and 3. The number of months in which flow was greater than the long-term average is also given in Table 3. Except for February, in all other months, these numbers were less than 50 %. In some months (April, September, and October) it was around 40-45 %. It means there is a high probability of having less energy generation than the calculated ones based on long-term monthly average flows. The consequence has a revenue implication for the project. It clearly shows that the chances of penalty to be paid by the developers are more likely as stipulated in NEA (NEA, 2017). To be fair to developers, this issue of uncertainty needs to be considered while devising PPA.

Table 3. Long term monthly flow at Arughat

Month	Data No.	Average flow (m^3/s)	Stdev (m^3/s)	Min flow (m^3/s)	Max flow (m^3/s)	No. of months with Q> Q_{avg}
Jan	51	35.1	5.4	23.9	48.3	25
Feb	51	**29.9**	4.8	21.2	43.0	24
Mar	51	34.4	7.3	20.2	53.2	26
Apr	51	56.2	14.9	27.2	96.7	22
May	51	101.6	30.1	50.0	189.3	25
Jun	51	221.8	54.3	111.8	390.0	24
Jul	51	408.6	58.6	290.6	570.1	24
Aug	51	**436.2**	65.3	330.2	597.2	25
Sep	51	313.6	58.4	207.9	459.8	20
Oct	51	150.0	34.8	85.8	257.8	22
Nov	51	76.8	16.7	47.5	114.3	23
Dec	51	47.7	8.7	30.7	74.3	25

Design flows

The Run of the River Power Plants can be designed for any design flow. However, it is, generally, designed for Q_{40} (40 % of the days in a year, the flow in the river is more than the design flow value) in Nepal (DOED, 2018). Flow duration curve (FDC) constructed from historical daily flow data is utilized to estimate the design flow which is given in Fig. 5 for the Arughat station. The analysis shows that the Q_{10}, Q_{40}, Q_{50}, Q_{60}, and Q_{90} for Arughat were 413, 125, 84, 59, and 30 m^3/s, respectively.

However, values of Q_{40} (design flow for RoR), Q_{60} (an intermediate value), and Q_{90} (sustained flow) were used to see the impact of flow variation on power generation hereunder.

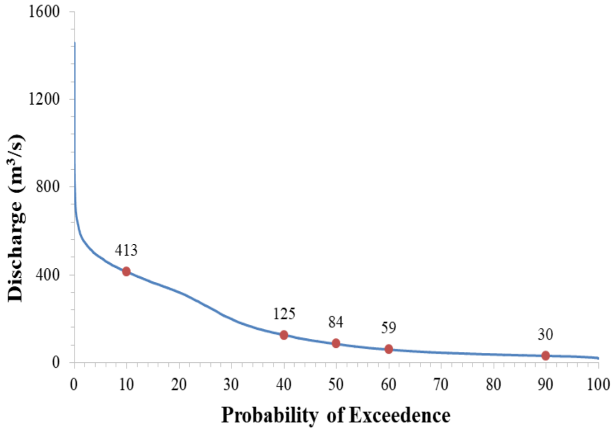

Fig. 5. Flow duration curve of Arughat Gauging site

Impact of flow variation

As stated above, energy calculation of the power plant was made, and PPA was done with NEA by power producer based on the long-term monthly average flows (Q_{LTMA}) and the designed flow (Qx where x represents probability of exceedance of flow, i.e., flow equal or greater the x percentage of days of the year). However, inter-annual variation in daily flow in a particular month can be more than the considered Q_{LTMA} in some years and less in other years. If the flow on a particular day is more than the design flow, it will spill. On the other hand, if it is less than the design flow, less power will be produced. The PPA rate was different for two seasons, i.e., Rs 8.40 and 4.50 per KWh for the dry season and wet season respectively for RoR Project (NEA, 2019). The impact assessment for RoR plants was, therefore, made separately for the dry and wet seasons. Three design flows were considered in the analysis: Q_{90} (sustained flow), Q_{60} (intermediate value), and Q_{40} (popular design Q for power plants).

Impact of flow variation on RoR projects

The long-term averages of loss/gain inflow for both dry and wet seasons for three design flows (Q_{90}, Q_{60}, and Q_{40}) are given in Fig. 6. They were respectively -0.72, -1.76, and -1.54 m^3/s for the dry season, and 0.0, -0.27, and -2.26 m^3/s for the wet season based on daily flow analysis. These results show that the impact of flow variation was found to be negative, i.e., there will be less flow available for power generation in RoR projects in all cases except in the wet season for the Q_{90} scenario where there is neither loss nor gain. This result unveiled the necessity of energy calculation based on daily flow while assessing the full extent of uncertainty in energy generation by a RoR project. Since Q_{90} flow is quite small (30.1 m^3/s) and all daily flows of the wet season exceed this value, no loss situation occured for this case. In other cases, daily flows were either more than both Q_x and Q_{LTMA} of the considered month or less than these flows or in between these two values. It has resulted in either flow gains in some years and lost in other years with a net loss inflow. In Fig. 6, the range in which the variation in loss or gain inflow values for these cases occurs is also shown. From this figure, we can see that the extent is more on the losing side than on the gain side in all cases. The range is becoming wider for higher Q_x. Although long-term average loss is small, uncertainty increases with the increase in Q_x. For example, the loss in flow for Q_{90} in one year reaches -4.37 but for Q_{40} it is -18.93 m^3/s while the gains for these scenarios are 0.02 and 16.0 m^3/s, respectively, for Q_{90} and Q_{40}. This is happening in the dry season. Similarly, the extent of gain and loss of flow in wet seasons for design discharge as Q_{40} were respectively 12.5 and 5.6 m^3/s.

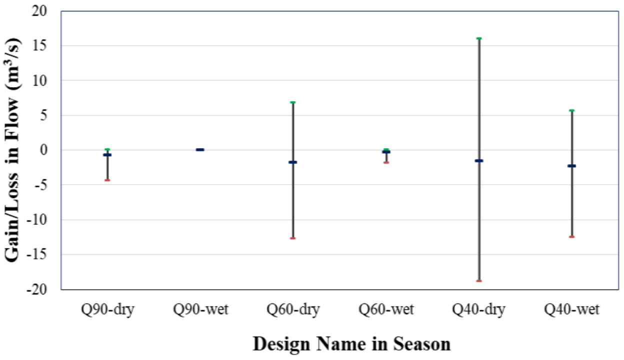

Fig. 6. Long term average loss of flow due to flow variation in the river, Q_x-dry: considered design flow is Q_x and season is dry, Q_x-wet: considered design flow is Q_x and season is wet (x: 90, 60, 40)

Out of 51 years, the number of years in which the flow less than the anticipated values (Q_{LTMA} for dry season and Q_{design} for wet season) is depicted in Fig. 7. From the figure, we can see that the number of years in which the flow is less than 50% in all cases except the Q_{90}-wet season. The numbers of years in which both wet and dry seasons lose the flow were respectively 27 and 24 for Q_{60} and Q_{40}. The above figures clearly show that the current basis of PPA is not in the favor of the energy producer as the probability of losing years is more likely than gaining years. As per (DOED, 2020) the application for survey and construction licenses is more than 15,000 MW and 7,000 MW respectively. Even now the production of hydropower by private developers is almost 10% more than that of the government (NEA, 2020). If the private developers are not getting a profit, their contribution to the hydropower sector will go down and the aspiration of the Government of Nepal of developing hydropower will be jeopardized.

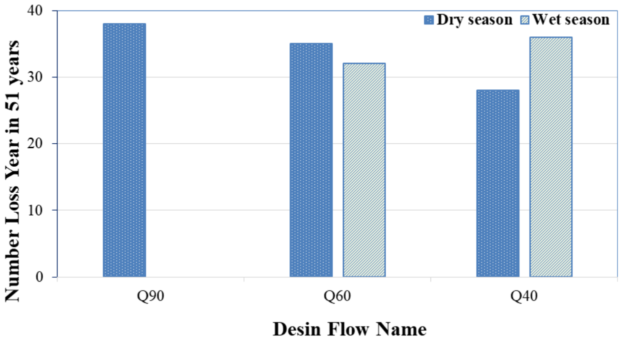

Fig. 7. Number of loss years in different scenarios, Q_x: considered design flow is Q_x (x: 90, 60, 40)

Impact of flow variation on power production of RoR projects

As per equation (3), the gain or loss of flow due to flow variation in a river has a direct impact on power generation i.e., y % reduction or augmentation inflow results in the y % loss or gain in power generation in RoR projects. During the dry season the daily flow in the river governs the power generation as it is generally less than design discharge, and in wet season design discharge governs power generation as it is less than the daily flow. The flow was less than the anticipated long-term monthly flow by 1.54 m^3/s (~3 %) for the dry season while it was 2.26 m^3/s (~ 2 %) for design flow for the wet season. It implies that the expected value of the dry season power loss is about 3 % and 2 % for the RoR projects proposed in the Budhigandaki basin. However, the annual variation in power production is quite high. The graph shows that the probability of losing and gaining power generation in a year are respectively 40 % and 30 % in the dry season (Fig. 8). Similarly, the probability of losing and gaining in power generation was about 10 % and 5 % respectively in the wet season.

Fig. 8 also depicts that there is a probability of producing less power than the estimated one for 11 consecutive years (> 20 %) in the dry season and 27 consecutive years (>50 %) for the wet season. It is noted here that the production will be less than the estimated for 11 consecutive years in both seasons. It indicates that the revenue generated by the developers of RoR projects in the Budhigandaki basin is likely to be less than the calculated one. The flow characteristics of other rivers of Nepal are also somewhat similar to that of the Bhudhigandaki River if we look at the data of DHM (2018). It implies that the private power producer is more likely to suffer if the current system of analysis continues.

Electricity helps to increase the productivity of all three major sectors of productions (agriculture, industry, and service sectors). It enhances the quality of education, health services and access to information, etc. (Satpathy, 2015) Economic development of a country was, thus, positively and strongly correlated with access to electricity and its consumption (Aslan, 2014; Kamaludin, 2013; Stern *et al.*, 2019). Hydropower is a clean, renewable, and environmentally friendly source of energy that helps to reduce greenhouse gas production and consequent climate change. The CO_2 emissions per GWh are 3-4 tonnes for run-of-the-river hydropower, and 10-33 tonnes for hydropower with a reservoir (WEC, 2004). These values are about 100 times less than the emissions from traditional thermal power (Berga, 2016).

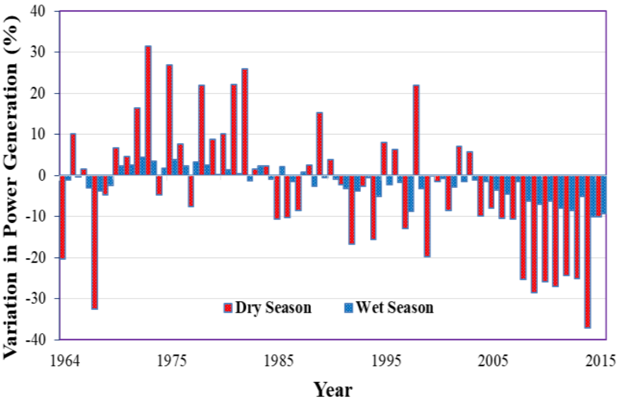

Fig. 8. Impact of flow loss/gain in power production from RoR plants in Budhigandaki basin

The demand for LPG gas is rapidly increasing as an alternative option for kerosene in the urban area and firewood in the rural area of Nepal. However, the high import of LPG is challenging for the sustainability and energy security of the country. In the Medium Growth Scenario, substituting LPG with electricity could save the country from \$21.8 million (2016) to \$70.8 million (2035) each year (Bhandari & Pandit, 2018). It all shows that Nepal should prioritize hydropower development for its prosperity as envisioned in its constitution (GoN, 2015) and private power producers are to be encouraged in this national endeavor. The analysis of this study found that the inter-annual flow variation issue should be dealt with rationally not to discourage RoR hydropower development in Nepal.

CONCLUSIONS

The long-term annual average flow at Arughat is 160 m^3/s. However, it varied from 120 to 210 m^3/s in the study period. The flow at this gauging station during monsoon, post-monsoon, winter, and pre-monsoon seasons were respectively 72 %, 12 %, 6 %, and 10 % of the total flow. It implies that the dry season has only 16 % whereas the wet season has as high as 84 % of the total flow. The fractional difference of upper 20 % to lower 20 % flows amounted to 14. The relatively high ratio and long-term monthly average flow ranging from 30 m^3/s in February to 436 m^3/s in August show high inter and intra annual variation in Budhigandaki River flow.

This study found that the flow was less than the anticipated long-term monthly flow by 1.54 m^3/s (~3 %) for the dry season while it was 2.26 m^3/s (~ 2 %) with respect to design flow for the wet season. In other words, the expected value of the dry season power loss was about 3 % and 2 % for the RoR projects proposed in the Budhigandaki River basin. Nevertheless, these figures are not so high; the probability of less production of power in a year may go up to 40 % for the dry season and 10 % in the wet season. Further, there is a probability of producing less power than the estimated one for 11 consecutive years (> 20 %) in the dry season and 27 consecutive years (> 50 %) for the wet season. The flow characteristics of other rivers of Nepal are also somewhat similar to that of the Bhudhigandaki River. This study concludes that uncertainty arising from daily flow variation should be assessed while estimating energy generation in hydropower projects, and it should be reflected in the power purchase agreement.

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