Assessment of Hydropower Potential of Topchi Site at the Bamyan River in Bamyan, Afghanistan

Mohammad Aman and R. K. Malik*

M. Tech. student, Department of Civil Engineering, Amity School of Engineering and Technology, Amity University Gurgaon, India.
*Professor of Hydrology and Water Resources Engineering and Head, Department of Civil Engineering, Amity School of Engineering and Technology, Amity University Gurgaon, India. E –mail – rkmalik@ggn.amity.edu

Abstract-For a site selection of a hydropower project, the stream flow discharges and the availability of appropriate head are fundamental considerations and the proposed site should have a good combination of these factors. In Afghanistan, there are many sites which have not been explored for the assessment of the hydropower potential or such information is scarce. A site at the Bamyan River near the Bamyan city in Afghanistan was investigated for the assessment of the hydropower potential. The gross head between the existing weir crest level and the ground level of the power house was assessed to be 35 m using Digital Elevation Model (DEM) in Arc GIS and after considering 10% head losses the net available head was estimated to be 31.5 m. The maximum and the minimum mean monthly flow rate were estimated to be 11.03 and 1.93 m^3/s, respectively. The power-law function was The Pelton turbine with 80% efficiency was identified for the proposed site.The hydropower potential was assessed to be 1720.60 KW for the maximum flow rate of 6.96 m^3/s at 15% probability level which is about to 2 times more than the estimated hydropower potential of 833.10 KW at the designed flow rate of 3.37 m^3/s at 40% probability level. The estimated hydropower potential of 1090.20 was computed at mean flow rate of 4.41 m^3/s while the minimum estimated hydropower potential of 473.57 KW was observed for the minimum flow rate of 1.77 m^3/s at 95% probability level. With the help of turbine selection chart and the hydraulic efficiency of the turbine, the Pelton turbine was selected for the proposed site.

Key words- Hydro power potential, stream flows, digital elevation model, arc Gis, pelton turbine, hydraulic efficiency, Topchi site, Afghanistan

INTRODUCTION

For the design and installation of a small hydropower plant, the assessment of the hydropower potential capacity of the proposed site is important because the hydropower potential is limited by the stream flow discharges and the available head. The intermittent nature of the stream flows have high flow discharges during the rainy seasons and very low discharges during the dry seasons. While the head at a site is constant, the available stream flow rates are highly variable necessitating the need for the study of the stream flows from the point of design and assessment of the installed capacity of a hydropower plant. The average stream flow is important from the consideration of the energy output and the minimum flows are required to predict the dependable hydropower plant capacity. So it is important to know the variations in the stream flow discharges throughout the year and the available gross head.

In Afghanistan, there are many sites which have not been explored for the assessment of the hydropower or potential and such information is scarce. One such a site is at the foot-hills of the Baba mountain ranges and is located at the Bamyan River near the Bamyan city in the Bamyan province in Afghanistan was investigated for the assessment of the hydropower potential in this study. The assessment of the hydropower potential of this proposed site at the Bamyan River requires the probability analysis of the long-term flows of the river for the selection of the maximum, mean, designed and the minimum flows at a particular probability levels. The topographic assessment of the site for the selection of the appropriate locations and alignments of the components of the power plant such as the diversion weir, forebay, penstock and the powerhouse as well as the determination of the net available head and the selection of a turbine machine that matches the designed flow discharge and the net available head are needed. So in this analysis the assessment of the hydropower potential at this proposed site was made.

METHODOLOGY

The area under this study is a part of the Kunduz watershed also called the Upper Kunduz River basin and is located at the Bamyan river near the Bamyan city in Bamyan province in Afghanistan [1]. The proposed site is at the foot-hills of the Baba mountain ranges. Wali [2] reported that the field measurements of the gross head are usually carried out either by using Digital Elevation Model (DEM), surveying techniques or by using the Global Positioning System (GPS). The generated topographic map of the watershed area and the results of the topographic survey conducted with a total station for the proposed alignment of the diversion channel and the penstock was used to propose the locations of the hydropower components and determined the designed elevations for the different components of the hydropower plant. In this study the Digital Elevation Model (DEM) 90 × 90 meters for the data obtained from the United States Geological Survey (USGS) website was used in the ArcGIS platform to delineate the watershed areas under study. The DEM was corrected for the depressions and then was used to generate the flow direction grids that determined the direction of the movement of the water flow from each individual grid within the watershed. The flow direction grids were then used to generate the drainage network of the watershed. The GPS point of the watershed outlets together with the above generated grids were used to delineate the watershed areas contributing water to the proposed outlets using the hydrology tools of the ArcGIS 10.2. The simulated flow of the proposed watershed was used to generate the flow duration curves (FDCs) for the site and for this the discharges were arranged in the descending order from the maximum to the minimum. The plotting position was ascertained from the most commonly used plotting position method of Weibull as described by Eq. (1) as reported by Chow[3]. The percent probability of the corresponding flow magnitude being equaled or exceeded is given as:

$$P_p = \frac{m}{N+1} \times 100 \qquad (1)$$

Where P_P is the probability that a given stream flow magnitude will be equaled or exceeded. m is the ranked position of the stream flow magnitude arranged in descending order from rank 1 given to the maximum magnitude of the flow and N assigned to the minimum flow magnitude i.e. N is the total number of hydrological events of the stream flows for the total period of the flow records. In this study the mean monthly flow discharges were considered.

The hydropower potential of the selected site at the Bamyan river was assessed for the power P in watts (W) available from this proposed hydropower scheme and is given by Weedy [4] as:

$$P = \rho\, g\, Q\, H \qquad (2)$$

Where Q is the flow rate (m^3/s) through the turbine, ρ is the density of the water (1000 kg/m^3), g is the acceleration due to gravity (9.81 m/s^2) and H is the gross head (m). Substituting the values of ρ and g, Eq. (2) for power P in KW is expressed as:

$$P = 9.81\, Q\, H \qquad (3)$$

Having estimated the gross head available for the generation of the hydropower, the head losses that arise due to the trash racks, pipes, bends and valves etc. were considered as 10% of the gross head and based on this the net head available to drive the turbine is equal to the gross head minus the sum of all the head losses as reported by Bansal [5] as:

$$H_n = H - \sum H_l \qquad (4)$$

Where H_n is the estimated net head (m) and $\sum H_l$ is the sum of all the head losses. The power P in KW generated from the hydraulic turbine as a function of the effective net head, flow rate and the hydraulic efficiency (η) of the turbine was reported by Voros et al. [6] as:

$$P = 9.81 \times Q \times H_n \times \eta \quad (5)$$

The selection of a particular type of turbine depends on the site data mainly the available net head and the flow discharges besides other technical parameters such as efficiency and the cost etc. The turbines are constructed to operate between the two extremes i.e. a minimum and a maximum working flow discharges. The hydraulic efficiency (η) of the turbine was taken from Table 1 suitable for the proposed hydropower plant and in this analysis turbine efficiency was assumed to be 80%.

Table 1: Typical efficiency of different type of turbines

Turbine	Efficiency range
Impulse turbine	
Pelton	**80-90%**
Turgo	**80-95%**
Cross flow	**65-85%**
Reaction turbine	
Francis	**80-90%**
Pump as turbine	**60-90%**
Propeller	**80-90%**
Kalpan	**80%**

Based on Fig. 1, the type of turbine was selected for the proposed site at the Bamyan river.

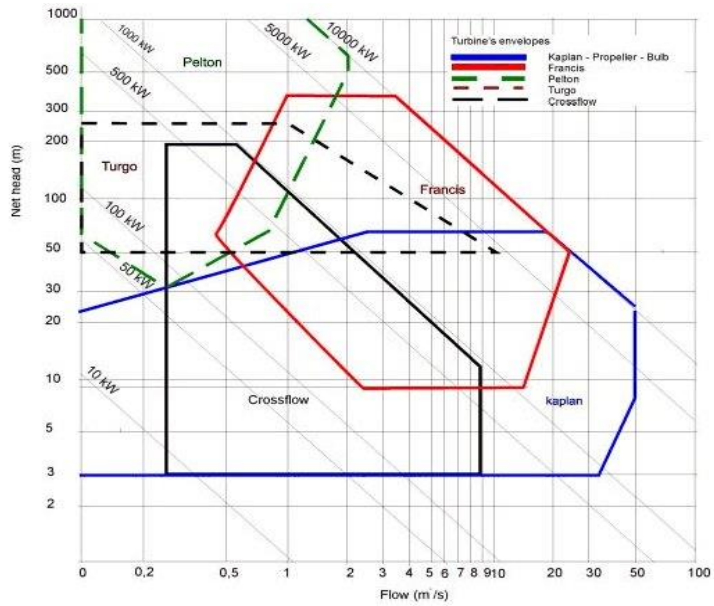

Fig. 1. Turbine selection chart

The installed capacity of the plant was considered based on the maximum flow which was taken as Q_{15} (i.e. flow rate at 15% probability) and the designed flow rate was taken Q_{40} (i.e. flow rate at 40% probability) while the mean flow rate Q_{av} was computed as reported by Adedokun et al. [7] as:

$$Q_{av} = 0.25(Q_0 + Q_{100}) + 0.05(Q_5 + Q_{95}) + 0.075(Q_{90} + Q_{10})$$

$$+0.10(Q_{20} + Q_{30} + Q_{40} + Q_{50} + Q_{60} + Q_{70} + Q_{80}) \quad (6)$$

Where Q_5, Q_{10}, Q_{20}, Q_{30}, Q_{40}, Q_{50}, Q_{60}, Q_{70}, Q_{80}, Q_{90}, Q_{95} are the flow discharges at 5, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 95% probability levels, respectively whereas Q_0 and Q_{100} are the flow rate occurring nearly at 0 and 100% probability levels, respectively. In this analysis, Q_0 has been taken as the flow rate with a probability of less than 5% and Q_{100} has been taken as the flow rate at more than 95% probability level.

RESULTS AND DISCUSSION

The topography of the watershed area of the Bamyan river varies from 4000 m at the watershed line to 2500 m at the fall of the river. The average slope of the watershed of the Bamyan River was

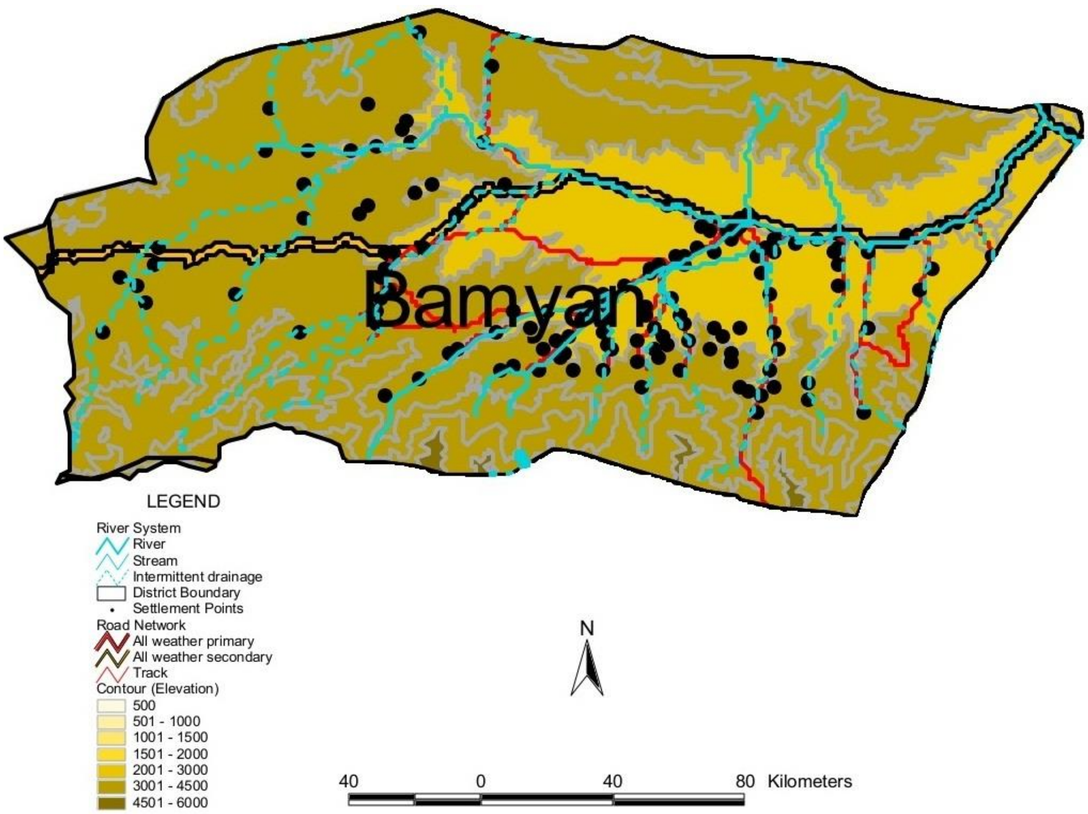

Fig. 2. Elevation map of the watershed area

estimated to be 1 in 20. The gross head was estimated to be 35 m and accounting for 10% head losses the net head available was computed to be 31.5 m.

The mean monthly discharges were assessed and are reported in Table 2 which varied from the maximum discharge of 11.03 m^3/s in the month of June to a minimum discharge of 1.93 m^3/s in the month of March. The average of the mean monthly flow discharge for all the 12 months of a year was estimated to be 3.88 m^3/s.

Table 2: The mean monthly flow discharges

Month	Mean monthly discharge (m^3/s)
Jan	1.97
Feb	2.00
Mar	1.93
Apr	2.79
May	5.83
Jun	11.03
Jul	6.68
Aug	3.85
Sept	3.55
Oct	2.56
Nov	2.23
Dec	2.18

The probability of occurrence for a particular magnitude of flow rate is reported in Table 3 in which the flow discharges have been arranged in descending order along with the rank number.

Table 3: The probability of occurrence of the mean monthly flow discharges

Mean monthly discharges arranged in descending order (m^3/s)	Ranked position	Probability of occurrence (%)
11.03	1	7.7
6.68	2	15.4
5.83	3	23.1
3.85	4	30.8
3.55	5	38.5
2.79	6	46.2
2.56	7	53.8
2.23	8	61.5
2.18	9	69.2
2.00	10	76.9
1.97	11	84.6
1.93	12	92.3

The mean monthly flow data Q_P alongwith its probability of occurrence P_p were used to describe the trend of the stream flow of the Bamyan river as shown in Fig.3 and a best fit for this trend was developed as:

$$Q_P = 51.67\ P_p^{-0.74} \quad (7)$$

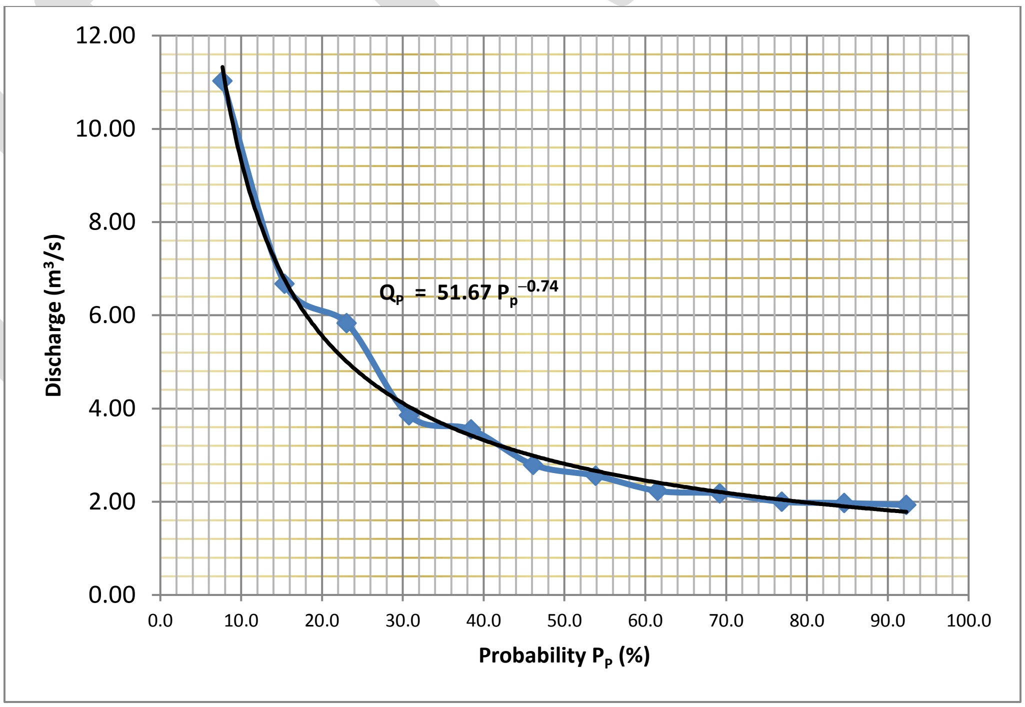

Fig.3. Flow duration curve of the Bamyan River

Using Eq. (7) the maximum, designed and the minimum flow rate and using Eq. (6) alongwith Eq. (7), the mean flow rate were assessed. Based on this flow rate the estimated hydropower potential considering the net available head of 31.5 m were assessed using Eq. (5) and are reported in Table 4.

Table 4: The estimated hydropower potential based on the net available head of 31.5 m

Type of flow rate	Flow discharge (m^3/s)	Estimated hydropower potential (KW)
Maximum flow rate (Q_{15})	6.96	1720.60
Mean flow rate (Q_{av})	4.41	1090.20
Designed flow rate (Q_{40})	3.37	833.10
Minimum flow rate (Q_{95})	1.77	473.57

Table 4 showed that the hydropower potential was assessed to be 1720.60 KW for the maximum flow rate of 6.96 m^3/s at 15% probability level which is about to 2 times more than the estimated hydropower potential of 833.10 KW at the designed flow rate of 3.37 m^3/s at 40% probability level. The estimated hydropower potential of 1090.20 was computed at mean flow rate of 4.41 m^3/s while the minimum estimated hydropower potential of 473.57 KW was observed for the minimum flow rate of 1.77 m^3/s at 95% probability level. With the help of turbine selection chart and the hydraulic efficiency of the turbine, the Pelton turbine was selected for the proposed site. The Pelton turbine with 80% efficiency was identified for the proposed site. This analysis showed that there is good potential for the generation of the hydropower by establishing a small hydropower plant.

CONCLUSION

The gross head between the existing weir crest level and ground level of the powerhouse was assessed to be 35m at a site of the proposed hydropower plant at the Bamyan River near the Bamyan City in Afghanistan using DEM in the Arc GIS and the net head available was assessed to be 31.5 m. the hydropower potential was assessed to be 1720.60 KW for the maximum flow rate of 6.96 m^3/s at 15% probability level which is about to 2 times more than the estimated hydropower potential of 833.10 KW at the designed flow rate of 3.37 m^3/s at 40% probability level. The estimated hydropower potential of 1090.20 was computed at mean flow rate of 4.41 m^3/s while the minimum estimated hydropower potential of 473.57 KW was observed for the minimum flow rate of 1.77 m^3/s at 95% probability level. The Pelton turbine with 80% efficiency was identified for the proposed site.

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