Run-of-River Hydropower Potential of Kunhar River, Pakistan

Khan, M.[1, 2], A. Z. Zaidi[2]

Abstract

Energy crisis has emerged as a serious issue all over the world in recent years. Pakistan is facing a similar crisis that has resulted in frequent power failures and load shedding throughout the country for past several years. The utilization of renewable energy resources may help reducing fossil fuel dependency of the country for power generation. There are various renewable energy options for Pakistan including solar, wind and hydropower. The objective of this study is to develop an approach that can be used to assess the run-of-river hydropower potential of Kunhar River using geospatial data and techniques. Kunhar River is a tributary of Jhelum River located in the Khyber Pakhtunkhwa province of Pakistan. Satellite data used in this study include ASTER Digital Elevation Model (DEM). Flow data are acquired from regional hydrologic gauges. Remote Sensing (RS) and Geographical Information Systems (GIS) tools are used for processing the satellite images, delineation of watershed and stream network, and identification of potential sites for hydropower projects. This study will aid decision-makers in the energy sector to optimize the available resources in selecting the suitable sites for small hydropower plants with high power potential. The proposed approach can further be utilized to assess an overall hydropower potential of the country.

Key Words: GIS, Hydropower, Remote Sensing, Renewable Energy, Run-of-River hydropower plant

Introduction

Rapid increase in population and global urbanization has put enormous pressure on natural resources all around the world. Today, progress of a nation is described by its per capita energy consumption. On the other hand, extensive production and use of energy may adversely impact the surrounding environment. A win-win situation may be reached by utilizing renewable energy sources to produce sufficient energy for meeting the expanding demand without degrading the environmental. There are various renewable energy options including wind, solar and hydroelectric energy sources. Hydropower is apparently the most common form of renewable energy option (OECD/IEA, 2010). The main principle of hydropower is to utilize the energy stored in the flowing water when it falls from a height. Flowing water carries enormous amount of energy and when it runs through a steep gradient the amount of energy exponentially increases. There are various sizes of hydropower plants ranging from very large with big dams to small run-of-river projects. The small hydropower projects need low initial investments, smaller area, shorter planning and construction time, locally trained manpower, indigenous material, and lower power generation cost as compared to larger power projects (Dudhani, et al., 2006). Run-of-river projects are classified into two types; low head and high head. Low head projects are usually suitable for large rivers that have gentle gradients, whereas, the high head types are more appropriate for small rivers having steep gradients (IEA, 2000).

This study presents a prototype cost effective model for assessment of run-of-river (ROR) hydropower potential and identification of suitable project sites using geospatial data and techniques. North Pakistan is in abundance of both water resources in the form of perennial streams and steep slopes. If harvested and utilized properly, the energy produced can help meet the local demand and to raise the quality of life and living standards of the nation. Since Kunhar River is a small river with steep gradient, it is quite suitable for high head projects. The proposed approach evaluated the hydropower potential of Kunhar River as a case study. Kunhar River is a tributary of Jhelum River located in the northern province of Pakistan named Khyber Pakhtunkhwa. Figure 1 shows the study area. The ultimate goal of this study was to develop a blueprint that can be used to assess the hydropower potential of the country.

[1] mk_swati@yahoo.com

[2] Department of Remote Sensing and Geo-information Science, Institute of Space Technology, SUPARCO Road, Karachi, Pakistan.

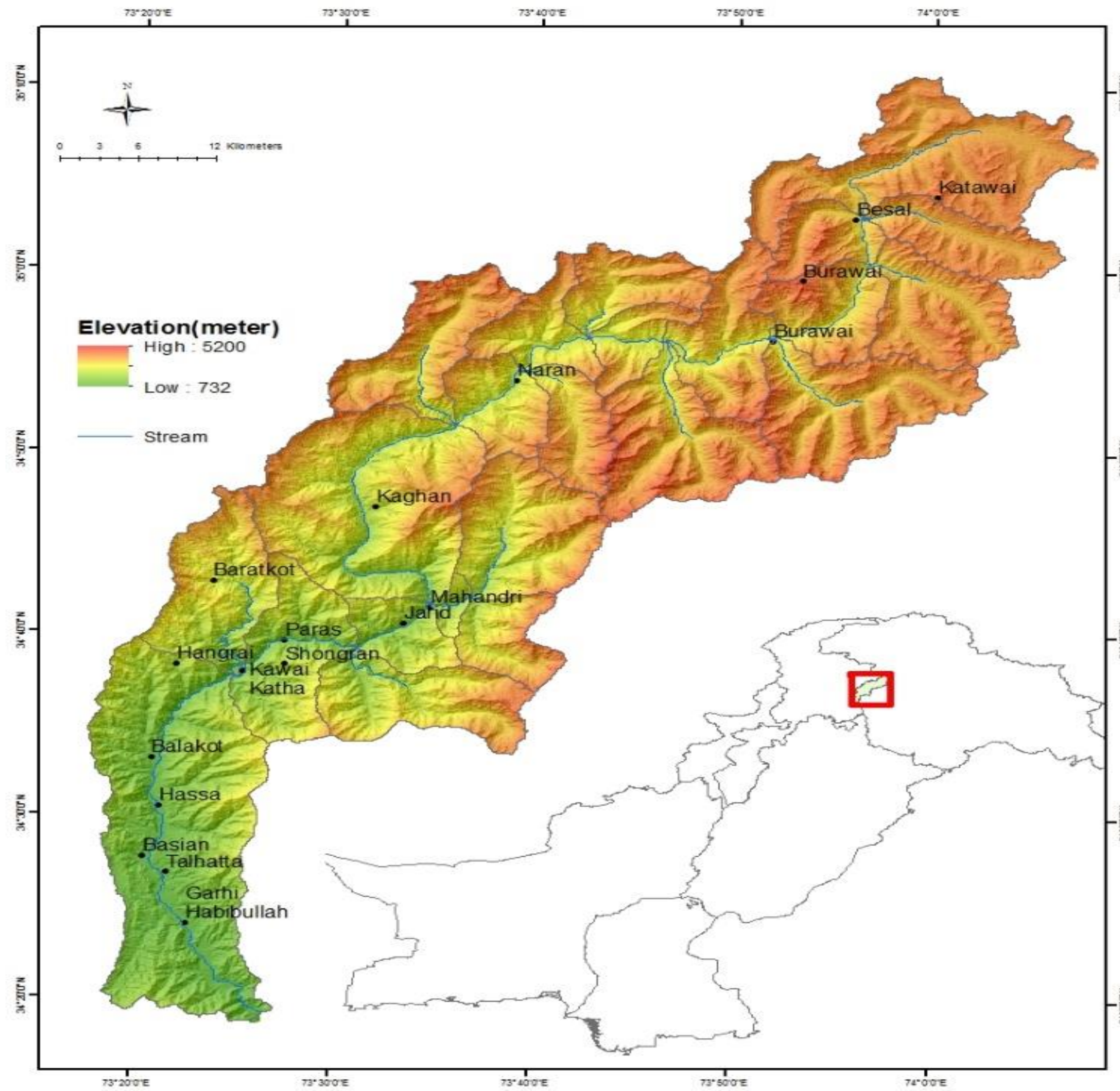

Figure 1: Study Area - Kunhar River Basin.

Methodology

Run-of-river hydroelectric plants manipulate flow of water and elevation drop (i.e. head) of streams to generate power. These projects are built using a small diversion dam called 'intake' that conveys water from the main water channel to a pipeline or penstock. The penstock further directs the flow to a powerhouse with a turbine (Monk et al., 2009). The power potential of flowing water is a function of the discharge (Q), the specific weight of water and the difference in head (H) between intake point and turbine. The mathematical expression for hydropower potential can be written as Equation (1) (Crowe et al., 2005). In Equation (1), the two parameters, Q and H, need to be calculated. If Q and H are known for a given segment of a stream, the hydropower potential can easily be estimated for that segment.

$$P = \gamma Q H \qquad (1)$$

Where; P = Power (W)

$\gamma = g\rho =$ Specific weight of water (N/m^3)

g = Acceleration due to gravity (m/s^2)

ρ = Mass density (kg/m^3) = 1,000 kg/m^3 for water

Q = Discharge (m^3/s)

H = Head (m)

Methodological framework of the study is shown in Figure 2. A widely used Geographical Information System (GIS) software ArcGIS 10.x was used for the processing of satellite derived Digital Elevation Model (DEM). Kunhar River watershed and stream network were delineated using ArcGIS extension Arc Hydro. Other ArcGIS tools, Editor and Spatial Analyst, were used to mark proposed sites and calculate their elevations respectively. Discharge analysis was aimed at plotting flow duration curve (FDC) and calculating 40, 50 and 60 percentile discharges (Q40, Q50 and Q60 respectively) using historical flow data. The flow data from two available gauges in the Kunhar River were further manipulated to determine the flow at ungauged sites. Finally the outcomes of the above process were fed into Equation (1) to calculate the hydropower potential at proposed sites.

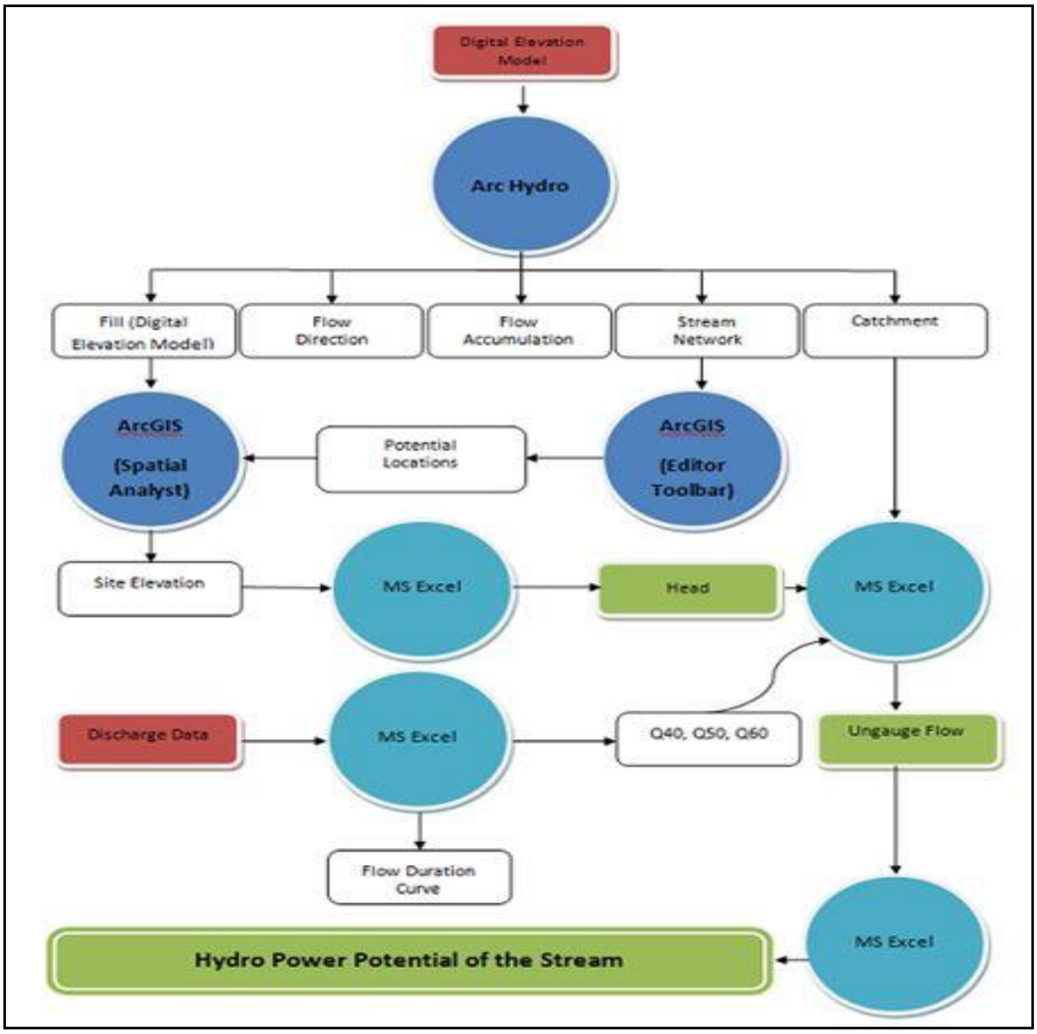

Figure 2: Methodological Framework.

Drainage Analysis

Watershed delineation is the first step in doing any kind of hydrologic modeling to determine the basic characteristics of a hydrologic data. Traditional methods used topographic maps for this purpose but in recent years the availability of DEM and GIS tool has made the process simpler and automated. ASTER DEM data of the study area were downloaded from the earth explorer website (http://earthexplorer.usgs.gov/). This DEM had a 30 meter spatial resolution. In this study, Arc Hydro tools were used to process 30 meter DEM to extract drainage patterns of Kunhar River basin. The same tools can be used to derive catchment and drainage lines from a selected point to calculate flow at the ungauged proposed sites.

Head Determination

Head is a vertical distance between two point (intake and turbine). It can also be defined as the pressure created by elevation difference between intake and turbine. A run-of-river plant does not require space for water storage and 500 meter horizontal distance between two plants is usually considered feasible. In this study, points are selected on a GIS map at an interval of 500 meters along the river centerline to mark proposed plant locations. Proposed sites were marked using ArcGIS Editor Toolbar. The elevation at each proposed site was extracted from DEM using Spatial Analyst Tools. Elevation difference or head between two successive proposed locations was calculated considering the first point as intake point and second as turbine location.

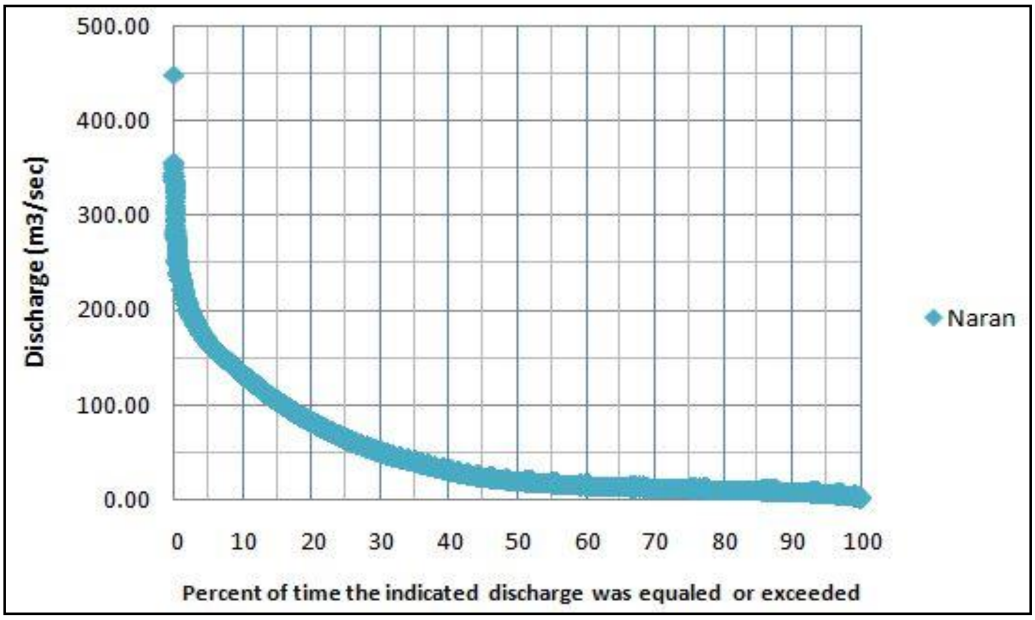

Figure 3: Flow Duration Curve for flow gauge at Naran.

Discharge Analysis

Discharge or volumetric flow is the rate of flow of water from any point along a stream per unit time. In this study discharge data were required for proposed sites that were located at 500 meter intervals. There are two gauge stations installed by Water and Power Development Authority (WAPDA) that record discharge of Kunhar River at Naran and Garhi Habibullah. The data that could be acquired at these gauge stations were from 1960 to 2009. The data were further processed to obtain 40, 50 and 60 percentile flows (Q40, Q50 and Q60 respectively) as shown in Table 1. FDC for Naran and Garhi Habibullah stations are shown in Figure 3 and Figure 4 respectively.

Table 1: Percentile discharges at Naran and Garhi Habibullah.

Percentile Discharge	Naran	Garhi Habibullah
Q40	14.70	39.86
Q50	19.59	55.77
Q60	30.58	84.95

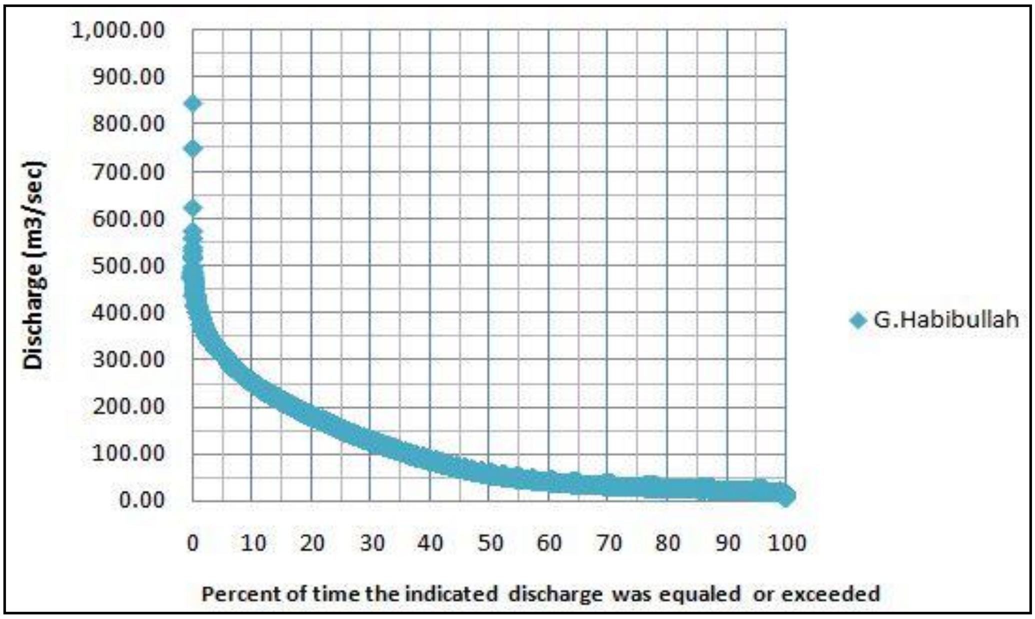

Figure 4: Flow Duration Curve for flow gauge at G. Habibullah.

Measuring Relative Discharge

Discharge value was required at every proposed location along the river where head was already calculated. Measured discharges at the two gauge stations were interpolated to obtain the relative discharges for unknown locations as explained by Raghunath Jha (2010). To explain it further, assume 'a' and 'b' as two gauges installed in a stream with Qa and Qb discharges as shown in Figure 5. Gauge 'a' is installed at an upstream location in the watershed, whereas, gauge 'b' is located at the downstream point. The respective sub-drainage areas of 'a' and 'b' are Aa and Ab. Let there are two more points 'x1' and 'x2', located respectively upstream and downstream of gauge 'a', where flow is needed to be estimated. Similarly, the sub catchment areas of 'x1' and 'x2' are Ax1 and Ax2 respectively. The flow Qx1 and Qx2 at ungauged location can be calculated using Equations (3) and (4).

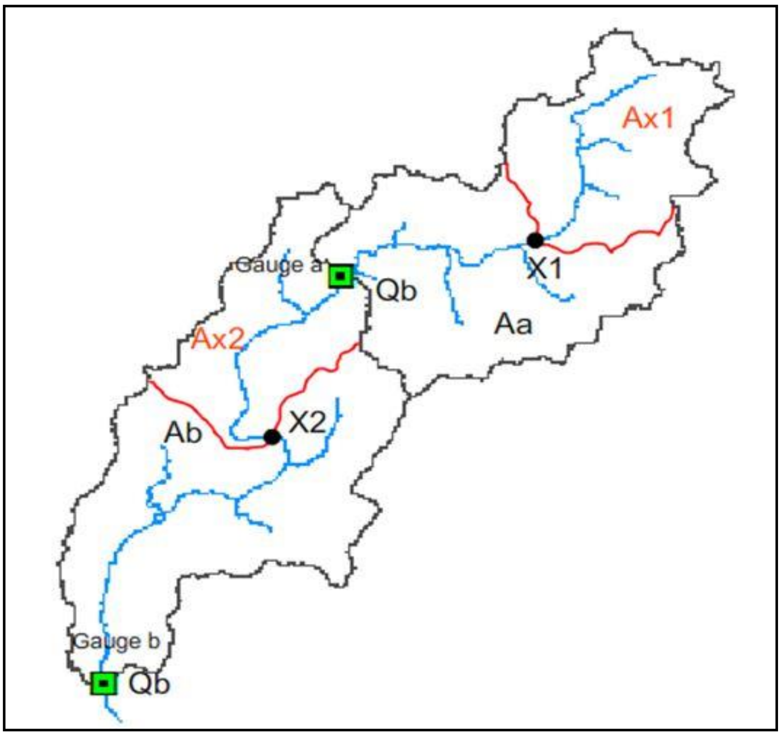

Figure 5: Measuring relative discharge at 'a' and 'b'.

i. Estimating Flow Qx1 at ‘x1’

Moving upstream from gauge ‘a' discharge needs to be subtracted relative to the area of sub catchment x1.

$$Q_{x1} = Q_a - (A_{x1}/A_a) \times Q_a \quad (3)$$

ii. Estimating Flow Qx2 at ‘x2’

Moving downstream from gauge ‘a', the cumulative discharge can be calculated for each proposed site using following equation.

$$Q_{x2} = Q_a + (A_{x2}/A_b) \times (Q_b - Q_a) \quad (4)$$

Results

There were two important parameters that can define the hydropower potential of a location along a stream. These parameters are elevation difference between upstream and downstream points which is also called head and discharge. Head can be calculated by subtracting the elevation of the upstream point from the downstream elevation. If flow monitoring gauges are not available at the selected locations then flow can be estimated by manipulating the data from other gauges located anywhere in the watershed. Total potential (in Watts) of Kunhar River, assuming 500 meter as an optimal interval between the proposed plants, is calculated for each percentile discharges i.e. Q40, Q50 and Q60 using the Equation. (5). For this study, heads are calculated at 500 intervals along the river using DEM and the corresponding discharges at these locations are estimated.

$$P_i = \sum_{j=1}^{n} g\rho H_j Q_{ij} \quad (5)$$

Where; i = index for flow percentiles (40, 50 and 60)

j = index for proposed plants = 1, 2, 3 ……n

n = total number of plants

Hj = head at plant j

Qij = discharge at percentile i and plant j

Using the above equation, power potentials P40, P50 and P60 are calculated for discharges Q40, Q50 and Q60 in Mega Watts as presented in Table 2.

Table 2: Cumulative hydropower potential on Kunhar (MW).

P40	P50	P60
554.32416	763.15546	1171.9888

Suitable Sites for Run-of-River Projects

Since power potential is directly proportional to the head and discharge at any site, therefore, greater head and discharge will produce higher energy. Based on this information, all proposed sites along Kunhar River can be grouped into various classes depending upon their power potentials as shown in Table 3. Figure 6 presents proposed sites with their power potentials for 50^{th} percentile flow in the Kunhar River. Similar layout can be drawn for Q40 and Q60 discharges.

Table 3: Potential sites for Q40, Q50 and Q60.

Power Potential(KW)	No of Sites		
	Q 40	Q50	Q 60
0 -5000	322	306	272
5001 -10000	23	30	49

10001-15000	5	10	15
15001-20000		4	9
20001-25000			2
25001-30000			3

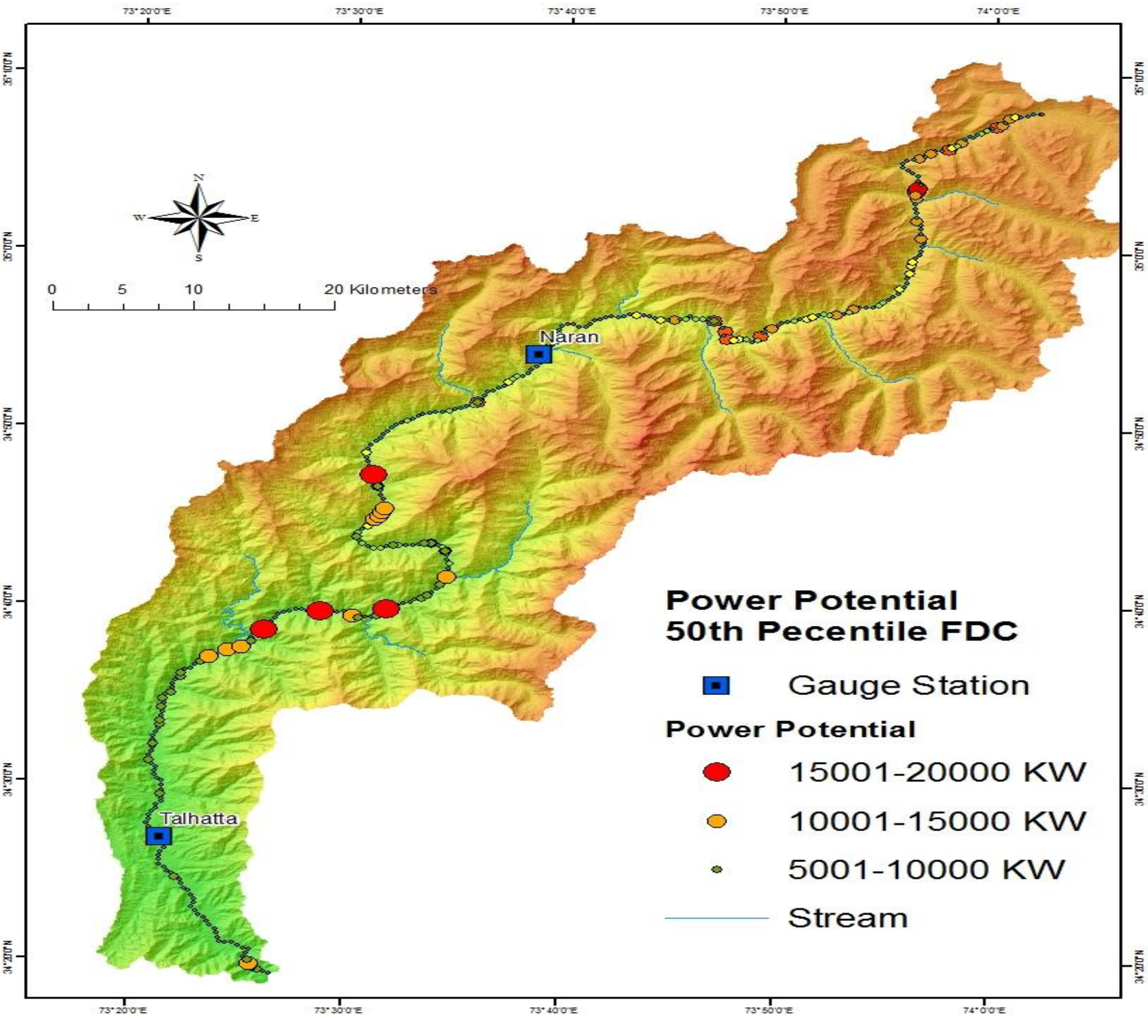

Figure 6: Spatial distribution of suitable sites for run-of-river projects and their hydropower potentials.

Conclusions

The recent energy crises in the country and overexploitation of non-renewable energy sources have created a gap between supply and demand of this vital commodity. Unserved communities living in small settlements far from the main energy grid stations are the main sufferers of this situation. Apart from unit electricity cost, the infrastructure development and maintenance cost may also increase energy tariffs for these settlements. The transmission losses are also not to be disregarded. This study is an effort to establish the importance of renewable energy sources and to present a methodology to investigate the feasibility of installing small plants at locations which have adequate hydropower potential. A case study of Kunhar River is discussed in this paper. A number of settlements are present along Kunhar River that can be served through these plants with minimum transmissions infrastructure requirements. The whole length of the river is investigated for calculating hydropower potential at the interval of 500 meters. The resulting maps identifies the hydropower potential at each investigated site. The study presented in this paper clearly shows that there is a large potential for run-of-river hydroelectric development in Kunhar River. This information can be combined with the potential demand sites to optimize energy supply to the end users.

Similar studies have been carried out in the country that involved huge investments and tedious field works. The proposed approach is cost effective and efficient since it used free satellite data and therefore can easily be replicated on other parts of the country for rapid hydropower assessment. This study used satellite derived Digital Elevation Model (DEM) with 30 meter resolution and GIS tools for automatic delineation of Kunhar River drainage network and watershed boundaries. Further analysis is done to find out the hydropower potential of the river using historical flow data. This study can be used to aid decision-makers in the energy sector and power development authority to optimize the available resources in selecting the suitable sites for small hydropower plants with high potential. A higher resolution satellite data, if used, can further enhance the results.

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