A GIS based approach for hydropower site selection and potential evaluation of the Kunhar River Basin, Pakistan

Abdul MOIZ, Akiyuki KAWASAKI and Toshio KOIKE

Abstract: This study proposes the use of GIS and a Water and Energy Budget-based Distributed Hydrological Model with improved snow physics (WEB-DHM-S), to identify potential high head run-of-river hydropower sites in the relatively mountainous and snowy basins and to estimate the associated theoretical hydropower potential. Using this approach, 16 potential sites were identified on the Kunhar River with a total hydropower potential of 659 MW at 50% flow exceedance.

Keywords: Hydropower, WEB-DHM-S, Run-of-river, Site selection, High head

1. Introduction

Hydropower is the renewable energy derived from the head created by falling water. Being a domestic resource and relatively cost effective, it is considered to be a reliable source of energy particularly for developing countries. Despite the many other competing sources of renewable energy, hydropower was still the primary contributor (16.6%) to the renewable energy share (22.8%) of global electricity production in 2014, with a global generating capacity of 1,055 GW (REN21, 2015).

Pakistan is facing a severe energy crisis situation since the last decade that is adversely affecting its economy, industry and the quality of life. In 2009 – 2010, the energy shortfall was recorded at around 5,000 MW (USAID, 2010). With the energy sector largely depending upon fossil fuels, in order to meet its energy requirements, there is a need to develop renewable energy sources in Pakistan, particularly small scale run-of-river hydropower developments (Awan and Khan, 2014). According to Pakistan Power and Infrastructure Board (2011), Pakistan has an estimated hydropower resource of about 60,000 MW, a substantial amount of which is yet to be exploited, with only 6,720 MW developed so far.

Recently, GIS has found tremendous application in estimating the hydropower potential of river basins and in locating suitable run-of-river (ROR) and storage type hydropower sites. ROR hydropower developments utilize the natural flow of the river to generate electricity in contrast to storage type developments that rely upon damming the river to store water. Head and discharge are the two main variables involved in estimating the hydropower potential. (Feizizadeh and Haslauer, 2012; Larentis et al., 2010). Developments in hydrological modelling techniques have lead researchers to estimate the flow variability in the stream using such models, for a more accurate estimate of hydropower potential with the possibility of estimating the future hydropower potential as well, subject to climate (Kusre et al., 2010; Pudashine et al., 2013).

Recent advancements in the hydrological modelling have led to the development of a Water and Energy Budget-based Distributed Hydrological Model (WEB-DHM) coupling the land-surface modelling capabilities of Simple Biosphere scheme 2 (SiB2) with the spatially distributed nature of a Geomorphology-based Distributed Hydrological Model

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(GBHM) to model the water, energy and CO_2 fluxes (Wang et al., 2009). Further improvement in the model has resulted in the inclusion of advanced snow and glacier physics by incorporating the three layer snow scheme of the Simplified Simple Biosphere scheme 3 (SSiB3) and prognostic albedo scheme of Biosphere-Atmosphere-Transfer-Scheme (BATS) into the basic model framework (Shrestha et al., 2015).

The objective of this study is to (a) identify suitable run-of-river sites in Kunhar River Basin using GIS (b) Set up WEB-DHM-S to model the basin hydrology and simulate discharge and (c) estimate the associated hydropower potential of basin.

2. Study Area

The study area – Kunhar River Basin – is located between the longitudes of 73°17'E to 74° 8'E and the latitudes of 34° 11'N to 35° 10'N and is a part of the much larger transboundary Jhelum River Basin. The basin has an area of 2,643 km^2 with the elevation ranging from 668 m to as high as 4879 m. The average annual precipitation at Balakot is around 1,550 mm whereas at Naran it is 1,640 mm.

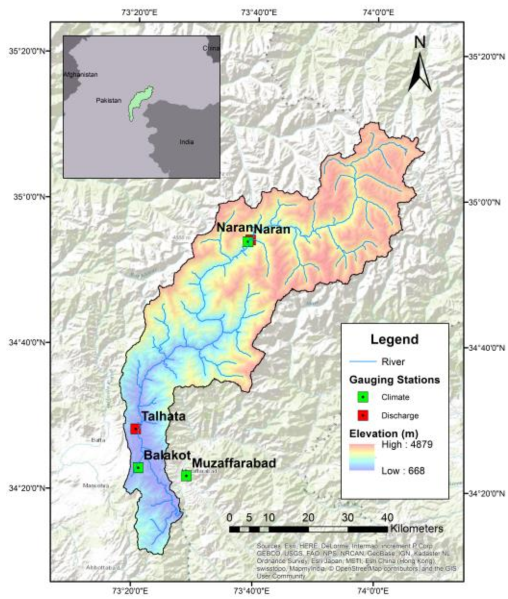

Figure 1. Kunhar River Basin

3. Methodology

3.1. Hydropower Site Selection

ROR type developments derive energy from the natural flow of river. Being a relatively steep and mountainous basin, head high developments – more than 50 m head – were considered more suitable and feasible. The entire analytical framework of the python routine developed in ArcGIS is shown in Fig. 2. In order to exploit maximum hydropower potential, schemes with the maximum head were selected, with the minimum distance between schemes set to 500 m and the headrace length of 3-5 km. Hydrosheds 3sec DEM was used as input to the model. The analysis was conducted only for 4th order stream, which in this case is the main Kunhar River.

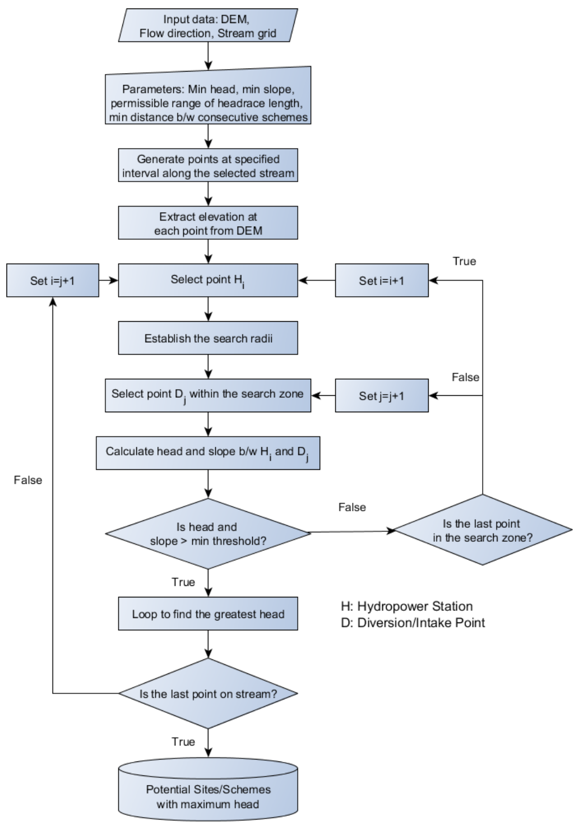

Figure 2. ROR hydropower power site selection framework

3.2. WEB-DHM-S Set Up

WEB-DHM-S was used to model the basin hydrological processes and simulate the discharge for the year 2007 - 2008 at a daily time scale and a 500 m grid resolution. The model simulates the discharge for each flow interval (with a virtual lumped stream) consisting of a number of model grids, defined by the time lag depending upon the distance to the outlet. Several land/soil parameters and snow parameters were adjusted to get a sufficient degree of agreement between the simulated and observed discharge. The model was calibrated for the year 2007 and validated against 2008. Nash-Sutcliffe efficiency (NSE), Percentage BIAS (PBIAS) and coefficient of determination (R^2) were used to evaluate the simulation accuracy of the model during calibration and validation period (Moriasi et al., 2007).

3.3. Hydropower Potential Estimation

Discharge series' were acquired from the model simulation for the flow intervals corresponding to the selected diversion points. Flow duration curves were constructed, as per equation (1) to estimate the discharge at 30%, 50% and 70% flow exceedance.

$$P\ (\%) = [R / (n + 1)] \times 100 \qquad (1)$$

where, 'P' is the probability of flow exceedance, 'R' is the rank of discharge value and 'n' is the total number of days for which the simulation was run. Finally, the hydropower potential at a site is calculated by using the following equation,

$$\text{Hydropower Potential (MW)} = 0.00981 \times Q \times H \qquad (2)$$

where, 'Q' is the discharge (m^3/s) at a certain flow exceedance and 'H' is the head (m) at the selected site.

4. Results & Discussion

Using the python routine developed in ArcGIS, 16 suitable sites were detected on the main river having a head ranging from 55 m to 257 m, as shown in Fig. 3. 12 out of 16 sites are located on the reach between Talhata and Naran.

The results of model calibration and validation are shown in Fig 4. Although, one of the selected schemes lies downstream of Talhata, it is assumed that the calibration and validation results are still valid there, since there is no major regulating structure or a confluence with a major river in between these points.

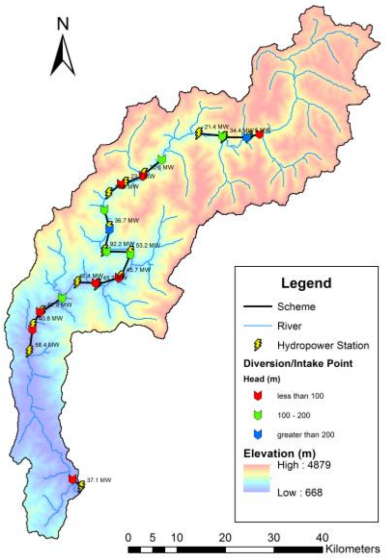

Figure 3. Selected sites and their hydropower potential at 50% flow exceedance

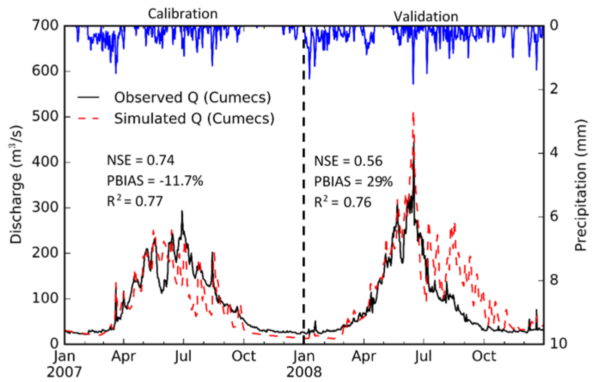

Figure 4. Calibration and validation at Talhata

During the validation period the discharge is largely overestimated from July to October, which may be a result of glacier melt, which is not included in this simulation. Moreover, modifying the precipitation by considering elevation bands can also significantly improve the results. The threshold for snow melt was set to 0ºC. Validating the simulated snow cover using remotely sensed data can further improve the results.

Table 1 shows that hydropower potential associated with the selected schemes at 30%, 50% and 70% flow exceedance.

Table 1. Hydropower potential at various flow exceedances

Potential (MW)	**Number of sites**		
Flow Exceedance	30%	50%	70%
0.1 - 5	0	0	1
5 - 15	0	1	4
15 - 50	1	11	11
> 50	15	4	0
Total Potential	**1,672**	**659**	**307**

However, 2 years cannot give a very satisfactory representation of streamflow variability. Simulation of discharge over many years is recommended to get a good estimate of the streamflow variability and hence the hydropower potential.

5. Conclusion

This paper presents a unique approach for selecting high head ROR sites in the mountainous and snowy basin by taking advantage of the spatial data handling capability of a GIS based environment and the improved snow modelling capability of WEB-DHM-S. 16 sites were detected on the main river with the total hydropower potential of the basin being 659 MW at 50% flow exceedance. The results of this study can help the decision making authorities of Pakistan better utilize and exploit the hydropower resources of the Northern Areas.

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