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Geospatial Technology for Mapping Suitable Sites for Hydro Power Plant

Nagraj S. Patil, I. T. Shirkol, S. G. Joshi

Abstract: ***Hydropower is one possible method of generating electric power close to potential consumers. The accessibility of the possible sites which are mostly located in rural and mountainous areas, large amount of data is required, consumes huge amount of money and time. Since small hydropower schemes, used to produce electrical energy which is benefited for nearby small towns, villages or small industries. Expensive ground investigations must be carefully targeted to the areas which are most likely to yield useful sites for hydropower development. In order to cope with these problems, the present study proposes the use of Geospatial Technology & Soil Water Analysis Tool (SWAT) hydrological model to select the feasible sites of small hydropower projects. The study using the above methodology to identifies suitable site in Bennihalla catchment, for small scale hydropower development. The hydrological factors yield a map representing an overall feasible potential site for small hydropower development. In the present study sub catchment 1 and outlet of the catchment are more suitable for small scale hydropower plant.***

Keywords: ***Micro/ Mini hydropower plant, Geospatial Technology, SWAT Hydrological Model, etc.***

I. INTRODUCTION

Water is a precious, finite and scarce natural resource. It is a prime natural resource, a basic human need and a national asset. Clean and fresh drinking water is essential to human and other life forms. It is an essential natural resource for ecological sustenance, agriculture productivity, industrial growth, power production etc. In the recent times the non-renewable and exhaustible sources of energy are getting depleted at a very fast rate, which has focused attention to the non-exhaustible and renewable sources of energy. Hydropower is one of the most common renewable sources abundantly available in the hilly region. However, large hydro power plants are not being taken up for execution in sufficient number as these involve huge amount of funds and also the planning and construction period is very high. Therefore, with the increasing demand for power, the activities on small hydropower projects have accelerated in recent times. The small hydropower schemes are the appropriate solution to power demand as these require small capital investment and can be completed in a very short period of time. Small hydropower plant, one of the earliest energy sources, has recently caught the countrywide attention despite a history of 100 years behind it, mainly because it is eco-friendly, has a short gestation period.

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The economic viability can be improved by using cost effective designs and new technology based turbines, controls, equipment and materials. In the present scenario of energy starvation, danger of global warming and depletion of fossil fuels and their rising prices, the small hydro has assumed significant complimentary role in the hydropower development, as means of environmental protection and socio-economic development of remote rural areas.

II. STUDY AREA

Bennihalla catchment is a tributary of Malapraba river, which is situated in Karnataka (Dharwad district) at latitude & longitude of 74:47:43.6 to 75:36:14.6 E, 15:49:33.8 to 15:06:17.02 N. Figure 1 shows the extent of Bennihall catchment.

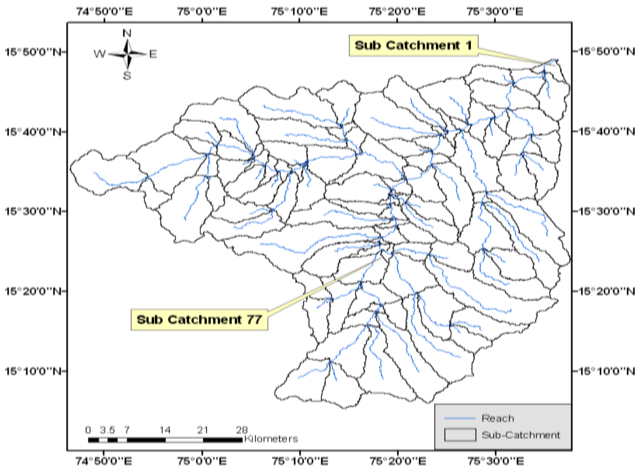

Figure 1. Bennihalla Catchment

III. METHODOLOGY

Small hydropower plant needs flow of water. A sufficient quantity of discharge of water must be available, for which hilly or mountainous sites are best.

In this study, the methodology to identify and assess the potential sites for small run-of-river hydropower projects is done in two basis viz.: 1. Elevation Profile 2. Discharge Analysis.

A. Elevation Profile

Head is the vertical distance that waterfall. It is usually measured in meters. Most small hydropower sites are categorized as low or high head. The higher head consumes less water to produce a given amount of power, and can use smaller, less expensive equipment. Low head refers to a change in elevation of less than 10 feet (3 meters). A vertical drop of less than 2 feet (0.6 meters) will probably make a small scale hydroelectric system unfeasible.

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B. Identification of sites having suitable head

- Catchment boundary is delineated using DEM and SWAT model.
- It is found that the elevation ranged from 400 m to 843 m in the watershed and using the DEM the flow direction map is generated.
- The direction of flow is determined by finding the direction of steepest descent from each cell.
- Flow accumulation map is created using the flow direction map. The flow accumulation function calculates accumulated flow, as the accumulated weight of all cells flowing into each down slope cell in the output raster. In the present work the flow accumulation ranged from 0 to 470716 in terms of cells.

Suitable sites are identified by using the DEM and flow accumulation map. While identifying the location of the sites, aspect map was also taken into consideration.

C. Classify-According to head

Head is classified using spatial analyst tool, of ArcGIS and as per the analysis sub catchment 1 and 77 have head availability up to a maximum of 90m. Sub Catchment 1 is at outlet of entire catchment and 77 being at middle of the entire catchment. Figure 2 shows slope map of the Catchment.

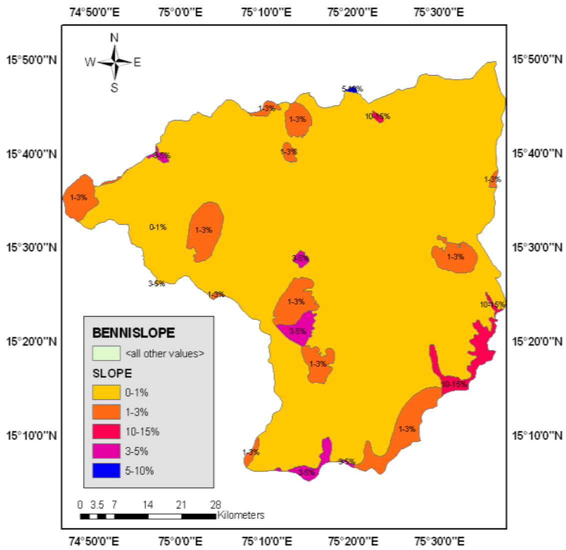

Figure 2. Slope Map of Catchment

IV. DISCHARGE ANALYSIS

Soil Water Assessment Tool (SWAT) model was set up for the Catchment to simulate the flows for the entire Catchment.

A. SWAT Hydrological Model

Soil Water Assessment Tool (SWAT) model is a river basin model developed to quantify the impact of land management practices in large watersheds to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large watersheds with varying soils, land-use, and management conditions over long periods of time [1]. SWAT has been widely used to study the spatial and temporal variations in stream-flow. The SWAT model was tested mainly on monthly and annual basis for predicting runoff and sediment yield [3] [8] [9] [11] [17]. At the same time SWAT model has also been validated on Indian watershed, on basis of daily and monthly runoff and sediment yields [12] [13] [14].

B. Data Requirement for Modelling

The data required for modelling the Bennihalla Catchment includes both, the static data and the dynamic data. A brief description of these data and its processing is described below:

Spatial Data

Spatial data used for the study area include:

A. Digital Elevation Model (DEM)

Shuttle Radar Topography Mission (SRTM) 90m resolution digital topographic database of Earth. SRTM data is developed by NASA and is in public domain. Figure 3 shows the DEM of the study area.

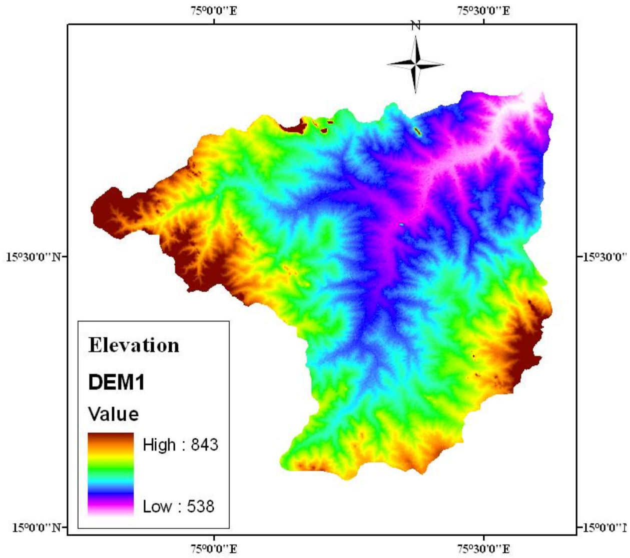

Figure.3. Digital Elevation Model (DEM) of the study area

B. Soil Layer Model:

FAO Digital Soil Map (Figure 3) of the world having scale of 1:5,000,000 has been used for the present study.

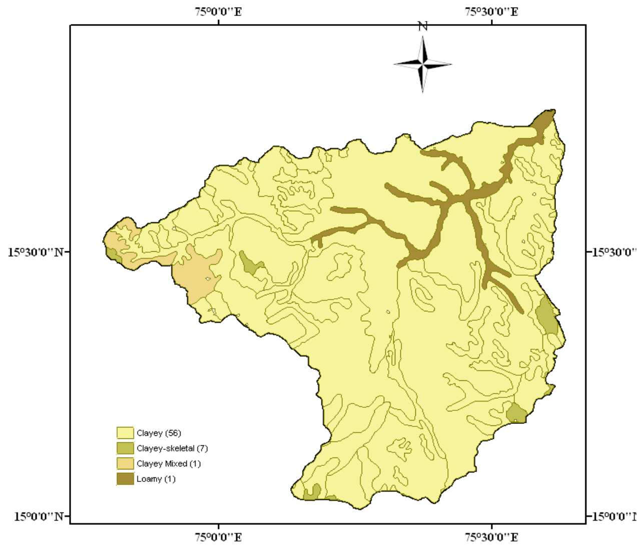

Figure 3. Soil Map of the Study Area

C. Land Use Layer

Land use layer for the study area (figure 4) was taken from the Global Land Cover Facility, with a resolution of one kilometer gird cell size.

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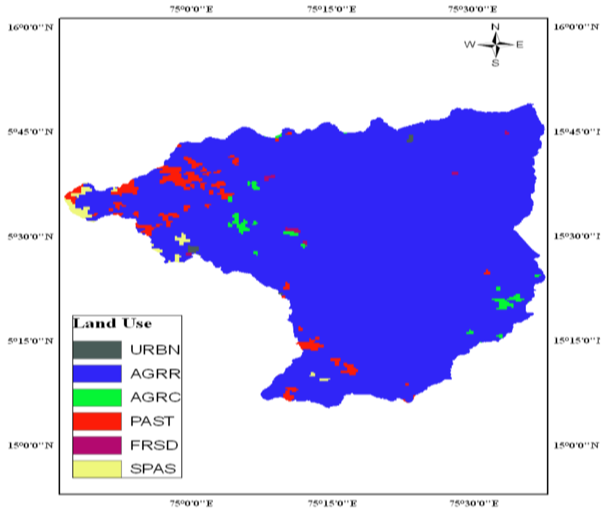

Figure 4. Landuse of Bennihalla Watershed (Source: Global Landuse)

D. Dynamic Data

Dynamic Data used for the study area include

1. High resolution (0.5° x 0.5° Lat/Long) girded daily rainfall data for the period 1986-2004, developed by National Climate Centre IMD Pune, India.
2. High resolution (1° Lat x 1° Long) daily girded temperature data set for the period 1986-2004, developed by National Climate Centre IMD Pune, India.
3. In the absence of other daily weather data on solar radiation, wind speed and relative humidity, long term statistics have been used to generate these weather parameters, developed by National Climate Centre IMD Pune, India.

C. Model Set Up

The SWAT hydrological model was set up for Bennihalla Catchment and was executed using IMD girded data for the period 1990-1997. Flow was simulated for the various Sub Catchments.

A. SWAT Model Calibration

Model calibration consists of changing values of model input parameters to match observed watershed response within some acceptable criteria. A careful study of the input parameters and its sensitivity of the output are required before calibration [7]. Lack of parameter characterization may lead in a model that may behave well for performance statistics but in reality it may not be true representative of the watershed characterization. The calibration period for the SWAT model was taken 1982-1989. The validation of the model is a verification process to ensure that the parameters tuned during calibration period are performing better or in similar manner in different time domain as well. The term calibration and validation are sometimes used as training and testing, respectively. The SWAT model was validated for the 1990-1997 for monthly stream flow. The model performance was evaluated using two objective functions. The most commonly used Nash-Sutcliff efficiency (NSE) [6] (equation 1) and correlation coefficient (R) as defined below [5]. The NSE can be thought of as the sum of the deviations of observations from a linear regression line with a slope of 1. Efficiencies equal to 1 indicate a perfect fit between the observed and predicted data, while values equal to 0 indicate that the model is predicting no better than using the average of the observed data. Negative efficiencies generally indicate that the average value of the output is a better estimate than the model prediction. Table 1 shows the List of parameters and final calibrated values.

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean}\right)^2} \right] \quad \ldots (1)$$

Table 1: List of parameters and final calibrated values

Parameter	Name	Initial Value	Final Value
CN2	Curve number	66-84	70- 92
GW_REVAP	Ground water re-evaporation coefficient	0.02	0.2
REVAPMN	Threshold depth of water in the shallow aquifer for re-evaporation to	1.0	90
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	0	2000
GW_DELAY	Groundwater delay (days)	31	20
ALPHA_ BF	Base flow recession fraction	0.048	0.002
RCHRG_DP	Deep aquifer percolation fraction	0.05	0.1

Figure 5 shows the Comparison of Simulated and Observed monthly flow for monthly time scale for the Validation Period.

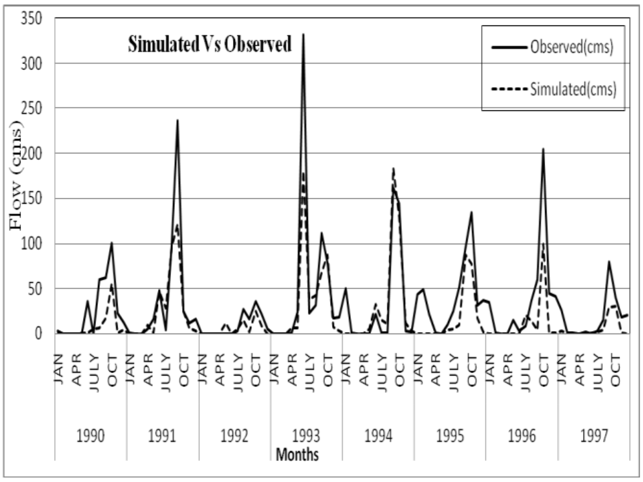

Figure 5. Comparison of Simulated and Observed monthly flow for monthly time scale for the Validation Period.

Figures 6 provide the scatter diagram between the model simulated and the observed flows during validation period. The value of R^2 (0.73) during calibration and R^2 (0.785) during validation indicates a good agreement between the simulated and measured values of monthly flows during calibration as well as validation period. Note that reported values of R^2 for various watershed across the globe computed at monthly time-scale during SWAT calibration validation range between 0.63 and 0.98 [2] [4] [10].

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It may further be noted that the efficiency of the model (NSE), which is a measure of the model's ability to predict values away from the mean is good during calibration (0.72) and validation (0.68), as per the general performance rating for recommended statistics for a monthly time step [5].

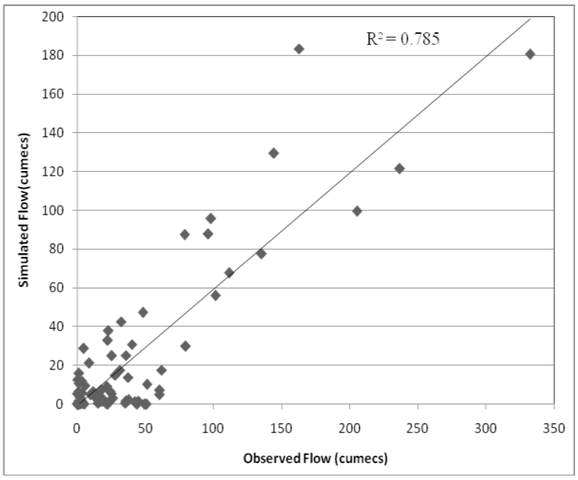

Figure 6. Scatter plot of monthly values of simulated and observed flow for model Validation at a monthly time scale

V. CLASSIFYING ACCORDING TO FLOW DURATION CURVE

The flow duration curve provides a means of representing the variability of flow at a proposed hydropower site in a concise graphical fashion. Flow duration curves have proven to be useful in hydropower design. After analyzing the all the sub catchment with respect to the flow, the sub catchment 77 and catchment outlet is selected for the flow analysis. Figure 7 and 8, shows the flow duration curve for the at the sub catchment 77 and at the outlet of the catchment.

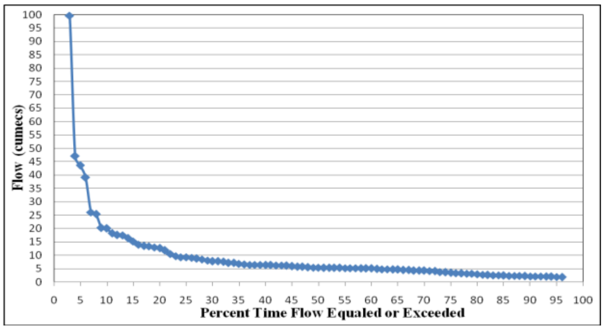

Figure 7. Flow Duration Curve for the Sub-Catchment 77

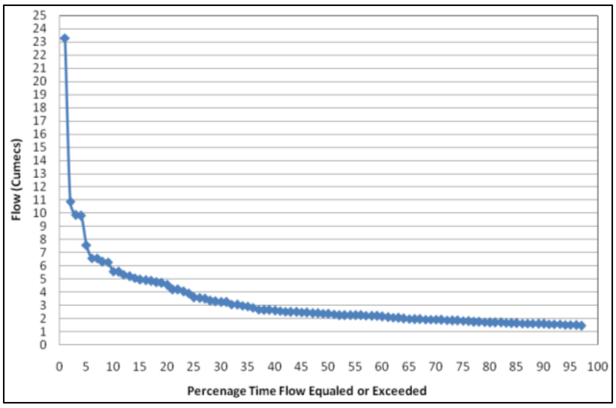

Figure 8. Flow Duration Curve at the Outlet of the catchment

a. Firm (Dependable) flow

The Firm flow is defined as the flow being available p% of the time, where p is a percentage specified by the user and usually equal to 90%. The firm flow is calculated from the available flow-duration curve. Firm flow at the subcatchment 77 (from figure 7) is equal to1.42 m^3/s and that at the outlet of the catchment (from figure 8) is equal to1.96 m^3/s.

VI. ESTIMATING POWER OUTPUT

The power output for a system is computed based on the equation proposed by the U.S. Department of Energy (DOE), for small hydro power plant [15], which is representative of most small hydropower systems. Multiply net head (the vertical distance available after subtracting losses from pipe friction) by flow (use U.S. gallons per minute) divided by 10. Which will yield the system's output in watts (W).

Power Output for Sub-Catchment 77
Power Output= net head [(feet) x flow (gpm)]/10 = W.
Power Output = (50 x 22507.45)/10 = 1125.37 KW
Power Output at the outlet of Catchment:
Power Output = (70 x 31066.63)/10 = 2174.66 KW

With the estimate power output from the sub catchment 77 and outlet of the catchment, it can be proposed, for micro hydro power plant.

VII. CONCLUSION

In the past, Small Hydro Power Plant resources survey has been carried out using onsite surveys and paper maps, which incurred a great deal of time and cost. Furthermore, when covering a large area, this traditional approach becomes time-consuming and might reduce the reliability of the results due to mistakes in manual work and by the influence of subjective judgment and errors. In contrast, the location analysis methodology proposed in this study is able to precisely survey a larger area than could be accomplished within a short period of time, significantly improving the convenience of the user. Hence the application of Geospatial technology in mapping of suitable site of Small Hydro Power Plant overcomes the difficulties faced in the old conventional method.

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