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Geomorphological Parameters: Are they Indicators for Installation of a Hydropower Site?

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ABSTRACT

Assure power potential is a key factor to run the hydropower successfully. Power potential is mainly regulated by the head and flow available at site which is nothing but the capacity of a catchment, underlying the hydropower, to produce the runoff. The capacity of gauged catchments can be obtained by available flow records but for ungauged catchments it is still ambiguous.

Hence this study has been initiated to determine the capacity of ungauged catchment to produce runoff through geomorphological study as prior investigation to install hydropower. An ungauged catchment of Solani River, a tributary of the Ganges from northern India hilly terrain, has been chosen for investigation. Further, the catchment has been divided in five sub catchments (sub catchments 1 to 5) to study the catchment capacity to produce runoff more precisely. Geographical Information System (GIS) has been used as a tool for geomorphological parameter estimation.

The study reveals that the sub catchment 1 is of medium size among all five sub catchments but having maximum drainage density (1.11 km/km^2) and maximum available relief ratio (0.023), which demonstrates better capacity to produce runoff among all. Hence sub catchment 1 can be considered as a site of interest for hydropower installation on Solani River as prior survey basis. Further, the relief value and slope value within the sub catchment 1 measured on main stream which used to explore the hydropower site.

1 INTRODUCTION

To decide if a hydropower scheme will be viable or not, it is necessary to begin by evaluating the water resource existing at that site. Mostly the hydropower sites can be installed in the hilly areas because of freely available water head and flow availability [Ramos, 2000] which helps to run the turbines smoothly. For selection of hydropower site topography and geomorphology survey are essential [Penche and Minas, 1998]. Moreover, the survey in hilly areas is quite drastic due to unavailability of transportation facility, bad climate, land sliding etc. In such case, the SRTM data available on internet [http://srtm.csi.cgiar.org/] is the boon to the surveyor for prior analysis of the area, for selecting a site through geomorphological study, in an office, rather than investigating the site through various field visits.

Hence in the present study, geomorphological study of an ungauged catchment of Solani River, a tributary of the Ganges from northern India hilly terrain was investigated to judge its capacity to produce runoff and head. Most of the hydrological analyses incorporate morphologic parameters as important base for the computation of runoff, infiltration and susceptibility to erosion within the catchment. One of the basic formulas is rational formula. A Morphometric study evaluates the streams through the measurement of various stream properties. River basins comprise a distinct morphologic region and have special relevance to drainage pattern and geomorphology [Doornkamp and Cuchlaine, 1971; Strahler, 1957]. Geographical Information system (GIS) has been employed for the estimation of the various geomorphologic parameters of the catchment.

2 STUDY AREA AND DATA

An ungauged catchment of Northern India hilly terrain, Solani River, tributary of the Ganges, which originates from Shiwalik orographic region and is a part of hydro-meteorological subzone 6 and 7 of India has been chosen. The extent of Solani watershed is from $77^o 45'22''E$, $30^o 16'21''N$ to $78^o 06'07''E$, $29^o 30'24''N$. A digital elevation model (DEM) with a resolution of 90 m SRTM data available on http://srtm.csi.cgiar.org/ were used as a base for the delineation of Solani river catchment and sub catchments (Fig. 1) and the data presented in SRTM DEM was cross checked with the scale of 1:50000 topographic maps issued by Survey of India.

3 METHODOLOGY

3.1 Extraction of stream networks

Surface stream features were extracted by means of ARC/INFO GIS [ESRI Inc., 2005] from the SRTM DEM. The ordering of the extracted streams was further defined using ARC/INFO according to Strahler's system [Strahler, 1952]. In this classification approach, streams with no tributaries are defined as first order; two first-order streams join to form a second-order stream. In general, two streams of the same order join to form a stream with a stream order increased by one. Fig. 2 shows the extracted stream pattern of different orders in the study area.

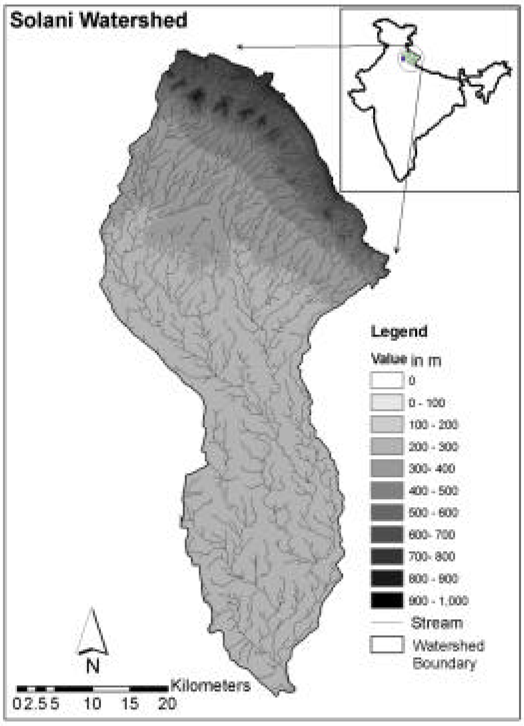

Fig. 1: Elevation map of Solani catchment

Fig. 2: Drainage density map of Solani catchment and its five sub catchments

3.2 Drainage Analysis

A drainage map of a basin provides a reliable index of the permeability of the rocks and also gives an indication of the yield of the basin [Wisler and Brater 1959]. The yield of a catchment is the flow per unit area and normally includes surface-water flows unless mentioned otherwise. Morphological parameters along with hydrological parameters are used to quantify and simulate the hydrological behaviour of the various catchments, particularly ungauged catchment [Maidment 1993; Chalam et al. 1969]. Drainage density map of the Solani catchment prepared from the SRTM data is given in Fig. 2.

The morphometric parameters were analysed and divided in three categories: (i) basic parameters, (ii) derived parameters and (iii) shape parameters. (i) Basic parameters includes area (A), perimeter (P), basin length (L), stream order (N_u), stream length (L_u), maximum (H) and minimum (h) heights. (ii)Derived parameters consist of bifurcation ratio (Rb), stream length ratio (Rl), RHO coefficient (RHO), stream frequency (Fs), drainage density (D_d), drainage texture (T), basin relief (R), relief ratio (Rr), constant of channel maintenance (Cm) and length of overland flow (Lg) (iii) shape parameters comprise elongation ratio (Re), circularity index (Rc) and form factor (Ff).

The drainage network of the basin was analysed as per Horton's [1945] laws and the stream ordering was made after Strahler [1964]. For brevity, detailed equations of basic parameters, derived parameters and shape parameters are not included in the text and reader may refer to the respective publications [Mesa, 2006; Reddy et al., 2004; Pakhmode et al., 2003] for basic equations associated with each parameters.

4 RESULTS

Total drainage area of Solani river catchment is 1552.047 km^2 and was divided into five sub catchments for the analysis (Fig. 2) viz. sub catchments 1, 2, 3, 4, and 5. Sub catchment 5 is the smallest (282.217 km^2) and sub catchment 3 is biggest (354.456 km^2) among the others.

Detailed analysis of basic parameters of Solani catchment and its five sub catchments are presented in Table 1. Sub catchment 4 has the highest (147.894 km) and sub catchment 1 is lowest (83.326 km) P value. The parent catchment length is 91.973 km; Sub catchment 4 and 1 has the longest (55.343 km) and shortest (27.074 km) value of L. The maximum height of Solani catchment is 908 m in the northern sector, in sub catchment 1, and the minimum height is 221 m in southern sector, in sub catchment 5, (Fig. 1). Stream Number relationship among Solani catchment and its five sub catchments are presented in Fig. 3 on the basis of Horton's first law [Horton, 1945]. Parent catchment is of sixth order, sub catchment 2 and 3 are of fifth order while sub catchment 1, 4 and 5 are fourth order catchments. The GIS analysis shows that lower order streams mostly regulate the catchment. The drainage network of the watershed is effective to provide a sufficient superficial draining with a high number of streams of low order that flow directly in the principal collector or in upper order streams. Stream length relationship of Solani catchment and its five sub catchments are presented in Fig. 4 on the basis of Horton's second law [Horton, 1945].

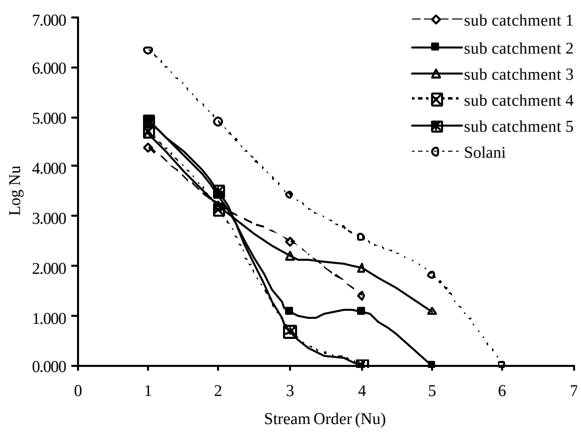

Fig. 3: Stream Number relationship among Solani catchment and its five sub catchments (1 to 5) on the basis of Horton's first law

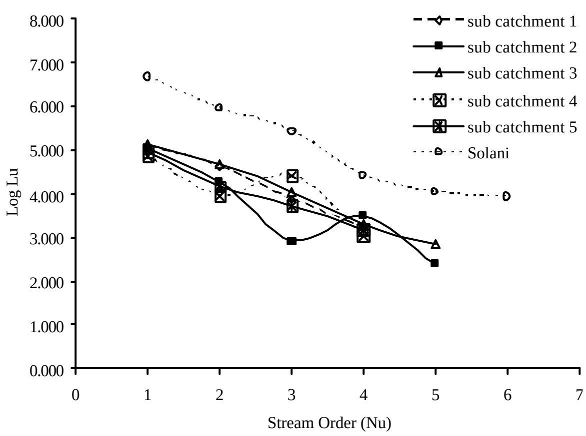

Fig. 4: Stream length relationship among Solani catchment and its five sub catchments (1 to 5) on the basis of Horton's second law

Derived parameters of Solani river catchment and its five sub catchments are shown in Table 2. Among the derived parameters, Rb for the catchment and sub catchments are the expected values relative to steep areas and the mean Rb (3.193) of parent catchment indicates that the drainage pattern is not much influenced by geological structures [Strahler 1964]. This value also is in relationship with the elongate shape of the catchment [Schumm 1956]. The Rb of the five sub catchments varies from 1.387 to 3.775. The relief R of the parent catchment is 687 m and that of the five sub catchments are depicted in Table 2. The higher R value (621.0) of sub catchment 1 is due to physiographic steep structure of the area. The sub catchment 2 having least value of D_d . Comparison of D_d and Cm among all sub catchments shows that sub catchment 1 have major contribution of runoff among all having maximum value of D_d (1.114) and least value of Cm (0.897). Relief ratio (Rr) of parent catchment is 0.0075 whereas among all sub catchment, sub catchment 1 having maximum Rr i.e. 0.0229. Higher value of Rr is an indicator of quick depletion of water, which results in large peak and steep limb hydrograph and it is also a measure of potential energy available to move water and sediment down slope.

Shape parameters of Solani river catchment and its five sub catchments are shown in Table 3. The values of Re are greater than $\mathrm{R}c$ values in case of parent as well as sub catchments which demonstrate the elongated shapes of the all catchments.

Table 1. Basic parameters of Solani catchment and its five sub catchments (1 to 5).

Basic Parameter	**Sub catchments**					**Parent catchment**
	1	**2**	**3**	**4**	**5**	
A (km^2)	300.829	313.255	354.456	301.290	282.217	1552.047
P (km)	83.326	90.550	96.209	147.894	102.801	233.144
L (km)	27.074	33.689	38.650	55.343	40.013	91.973
N1	81	140	107	112	137	574
N2	25	31	25	23	33	132
N3	12	3	9	2	2	31
N4	4	3	7	1	1	13
N5	0	1	3	0	0	6
N6	0	0	0	0	0	1
NT	122	178	151	138	173	757
L1	1.999	1.098	1.602	1.144	1.050	1.375
L2	4.012	2.303	4.292	2.300	1.940	2.891
L3	3.957	6.190	6.260	41.395	20.650	7.417
L4	6.373	11.128	3.860	20.721	23.683	6.385
L5	0.000	10.871	5.680	0.000	0.000	9.470
L6	0.000	0.000	0.000	0.000	0.000	50.711
LT1	161.952	153.764	171.405	128.117	143.784	789.466
LT2	100.306	71.389	107.293	52.902	64.024	381.673
LT3	47.481	18.569	56.338	82.790	41.301	229.917
LT4	25.492	33.383	27.021	20.721	23.683	83.007
LT5	0.000	10.871	17.041	0.000	0.000	56.822
LT6	0.000	0.000	0.000	0.000	0.000	50.711
LT	335.232	287.976	379.098	284.530	272.793	1591.595
H (m)	908	345	858	720	280	908.000
h (m)	287	244	243	222	221	221.000

Table 2. Derived parameters of Solani river catchment and its five sub catchments (1 to 5)

Derived Parameter	Sub catchment					Parent catchment
	1	2	3	4	5	
Rb1	3.240	4.516	4.280	4.870	4.152	4.348
Rb2	2.083	10.333	2.778	11.500	16.500	4.258
Rb3	3.000	1.000	1.286	2.000	2.000	2.385
Rb4	0.000	3.000	2.333	0.000	0.000	2.167
Rb5	0.000	0.000	0.000	0.000	0.000	6.000
Rb6	0.000	0.000	0.000	0.000	0.000	0.000
Rb	1.387	3.142	1.779	3.062	3.775	3.193
Rl 1	0.619	0.464	0.626	0.413	0.445	0.483
Rl 2	0.473	0.260	0.525	1.565	0.645	0.602
Rl 3	0.537	1.798	0.480	0.250	0.573	0.361
Rl 4	0.000	0.326	0.631	0.000	0.000	0.685
Rl 5	0.000	0.000	0.000	0.000	0.000	0.892
Rl 6	0.000	0.000	0.000	0.000	0.000	0.000
Rl	0.272	0.475	0.377	0.371	0.277	0.504
RHO	0.196	0.151	0.212	0.121	0.073	0.158
Dd	1.114	0.919	1.070	0.944	0.967	1.025
Fs	0.406	0.568	0.426	0.458	0.613	0.488
Cm	0.897	1.088	0.935	1.059	1.035	0.975
Lg	0.449	0.544	0.467	0.529	0.517	0.488
T	0.452	0.522	0.456	0.433	0.593	0.500
R (m)	621.000	101.000	615.000	498.000	59.000	687.000
Rr	0.0229	0.0030	0.0159	0.0090	0.0015	0.0075

Table 3. Shape parameters of Solani catchment and its five sub catchments (1 to 5)

Shape Parameter	Sub catchments					Parent catchment
	1	2	3	4	5	
Re	0.723	0.593	0.549	0.354	0.474	0.483
Rc	0.544	0.480	0.481	0.173	0.336	0.359
Ff	0.410	0.276	0.237	0.098	0.176	0.183

5 DISCUSSION

5.1 Evaluation of sub catchment for runoff

From the above results it is revealed that sub catchment 1 have higher capacity to produce stream flow (Q) as it having the maximum D_d , R , Rr and having less Rb , Fs , Cm , Lg among all sub catchments.

5.2 Site selection within sub catchment1

To locate hydropower site main streams of sub catchment 1, having maximum runoff producing capacity, were selected for further analysis for deciding the location of hydropower site. In persistence, main stream of sub catchment 1 is divided in sections successively at 1 km distance from the outlet to locate a point on main stream for hydropower site. Then slope of created sections (0-0 to A-13 and 0-0 to B-7) were calculated (Fig.5). The section having highest slope and R (i.e. A-11 to A-12) is considered as suitable location for hydropower site.

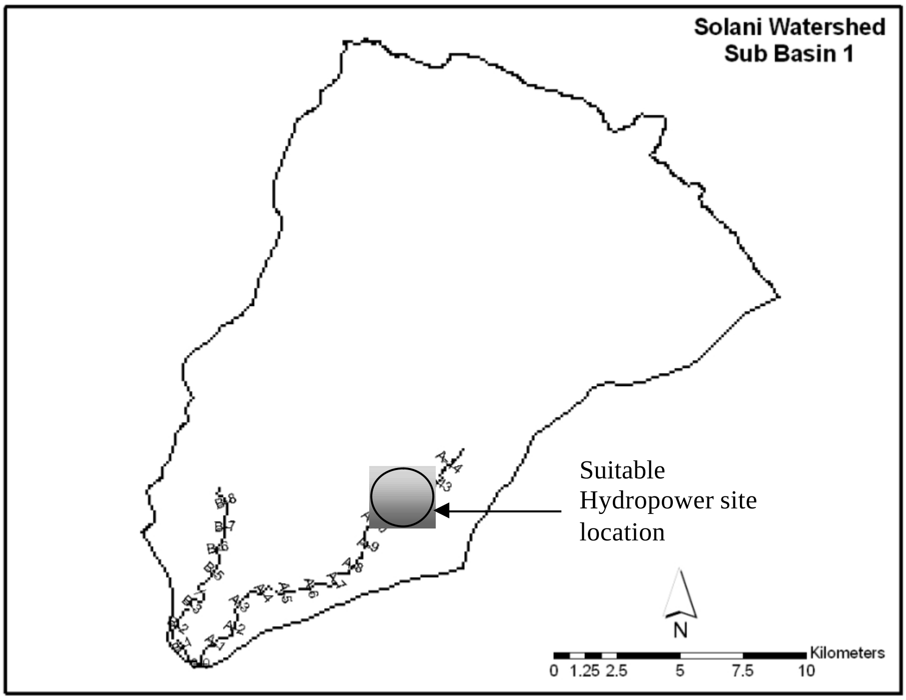

Fig. 5: Main stream of sub catchment 1 with various sections of 1 km from outlet

6 CONCLUSION

This study has been started with the aim of locating a hydropower site on a toposheet in an office rather than deciding the same through various field visits for an ungauged catchment in hilly areas. For this, geomorphological analysis of the catchment was done with the help of SRTM data and toposheets. From this study, following conclusions were drawn:

1) Geomorphologic characteristics can be efficiently used as tool for determination of the catchment capacity to produce runoff under interest of hydropower site.
2) By using freely available SRTM data and toposheet one can effectively decide the location of hydropower site in an office with benefits of cost saving in various field visits, reducing life risk and so on.

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