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Selection of Site for Small Hydel Using GIS in the Himalayan Region of India

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Abstract

The choice of site for small hydro in the inaccessible tracts of Himalayan region is a difficult task by the conventional methods. This leads to a considerable loss of time and money in selecting a proper site for small hydel. In this paper an attempt has been made to use GIS and Remote Sensing technology to arrive at various alternative sites available in the study area and finally to select the most technically suitable site. The Soil Conservation Service (SCS) Curve Number (CN) method has been utilized to identify the monthly average runoff of the site. The distributed curve number technique has been used in this work.

Keywords: Sub-watershed, Remote Sensing, GIS, Curve Number, Runoff.

Introduction

In 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. (Judson Woods, et. al. 1990; Milkailov, L. et. al. 1991). It enhances our energy security and is ideal for meeting the peak demand. Small hydropower projects (SHPs) are normally run-off-the-river schemes with no storage of water. The globally accepted classification for hydro is in terms of power output, but the norms vary from country to country. In India a hydro power plant of capacity lower than 15 MW is termed 'small hydro' (Bahadur J., 1997; Chakrabarti.A.K, 2002, Gosshalk, E.M. et. al., 1989)

In India the Himalayan region provides a suitable tract where small hydels can be located (Kumar.A. et.al, 2002; Grove, M. et. al, 1998). Identifying sites in this inaccessible mountainous area is a tremendous task. Remote sensing and GIS technology can play a vital role in scientific assessment of the suitable sites for such identification, which no other method can provide (Kumar.A. et.al, 2002; Chakrabarti.A.K., 2002).

In this work an attempt has been made to use GIS to identify sites, which suit the head requirement for setting small hydel power plant. GIS has then been used to arrive at the best location within the identified sites. SCS CN method has been used to calculate the average monthly runoff for the identified site. The distributed curve number technique has been used in calculating the runoff. The base flow has been measured at an accessible point in different watersheds/sub-watersheds having similar characteristics in the same area. The streams are all ungauged and so regression analysis has been done to arrive at an equation for calculation of the base flow on the basis of number of pixels draining at the point of measurement and the average slope of the watershed/sub watershed. The base flow at the site in the sub watershed has been ascertained on relational basis. Knowing the total flow and the head the power generating capacity at the site was ascertained.

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One of the watersheds in the Darjeeling district of West Bengal has been selected for this study. The main stream "Balabas" is a perennial stream and has its source from melting of snow in the Himalayan region.

Methodology

The physiographic characteristics of the watershed (Figure 1) are as given below:

Name of Catchment	: Balabas
River	: Balabas
District	: Darjeeling, West Bengal, India
Latitudinal Extent	: 27° 00' 30" N - 27° 04' 48"N
Longitudinal Extent	: 88° 12' 00" E - 88° 16' 12"E
Fed	: Snow
Highest Elevation	: 2332.5 mts.
Lowest Elevation	: 704.5 mts.

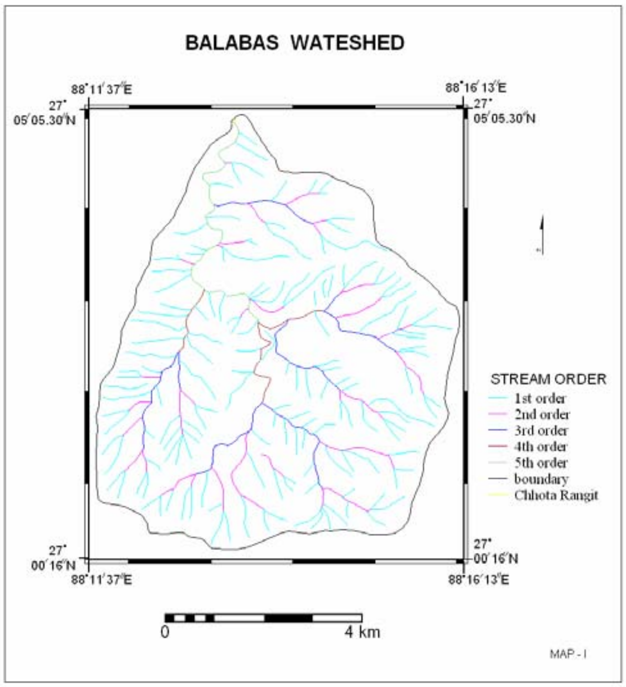

Figure 1: Catchment boundary and streams of Balabas watershed

The basic methodology constitutes of following steps:

i) Identification of sites in the watershed having suitable elevation for small hydel using GIS.

ii) Calculation of available flow of water at the selected site.

a) Calculation of base flow: This has been done by actual measurement of flow at accessible points of various sub-watersheds in the same region and having similar characteristics. The minimum flow has been considered as base flow for that sub-watershed. A regression analysis has been done using the following parameters to determine an equation to identify the base flow of any other sub-watershed of that region:

1. Number of pixels draining at that point where observation has been taken.
2. Average slope of the sub-watershed whose measurement has been done
3. Quantity of flow as measured at actual sites of the sub-watersheds.

The regression equation obtained has been used to calculate the base flow of the selected site for small hydel.

b) Calculation of run off: Runoff of the selected site has been calculated by using distributed CN method in the GIS platform.

c) Total flow: Total flow of the selected site is the sum of the base flow and the runoff.

iii) Calculation of generating capacity: The power generating capacity has been calculated using the formulae:

P = 9.81 * Q * H * E (Prasad. B., 2003) ….. (I)

Where P = Power in kw

Q = Discharge available in m^3/sec

H = Net head in mt

E = Overall unit efficiency (85% to 90%)

Results and discussion

Identification of sites having suitable head

Catchment boundary was located using the contour lines on a topographical map. Boundary was drawn by following the ridge tops, which appear on topo maps as downhill pointing V-shaped crenulations. The contour map of the watershed, having a contour interval of 10mts, was digitized to create the contour map of the watershed and this map was used to create the digital elevation model (DEM) of the study area. It was found that the elevation ranged from 704.5mts to 2332.5mts in the watershed. Using the DEM the flow direction map was generated. The direction of flow was determined by finding the direction of steepest descent from each cell. Flow accumulation map (Figure 2) has been created by 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 study area the flow accumulation ranged from 0 to 44336. The area which has the flow accumulation 10000 or more has been extracted from the flow accumulation map. Suitable sites have been identified by using the DEM and flow accumulation map. While identifying the location of the sites, aspect map was also taken into consideration. The details of the site as identified are given below.

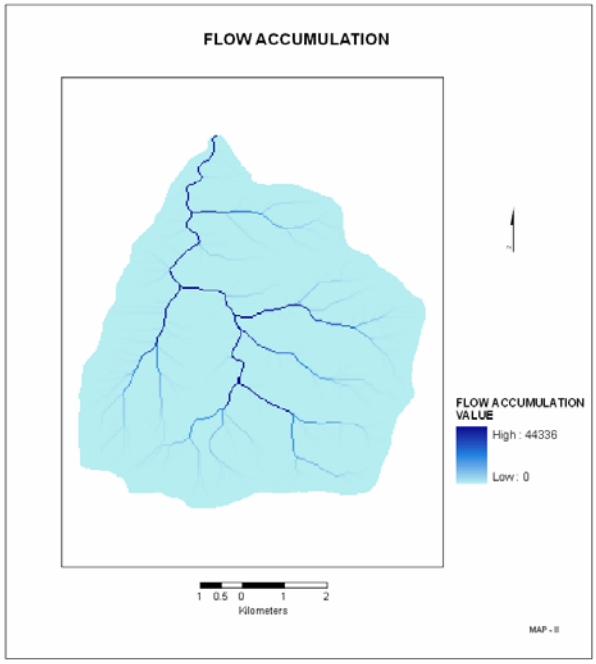

Figure 2: Flow accumulation map of Balabas watershed

Probable location of Generating station: 27°03’05. 36”N, 88°12’42. 35”E

Probable location of reservoir: 27°03’05. 36”N, 88°13’30. 36”E

Details of Penstock are given below in Table 1:

Table 1: Specification of Penstock

Elevation		Distance	Existing natural Gradient
From	To		
978.2m	880m	650m	1 in 6.6

Details of Headrace are given below in Table 2:

Table 2: Specification of Headrace

Sl.No.	Coordinates of determined location of drawing of water	Elevation		Distance	Existing natural Gradient
		From	To		
1	27°02'28.04"N 88°12'42.35"E	1055m	978.2m	2290m	1 in 29.8
2.	27°03'01.23"N 88°13'34.26"E	990m	978.2m	186m	1 in 15.7

Identification of flow

<u>Calculation of base flow</u>

The minimum flow of water at the point of measurement throughout the year has been considered as the base flow. This has been measured at accessible locations of five sub-watersheds (Figure 3) in the same region having similar characteristics, through a considerable period using pygmy type flow meter. The contour maps and boundary maps of the sub-watersheds were prepared. The number of pixels draining into the point where measurement has been taken was determined using ARCGIS. The slope map provided the average slopes of the sub-watersheds. The details are as given in Table 3.

Table 3. Details of the sub watersheds used for regression analysis

Sl.No.	Name of Sub-watershed	Number of pixels draining into the point (N)	Flow in m^3/Sec (Q)	Average slope in degrees (G)
1	Pala	188414	0.15	25.53
2	Git2	1608289	0.31	18.96
3	Git1	124658	0.42	24.51
4	Khani	197367	0.07	26.70
5	Rilli	587950	0.49	22.34

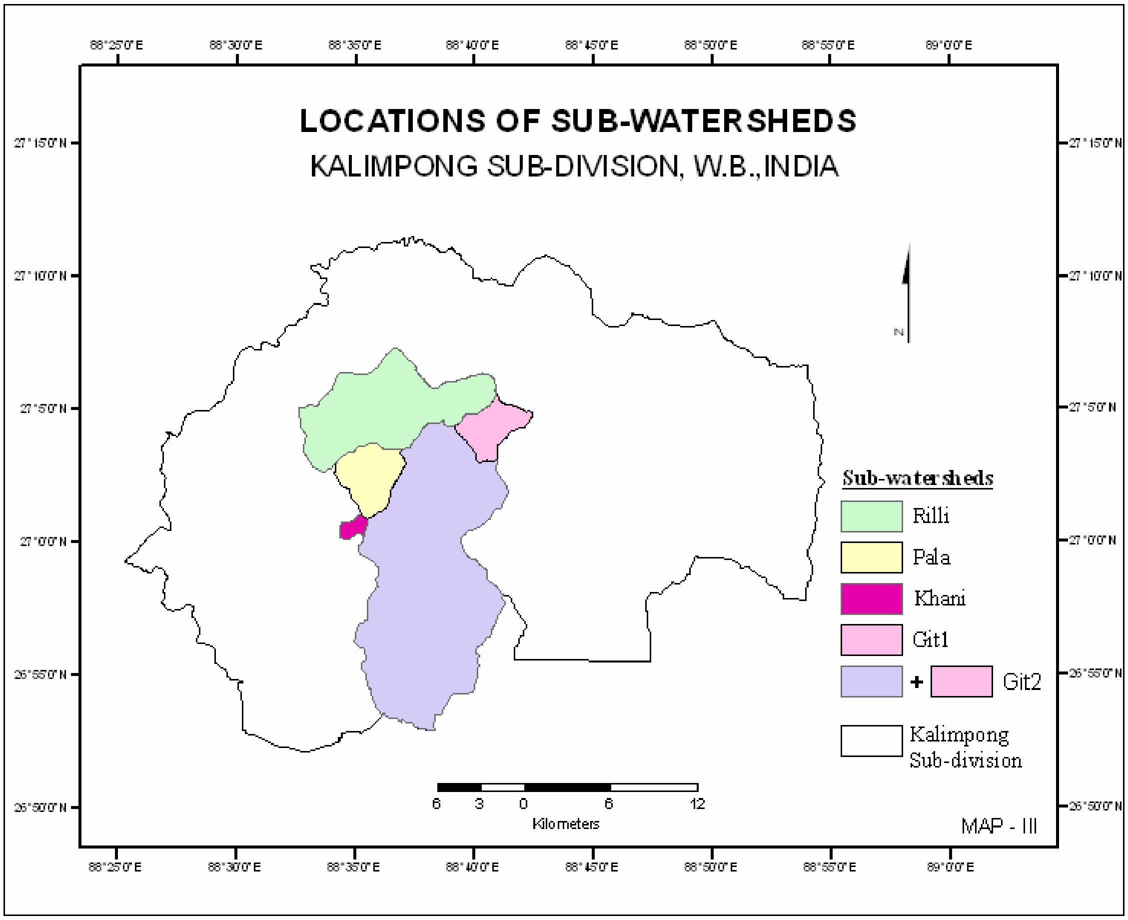

Figure 3: Location of sub-watersheds used for base flow calculation

Regression analysis of this data yielded the following relationship:

$Q = 4.329 – 6.50 \times 10^{-7} * N – 0.156 * G$ ….. (II)

Where Q = Flow in m^3

N = Number of pixels draining into the point

G = Average slope in degrees of the sub-watershed.

The result of correlation between the observed and predicted values of the dependent variable showed a very strong positive relationship with R value of 0.969.

The equation was validated on Balabas watershed and the results obtained are as tabulated (Table 4) below:

Table 4: Calculated Flow of Balabas watershed

Measured velocity of water in (m/sec)	Area of the stream at the point of measurement in m^2	Flow calculated from the observation (m^3/sec)	Number of pixels draining into the point of measurement	Average slope of the sub watershed	Calculated flow in (m^3/sec)
0.45379	1.915	0.87	49147	22.13	0.845

The calculated and the observed results showed a moderately good correlation and can be used for finding base flow of sites for small hydels.

The sub-watershed, which has been selected as site for small hydel has 29241 pixels draining at that point and has an average slope of 24.32 degrees. The amount of base flow as calculated from equation (II) is 0.52 m^3/sec.

Runoff using distributed CN method:

The SCS CN method is the most widely used technique for estimating surface runoff for a given rainfall event from small watersheds. It has been found from different simulation runs that estimated runoff depth using distributed CNs is about 100% higher than that when composite CN values are used (Report of UNDP-GEF, 2002; Stube, M.M and Johnston, D.M, 1990; White, D. 1998). In the SCS curve number method the runoff is determined as follows:

$$V_R = (P - 0.2S)^2 / (P + 0.8S)$$
$$S = (2540 / CN) - 25.4$$
$$V_A = (V_R / 100) * A$$

Where V_R = Runoff (rainfall excess) in cm.
P = Precipitation in cm.
S = Maximum potential abstraction after runoff begins.
CN = A constant which is dependent on landuse and soil type.
V_A = Runoff of the sub-watershed in m^3/sec.
A = Area of the sub-watershed in m^2.

There are three types of soils in the area. One is deep, well-drained, fine loamy soil occurring on steep side slopes. The second type is excessively drained, coarse, loamy soil occurring on gentle slopes. The third type of soil is shallow, well-drained, gravelly loamy soil occurring on steep slopes. The area consists of four landuse types. Using the soil type and landuse map CN values for different pixels of the watershed map has been assigned using ARCGIS (Figure 4). Antecedent moisture condition II has been taken into consideration for the analysis. Using CN value map the maximum potential abstraction map has been prepared. The total monthly precipitation has been determined by averaging last three year's monthly precipitation of the watershed. The part of Balabas watershed, which is contributing its runoff to the selected site, has been considered as a sub-watershed. The area of the sub-watershed has been determined from the boundary map of the sub-watershed. The monthly precipitation, potential abstraction map and the sub-watershed map have been utilized for identifying the monthly runoff of the sub-watershed. The value so obtained, the total flow and power generating capacity at the selected site determined using eqn. I is as given in Table 5.

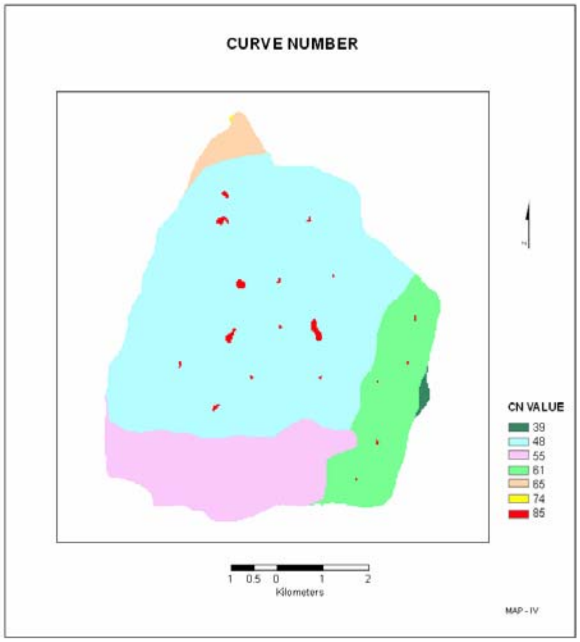

Figure 4: Curve Number Value of Balabas Watershed

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Table 5: Total monthly flow and power generation of the selected sub-watershed

Month	Rainfall in mm.	Runoff in m^3/sec of the sub-watershed (V_A)	Base flow calculated from eqn 1I in m3/sec (Q)	Total flow In m^3/sec of the sub-watershed (V_A+ Q)	Power generated in KW calculated from eqn.I
January	10.9	0.04805476	0.52	0.568	474.00
February	31.7	0.24836505	0.52	0.768	641.00
March	54.1	0.42845209	0.52	0.948	791.2
April	113	1.0080967	0.52	1.528	1275.4
May	237.4	2.0827619	0.52	2.602	2171.8
June	597.1	5.69238932	0.52	6.212	5185.1
July	792.2	7.33710741	0.52	7.857	6558.2
August	634.4	5.85830251	0.52	6.378	5323.7
September	445.5	4.22449356	0.52	4.744	3959.8
October	142.2	1.24825981	0.52	1.768	1467.4
November	29.6	0.16674616	0.52	0.686	572.6
December	6.3	0.0171987	0.52	0.537	448.2

The determined power generation capacity indicates that the site (Figure 5) has a potential for installation of small hydel plant.

Conclusions

Location of sites in hilly terrain like Himalayas can be a very difficult task, which may lead to selection of erroneous locations for the different components of a small hydel plant. GIS with its spatial and three-dimensional capability can be successfully used for this purpose. Use of GIS can reduce the number of locations to a handful and these locations can then be verified and detailed by further scientific methods. Though the work has been done on a contour map of 10m. contour interval, but it would be better if maps with lower contour interval were available. This will enhance the accuracy of the work. While selecting sites for small hydel, it is one of the foremost necessities that cost parameters should be low, as the return from investment is not so high. The methodology proposed can reduce the preliminary cost to a great deal, and hence improve the cost benefit ratio of such an installation.

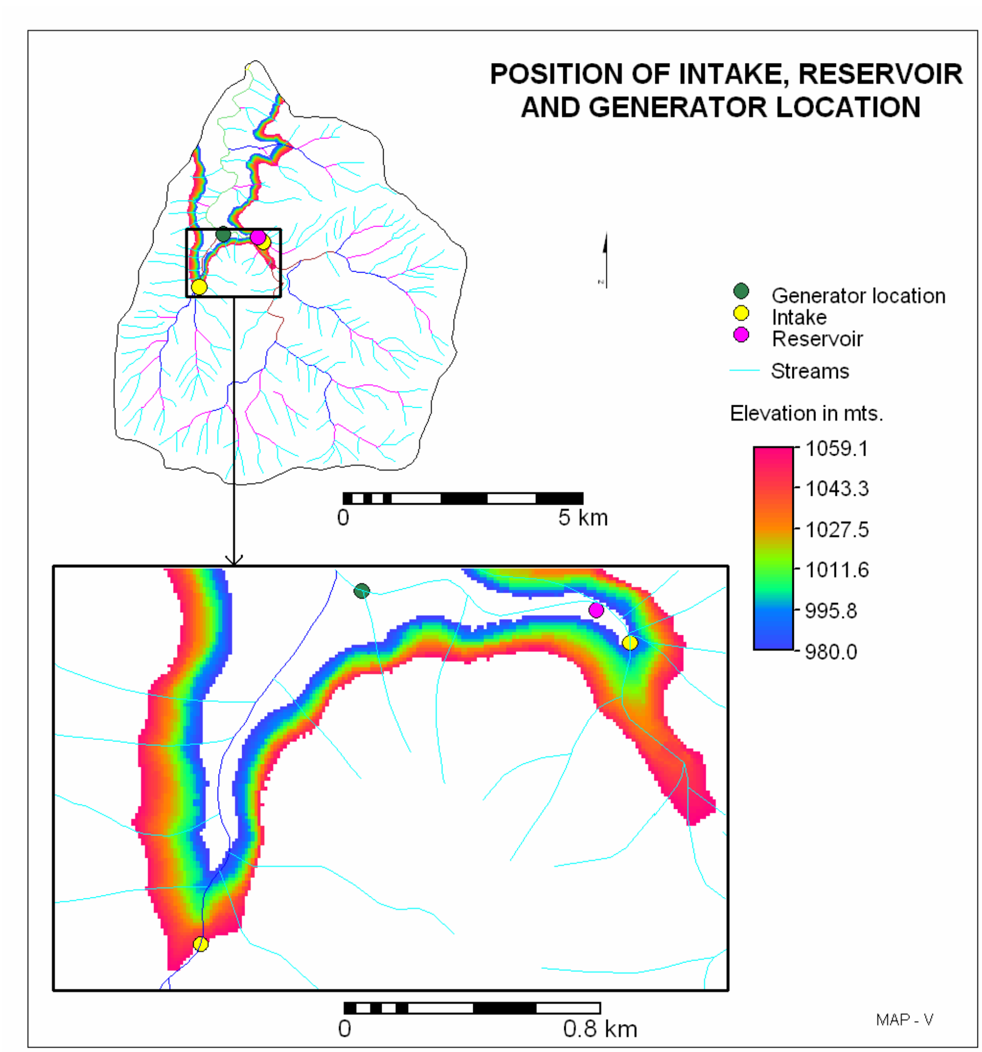

Figure 5: Selected positions for intake, reservoir and generator location in Balabas watershed

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