Application of GIS and Remote Sensing Techniques for Effective Watershed Management

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Abstract- **Water is primary element for every form of life on the Earth. GIS and Remote Sensing are very important and useful tools for evaluating or finding characteristics like geomorphology of any watershed. With the help of GIS and RS this work becomes very easy, less hectic and level of accuracy attained is very high. GIS is not too old technology and still we are trying to find new ways and possibilities to apply it to all aspects of planning. The first step in any management exercise isto identify the watershed area. Watersheds are not always easy to distinguish and define, it is very difficult to define watershed in plane area like Ganga plane. Action plans for conservation of land and water resources, GIS and Remote sensing techniques are used. Survey of India topographical maps, cadastral maps etc. mapsare used to generate spatial database on stream channel network, topographic relief, vegetative maps, soil types, land use, contours, geology, drainage etc. with the help of this primary resource data, the secondary vector layers and data structures corresponding to slope, erosion class, soil depth, land capability etc. are generated. Specific problems are identified on the basis of rules framed to arrive at certain suitable solution for the watershed area. This paper will describe the techniques of GIS and Remote Sensing for watershed management.**

Keywords: Watershed; GIS; Geomorphology; SCS-CN

I. INTRODUCTION

A watershed is an area in which all water flowing into it goes to a common outlet. Watershed is considered the most ideal unit for analysis and management of natural resources for planning point of view. The different phases of hydrological cycle in a watershed are dependent on the various natural features and human activities. Watershed is not simply the hydrological unit but also socio-political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people [1].

Many researchershave described watersheds as an important source of energy, water and biological diversity. Watershed management deals with optimizing the use of land, water, vegetation, and environment to prevent soil erosion, improve water availability, increase, food, fuel and timber production ona sustainable basis [2]. Conservation of watershedsenhances the protection of many habitats that are essential to other life support systems of the planet. For optimal use of environmental resources in a region, integrated watershed development approach is still viewed by many to be the most ideal as it helps in maintaining the ecological basis of resources utilization. To further role of watersheds requires a further digression towards the attributes and the importance of watersheds from a global perspective. With the goal of protecting the Earth's basic riparian resources and environmental systems, the conservation of watersheds is of great importance, in part because they are significant intheir own right, but also because they cover many regions of the world in the form of as forests, which contribute genetic diversity

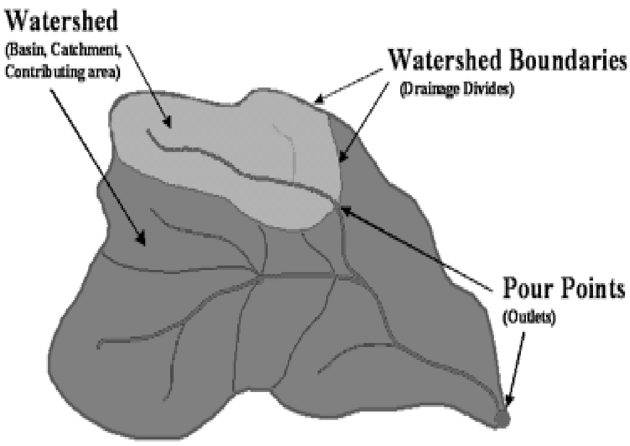

FIGURE 1 A typical watershed showing boundaries and outlets.

II. MATERIALS AND METHODS

A. Delineating Watersheds

Watersheds can be delineated from a DEM by computing the flow direction and using it in the Watershed function as shown in Figure 2. The Watershed function uses a raster of flow direction to determine contributing area.

A flow accumulation threshold or the pour points can be used to delineate watersheds. When the threshold is used to define a watershed, the pour points for the watershed will be the junctions of a stream network derived from flow accumulation. Therefore, a flow accumulation raster must be specified as well as the minimum number of cells that constitute a stream (the threshold value).When a feature dataset is used to define a watershed, the features identify the pour points. The most common digital data of the shape of the earth's surface is cell-based digital elevation models (DEMs). This data is used as input to quantify the characteristics of the land surface.

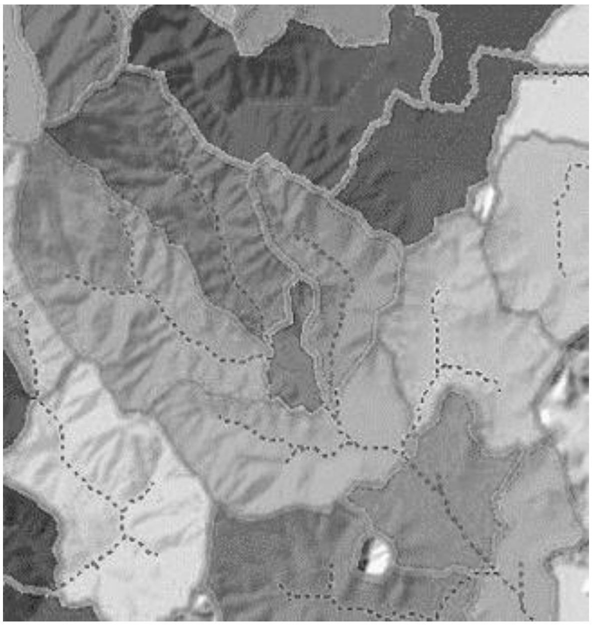

FIGURE2 Delineation of watersheds.

B. Land Use Map Preparation

The land use layer was digitized in ArcGIS using geo-referenced imagery, visual interpretation and ground truthing. The area was digitized and classified in various land uses as Agricultural land, Barren Land, Degraded Forest, Dense forest, Dense greenery, Grassland, Settlement etc. Different land uses can be identified on the basis of the true colour image in Land Sat ETM and ground truthing. Barren lands are identified as those lands, which do not have any cover as seen in image and not under agricultural use. Degraded forest are identified as the area in forested zones, having sparse vegetation or shrubs and the forested area having dense vegetation are identified as dense forest. The land, having dense vegetation cover but not in the forested zone is identified as dense greenery. Grassland is the land having the grasses as the cover, seen in image and identified by ground truthing. All land uses are digitized in ArcGIS.

C. *Geomorphologic Parameters*:

Physical characteristics of the drainage basin and drainage network are of prime importance as they reflect hydrological behaviour, and also used for evaluating the hydrologic response of the basins. The drainage basin include drainage area; basin shape, ground slope, and centroid (i.e. centre of gravity of the basin) arePhysical characteristics. Channel characteristics include channel order, channel length, channel slope, channel profile, and drainage density. GIS based Geomophological characteristics had been used to generate Geomorphologic Instantaneous Unit Hydrograph for Varuna river basin[3].

1. Stream Order

Stream ordering is a method of assigning a numeric order to links in a stream network. This order is a method for identifying and classifying types of streams based on their number of tributaries. Some characteristics of streams can be inferred by simply knowing their order. Stream order designated according to [4] and slightly modified by [5].Each length of stream is indicated by its order (for example, 1rst-order, second-order, etc.). The start or headwaters of a stream, with no other streams flowing into it, is called the 1rst-order stream. First-order streams flow together to form a second-order stream. Second-order streams flow into a third-order stream and so on. Stream order describes the relative location of the reach in the watershed.

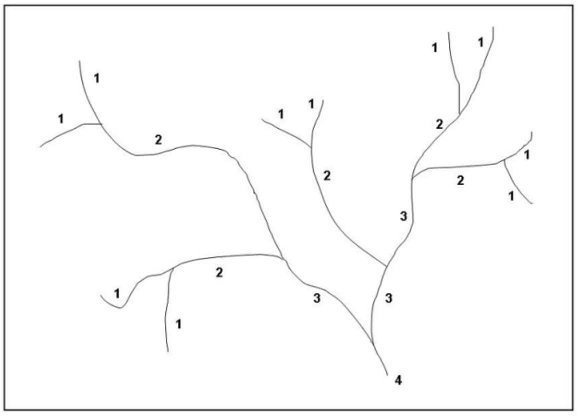

FIGURE 3 Order of stream network

2. Law of stream number

According to [4], the numbers of stream segments of each order form an inverse geometric sequence with order as:

$$N_u = R_b^{\,k-u}$$

Where, k = order of the trunk segment.

3. Law of stream length

This law was given by [4] which says the mean lengths of stream segments of each of the successive orders of a basin tend to approximate a direct geometric sequence. $\overline{L_u} = \overline{L_1} R_L^{u-1}$

Where, $\bar{L}$ = mean length of the stream of first order; and R_L = length ratio defined as the ratio of mean length of segments of order u to mean length of segments of next lower order (u-1).

4. Drainage area

Drainage area (A) is represented by the area enclosed within the boundary of the watershed divide. It is the most important characteristic for hydrologic design.

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In the general case, the total area (A_u) of a basin of the order 'u' may be written as

$$A_u = \left(\sum_{i=1}^{N_u} A_1 + \sum_{i=1}^{N_u} A_2 + \ldots\ldots + \sum_{i=1}^{N_u} A_{u-1}\right) + + \left(\sum_{i=1}^{N_u} A_{01} + \sum_{i=1}^{N_u} A_{02} + \ldots\ldots + \sum_{i=1}^{N_u} A\right.$$

where,

A_1, A_2 …………A_u = Area of different orders and A_{01}, A_{02}, ……...A_{0u} = Inter basin areas of different orders.

5. Drainage basin similarity

Strahler[4] hypothesized the drainage basin similarity as follows:

$$C = \frac{A}{L^2}$$

Where, *A* is the area of the drainage basin, *L* is the length of the basin and *C* is the constant for basin similarity.

6. Determination of Horton's ratio

Three of Horton's ratios namely bifurcation ratio (R_b), stream-length ratio (R_l) and stream-area ratio (R_a) are unique representative parameters for a given watershed and are fixed values for a given watershed system.

a) Bifurcation ratio (Rb)

Bifurcation ratio (R_b) will be computed using Horton's law of stream numbers which stated, "The number of stream segments of each order form an inverse geometric sequence with order number" or

$$R_b = N_i / N_{i+1}$$

Where, N_i and N_{i+1} are the number of streams in order *i* and *i*+1 respectively, $i = 1, 2, 3 \ldots \Omega, and\ \Omega$ is the highest stream order of the watershed. The value of R_b for watersheds varies between 3 to 5. This law is an expression of topological phenomenon, and is a measure of drainage efficiency.

b) Stream-length ratio (Rl)

This law was given by Horton (1945) which says the mean lengths of stream segments of each of the successive orders of a basin tend to approximate a direct geometric sequence.

$$R_l = \overline{L}_{i+1} / \overline{L}_i$$

Where

$$\overline{L}_i = \frac{1}{N} \sum_{j=1}^{N_i} L_{i,j}$$

is the average length of channel of order *i*,

The lengths of channels of a given order are determined largely by the type of soil covering the drainage basin.

c) Stream-area ratio (Ra)

The Channel area of order *i*, $A_i$is the area of the watershed that contributes to the channel segment of order *i* and all lower order channels. It can be quantified as:

$$R_a = \overline{A_{i+1}} / \overline{A_i}$$

Where A_i is the average area of order *i*and

$$\overline{A_i} = \frac{1}{N_i} \sum_{j=1}^{N_i} A_{i,j}$$

is the total area that drains into the stream of order *i*.

7. Drainage density

Drainage density (D_d) is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area or

$$D_d = \frac{Total\ channel\ length\ of\ all\ orders}{Total\ area\ of\ the\ basin}$$

8. Stream frequency

Stream frequency (F) is the number of stream segments per unit area, or

$$F = \frac{Total\ number\ of\ segments\ of\ all\ basin}{Total\ area\ of\ the\ basin}$$

9. Circulatory ratio

Basin circulatory ratio (R_c) is estimated as the ratio of the basin area (A) to the area of a circle (A_c) having circumference equal to the perimeter of the basin.

$$R_c = \frac{A}{A_c}$$

10. Elongation ratio

Elongation ratio (R_e) defined as the ratio of the diameter of a circle (d_c) with the same area as the basin to the basin length.

$$R_e = \frac{d_c}{L}$$

11. Form factor

The form factor (R_f) is calculated as the ratio of basin area (A) to the square of basin length (L_b) as defined by Horton[4] as:

$$R_f = \frac{A}{L^2}$$

12. Drainage texture ratio

Drainage texture ratio (R_t) is estimated as the ratio of total number of stream segments (N_u) of all orders to the perimeter (P_e) of that area. This definition of drainage texture ratio was given by Horton [4].

$$R_t = \frac{\sum_{i=1}^{k} N_u}{P_e}$$

D. Surface Hydrology

Estimation of runoff using SCS curve number method:- USDA-SCS curve number method is one of the most widely used methods for runoff estimation from small watersheds [7].. Soil maps, which are prepared by Geological Survey of India, are very useful to decide the CN. Curve numbers (CN) obtains using standard table for curve number [6] and weighted CN values is calculate for the study area. The daily/monthly or early surface runoff may be estimate by using the soil conservation services (SCS) curve number method for defined period.

1) Curve number

A curve number is an index that represents the combination of a hydrologic soil group, land use and treatment classes. Curve Number (CN) is known as the watershed coefficient, which represent the runoff potential of the land cover soil complex [8]. SCS-CN method has been applied to evaluation the runoff for Nambiyar watershed of Thamiravaruni river basin [9].The curve number method requires individual storm rainfall, land use type, hydrologic soil group and antecedent moisture condition of watershed as input. In this method, the potential maximum retention storage of watershed is related to a discrete number called curve number. Curve number is dimensionless and its value varies from 0 to 100. The runoff curve number for various hydrologic conditions, land use and hydrologic soil group are given by Technical Release 55 (TR-55) [10], SCS. The curve numbers (TR-55) may apply for normal antecedent moisture conditions (AMC II). The weighted curve number (WCN) for the watershed, having more than one land use, treatment or soil type was found by weighing each curve number according to its area as:

$$WCN = \frac{A_1 CN_1 + A_2 CN_2 + \ldots\ldots + A_n CN_n}{A_1 + A_2 + \cdots \ldots\ldots A_n}$$

Where $A_1, A_2 \ldots A_n$ are the respective area under CN values $CN_1, CN_2 \ldots CN_n$ and sum of $A_1, A_2 \ldots A_n$ is the total area of the watershed. For dry conditions (AMC I) or wet conditions (AMCIII), equivalent curve numbers were computed using the conversion factor given in Table 1 .

a) Hydrologic soil groups:The following hydrologic soil groups were considered as defined by SCS.

TABLE1 Conversion of CN from AMC II to AMC I and AMC III.

Curve Number at AMC-II	Factor to convert the Curve Number at AMC-II to	
	AMC-I	*AMC-III*
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

TABLE2 Hydrologic soil classification based on Soil Conservation Service.

Soil character	Hydrologic soil groups			
	A	B	C	D
Effective depth (cm)	〉100	51-100	26-50	〈25
Texture	s, ℓs	sℓ, siℓ, ℓ	si, scℓ, cl, sicℓ	sc, sic
Clay percentage	0-8	9-25	26-50	〉40
Structure	Simple, grained, granular, crumb	Granular crumb, sub-angular, blocky	Sub-angular, blocky, columnar, prismatic	Platy, massive
Infiltration rate (cm/hr)	〉 8.0	5.1-8.0	1.6-5.0	〈 1.6
Symbol: cl-clay, ℓ-loam, ℓs-loamy sand, s-sand, sc-sandy clay, scℓ-sandy clay loam, si-silt, sic-silty clay, sicℓ-silt clay loam, siℓ-silty loam, sℓ-sandy loam				

b) Antecedent moisture condition

The antecedent moisture condition (AMC) is the index of watershed wetness, which is determined by the total rainfall in five days period preceding a storm. An increase in index means an increase in the runoff potential. Such indices are only rough estimates; because they do not include the effects of evapo-transpiration and infiltration on watershed wetness. Three levels of AMC used are: AMC-I: Lowest runoff potential, AMC-II: The average potential and AMC-III: Highest runoff potential.

Table 3. Rainfall limits for estimating antecedent moisture conditions

Antecedent moisture condition	5 days total antecedent rainfall (mm)	
	Dormant season	Growing season
I	Less than 12.5	Less than 35
II	12.5-27.5	35 to 52.5
III	Over 27.5	Over 52.5

c) Runoff volume

The SCS curve number method useful to estimate runoff for individual storm in a 24 hr period for the watershed. The runoff volume has calculated for watersheds to study the groundwater recharging in particular. The equation for runoff estimation may be expressed as:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \; for\ P > 0.2S$$

$$Q = 0 \; for\ P \le 0.2S$$

Where, Q = Runoff depth (mm), P = Rainfall depth (mm) and S = Maximum retention potential (mm).[11] Presented following formulae for different regions of India.

$Q = \frac{(P-0.3S)^2}{(P+0.7S)}$ and $Q = \frac{(P-0.1S)^2}{(P+0.9S)}$ for black soil region

The value of S is determined based on antecedent moisture condition (AMC) and given by the following relationship [6].

$$S = \left(\frac{25400}{CN}\right) - 254$$

Groundwater Study: Preparation of groundwater prospect map

The groundwater study has carried out by preparing groundwater prospect map using land use map, soil map, slope map, aspect map and lineament map. This groundwater study is useful to selecting suitable site for digging new wells.

Generate the groundwater prospect map using satellite data and GIS techniques in conjunction with limited field work. Various steps involved in the preparation of groundwater prospect map. The total methodology can be divided into two main parts. The first part deals with the delineation of hydrogeomorphological units considering parameters which influence the hydrogeological properties. It consists of

- Creation of individual thematic layers on lithology, geomorphology, structures, hydrology along with base map details based on the visual interpretation of satellite data in conjunction with limited field/existing data, and

- Derivation of hydrogeomorphological units by integrating the thematic data.

The second part deals with the evaluation of hydrogeomorphic units based on hydrogeological characteristics of controlling parameters. It consists of i) estimation of groundwater prospect by taking into account the well observatory data, and ii) identification of suitable locations for constructing recharge structures along with prioritization of the units. The data thus created at different stages is organized into a digital data base as per the standards and specifications. The database consists of i) basicdata as different layers;ii) individual thematic maps for all the four parameters and for base map details and iii) integrated groundwater prospect map as a final output.

III. CONCLUSIONS

When a wide range of mono-disciplinary resource maps are available, the users must seek ways in which the available information can be combined to give an integrated overview, or reclassification or generation as needed [12]. The criteria for any analysis are dependent on the objective and also on the data sets. Mapping of these surface features may be performed through visual interpretation of satellite data aided by field verifications. Digitization, layer creation and analysis willbe carried out for the proper accomplishment of thework. The detailed digital information provided by the composite maps(s) will be useful for selecting artificial recharge sites. This digital database, created for site selection purposes, will aid the planning, development and management of groundwater. Cross analysis may also be performed between the lineament density raster map and the hydrogeomorphology raster map, and the product will show suitable sites for construction of artificial recharge structures. The high drainage density raster map was crossed with the land cover map and the product shows suitable sites for construction of artificial recharge structures. The medium drainage density raster map was crossed with the land cover map to get an idea of the distribution of artificial recharge sites under this condition. Multiple composite maps were produced to avoid complexities in a single composite map. However, in construction of artificial recharge structures on sites recommended through the application of spatial technologies has proved useful.

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