Prioritization using Morphometric Analysis and Land Use/Land Cover Parameters for Vazhichal Watershed using Remote Sensing and GIS Techniques

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Abstract

Watershed prioritization has gained importance in natural resources management, especially in the context of watershed management. Vazhichal watershed is a constituent of the Neyyar river basin, in Tiruvanathapuram district and covers an area of 91.35 km². The Vazhichal watershed has been divided into eight sub-watersheds, designated as SW1 to SW8, for prioritization purpose. The prioritization of sub-watersheds has been done on the basis of morphometric parameters and land use/land cover categories. Various morphometric parameters have been determined for each sub -watershed and assigned rank on the basis of value/relationship with erodibility so as to arrive at a compound value for final ranking of sub watersheds. Land use /land cover mapping has been carried out using IRS LISS IV data. Based on morphometric land use /land cover analysis the sub-watersheds have been classified into very high, high, medium, and low in terms of priority for conservation and management of natural resources. The prioritization results based on morphometry reveal that only SW6 fall under very high priority, whereas SW2 & SW3 fall under very high priority on the basis of land use /land cover analysis. However on the integration of morphometry and land use /land cover SW1 & SW5 show common priority whereas rest have little or no correlation.

Keywords: Morphometry, Prioritization, Land use/Land cover, Watershed

I. INTRODUCTION

A watershed is the surface area drained by a part or the totality of one or several given water courses. It is an ideal unit for management of natural resources like land and water and for mitigation of the impact of natural disasters for achieving sustainable development. The watershed management concept recognizes the interrelationships among the linkages between uplands, low lands, land use, geomorphology, slope and soil. Watershed prioritization is the key issue in watershed management while demarcating watersheds. Watershed prioritization is the ranking of different sub watersheds of a watershed according to the order in which they have to be taken for treatment and soil conservation measures. Integrated use of remote sensing and GIS techniques can be used for detailed morphometric analysis and land use/land cover analysis for watershed prioritization studies. Remote sensing and GIS techniques are currently used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information. In the present study, morphometric and land use /land cover analysis has been carried out in Vazhichal watershed, falling in tiruvananthapuram district.Kerala using remote sensing and GIS. An attempt has been made to prioritize sub-watersheds on the basis of morphometric and land use /land cover analysis.

II. STUDY AREA

Vazhichal watershed in the Tiruvananthapuram district, Kerala and covers an area of 91.35 km² lying between N.Lat.8°15’and 8°40’ and E. Long.77°0’ and 77°20’ been selected for the study. The area is approachable by road and railways from state capital tiruvandrum and well connected with other parts of the state. Vazhichal watershed is one of the major watersheds of Neyyar river basin. It originates at Agasthyamalai (1866 m) in Western Ghats and flows westward through the three physiographic zones
(high-, mid- and low-lands), to debouch finally into the Lakshadweep sea at Poovar. Neyyar and its 19 tributaries drain parts of Thrissur district, the prominent among them being the Chittar and Aruviode thodu. The drainage system of NRB exhibits sub-dendritic to rectangular patterns. The river flows through an undulating terrain of different types of lithologies and land surfaces. The upstream part is underlain by crystalline rocks, the middle reaches by laterite and the downstream portions by the coastal alluvium. Lateritic soil covers the major parts of the basin, while clayey loam covers a small area in the western part of the basin. The modification of drainages in the basin is intrinsically linked to the fast changing land use pattern of the region.

III. METHODOLOGY

Survey of India (SOI) top maps, Indian Remote Sensing satellite data and collateral data were used for the present study. The stream ordering was carried out using the Horton’s law. The fundamental parameters namely; stream length, area, perimeter; number of streams and basin length were derived from the drainage layer. The morphometric parameters for the delineated watershed area were calculated based on the formula suggested by Horton [1945], Strahler [1964]. The morphometric parameters i.e., Mean bifurcation ratio (Rbm), drainage density (Dd), mean stream length (Lsm), compactness coefficient (Cc), basin shape (Bs), stream frequency (Fs), texture ratio (Rt), length of overland flow (Lg), form factor (Rf), circularity ratio (Rc) and elongation ratio (Re) are also termed as erosion risk assessment parameters and have been used for prioritizing sub-watersheds.

Fig. 2: Methodology flow chart
The linear parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow have a direct relationship with erodibility. Hence prioritization of sub-watersheds, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Shape parameters such as elongation ratio, compactness coefficient, circularity ratio, and basin shape and form factor have an inverse relationship with erodibility lower the value more is the erodibility. Thus the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Hence, the ranking of the sub-watersheds has been determined by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters. After the ranking has been done based on every single parameter, the ranking values for all the linear and shape parameters of each sub-watersheds were added up for each of the eight sub-watersheds to arrive at compound value (Cp). Based on average value of these parameters, the sub-watersheds having the least rating value was assigned highest priority, next higher value was assigned second priority and so on. Various land use /land cover categories were delineated on the basis of spectral signatures and terrain characteristics which were later supplemented by limited ground truth verification the thematic map derived through satellite data was imported to Arc GIS software for further analysis.

IV. RESULTS AND DISCUSSION

A. Morphometric Analysis

The designation of stream order is the first step in morphometric analysis of a drainage basin, based on hierarchy making of streams proposed by Strahler (1964). Vazhichal watershed has been demarcated into eight watersheds. The morphometric analysis is discussed under linear, shape and relief parameters.

1) Linear Parameters

Drainage parameters such as bifurcation ratio, drainage density, stream frequency, drainage texture and length of overland flow are grouped under linear parameters and discussed below:

a) Bifurcation Ratio (Rb)

It is the ratio of the number of streams of a given order to the number of streams of the next higher order. Strahler [1957] demonstrated that Rb shows only a small variation for different regions on different environment except where powerful geological control dominates. Lower Rb values are the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern. The mean bifurcation ratio (Rbm) may be defined as the average of bifurcation ratios of all order. In the present study, Rbm varies from 2.83 to 3.93 and all sub-watersheds fall under normal basin category. The values usually ranges from 4.15 to 6.96 for networks formed in homogenous rocks and with more than 10 where structural control plays dominant roles.

b) Drainage Density (Dd)

Horton [1932] introduced the drainage density (Dd) is an important indicator of the linear scale of land-form elements in stream –eroded topography. It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of km/sq.km. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. High drainage density is the result of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. Low drainage density indicated the basin is highly permeable subsoil, thick vegetation cover, low relief and course drainage texture.
c) **Stream Frequency (Fs)**

Stream frequency/channel frequency (Fs) is the total number of stream segments of all orders per unit area. Hypothetically, it is possible to have the basin of same drainage density differing in stream frequency and basins of stream frequency differing in drainage density. It is noted that the Fs exhibits positive correlation with the drainage density values of the sub-watersheds indicating the increase in stream population with respect to increase in drainage density.

d) **Drainage Texture (Rt)**

It is the total number of stream segment of all orders per perimeter of that area [Horton, 1945]. Horton recognized infiltration capacity as the single important factor which influences drainage texture (Rt) and considered the drainage texture to include drainage density and stream frequency. Smith [1950] has classified drainage density into five different texture i.e. very coarse (<2), Coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8). In the present study drainage densities are vary from 2.23 to 11.35. The lower values of texture ratio indicate that the basin is plain with lower degree of slopes.

e) **Length of Overland Flow (Lg)**

Length of Overland Flow It is the length of water over the ground before it gets concentrated into definite stream channels. This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. It approximately equals to half of reciprocal of drainage density [Horton, 1945]. Computed value of Lg for all sub-watersheds varies from 0.06 and 0.22. The value of Lg higher in case of SW2 and SW3 indicating low relief

2) **Areal Parameters**

Drainage parameters such as basin shape, form factor, circularity ratio, elongation ratio and compactness are grouped under shape parameters and are discussed below:

a) **Basin Shape (Bs)**

Basin shape is the ratio of the square of basin length (Lb) to the area of the basin (A). The Bs values of sub-watersheds indicates that SW1,SW2,SW3,SW4,SW5,SW6, and SW8 have weaker flood discharge periods, whereas SW7 have sharp peak flood discharge.

b) **Form Factor (Rf)**

It is defined as the ratio of basin area to square of the basin length [Horton, 1932]. The value of form factor would always be less than 0.7854 (for a perfectly circular basin). Smaller the value of form factor, more elongated will be the basin. The basins with high form factors have high peak flows of shorter duration, whereas, elongated sub-watershed with low form factors have lower peak flow of longer duration. Rf values of the study area is vary from 0.26 to 0.76 indicate that they are to be elongated circular shape and suggesting flatter peak flow for longer duration. Flood flows of such elongated circular basins are easier to manage than those of the circular basin.

c) **Circulatory Ratio (Rc)**

It is ratio of the area of the basin to the area of circle having the same circumference as the perimeter of the basin. It is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. In the present case Rc ranges from 0.42 to 0.78 indicating that all the sub-watersheds except SW4 are more or less circular and are characterized by high to moderate relief and drainage system is structurally controlled. The sub-watershed SW4 having an Rc value of 0.42 indicating that it is elongated.

d) **Elongation Ratio (Re)**

It is the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin. A circular basin is more efficient in run-off discharge than an elongated basin. The value of elongation ratio (Re) generally varies from 0.25 to 0.51 associated with a wide variety of climate and geology. Values close to 1.0 are typical of regions of very low relief whereas that of 0.5 to 0.8 are associated with high relief and steep ground slope. These values can be grouped into three categories, namely circular (>0.9), oval (0.9-0.8) and elongated (<0.7). The elongation ratio of SW7 is 0.51 and indicating that it is elongated.

e) **Compactness coefficient (Cc)**

Compactness coefficient is used to express the relationship of a hydrologic basin to that of a circular basin having the same area as the hydrologic basin. A circular basin is the most susceptible from a drainage point of view because it will yield shortest time of concentration before peak flow occurs in the basin. The values of Cc in the study area vary from showing wide variations across sub watersheds.
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3) Relief parameters

a) Relief Ratio (Rh)

The elevation difference between the highest and lowest points on the valley floor of a sub-watershed is its total relief, whereas the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is Relief Ratio (Rh). It measures the overall steepness of a drainage basin and is an indicator of intensity of erosion processes operating on the slopes of the basin. The areas with high relief and steep slope are characterized by high value of relief ratios. Low value of relief ratios are mainly due to the resistant basement rocks of the basin and low degree of slope. The Rh normally increases with decreasing drainage area and size of a given drainage basin. Rh value of the study area varies from 0.08 to 0.39.

b) Ruggedness Number (Rn)

Ruggedness number (Rn) is defined as the product of the basin relief and its drainage density. From the analysis it has been found that, high value of Rn is observed in SW8 (11.5) compared to SW2 (1.26). This indicates that the SW8 is more susceptible to soil erosion than that of SW2.

c) Relative Relief (Rh)

Relief ratio is the dimensionless height length ratio equal to the tangent of the angle formed by the two planes intersecting at the mouth of the basin, one representing the horizontal and the other passing through the highest point of the basin. Relief ratio of both SW6 and SW2 are 0.12 and 0.02 respectively. It has been observed that, there is a high degree of correlation between high relief and high drainage frequency, high stream frequency and high stream channel slopes which brings about high discharges in short duration. Higher Rh value (0.12) indicates more hilly regions in SW6 which results in lower infiltration and greater discharge compared to that of SW2.

d) Melton Ruggedness Number (Mrn)

Melton ruggedness number (MRn) is a simple flow accumulation related index, calculated as difference between maximum and minimum elevation in catchment area divided by square root of catchment area size. The calculation is performed for each grid cell, therefore minimum elevation is same as elevation at cell’s position. MRn values varies from 0.13 to 0.53

B. Land Use /Land Cover Analysis

Land use /land cover analysis was carried out at sub watershed level using LISS IV False Colour Composite (FCC) visual interpretation of the data led to identification and delineation of land use /land cover categories such as cultivated land, open forest, waste land, water body, built-up land etc. Various Land use /land cover categories exhibit unique spectral image characteristics through their spectral signatures which were subsequently helpful for identification and delineation on the satellite data. The study area comprises land use /land cover categories such as cultivated land, dense forest, open forest, open scrub, waste land, water body, built-up land, rocky area etc. The base map of the area was overlaid on satellite data to delineate various categories of land use/land cover through standard visual interpretation method based on photo recognition elements such as tone, texture, size, shape, pattern, association.

![Land use /land cover map for vazhichal watershed](image)

Fig. 3: Land use /land cover map for vazhichal watershed

1) Cultivated Land

Cultivated land may be defined as the land primarily used for farming and production of food, and other commercial crops. Cultivated land, is the dominant land use category present in the study area and covers an area 50.754 hectare of the watershed.
area. The sub-watershed with lower percentage of cultivated land is has been given higher priority, whereas sub-watersheds having higher percentage of cultivated land are assigned lower priority.

2) **Forest Cover**

Based on standard visual interpretation, forest cover has been delineated which is the dominant land cover category comprises dense forest open forest, dense forest and open scrub. It is mostly confined to hill slopes and distributed in the study area. The forest cover is reported from all the sub-watersheds and the highest area under forest is reported from SW1 while lowest area is reported from SW3. Higher priority has been given to the sub-watersheds having lower percentage of forest cover and vice versa.

3) **Waste Land**

Waste land may be described as degraded land which is currently under or unutilized. The land may be deteriorating due to lack of appropriate water and soil management or due to natural causes. It has been reported from the eastern and north eastern part of the Vazhichal watershed. The waste land is reported from all the sub watersheds and the highest area under waste land is reported from SW4 while lowest area is reported from SW2. Sub-watersheds having higher percentage of waste land were given higher priority and vice versa.

4) **Water Body**

Both natural and man-made water features such as rivers/streams, lakes, tanks, and reservoirs are included in the category of water bodies. The water features appear in black or bluish tones in the satellite imagery. In the study area a number of ponds and tanks are located along the south western part of the basin. The water body is reported from all the sub watersheds and the highest area under water body is reported from SW2 while lowest area is reported from SW3, SW6, SW7, SW8.

C. **Prioritization of Sub-Watersheds On The Basis Of Morphometric Analysis**

The morphometric parameters are also termed as erosion risk assessment parameters and have been used for prioritizing sub-watersheds. The linear parameters such as drainage density, stream frequency, bifurcation ratio, drainage texture, length of overland flow have a direct relationship with erodibility. Hence prioritization of sub-watersheds, the highest value of linear parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Shape parameters such as elongation ratio, compactness coefficient, circularity ratio, basin shape and form factor have an inverse relationship with erodibility lower the value more is the erodibility. Thus the lowest value of shape parameters was rated as rank 1, next lower value was rated as rank 2 and so on and the highest value was rated last in rank. Hence, the ranking of the sub-watersheds has been determined by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters. After the ranking has been done based on every single parameter, the ranking values for all the linear and shape parameters of each sub-watershed were added up for each of the eight sub-watersheds to arrive at compound value (Cp). Based on average value of these parameters, the sub-watersheds having the least rating value was assigned highest priority, next higher value was assigned second priority and so on. The sub-watersheds were categorized as very high, high, Medium, Low priority on the compound value. Out of eight sub watersheds SW6 fell under very high priority. SW8 & SW1 fall in high priority, SW4, SW5, SW7 fall in medium priority category. SW2 & SW3 fall under low priority. Fig4 shows priority of sub watersheds based on morphometric analysis.
D. Prioritization of Sub-Watersheds On The Basis Of Land Use /Land Covers Categories

Prioritization of Sub-Watersheds On The Basis Of Land Use /Land Covers Categories

Ranking of the sub-watersheds has been determined by assigning the highest priority/rank based on highest value in case of water bodies and lowest value in case of forest and waste lands. After the ranking has been done based on every single parameter, the ranking values for all the land use /land cover categories of each sub-watersheds were added up for each of the eight sub-watersheds to arrive at compound value (Cp). Based on average value of these parameters, the sub-watersheds having the least rating value was assigned highest priority, next higher value was assigned second priority and so on.

Table 2: Prioritization based on Land use /Land cover categories

<table>
<thead>
<tr>
<th>SUB WATERSHED</th>
<th>FC</th>
<th>WL</th>
<th>WB</th>
<th>CP</th>
<th>PRIORITY</th>
<th>COMMONPRIORITY</th>
</tr>
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<tbody>
<tr>
<td>SWS1</td>
<td>91.81</td>
<td>7.83</td>
<td>0.45</td>
<td>3.66</td>
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<td>HIGH</td>
</tr>
<tr>
<td>SWS2</td>
<td>76.98</td>
<td>1.36</td>
<td>17.88</td>
<td>2.33</td>
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<td>-</td>
</tr>
<tr>
<td>SWS3</td>
<td>93.86</td>
<td>-</td>
<td>6.24</td>
<td>3.5</td>
<td>HIGH</td>
<td>-</td>
</tr>
<tr>
<td>SWS4</td>
<td>79.80</td>
<td>19.80</td>
<td>0.40</td>
<td>3.30</td>
<td>HIGH</td>
<td>-</td>
</tr>
<tr>
<td>SWS5</td>
<td>98.93</td>
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<td>1.15</td>
<td>5.00</td>
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<td>MEDIUM</td>
</tr>
<tr>
<td>SWS6</td>
<td>100.0</td>
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<td>8.00</td>
<td>-</td>
<td>LOW</td>
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<tr>
<td>SWS7</td>
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<tr>
<td>SWS8</td>
<td>96.33</td>
<td>3.67</td>
<td>-</td>
<td>5.00</td>
<td>MEDIUM</td>
<td>-</td>
</tr>
</tbody>
</table>

Fig. 4: Priority of sub watersheds based on morphometric analysis

Fig. 5: Priority of sub watersheds based on land use /land cover categories
V. CONCLUSION

Watershed prioritization is considered as one of the most important aspects of planning and development for natural resources for water conservation measures. The present study recapitulates the integrated approach for developing a preliminary prioritization of sub watersheds in Vazhichal watershed. The result of prioritization on the basis of morphometric analysis revealed that SW6 and SW7 fall under very high priority on the basis of land use/land cover categories. SW2 & SW7 have very high priority. However, on the superimposition of the thematic layer of morphometric and land use/land cover analysis in GIS environment, only SW1 & SW5 has indicated a common priority whereas the rest of the sub-watersheds show little or no correlation. The sub-watersheds which are falling under very high priority may be taken up for implementation of soil and water conservation measures. The study demonstrates the utility of remote sensing and GIS techniques in prioritization of watershed which may be helpful planners and decision makers for planning at sub-watershed level.

REFERENCES