Geospatial study on morphometric characterization of Umtrew River basin of Meghalaya, India

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Geospatial technology that is, remote sensing (RS), geographical information system (GIS) and global positioning system (GPS) have proved to be an efficient tool in the field of modern day geographical and geological studies. GIS and Remote sensing techniques have been adopted for the identification of different morphological features and to analyze their existence in a hilly river basin of Meghalaya plateau, which is located in the two North-East Indian states of Meghalaya and Assam. Morphometric analysis of any drainage basin can be very much effective in determining the landform characteristics and the processes and components behind its development. The morphometric parameters of the study area have been discussed with respect to linear, areal and relief aspects. The geological formation of the basin area varies from Shillong group of rocks in the undulated hilly areas of Meghalaya plateau to unconsolidated river alluvium in the plain parts of Brahmaputra valley. It is a 7th order drainage basin and the entire drainage network can be defined as “Trellis” in nature. It has been observed that the drainage density value is in between medium to low which indicates that the basin has highly permeable sub-soil material and thick vegetative cover in the most of its areas. The moderate values of bifurcation ratio in the basin area indicates the possibilities of structural control over the development of the entire drainage network. The circularity ratio value reveals that the basin is elongated in shape and a predominance of highly permeable homogenous geologic material. The aim of the present study is to find out the various sets of inherent factors which were behind the formation of this river basin and its hydrologic nature.

Key words: Umtrew River basin, drainage, morphometric, hydrologic, geographical information system (GIS)

INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of the earth’s surface, shape and dimension of its landforms (Agarwal, 1998; Reddy et al., 2002). Morphometric studies in the field of hydrology were first initiated by Horton (1940) and Strahler (1950). The morphometric analysis of the drainage basin and channel network play a vital role for understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural control, etc. Besides, the primary aim of studying drainage basin is to understand the hydrologic nature and its morphometric expression of the basin area.

Recently, many researchers have used remote sensing data and analyzed them on Geographical Information System (GIS) platform to understand the inherent morphometric ingredients of the catchment (Nag, 1998). The rapid development of geospatial technology has recently become an effective tool to overcome many problems associated with identification and interpretation of basin morphometric parameters and to design an
effective land and water resource plan for the basin area. Many researchers and scholars including Srinivasa (2004), Nag and Chakraborty (2003), and Srivastava (1997) have studied the morphometric characteristics of different parts of India by using geospatial technology. The objective of the present study is to analyze the morphometric attributes of Umtrew River basin which is a major drainage system in the state of Meghalaya and so far not any systematic work on the morphometry of the basin has been carried out because the optimal and sustainable utilization of the resource is very much essential to avoid future problems regarding its qualitative and quantitative availability. This particular study will give a detail picture on the water bearing properties of the basin which could be beneficial in the process of preparing a sustainable river basin or watershed management plan.

The extent of the location of the present study area is very important from geographical and geological perspective. It is located between the confrontation zone of Shillong plateau in its south to plain Brahmaputra valley in the northern part. The findings of this manuscript try to highlight the physical and morphometric nature of this environmentally and geographically important river basin of North-East India. The different morphometric attributes which have been studied in this particular manuscript were observed to get a clear picture of geomorphological, geological and hydrological setting of the study area.

Study area

The investigated area lies between 25°40′00″ N to 26°10′00″ N latitude and 91°30′00″ E to 92°00′00″ E longitude covering an area of 1369.6 km², falling in Survey of India toposheet (SOI) no. 78 N/16, 78 O/9, 78 O/13 and 78 O/14 on 1:50000 scale (Figure 1). Geologically, the study area is occupied by Shillong group of rocks comprising of Phyllites, Quartz schists, Quartzite and Intra formational conglomerates in the Meghalaya part of the basin to unconsolidated alluvium fills in the plain land areas of Assam (Chottopadhyay et al., 1984). The area enjoys sub-tropical climate throughout the year. The topography is undulating in nature having elevation of 171 m in the plains of Assam and about 1790 m at the highest peak of the basin (Figure 2). Physiographically, Umtrew Umtrew River basin
River basin can be grouped into two divisions (i) High elevated southern part and (ii) Low lying Northern River plains. Umtrew River basin comprises of undulated hilly terrain of different altitudes along with inter-mountain deep gorges, small stretch of plains and marshy areas. Soil texture of the basin area varies from clay loam to sandy clay loam in the upper part where as fine loam and coarse loam soil is predominant in the lower territory.

MATERIALS AND METHODS

The drainage map of the study area has been prepared by using IRS P6 LISS-III geo-coded satellite data and verified with Survey of India (SOI) toposheets no. 78 N/16, 78 O/9, 78 O/13 and 78 O/14 on 1:50000 scale with selected ground truths. The SOI toposheets and satellite data were geometrically rectified and georeferenced to World space coordinate system using ERDAS IMAGINE 9.2 software package. The assigned projection system was Universal Transverse Mercator (UTM), WGS 84 datum and spheroid system, the root mean square error (RMS) was accounted as less than 0.25 value. In any Georeferencing process the root mean square error should be below 0.25. For the proper interpretation and identification of different geological and geographical features, satellite imageries were rectified by the techniques like image enhancement, edge detection and high pass filtering etc. The morphometric parameters of the entire basin have been computed by using Arc GIS 9.3 and ERDAS Imagine 9.1 software packages. The “Spatial analysis” tool of Arc GIS 9.3 software was used immensely throughout the study to carve out different topographic and morphometric components of the study area. The Area (A) and Perimeter (P) of the study site have been calculated by using “measure tool” option of ERDAS Imagine software. Digital Elevation Model (DEM) has been prepared to find out different sets of relevant morphometric data.
Table 1. Linear aspects of Umtrew River basin.

<table>
<thead>
<tr>
<th>Stream order u</th>
<th>Number of streams (Nu)</th>
<th>Total length of streams Lu (km)</th>
<th>Log Nu</th>
<th>Log Lu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st</td>
<td>4754</td>
<td>2581.85</td>
<td>3.677</td>
<td>3.411</td>
</tr>
<tr>
<td>2nd</td>
<td>1021</td>
<td>763.94</td>
<td>3.009</td>
<td>2.883</td>
</tr>
<tr>
<td>3rd</td>
<td>259</td>
<td>366.76</td>
<td>2.413</td>
<td>2.564</td>
</tr>
<tr>
<td>4th</td>
<td>74</td>
<td>199.12</td>
<td>1.869</td>
<td>2.564</td>
</tr>
<tr>
<td>5th</td>
<td>15</td>
<td>98.23</td>
<td>1.176</td>
<td>1.992</td>
</tr>
<tr>
<td>6th</td>
<td>5</td>
<td>33.10</td>
<td>0.698</td>
<td>1.519</td>
</tr>
<tr>
<td>7th</td>
<td>1</td>
<td>68.37</td>
<td>3.677</td>
<td>1.834</td>
</tr>
</tbody>
</table>

After the completion of drainage network analysis the stream order to each of the stream was assigned by following Strahler (1964) method. The methodology and mathematical equations adopted for the quantitative analysis of different morphometric parameters has been mentioned in Table 3 and the results summarized have been mentioned in Table 2. To understand the topographic expression of the study area parameters like slope, relief pattern and DEM were analyzed thoroughly. Similarly for the formulation of sustainable basin management strategy factors like length of the overland flow and channel maintenance factors were studied based on the equations developed by Chorley (1969).

RESULTS AND DISCUSSION

The study of morphometric characteristics of any basin area helps in understanding the transmission pattern of hydrological regime and sediment load carried through the entire basin area. In the present study the morphometric analysis is carried out with respect to parameters like stream order Table 1, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, relief ratio, etc. using mathematical equations as given in Table 3. The properties of the stream networks are very important to study the landform development process (Strahler and Strahler, 2002). Morphometric parameters such as relief, shape and length also influence basin discharge pattern strongly through their varying effects on lag time (Gregory and Walling, 1968).

Linear aspects

In the present study the linear aspects of Umtrew River basin include the parameters like stream order, stream length, mean stream length, stream length ratio and bifurcation ratio (Table 1).

Stream Order (Nu)

The designation of stream order is the first step in drainage basin analysis and expresses the hierarchical relationship between stream segments, their connectivity and the discharge coming from contributing watersheds or sub-watersheds. In the present study, the channel segment of the basin area has been ranked according to Strahler’s stream ordering method. According to Strahler (1964), the smallest fingertip tributaries are designated as order I. Where two first order channels join, a channel segment of order II is formed; Where two of order II joins, a segment of order III is formed, etc. The trunk stream through which all discharge of water and sediment passes is therefore the stream segment of the highest order. The present study area is a VII order drainage basin in nature. The total number of 6129 streams were identified of which 4754 are Ith order streams, 1021 are IIth order, 259 are IIIth order, 74 in IVth order, 15 in Vth order, 5 in VIth order and 1 is indicating as VIIth order stream. The overall drainage pattern of the basin area highlights a Trellis pattern because the entire drainage network has been constituted by a network of tributaries and the master consequent stream which is flowing in the regional slope direction and are well adjusted to the geological structures.

Stream Number (u)

The total order of wise stream segments is known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number. It has been mentioned earlier that the total number of streams in the study area is 6129. This shows that Umtrew River basin is spreading in a vast stretch of land throughout both hill and plain areas of Meghalaya and Assam State.
Table 3. Different morphometric parameters of Umtrew River basin.

<table>
<thead>
<tr>
<th>Morphometric Parameters</th>
<th>Formula</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>A Where, A is the total area of the basin</td>
<td>1369.6</td>
</tr>
<tr>
<td>Perimeter (km)</td>
<td>P</td>
<td>339.8</td>
</tr>
<tr>
<td>Length of Basin (km)</td>
<td>Lb</td>
<td>69.45</td>
</tr>
<tr>
<td>Drainage Density (km/km²)</td>
<td>Dd = Lu/A</td>
<td>3.00</td>
</tr>
<tr>
<td>Stream Frequency (Fs)</td>
<td>Fs = Nu/A</td>
<td>4.47</td>
</tr>
<tr>
<td>Drainage Texture (Rt)</td>
<td>Rt = Nu/P</td>
<td>18.03</td>
</tr>
<tr>
<td>Infiltration Number (If)</td>
<td>If = Rt * Fs</td>
<td>80.59</td>
</tr>
<tr>
<td>Length of overland flow (Lg)</td>
<td>Lg = 1/D x 2</td>
<td>0.16</td>
</tr>
<tr>
<td>Form Factor (Rf)</td>
<td>Rf = A/ Lb²</td>
<td>0.28</td>
</tr>
<tr>
<td>Circulatory Ratio (Rc)</td>
<td>Rc = 4πA/P²</td>
<td>0.148</td>
</tr>
<tr>
<td>Basin Relief (H)</td>
<td>H = Hr - Hd</td>
<td>1640</td>
</tr>
<tr>
<td>Relief Ratio (Rh)</td>
<td>Rh = H/Lh</td>
<td>23.59</td>
</tr>
<tr>
<td>Relative Relief (Rr)</td>
<td>Rr = H / P*100</td>
<td>482.63</td>
</tr>
<tr>
<td>Ruggedness Number (Rn)</td>
<td>Rn = H x Dd</td>
<td>4920</td>
</tr>
<tr>
<td>Channel maintenance factor (Cm)</td>
<td>Cm = 1/Dd</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Stream Length (Lu)

The total stream network of Umtrew River basin has been categorized into several orders, which have computed with the help of SOI topographical sheets and "Measure" tool option of Arc GIS software. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in the basin of increasing order (Strahler, 1964). The stream length based on the law proposed by Horton (1945) has been computed.

Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of stream segments of given order to the number of segments of next higher order. Bifurcation ratio is an index of relief and dissection (Horton, 1945). It is well demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environment except where geological control dominates. It has been found that the bifurcation ratio characteristically ranges between 3.0 and 5.0 for the basin in which geology is reasonably homogeneous and with no structural disturbances. The lower values of Rb indicate that the study area has suffered less structural disturbances and the drainage pattern is not distorted. Furthermore, the low Rb values signify a high drainage density, low permeability of the terrain and indicate areas with uniform surficial materials where geology is reasonably homogeneous.

Mean Bifurcation Ratio

To arrive at a more representative bifurcation number Strahler (1952) used a mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values. Mean bifurcation ratios vary from about 2.0 for flat or rolling basins to > 3.0 for mountainous hilly dissected basins (Horton, 1945). As the mean bifurcation ratio of our present study area is showing a value greater than 3, it denotes that the area is very hilly and dissected in nature.

Length of the Main Stream

This is the length along the longest watercourse from the outflow point of designated basin to the upper limit to the basin boundary. During the study period, main channel length was computed using ArcGIS-9.3 software. The analysis shows that the length of the main stream is 69.45 km.

Areal aspects of Umtrew River Basin

The areal aspects include drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow. Basin area is hydrologically important because it directly affects the size of the storm hydrograph and the magnitudes of peak and mean runoff. It is interesting that the maximum flood discharge per unit area is inversely related to size of the basin (Chorley, 1957).

Drainage density (Dd)

The drainage density is an important indicator of the linear scale of landform element in stream eroded
topography and defined as the total length of stream of all orders/drainage area and may be an expression of the closeness of spacing of channels (Horton, 1932). The significance of drainage density is recognized as a factor determining the time travel by water (Schum, 1956). The low drainage density is favored in regions of highly permeable subsoil material, under dense vegetative cover where relief is low, while high drainage density is favored in regions of weak or impermeable sub-surface materials, sparse vegetation and high mountain relief. The low drainage density is also indicative of relatively long overland flow of surface water. The drainage density of the study area is 0.28 which indicates a lower value considered as a dominant texture (Smith, 1950). In the present study the drainage texture value of Umtrew basin stands at 18.03, it indicates that the texture pattern of Umtrew basin is very fine drainage texture.

**Drainage Texture (Dt)**

An important geomorphic concept is drainage texture which means the relative spacing of drainage lines (Smith, 1950). Similarly, Horton (1945) defined drainage texture on the basis of stream frequency. Drainage texture less than 2 indicates very coarse, between 2 and 4 as coarse, between 4 and 6 as moderate, between 6 and 8 as fine and greater than 8 as very fine drainage texture (Smith, 1950). In the present study the drainage texture value of Umtrew basin stands at 18.03, it indicates that the texture pattern of Umtrew basin is very fine drainage texture.

**Stream Frequency (Fs)**

The stream frequency is defined as the total number of stream segment of all order per unit area (Horton, 1932). The greater the drainage density and stream frequency in a basin, the faster the runoff, and therefore, flooding is more likely in basins with a high drainage and stream frequency (Kale and Gupta, 2001). The stream frequency of Umtrew River basin stands at 4.47. Thus, the stream frequency of the study area falls in the moderate frequency class. The stream frequency of the study area represents a positive correlation with the drainage density, which indicates that the stream population increases with the increase of drainage density.

**Infiltration Number (If)**

Infiltration number of a drainage basin is the product of drainage density and stream frequency of a basin. It is the number by virtue of which an idea regarding the infiltration characteristics of the basin is obtained. The higher value indicates low infiltration and high runoff. The study area has the infiltration value of 80.59 which shows a comparatively higher nature of infiltration number.

**Form Factor (Rf)**

The form factor is the ratio of basin area to square of basin length and it is a quantitative expression of drainage basin outline (Horton, 1932). It is a dimensionless ratio of basin area to the square of basin length. Basin shape may be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length (Singh, 1998). The form factor value of Umtrew River basin is 0.28 which indicate lower value of form factor and thus represents an elongated shape. The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration.

**Circulatory Ratio (Rc)**

Circularity ratio is defined as the ratio of basin area to the area of a circle having the same perimeter as the basin and it is pretentious by the lithological character of the basin. Miller (1953) has described the basin of the circularity ratios range between 0.4 to 0.5, which indicates strongly elongated and highly permeable homogenous geologic materials. Circulatory ratio also indicates the tendency of small drainage basin in homogenous geologic materials to preserve geometrical similarity (Suresh, 2000). The circulatory ratio value of 0.148 corroborates with Miller's range, which is indicating that the basin is elongated in shape, low discharge of runoff and high permeability of subsoil material.

**Length of Overland Flow (Lg)**

Length of the overland flow, considered as a dominant hydrologic and morphometric factor, is the mean horizontal length of the flow-path from the water divide to the stream in a first order basin and is a measure of stream spacing and degree of dissection and approximately one half the reciprocal of the drainage density (Chorley, 1969). Length of the overland flow is one of the most important morphometric variables, which affects the hydrological and topographic development of the basin. The length of overland flow depends primarily on the degree of relief fragmentation, and hence on the drainage density. Overland flow is significantly affected by infiltration (exfiltration) and percolation through the soil, both varying in time and space (Schmid, 1997). In this study, the computed value of length of overland flow is 0.16 which shows low surface runoff of the study area.

**Relief aspects of Umtrew River Basin**

The relief aspects determined include relief ratio, relative
relief and ruggedness number. The results of the relief aspects are given in Table 3.

Relief Ratio (Rh)

Difference in the elevation between the highest point of a basin and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line. The possibility of a close correlation between relief ratio and hydrologic characteristics of a basin suggested by Schumm who found that sediments loose per unit area is closely correlated with relief ratios. In the study area the value of relief ratio is 23.59 (Table 3). It has been observed that the area is hilly in nature, steeply sloping and the intensity of erosion is high, besides the presence of waterfalls here and there in the basin area increases the intensity of erosion process due to the presence of fault/share zones and the structural controls.

Relative Relief (Rr)

The relative relief value of Umtrew River basin have been determined and given in Table 3 which has been computed by the equation developed by Melton (1958). Furthermore, the visual study of the ASTER G-DEM (Figure 2) indicates that the average elevation of the basin area varies from 171 to 1790 m.

Ruggedness Number (Rn)

It is the product of maximum basin relief (H) and drainage density (D), where both parameters are in the same unit. An extreme high value of ruggedness number occurs when both variables are large and slope is not only steep but long as well (Strahler, 1956). In the present study, the value of ruggedness number (Table 3) is low which indicates moderate to steep slope of the basin area. The value of ruggedness number stands at 4920.

Slope analysis

Slope is the most important and specific feature of the earth's surface form. Maximum slope is well marked in the direction of a channel reaching downwards on the ground surface. There are many contributions to slope-geomorphology and various methods of representing the slope, but the contributions made by Wentworth (1930), Smith (1938-1939), Calef (1950), Calef and Newcomb (1953), Strahler (1956) and Miller (1953) are very important. Slope can evaluated as a quantitative parameter. Slope map (Figure 4) in the present study has been prepared by using “3D Analysis” tool of Arc GIS 9.2 software package.

The slope analysis of Umtrew River basin shows that a substantial portion of area falls under the slope category of more than 15° (Figure 5). Though 0 to 5° slope category is dominant in low lying areas and in some parts of southern flatlands but more than 20° slopes are still spreading everywhere in the study area. Low slope (0 to 5°) category is mostly visible in the plain patches of land which fall in the plain stretches of Assam. Highly steep slope areas (more than 25°) are located in the central mid land to entire eastern and western part of Umtrew River basin. Moreover, the slope map of the study area enables to highlight the impact of underlying geological structures on the morphometric expression of the region. So, from environmental point of view gradually accelerating rate of deforestation in these patches of land may lead to the excessive rate of soil loss in the entire basin area.

Conclusion

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management at a micro level. The morphometric analysis carried out in the Umtrew River basin shows that the basin is having a mixture of landform comprising of high hilly region to low lying plains. Umtrew River basin holds a very important position in the entire physiographic setting of Meghalaya plateau. Drainage network of the study area is trellis in nature, due to the entire basin area elongated tributaries flowing parallel or sub-parallel to the main stream; and also multiplicity in drainage texture and more significance of structural control over the formation of drainage network. In some parts of the basin, the dipping and jointing of the topography reveals parallel and radial pattern. The analysis of drainage pattern shows it that in the central upland part of the basin the drainage has taken a more or less dendritic shape, which has contributed immensely in the overall spread of the network in all the directions. Low value of length of the overland flow also signifies that most part of the basin has been developed in the undulating hilly topography, where different geological structures has played an important role in the development of a true mountainous drainage network. The study reveals that remotely sensed datasets merged with GIS based tools in evaluation of drainage morphometric parameters and their influence on landforms, soils and eroded land characteristics at river basin level is more appropriate than the conventional methods. The bifurcation ratio in the basin indicates that the area has received significant structural disturbances and the drainage pattern is not distorted. Furthermore,
the low Bifurcation ratio values signify a high drainage density, low permeability of the terrain and indicate areas with uniform surficial materials where geology is reasonably homogeneous. The stream frequency of the study area shows a positive correlation with the drainage density, which indicates that the stream population increases with the increase of drainage density. GIS based approach facilitates analysis of different morphometric parameters and to explore the relationship between the drainage morphometry and properties of landforms, soils and eroded lands. GIS techniques characterized by very high accuracy of mapping and measurement prove to be a competent tool in morphometric analysis. The morphometric analyses in the present study were carried out through measurement of linear, areal and relief aspects of the basin area with different sets of morphometric parameters. The variation in stream characteristics might be due to change in slope.
Figure 4. Slope map of Umtrew River basin.

Figure 5. Digital Elevation Model (DEM) of Umtrew River basin.
and topography.

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