Mathematical analysis of Solani Watershed, North India

Subhanil Guha
Department of Geography, Dinabandhu Andrews College, Kolkata, India
subhanilguha@gmail.com

ABSTRACT

The present paper involves an attempt to study the measurement and mathematical analysis of Solani watershed in Uttarakhand and Uttar Pradesh, North India. Author has evaluated the morphometric parameters based on the Survey of India toposheets at 1:50,000 scale, SRTM-DEM and Landsat 8 data. For this detailed study, SRTM based DEM and GIS have been applied in evaluation of linear, areal and relief aspects of drainage morphometry. Stream length, stream ordering, sinuosity index etc. have been prepared using sophisticated GIS software, and DEM. Author has computed more than 49 morphometric parameter of all aspects. Based on the morphometric analysis it can be said that the erosional development of the area by the streams has progressed in the old stage and those lithological characteristics has had an influence in the development of drainage system. This study is very much beneficial for rainwater harvesting and watershed management.

Keywords: Morphometry, SRTM-DEM, Landsat 8, GIS, Watershed

1. Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998). A major emphasis in geomorphology over the past several decades has been on the development of quantitative physiographic methods to describe the evolution and behavior of surface drainage networks (Horton, 1945). The source of the watershed drainage lines have been discussed since they were made predominantly by surface fluvial runoff has very important climatic, geological and geomorphological impacts e.g. (Laity, et al., 1985; Malin, et al., 2000; Hynek, et al., 2003). Morphometric analysis of a watershed provides a numerical description of the drainage network, which is one of the very important aspects of the characteristics of watersheds (Strahler, 1964). Geospatial techniques are recently frequently applied for the assessment of different types of terrain and morphometric parameters of the drainage basins, catchments and watersheds, as they provide a sophisticated scientific environment and a reliable tool for the analysis of spatial information maintaining a maximum level of accuracy.

2. Physical Setting

The study area is Solani watershed, located in in Uttarakhand and Uttar pradesh, India (Fig. 1). The total study area is 914.7411 Sq Km and situated between 29.84 North to 30.27 North latitude and 77.74 East to 78.07 East longitude. The study area falls in Survey of India (1:50,000) toposheets No. 53F/15, 53F/16, 53G/13, 53J/4 and 53K/1. The Solani River originates near Kaluwala pass at about 787 m (30.26 N latitude & 77.87 E longitude). Solani River is 65.265 Km long, however there is no main tributary of the Solani River, there are some small tributaries pouring into the river, notable amongst there are Shahjahanpur Rao, Khajnawar Rao, Rajwa Rao, Mohan Rao, Ratmau Rao, Sipla Nala etc. It is a moderate size
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right bank tributary of river Ganga. Before join the Ganga River at near Jansath tehsil of Muzaffarnagar districts of U.P. It traverses over Roorkee tehsil of Haridwar district of Uttarakhand, and Saharanpur and Muzaffarnagar districts of Uttar Pradesh.

Figure 1: Image showing the location map of the study area

2.1 Geology

The watershed, forming a part of the Indo-Gangetic alluvial tract in the south and the Shiwalik Hills in the north comprises with the following successions of rock groups arranged in order of increasing age from top to bottom: The Shiwalik mainly consists of sandstone, grit, conglomerate, pseudo-conglomerate, clay, and silt having the character of fluvial deposits of torrential streams and floods in shallow fresh water basins. The sandstone shows poor stratification and is generally upgraded as to grain size. The Shiwalik Hills on the southern portion is fringed by the talus fans. The upper portion of the talus fan is composed by rock fragments, gravel, soil and supports with rich forest coverage. This zone is known as the Bhabar, which has a vertical extent of less than 300 m. A number of noted geomorphologists and geologists analysed the study area using suitable geological parameters. Among them, Gilbert,1877; Davis,1902; Tomlinson,1925; De Terra,1939; Krishnan, et al.,1940; Wadia, et al.,1964; Babu,1972; Woodroffe,1980; Bukbank,1983 and Boison, et al.,1985 are much significant personalities.

3. Materials and Methods

The extraction of the drainage network of the study area carried out from a SRTM-DEM of 90 m spatial resolution and with reference to the Survey of India toposheets at 1:50,000 scale. Hydrology tool under GIS software has been applied to extract drainage network and other significant parameters. The automatic method for calculating streams followed a sequence i.e. DEM, fill, flow direction, flow accumulation and stream order.
4. Results and Discussion

The measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landform provides the basis of the investigation of maps for a thorough geomorphological survey. This approach has also been termed as morphometry. The area, elevation, perimeter, slope, profile and texture of landforms and drainage consist major parameters of investigation. Dury, 1952 and Christian, 1957 applied various methodologies for analysis of landform and that could be classified in a number of ways and their outputs presented in graph, chart, map or statistical expression.

The morphometric analysis of the Solani watershed was carried out on the Survey of India topographical maps No. 53F/15, 53F/16, 53G/13, 53J/4 and 53K/1 on the scale 1:50,000, Landsat 8 satellite image of 3 May, 2015 and SRTM-DEM with 90 m spatial resolution. The stream length and area of the watershed were measured by using GIS software, and stream ordering has been generated by Strahler (1952) method with the help of GIS software. Several methods have been used for linear, areal and relief aspects studies i.e. Gravelius (1914) for compactness coefficient; Wentworth (1930) for slope analysis, Smith (1939) for drainage texture; Horton (1945, 32) for stream ordering, stream number, stream frequency, stream length, stream length ratio, rho coefficient, bifurcation ratio, length of overland flow and form factor; Strahler (1952, 68) for ruggedness number, hypsometric analysis, mean stream length & weighted mean bifurcation ratio; Schumm (1956) for basin area, basin length, texture ratio, elongation ratio & relief ratio; Hack (1957) for length area relation; Chorely (1957) for lemniscate’s; Melton (1957, 58) for drainage density & fitness ratio; Miller (1960) for circularity ratio; Wolman (1964) for sinuosity index analysis; Smart (1967) for wandering ratio; Mueller (1968) for channel & valley index; Faniran (1968) for drainage intensity and Black (1972) for watershed eccentricity.
4.1 Linear Aspects

4.1.1 Stream Order (Su)

Stream ordering is the first step of numerical analysis of the watershed. The stream ordering method has first advocated by Horton (1945) but Strahler (1952) has proposed this stream ordering method with some rectifications. Author has been carried out the stream ordering based on the method proposed by Strahler (Table 1). It has been noticed that the maximum frequency is in the case of first order streams. It has also been observed that there is a inverse relationship between stream number and stream order.

4.1.2 Stream Number (Nu)

The total order wise stream segments are known as stream number. Horton (1945) states that the numbers of stream segments of each order form an inverse geometric sequence with order number (Table 1).
4.1.3 Stream Length (Lu)

The total stream lengths of the Solani watershed have been computed with the help of topographical sheets, SRTM-DEM and GIS software. Horton’s law of stream lengths supports the theory that geometrical similarity is preserved generally in watershed of increasing order (Strahler, 1964). Author has computed the stream length based on the law proposed by Horton (1945) as shown in Table 1.

Table 1: Table showing the Stream number & Stream length for SRTM-DEM based analysis

<table>
<thead>
<tr>
<th>Stream Order</th>
<th>Stream Number</th>
<th>Stream Length</th>
<th>Bifurcation Ratio</th>
<th>No. of Stream used in Ratio</th>
<th>Product of Column 6 &amp; 7</th>
<th>Weighted Mean Bifurcation Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>I</td>
<td>232</td>
<td>424.383</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>118</td>
<td>256.582</td>
<td>1.9425</td>
<td>350</td>
<td>679.875</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>55</td>
<td>121.331</td>
<td>2.554</td>
<td>173</td>
<td>441.842</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>53</td>
<td>100.527</td>
<td>2.34275</td>
<td>108</td>
<td>145.017</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>458</td>
<td>902.823</td>
<td></td>
<td>631</td>
<td>1266.735</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>2.27975</td>
<td></td>
<td></td>
<td>2.0075</td>
</tr>
</tbody>
</table>

4.1.4 Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of the stream segments of given order ‘Nu’ to the number of streams in the next higher order ‘Nu+1’ (Table 1). Horton (1945) considered the bifurcation ratio as the index of relief and dissertation. According to Strahler (1957), bifurcation ratio presents a small range of variation for different regions or for different environment except the geologically dominated portions. It is noticed from the Rb is not same from one order to its next higher order. This numerical inequality is primarily dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). Normally, the value of bifurcation ratio varies from 3.0 to 5.0. The lower values of Rb have been suffered from less structural disturbances (Strahler, 1964) and the drainage pattern has not been distorted because of the structural disturbances (Nag, 1998). Here the higher values of Rb indicate strong structural dominance on the drainage system, while the lower values of Rb indicate that the watershed is not controlled by structural disturbances.

4.1.5 Weighted Mean Bifurcation Ratio (Rbwm)

To get a more representative bifurcation number Strahler (1952) applied a weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total number of streams involved in the ratio and taking the mean of the sum of these values. Schumm (1956, pp. 603) has also applied this method to compute the mean bifurcation ratio for the drainage of Perth Amboy, N.J. The value of the weighted mean bifurcation ratio for the present study area is 2.874. (Table 1).

4.1.6 Mean Stream Length (Lum)

Mean Stream length is a drainage property presenting the characteristic size of components of a drainage network and its corresponding watershed surfaces (Strahler, 1964). It is computed
by simply dividing the total stream length of an order by the total number of segments in that particular order (Table 2).

4.1.7 Stream Length Ratio (Lurm)

Horton (1945, pp. 291) states that the stream length ratio as the ratio of the mean of segments of a order ‘Lu’ to mean length of the segments of the next lower order ‘Lu-1’. Normally, the value tends to be constant throughout the successive orders of a drainage basin. Horton's law of stream length refers that the mean stream lengths of stream segments of each of the successive orders of a watershed tend to approximate a direct geometric sequence in which the stream length is the average length of segments of the first order (Table 2). Change in stream length ratio from a particular order to the next order indicating their late youth stage of geomorphological age (Singh et al., 1997).

Table 2: Table showing the SRTM-DEM based analysis for stream length, stream length ratio and weighted mean stream length ratio

<table>
<thead>
<tr>
<th>Stream Order</th>
<th>Stream Length</th>
<th>Stream Length/Order</th>
<th>Stream Length Ratio</th>
<th>No. of Stream Length used in Ratio</th>
<th>Product of Column 4 &amp; 5</th>
<th>Weighted Mean Stream Length Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>424.383</td>
<td>424.383</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>256.582</td>
<td>128.291</td>
<td>3.308</td>
<td>680.965</td>
<td>2252.632</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>121.331</td>
<td>48.444</td>
<td>2.648</td>
<td>377.913</td>
<td>1000.714</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>100.527</td>
<td>25.132</td>
<td>1.928</td>
<td>221.858</td>
<td>427.742</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>902.823</td>
<td>626.25</td>
<td></td>
<td>1280.736</td>
<td>3681.088</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td>2.628</td>
<td></td>
<td></td>
<td>2.874</td>
</tr>
</tbody>
</table>

4.1.8 Sinuosity Index (Si)

Sinuosity deals with the pattern of channel of a drainage basin. Sinuosity may be defined as the ratio of channel length to down valley distance. Generally, its value varies from 1 to 4 or more. Rivers having a sinuosity value of 1.5 are called sinuous, and above 1.5 are called meandering (Wolman et al. 1964, pp. 281). It is an important numerical index to interpret the significance of streams in the evolution of landscapes and beneficial for geologists, geomorphologists, hydrologists and hydrogeologists. To measure the sinuosity index Mueller (1968, pp. 374-375) has suggested some important computations that deal various types of sinuosity indices. He defines topographic and hydraulic sinuosity index concerned with the flow of natural stream courses and with the development of flood plains. Here the computed value of topographic, hydraulic and standard sinuosity index is 35.568%, 64.431% and 1.197% respectively (Table 3).

4.1.9 Length of Main Channel (Cl)

This is the length along the longest watercourse from the outflow point of designated sub-watershed to the upper limit to the watershed boundary. Author have computed the main channel length by using GIS software, which is 65.265 Km (Table 3).
4.1.10 Channel Index (Ci) & Valley Index (Vi)

The river channel has been divided into a number of segments as suggested by Mueller (1968) for the determination of sinuosity index. The length of channel and valley and also the shortest distance between the source and mouth of the river (Adm) i.e. air length is used for calculating the Channel index and valley index (Table 3).

4.1.11 Length of Overland Flow (Lg)

Horton (1945) used this term to refer to the length of the run of the rainwater on the ground surface before it is localized into definite channels. Horton estimated the length of overland flow as almost equal to the half of the reciprocal of the drainage density. Here, the length of overland flow of the Solani watershed is 0.507 Km (Table 3), which shows low surface runoff of the study area.

4.1.12 Rho Coefficient (ρ)

The Rho coefficient is an important parameter relating drainage density to physiographic development of a watershed which facilitate evaluation of storage capacity of drainage system and hence, a strong determinant of drainage development in a given watershed (Horton, 1945). These physical and anthropogenic factors determine the changes in this parameter. Rho values of the Solani watershed is 1.359 (Table 3). This is suggesting higher hydrologic storage during floods and attenuation of effects of erosion during elevated discharge.

Table 3: Table showing the important morphometric parameters for linear aspects

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Morphometric Parameter</th>
<th>Formula</th>
<th>Reference</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Main Channel Length (Cl) Km</td>
<td>Cl</td>
<td>-</td>
<td>65.265</td>
</tr>
<tr>
<td>2</td>
<td>Valley Length (Vl) Km</td>
<td>Vl</td>
<td>-</td>
<td>54.519</td>
</tr>
<tr>
<td>3</td>
<td>Minimum Aerial Distance (Adm) Km</td>
<td>Adm</td>
<td>-</td>
<td>48.60</td>
</tr>
<tr>
<td>4</td>
<td>Channel Index (Ci)</td>
<td>Ci = Cl / Adm</td>
<td>Mueller (1968)</td>
<td>1.343</td>
</tr>
<tr>
<td>5</td>
<td>Valley Index (Vi)</td>
<td>Vi = Vl / Adm</td>
<td>Mueller (1968)</td>
<td>1.122</td>
</tr>
<tr>
<td>6</td>
<td>Hydraulic Sinuosity Index (Hsi) %</td>
<td>Hsi = ((Ci - Vi)/(Ci - 1))*100</td>
<td>Mueller (1968)</td>
<td>64.431</td>
</tr>
<tr>
<td>7</td>
<td>Topographic Sinuosity Index (Tsi) %</td>
<td>Tsi = ((Vi - 1)/(Ci - 1))*100</td>
<td>Mueller (1968)</td>
<td>35.568</td>
</tr>
<tr>
<td>8</td>
<td>Standard Sinuosity Index (Ssi)</td>
<td>Ssi = Ci / Vi</td>
<td>Mueller (1968)</td>
<td>1.197</td>
</tr>
<tr>
<td>9</td>
<td>Length of Overland Flow (Lg) Km</td>
<td>Lg = A / 2 * Lu</td>
<td>Horton (1945)</td>
<td>0.507</td>
</tr>
<tr>
<td>10</td>
<td>Rho Coefficient (ρ)</td>
<td>ρ = Lur / Rb</td>
<td>Horton (1945)</td>
<td>1.359</td>
</tr>
</tbody>
</table>

4.2 Areal Aspects

4.2.1 Basin Area (A)
The area of the watershed is another important parameter like the length of the stream drainage. Schumm (1956) established an interesting relation between the total watershed areas and the total stream lengths. The basin area has been measured through GIS software, which is 914.7411 km$^2$ (Table 4).

**Table 4:** Table showing the important morphometric parameters for basin geometry

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Morphometric Parameter</th>
<th>Formula</th>
<th>Reference</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basin Area (A) Sq Km</td>
<td>-</td>
<td>Schumm (1956)</td>
<td>914.7411</td>
</tr>
<tr>
<td>2</td>
<td>Basin Length (Lb) Km</td>
<td>-</td>
<td>Schumm (1956)</td>
<td>48.60</td>
</tr>
<tr>
<td>3</td>
<td>Basin Perimeter (P) Km</td>
<td>-</td>
<td>Schumm (1956)</td>
<td>139.776</td>
</tr>
<tr>
<td>4</td>
<td>Length Area Relation (Lar)</td>
<td>( Lar = 1.4 \times A^{0.6} )</td>
<td>Hack (1957)</td>
<td>59.811</td>
</tr>
<tr>
<td>5</td>
<td>Lemniscate’s (k)</td>
<td>( k = Lb^2 / A )</td>
<td>Chorely (1957)</td>
<td>2.521</td>
</tr>
<tr>
<td>6</td>
<td>Form Factor Ratio (Rf)</td>
<td>( Ff = A / Lb^2 )</td>
<td>Horton (1932)</td>
<td>0.387</td>
</tr>
<tr>
<td>7</td>
<td>Shape Factor Ratio (Rs)</td>
<td>( Sf = Lb^2 / A )</td>
<td>Horton (1932)</td>
<td>2.521</td>
</tr>
<tr>
<td>8</td>
<td>Elongation Ratio (Re)</td>
<td>( Re = 2 / Lb \times (A / \pi)^{0.5} )</td>
<td>Schumm (1956)</td>
<td>0.702</td>
</tr>
<tr>
<td>9</td>
<td>Elipsoidity Index (Ie)</td>
<td>( Ie = \pi \times V_l / 4 \times A )</td>
<td>-</td>
<td>2.552</td>
</tr>
<tr>
<td>10</td>
<td>Texture Ratio (Rt)</td>
<td>( Rt = N_l / P )</td>
<td>Schumm (1956)</td>
<td>3.036</td>
</tr>
<tr>
<td>11</td>
<td>Circularity Ratio (Rc)</td>
<td>( Rc = 12.57 \times (A / P^2) )</td>
<td>Miller (1960)</td>
<td>0.589</td>
</tr>
<tr>
<td>12</td>
<td>Circularity Ration (Rcn)</td>
<td>( Rcn = A / P )</td>
<td>Strahler (1964)</td>
<td>6.544</td>
</tr>
<tr>
<td>13</td>
<td>Drainage Texture (Dt)</td>
<td>( Dt = N_u / P )</td>
<td>Horton (1945)</td>
<td>3.277</td>
</tr>
<tr>
<td>14</td>
<td>Compactness Coefficient (Cc)</td>
<td>( Cc = 0.2841 \times P / A^{0.5} )</td>
<td>Gravelus (1914)</td>
<td>1.313</td>
</tr>
<tr>
<td>15</td>
<td>Fitness Ratio (Rf)</td>
<td>( Rf = C_l / P )</td>
<td>Melton (1957)</td>
<td>0.467</td>
</tr>
<tr>
<td>16</td>
<td>Wandering Ratio (Rw)</td>
<td>( Rw = C_l / Lb )</td>
<td>Smart (1967)</td>
<td>1.343</td>
</tr>
<tr>
<td>17</td>
<td>Watershed Eccentricity (( \tau ))</td>
<td>( \tau = (Lcm^2 - Wcm^2) / Wcm )</td>
<td>Black (1972)</td>
<td>0.621</td>
</tr>
<tr>
<td>18</td>
<td>Centre of Gravity of the Watershed (Gc)</td>
<td>-</td>
<td>-</td>
<td>30.05N, 77.91E</td>
</tr>
</tbody>
</table>

**4.2.2 Length of the Basin (Lb)**

A number of geomorphologists defined basin length in different ways, such as Schumm (1956) defined the basin length as the longest dimension of the basin parallel to the principal drainage line. Gardiner (1975) defined the basin length as the length of the line from a basin mouth to a point on the perimeter equidistant from the basin mouth in either direction around the perimeter. The author has determined the length of the Solani watershed in accordance with the definition of Schumm (1956) that is 48.60 Km (Table 4).

**4.2.3 Basin Perimeter (P)**

Basin perimeter is the outer boundary of the watershed that enclosed its area. It can be measured along the watershed divide and may be used as an indicator of watershed size and shape. The basin perimeter of the study area is 139.776 km (Table 4).
4.2.4 Length Area Relation (Lar)

Hack (1957) found that for a large number of basins, the stream length and the basin area are related by a simple power function as follows: \[ \text{Lar} = 1.4 \times A^{0.6} \]. The value of length area relation for Solani watershed has been computed as 59.811.

4.2.5 Lemniscate’s (k)

Chorely (1957) express the Lemniscate’s value to determine the slope of the basin. In the formula \( k = \frac{Lb^2}{A} \). Where, Lb is the basin length (Km) and A is the area of the basin (km\(^2\)). The lemniscate (k) value for the watershed is 2.521 (Table 4), which shows that the watershed occupies the maximum area in its regions of inception with large number of streams of higher order.

4.2.6 Form Factor (Ff)

According to Horton (1932) form factor may be defined as the ratio of basin area to square of the basin length. If a watershed is perfectly circular, the value of form factor would always be less than 0.754. The decreasing value reflects the decrease in circularity. High value of form factor indicates high peak flows of shorter duration. Low form factor value indicates the elongated shape and flow for longer duration (Table 4).

4.2.7 Elongation Ratio (Re)

According to Schumm (1956, pp. 612) elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. Strahler states elongation ratio ranges between 0.6 and 1.0 over a wide climatic and geologic differences. The varying slopes of watershed can be classified with the help of the index of elongation ratio, i.e. circular (0.9 to 1.0), oval (0.8 to 0.9), less elongated (0.7 to 0.8), elongated (0.5 to 0.7) and more elongated (< 0.5). The elongation ratio of Solani watershed is 0.702 depicts the less elongated to oval (Table 4) shape of the study area.

4.2.8 Texture Ratio (Rt)

According to Schumm (1956) texture ratio is an important factor in the drainage morphometric analysis which primarily depends on the lithological components, infiltration capacity and relief aspects of the area. The texture ratio is the ratio between the first order streams and the perimeter of the basin (\( Rt = \frac{Nl}{P} \)). The texture ratio of the watershed is calculated as 3.036 which is considered as a high range (Table 4).

4.2.9 Circularity Ratio (Re)

For the out-line form of watershed (Strahler, 1964, pp. 4-51 and Miller, et al., 1960, pp. 8) used circularity ratio as a quantitative method. Circularity ratio is the ratio of watershed area to the area of a circle having the same perimeter as the watershed and it is pretentious by the lithological character of the watershed. Drainage basin with circularity ratio ranges between 0.4 and 0.7 indicates strongly elongated and highly permeable homogenous geologic materials (Miller, et al., 1960). The circularity ratio value (0.589) of the watershed corroborates the Miller’s range, which indicating the slightly elongated shape with low discharge of runoff and highly permeability of the subsoil condition (Table 4).
4.2.10 Drainage Texture (Dt)

Drainage texture is one of the important concept of geomorphology which means that the relative spacing of drainage lines. Dt is the total number of stream segments of all orders per perimeter of the area (Horton, 1945). Smith (1939) has classified drainage texture into five different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). In the present study, the drainage texture of the watershed is 3.277 (Table 4). It indicates that category is very fine drainage texture.

4.2.11 Compactness Coefficient (Cc)

According to Gravelius (1914) compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals to the area of the watershed. The Cc is not dependent on the size of watershed rather dependent on the slope. The compactness coefficient of Solani watershed is 1.313 (Table 4).

4.2.12 Fitness Ratio (Rf)

Melton (1957) applied a new measure of topographic fitness known as fitness ratio, which is the ratio of main channel length to the length of the watershed perimeter. The fitness ratio of the study area is 0.467 (Table 4).

4.2.13 Wandering Ratio (Rw)

According to Smart, et al., (1967) wandering ratio is defined as the ratio of the mainstream length to the valley length. Valley length is the straight distance from the outlet of the basin to the farthest point on the ridge. The wandering ratio of the watershed is 1.343 (Table 4).

4.2.14 Watershed Eccentricity (τ)

Black (1972) has given the expression for watershed eccentricity, which is: \[ \tau = \sqrt{\frac{|L_{cm}^2 - W_{cm}^2|}{W_{cm}}} \] Where: \( \tau \) = Watershed eccentricity, a dimensionless factor, \( L_{cm} \) = Straight length from the watershed mouth to the centre of mass of the watershed, and \( W_{cm} \) = Width of the watershed at the centre of mass and perpendicular to \( L_{cm} \). The watershed eccentricity for the Solani watershed is 0.621 (Table 4).

4.2.15 Centre of Gravity of the Watershed (Gc)

It is the length of the channel measured from the outlet of the watershed to a point on the stream nearest to the centre of the watershed. The centre of the Solani watershed has been determined using following steps:
1. A cardboard piece was cut in the shape of Solani watershed.
2. The centre of gravity was located on that cardboard piece using point balance standard procedure.
3. The cardboard piece marked with the centre of gravity was superimposed over the watershed plan.
4. By pressing a pin over the centre of gravity of the cardboard piece it was marked on the watershed.

Author has computed the centre of gravity of the watershed by using GIS software, which is a point showing the latitude 30.05 N and the longitude 77.91 E (Table 4).
4.2.16 Stream Frequency (Fs)

The drainage frequency introduced by (Horton, 1932, pp. 357 and 1945, pp. 285) means stream frequency (or channel frequency) Fs as the number of stream segments per unit area. For the study area the value of stream frequency is 0.5007 (Table 5).

4.2.17 Drainage Density (Dd)

Drainage density is the stream length per unit area in region of watershed (Horton, 1945, pp.243 and 1932, pp. 357; Strahler, 1952, Melton, 1958) is an important element for the analysis of drainage system. Drainage density is one of the finest quantitative expressions to the dissection and analysis of landform. The calculated value of the drainage density for the present study area is 0.9869 Km/Km$^2$ indicating moderate drainage densities (Fig. 5 & Table 5). It is suggested that the moderate drainage density indicates the basin is moderate permeable sub-soil and thick vegetative cover (Nag, 1998).

Table 5: Table showing the important morphometric parameters for drainage texture analysis

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Morphometric Parameter</th>
<th>Formula</th>
<th>Reference</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Stream Frequency (Fs)</td>
<td>Fs = Nu / A</td>
<td>Horton (1932)</td>
<td>0.5007</td>
</tr>
<tr>
<td>2</td>
<td>Drainage Density (Dd) Km / Km$^2$</td>
<td>Dd = Lu / A</td>
<td>Horton (1932)</td>
<td>0.9869</td>
</tr>
<tr>
<td>3</td>
<td>Constant of Channel Maintenance (Km$^2$/Km)</td>
<td>C = 1 / Dd</td>
<td>Schumm (1956)</td>
<td>1.0133</td>
</tr>
<tr>
<td>4</td>
<td>Drainage Intensity (Di)</td>
<td>Di = Fs / Dd</td>
<td>Faniran (1968)</td>
<td>0.5073</td>
</tr>
<tr>
<td>5</td>
<td>Infiltration Number (If)</td>
<td>If = Fs * Dd</td>
<td>Faniran (1968)</td>
<td>0.4941</td>
</tr>
<tr>
<td>6</td>
<td>Drainage Pattern (Dp)</td>
<td></td>
<td>Horton (1932)</td>
<td>Dendritic, Parallel</td>
</tr>
</tbody>
</table>

4.2.18 Drainage Intensity (Di)

Faniran (1968) defines the drainage intensity, as the ratio of stream frequency to drainage density. The low value (0.5073) of drainage intensity of the study area (Table 5) implies that drainage density and stream frequency have very little effect on the extent to which the surface has been lowered by agents of denudation. The low value of drainage density, stream frequency and drainage intensity does not allow the surface runoff to remove quickly from the watershed and making it highly susceptible to landslide, flood and soil erosion.

4.2.19 Infiltration Number (If)

The infiltration number of a watershed is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the watershed. The low infiltration number (0.4941) shows the low run-off in the Solani watershed (Table 5).
4.2.20 Drainage Pattern (Dp)

In the watershed, the drainage pattern reflects the dominance of slope, structure and lithology. The analysis of drainage pattern and drainage texture also helps to identify the stage of cycle of erosion. Some geologic and lithologic characteristics may be concluded using the drainage patterns. Drainage texture indicates the influence of geology, relief, climate, soil and vegetation. Howard (1967) related drainage patterns to geological information. The study area presents mainly dendritic and parallel drainage pattern. Dendritic pattern is the most common pattern developed in the drainage basin composed of fairly homogeneous rock without control by the underlying geologic structure.

4.3 Relief Aspects

4.3.1 Relief Ratio (Rh1)

Difference in the elevation between the highest point of a watershed and the lowest point on the valley floor is known as the total relief of the river basin. The relief ratio is considered as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956). 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 the relief ratios. Here the calculated value of relief ratio is 13.663 (Table 6). It has been observed that areas with low to moderate relief and slope are characterized by moderate value of relief ratio. Low value of relief ratio indicates the resistant basement rocks of the basin and low degree of slope.

Table 6: Table showing the important morphometric parameters for relief aspects

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Morphometric Parameter</th>
<th>Formula</th>
<th>Reference</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Height of Basin Mouth (z) m</td>
<td>-</td>
<td>-</td>
<td>244</td>
</tr>
<tr>
<td>2</td>
<td>Maximum Height of the Basin (Z) m</td>
<td>-</td>
<td>-</td>
<td>908</td>
</tr>
<tr>
<td>3</td>
<td>Total Basin Relief (H) m</td>
<td>H = Z - z</td>
<td>Strahler (1952)</td>
<td>664</td>
</tr>
<tr>
<td>4</td>
<td>Relief Ratio (Rhl)</td>
<td>Rhl = H / Lb</td>
<td>Schumm (1956)</td>
<td>13.663</td>
</tr>
<tr>
<td>5</td>
<td>Dissection Index (Dis)</td>
<td>Dis = H / Ra</td>
<td>Singh (1994)</td>
<td>0.731</td>
</tr>
<tr>
<td>6</td>
<td>Ruggedness Number (Rn)</td>
<td>Rn = Dd * (H / 1000)</td>
<td>Strahler (1968)</td>
<td>0.655</td>
</tr>
</tbody>
</table>

4.3.2 Dissection Index (Dis)

Dissection index is a parameter implying the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or watershed (Singh, et al., 1994). On average, the values of Dis vary between ‘0’ (complete absence of vertical dissection/erosion and hence dominance of flat surface) and ‘1’ (for vertical cliff). Dis value of Solani watershed is 0.731 (Table 6), depicts that the watershed is moderately dissected.
4.3.3 Ruggedness Number (Rn)

Strahler’s (1968) ruggedness number is the product of the basin relief and the drainage density and usefully combines slope steepness with its length. The ruggedness number of Solani watershed has been calculated as 0.655 (Table 6). The low ruggedness value of watershed implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density.

4.3.4 Hypsometric Analysis (Hs)

Langbein (1947) appear to have been the first to use such a line of study to collect hydrologic data. However, again Strahler (1952) popularized it in his excellent paper. According to Strahler (1952) topography produced by stream channel erosion and associated processes of weathering, mass-wasting and surface runoff is extremely complex. Hypsometric curve and hypsometric integral are important elements in describing the present status of topographic stage. Because in the youth stage hypsometric integral is large but it decreases with the erosion and denudation of landforms towards the mature and the old stage (Strahler, 1952, pp. 118). The author used the percentage hypsometric method. It is simply the ratio of relative height/relief and relative area with respect to the total height/relief and the total area of a drainage basin. It has been calculated using the ratios given below:

- \( \frac{a}{A} \), where ‘a’ is the area enclosed by a pair of contours, and ‘A ’ is the total basin area which is represented on the abscissa; and
- \( \frac{h}{H} \), where ‘h’ is the highest elevation between each pair of contours, and ‘H’ is the total basin relief/height.

These data are shown in Table 7. The hypsometric curve was obtained in the graphical plots (Figure 4).

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Elevation range (m)</th>
<th>Height (m)</th>
<th>Area (Km(^2)) (a)</th>
<th>(h/H), where (H=664) m</th>
<th>(a/A), where (A = 914.7411) Km(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>908</td>
<td>664</td>
<td>0.008</td>
<td>1.000</td>
<td>0.001</td>
</tr>
<tr>
<td>2</td>
<td>825-908</td>
<td>581</td>
<td>2.107</td>
<td>0.875</td>
<td>0.002</td>
</tr>
<tr>
<td>3</td>
<td>742-908</td>
<td>498</td>
<td>18.530</td>
<td>0.750</td>
<td>0.020</td>
</tr>
<tr>
<td>4</td>
<td>659-908</td>
<td>415</td>
<td>66.565</td>
<td>0.625</td>
<td>0.073</td>
</tr>
<tr>
<td>5</td>
<td>576-908</td>
<td>332</td>
<td>139.913</td>
<td>0.500</td>
<td>0.153</td>
</tr>
<tr>
<td>6</td>
<td>493-908</td>
<td>249</td>
<td>192.534</td>
<td>0.375</td>
<td>0.210</td>
</tr>
<tr>
<td>7</td>
<td>410-908</td>
<td>166</td>
<td>267.231</td>
<td>0.250</td>
<td>0.292</td>
</tr>
<tr>
<td>8</td>
<td>327-908</td>
<td>83</td>
<td>429.665</td>
<td>0.125</td>
<td>0.470</td>
</tr>
<tr>
<td>9</td>
<td>244-908</td>
<td>0</td>
<td>914.741</td>
<td>0.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>
4.3.5 Hypsometric Integrals (Hi)

The hypsometric and erosion integrals give accurate knowledge of the stage of the cycle of erosion. These values can be calculated from the percentage hypsometric curve. The following hypothetical standards have been recognized for determining the stages of hypsometric integrals (Table 8).

<table>
<thead>
<tr>
<th>% of Hypsometric Integrals</th>
<th>Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;30</td>
<td>Old</td>
</tr>
<tr>
<td>30-60</td>
<td>Mature</td>
</tr>
<tr>
<td>60-80</td>
<td>Youth</td>
</tr>
<tr>
<td>80-100</td>
<td>Initial</td>
</tr>
</tbody>
</table>

The hypsometric integral (King, 1966) of Solani watershed has been computed as 21.315% and the erosion integral or the percentage of mass removed of the watershed is 78.685%, which indicates the old stage of the Solani watershed.

5. Concluding Remarks

The study reveals that remotely sensed data i.e. Landsat 8 data, SRTM-DEM data and GIS based approach in evaluation of drainage morphometric parameters and their influence on lithology, topography, soil and land erosion at river basin level is more appropriate than the traditional methods. GIS based study facilitates analysis of different morphometric parameters and to explore the relationship of drainage morphometry with topography and soil. The morphometric analyses have been carried out with the measured values of linear, areal and relief aspects of the watershed with more than 49 morphometric parameters. The morphometric analysis of the watershed shows moderate drainage texture. The difference in stream length ratio might be due to the change in slope and topography. From the bifurcation ratio it can be said that the study area falls under normal watershed category and the presence...
of moderate drainage density suggesting that it has moderate permeable sub-soil and coarse
drainage texture. It is clear from stream frequency value the watershed shows positive
correlation with increasing stream population with respect to increasing drainage density.
From the value of form factor and circulator ratio it can be suggested that the shape of Solani
watershed is less elongated to oval.

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