CHAPTER – IV

Morphometric Analysis
Morphometric Analysis

4.1. General Statement

The drainage basin or watershed is the fundamental unit in geomorphology within which the relations between landforms and process that modify them is studied. It is a natural laboratory of hydrology which can be defined as the area that drains the entire precipitation into a particular stream outlet. Morphometric analysis of drainage basin and channel network plays a vital role to understand the hydrogeological behavior of drainage basin. Morphometric studies in the field of hydrology were first initiated by Horton, (1932) and then modified by Strahler, (1950). Drainage basin morphometric parameters like linear, aerial, gradient of channel network and contributing ground slopes can be used to describe the basin characteristics. These parameters have been used in various geomorphological studies, surface and sub-surface hydrology, such as flood characteristics, sediment yield, and evolution of basin morphology (Jolly, 1982, Ogunkoya, et al., 1984; Aryadike and Phil-Eze, 1989). Morphometric descriptors represent relatively simple approaches to describe basin processes and to compare basin characteristics (Mesa, 2006) that enable an enhanced understanding of the geomorphic history of a drainage basin (Strahler, 1964).

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal, 1998; Obi Reddy, et al., 2002). The study of basin morphometry attempts to relate basin and stream network geometries to the transmission of water and sediment through the basin. The quantitative analysis of drainage system is an important aspect of characterization of watersheds. The size of a drainage basin influences the amount of water yield, since the length, shape and relief affect the rate at which water is discharged from the basin and total yield of sediments. However, properties of the stream networks are very important to study the landform making processes and to understand the sub-surface conditions.

The relationship between various drainage parameters has been well recognized by Horton, 1945; Strahler, 1957; Melton, 1959; Pakhmode, et al., 2003 and Gangalakunta, et al., 2004. Further, the quantitative hydrogeomorphic analysis of
drainage basin introduced by Langbein, (1947) was adopted by various workers, viz; Golding, and Low, 1950; Strahler, 1945, 1950, 1952a, 1954, 1957 and 1958; Schumm, 1956 and Coats, 1958. Geographical Information System (GIS) techniques in conjugation with remotely sensed data are successfully used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a favorable environment and a powerful tool for the manipulation and analysis of spatial information. Recently many workers using remote sensing data and data generated using GIS on morphometric parameters, have concluded that remote sensing has emerged as a powerful tool in analyzing the drainage morphometry (Srivastava, and Mitra, 1995; Agarwal, 1998; Nag, 1998; Das, and Mukherjee, 2005).

The development of drainage pattern gives important information about the surface as well as sub-surface condition of the area, either the streams follow the pre defined path formed by various natural or human influences or cut their way through the soil surface forming definite pattern. Drainage map (Fig 4.1) and splitted drainage map (Fig 4.2) were prepared in order to understand various drainage characteristics. Mathematical equations used to calculate various morphometric parameters are given in Table-4.1. Morphometric maps were prepared in GIS environment and detailed morphometric study is carried out and discussed as:

1. Linear Aspects of the Drainage Network
2. Areal Aspects of the Drainage Network
3. Relief aspects of the Drainage Network

4.2. Linear aspects of the drainage network

4.2.1. Stream Segments, and Stream Order (Nu)

The first attribute to be quantified in morphometric analysis is the hierarchy of stream segments. In this system, channel segments were ordered numerically from a stream's head waters to a point somewhere down stream. This is a section of stream channel between two channel junctions or "fingertip" tributaries, between a junction and upstream termination of a channel. It is a fundamental property of stream networks since it is related to the relative discharge of a channel segment.
Fig. 4.2: Split Drainage Map of the Study Area
Table 4.1: Morphometric Parameters used in Present Study

<table>
<thead>
<tr>
<th>Morphometric Parameters</th>
<th>Formula/Definition</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stream order</td>
<td>Hierarchical Rank</td>
<td>Strahler (1952, b)</td>
</tr>
<tr>
<td>2. Bifurcation Ratio (Rb)</td>
<td>Rb = N_u / N_u+1</td>
<td>Schumm, 1956</td>
</tr>
<tr>
<td>3. Mean Bifurcation Ratio (Rbm)</td>
<td>Rbm = Average of bifurcation ratios of all orders</td>
<td>Strahler (1957)</td>
</tr>
<tr>
<td>4. Stream Length (Lu)</td>
<td>Length of the Stream (km)</td>
<td>Horton (1945)</td>
</tr>
<tr>
<td>5. Mean Stream Length (Lsm)</td>
<td>Lsm = Lu / N_u, km</td>
<td>Strahler (1964)</td>
</tr>
<tr>
<td>6. Stream Length Ratio</td>
<td>SLR= Lu/Lu-1</td>
<td>Horton (1945)</td>
</tr>
<tr>
<td>7. Elongation Ratio (Re)</td>
<td>Re= √(Au/π) / Lb</td>
<td>Schumm (1956)</td>
</tr>
<tr>
<td>8. Circularity Ratio (Re)</td>
<td>Re = 4πAu / P²</td>
<td>Miller (1953)</td>
</tr>
<tr>
<td>9. Form Factor (Rf)</td>
<td>Rf= Au / Lb²</td>
<td>Horton (1932)</td>
</tr>
<tr>
<td>10. Drainage Density (Dd)</td>
<td>Dd= Σ Lu / Au ) km/km²</td>
<td>Horton (1932)</td>
</tr>
<tr>
<td>11. Channel of Constant Maintenance (C)</td>
<td>C=1/D</td>
<td>Schumm, 1956</td>
</tr>
<tr>
<td>12. Stream Frequency (Fs)</td>
<td>Fs = Σ N_u / Au</td>
<td>Horton (1932)</td>
</tr>
<tr>
<td>13. Drainage Texture(Dt)</td>
<td>Dt = Σ N_u/P</td>
<td>Horton (1945)</td>
</tr>
<tr>
<td>14. Infiltration Number,(Ig)</td>
<td>D × Fs</td>
<td>Horton (1945)</td>
</tr>
<tr>
<td>15. Length of Over Land Flow (Lg)</td>
<td>Lg = 1 / D×2 Km</td>
<td>Horton (1945)</td>
</tr>
<tr>
<td>16. Relief Ratio (Rh)</td>
<td>Rh = H / Lbmax</td>
<td>Schumm (1956)</td>
</tr>
<tr>
<td>17. Relative Relief (Rhp)</td>
<td>Rhp = H × (100) / P</td>
<td>Melton, (1957)</td>
</tr>
<tr>
<td>18. Ruggedness Number (HD)</td>
<td>HD= H×Dd</td>
<td>Strahler, (1958)</td>
</tr>
</tbody>
</table>
The most frequently used stream ordering systems given by Strahler, (1957) and Shreve, (1966). Strahler system is used in present work, where a stream segment without any tributary designates a first order segment. A second order segment is formed by joining of two first order segments, a third order segment by joining of two second order segments and so on.

The stream segments in each order were counted and presented in Table 4.2. It is observed that the number of stream segments of any given order is fewer than for the next lower order but more numerous than for the next higher order. This observation verifies the Horton's Law of stream number (1945) i.e. the number of stream segments of each order forms an inverse geometric sequence with order number. The sub-watersheds CH-II, KW-III and KW- IV (Fig.4.2) have more than 250 first order streams which indicate soft lithology of high dissection in these sub-watersheds. CH-II is the only sub-watershed having one Vth order and three IVth order streams while all the other sub-watersheds have two IVth order streams but no Vth order stream, suggest unconsolidated nature of alluvium in CH-II sub-watershed.

4.2.2. Bifurcation Ratio (Rb)

The frequency with which streams of certain order flow into those of next higher order is refer to as bifurcation ratio. It is the ratio of the number of stream of a given order to the number of stream of next higher order (Schumm, 1956). Horton (1945) considered it as index of relief and dissection. The risk factor of flood is indirectly related with the bifurcation ratio (Waugh, 1996). Mathematically Rb can be defined as:

\[ Rb = \frac{Nu}{Nu+1} \]

Where,

- Nu: Number of stream segments present in the given order.
- Nu+1: Number of next higher order stream

It has been found that the bifurcation ratios characteristically range between 3.0 and 5.0 for watersheds in which geology is reasonably homogeneous or geological structure does not disturb the drainage pattern. However the present study shows that sub-watershed KW-III and KW-IV having higher values of Rb,7.5 and 9 respectively.
Fig. 4.3: Mean Bifurcation Ratio Map
Table 4.2: Stream Number and Bifurcation Ratio

<table>
<thead>
<tr>
<th>Stream Orders</th>
<th>CH-I</th>
<th>CH-II</th>
<th>CH-III</th>
<th>KW-I</th>
<th>KW-II</th>
<th>KW-III</th>
<th>KW-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nu</td>
<td>Rb</td>
<td>Nu</td>
<td>Rb</td>
<td>Nu</td>
<td>Rb</td>
<td>Nu</td>
</tr>
<tr>
<td>I</td>
<td>135</td>
<td>4.2</td>
<td>251</td>
<td>4.04</td>
<td>136</td>
<td>4.25</td>
<td>143</td>
</tr>
<tr>
<td>II</td>
<td>32</td>
<td>3.55</td>
<td>62</td>
<td>3.87</td>
<td>32</td>
<td>4</td>
<td>34</td>
</tr>
<tr>
<td>III</td>
<td>9</td>
<td>4.5</td>
<td>16</td>
<td>5.33</td>
<td>8</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>IV</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>V</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4.4: Semi log plot of Stream Order Vs Stream Number
indicates that the structures have little control over drainage development in these sub-watersheds. All the other sub-watersheds have values in the range of 3-5 which may be attested the presence of very thick alluvium over the Vindhyan sediment. The variable Rb values in the watersheds of the study area possibly depend upon the drainage basin. The lower values are characteristics of the sub-watershed, suffered less structural disturbances (Strahler, 1964) and the drainage patterns have not been distorted. Further, the low Rb values signify high drainage density in the study area, clearly indicates uniform surficial material where geology is reasonably homogeneous. High Rb values indicate structural control of drainage directions and signify higher average flood potential due to numerous tributary segments, drain into relatively few trunks. A long basin with a high bifurcation ratio results in a hydrograph, yield a low extended peak flow while a round basin with a low bifurcation ratio would yield a sharp peak (Strahler, 1964). The present study show that the mean Rb value ranges between 4.06 and 5.46 (Table 4.3, Fig.4.3) which appear higher than the range expected for dendritic drainage pattern (3.5-4) indicates that the drainage basin has dendritic to sub-dendritic drainage pattern. Semi log plots of Stream order vs Stream numbers have been drawn and a straight line was fitted through these points (Fig.4.4). The slope of these lines gives the bifurcation ratio.

4.2.3. Stream Length (Lu)

It is the length of stream of various orders from their mouth to drainage divide. The stream length has been computed based on the law proposed by Horton (1945). First order streams have maximum total stream length which gradually decreases with higher order streams due to flow of stream from high altitude, change in rock type, moderately steep slope and probable uplift across the watershed (Singh and Singh, 1997, Vittal et al 2004, Chopra et al, 2005). This trend is showed in all the sub-watersheds except sub-watershed CH-III (Table. 4.4).

4.2.4. Mean Stream Length (Lsm)

Mean Stream length is calculated by dividing the total stream length of order ‘U’ and number of stream of segment of order ‘U’ using the formulae:

$$L_{sm} = \frac{L_{u}}{N_{u}}$$

Where, Lu: mean stream length of a given order, Nu: number of stream of that order.
Table 4.3: Total Number, Total Stream Length and Mean Bifurcation Ratio of Sub-watersheds

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of Sub-watersheds</th>
<th>$\Sigma N_u$</th>
<th>$\Sigma L_u$</th>
<th>Mean Rb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CH-I</td>
<td>178</td>
<td>99.82</td>
<td>4.08</td>
</tr>
<tr>
<td>2</td>
<td>CH-II</td>
<td>333</td>
<td>180.62</td>
<td>4.06</td>
</tr>
<tr>
<td>3</td>
<td>CH-III</td>
<td>178</td>
<td>90.27</td>
<td>4.08</td>
</tr>
<tr>
<td>4</td>
<td>KW-I</td>
<td>188</td>
<td>117.05</td>
<td>4.13</td>
</tr>
<tr>
<td>5</td>
<td>KW-II</td>
<td>223</td>
<td>126.28</td>
<td>4.41</td>
</tr>
<tr>
<td>6</td>
<td>KW-III</td>
<td>323</td>
<td>163.09</td>
<td>5.23</td>
</tr>
<tr>
<td>7</td>
<td>KW-IV</td>
<td>343</td>
<td>181.63</td>
<td>5.46</td>
</tr>
</tbody>
</table>

The mean stream length of a channel segment of order ‘U’ is a dimensional property, revealing the characteristic size of component of drainage network and contributing basin surface (Strahler, 1964). Lsm of any given order is greater than that of lower order and less than that of its next higher order. In the study area the value of mean stream length (Table 4.4 and Fig 4.5) varies from 0.44 - 4.43 km in CH-II sub-watershed, suggest gentle relief and topography of the area.

4.2.5. Stream Length Ratio (SLR)

Stream Length ratio can be defined as the ratio of mean stream length of a given order to mean stream length of next lower order and is determined by the formula:

$$SLR = \frac{L_u}{L_{u-1}}$$

Where,

$Lu$: Mean Stream Length of a given order.

The mean stream length also has important relationship with the surface flow discharge and erosional stage of the basin (Sreedevi et al, 2009). Horton (1945) law of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate direct geometric series with streams length increasing towards higher order of streams. From Table 4.4 it is noted that the variable stream length is possibly due to variation in slope and topography of the basin. The sub-watersheds CH-I, CH-III and KW-IV show increasing trend in stream
### Mean Stream Length and Stream Length Ratio

<table>
<thead>
<tr>
<th></th>
<th>CH - II</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SL (Km)</td>
<td>MSL (Km)</td>
<td>SLR</td>
<td>SL (Km)</td>
<td>MSL (Km)</td>
<td>SLR</td>
<td>SL (Km)</td>
<td>MSL (Km)</td>
<td>SLR</td>
<td>SL (Km)</td>
<td>MSL (Km)</td>
</tr>
<tr>
<td>11.84</td>
<td>0.44</td>
<td>0.60</td>
<td>60.06</td>
<td>0.44</td>
<td>0.63</td>
<td>71.81</td>
<td>0.50</td>
<td>0.49</td>
<td>0.47</td>
<td>0.30</td>
</tr>
<tr>
<td>39.24</td>
<td>0.63</td>
<td>0.40</td>
<td>18.32</td>
<td>0.56</td>
<td>0.39</td>
<td>23.79</td>
<td>0.69</td>
<td>0.60</td>
<td>23.23</td>
<td>0.58</td>
</tr>
<tr>
<td>17.84</td>
<td>1.11</td>
<td>0.45</td>
<td>7.27</td>
<td>0.90</td>
<td>0.20</td>
<td>14.31</td>
<td>1.59</td>
<td>0.33</td>
<td>16.62</td>
<td>0.28</td>
</tr>
<tr>
<td>7.27</td>
<td>2.42</td>
<td>0.35</td>
<td>7.73</td>
<td>2.31</td>
<td>1</td>
<td>7.14</td>
<td>3.57</td>
<td>5.10</td>
<td>2.55</td>
<td>5.11</td>
</tr>
<tr>
<td>4.43</td>
<td>4.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Fig.4.5: Semi Log Plot of Stream Order and Mean Stream Length**
length ratio from lower to higher order, indicating mature geomorphic stage of development, whereas all other sub-watersheds depict variable values of stream length suggest late youth stage of geomorphic development.

4.3. Aerial Aspects of the Drainage Network

4.3.1. Basin Area

Delineation of drainage basin is carried out manually using topographic information. However, widespread availability of elevation data in digital format has bolstered the development of automated tools that can be used to delineate drainage basin and their associated stream network. In the present study sub-watersheds are delineated from the ASTER 30m elevation data through automated process. Total area of the watershed is 183 km². Among all the sub-watersheds, maximum drainage area is covered by the sub watershed CH–I, whereas minimum drainage area is covered by sub-watershed KW–IV (Table 4.5).

4.3.2. Basin Shape (Bs)

Drainage basin shape is defined as shape or outline of a drainage basin, projected upon the horizontal datum plane of a map. The shape of the basin is used to determine discharge characteristics of streams and may considerably affect stream flow hydrograph and peak flow. Horton (1945) described the outline of a normal drainage basin as a pear shape ovoid. The various parameters which are used to define the shape of the basin include Elongation Ratio (Re), Form Factor (Rf) and Circularity Ratio (Rc).

4.3.2.1. Elongation Ratio (Re)

Schumm, (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The elongation ratio ranges between 0.6 and 1.0 over a wide variety of climate and geographical types. The elongation ratio near to 1 is typical in the region of very low relief, whereas values between of 0.6 and 0.8 are generally associated with high relief and steep ground slope. High Re value indicates that the area has high infiltration capacity and low run off while low values are susceptible to high erosion and sedimentation load. These
Fig. 4.6: Elongation Ratio Map
values are further categorized as circular (>0.9), oval (0.9-0.8) and less elongated (<0.7). The sub-watershed of the study area characterized by low elongation ratios (0.12 to 0.23) having strong relief, steep ground slope and high erosion and sedimentation with less elongated shape. Elongation ratio may be determined by using formulae:

\[ Re = \frac{\sqrt{A u \pi}}{Lb} \]

Where,

- \( Au \): Basin Area (Sq km)
- \( Lb \): Maximum Basin Length

Further, low values of elongation in the study area indicate low infiltration and high runoff, susceptible to gullied and ravine erosion. The low value (0.12) of \( Re \) determined in sub-watershed KW-III clearly indicated that the sub-watershed is having steep slope, high relief, and elongated shape (Fig. 4.6) tends to be affected by soil erosion mainly by running water.

4.3.2.2. Circularity Ratio (\( Re \))

Circulatory ratio is expressed as the ratio of basin area (\( Au \)) to the area of a circle having the same perimeter (\( P \)) as the basin (Strahler, 1964) and can be determined by the formulae:

\[ Re = \frac{4\pi Au}{P^2} \]

Where,

- \( Au \): Basin Area (Sq km)
- \( P \): Perimeter of the basin (km)

Circularity Ratio is dimensionless and expresses the degree of circularity of the basin. It is influenced by length and frequency of streams, geological structure, landuse/landcover cover, climate, relief and slope of the basin (Vittal, et al., 2004). Horton (1945) has given the values of circularity ratio from 0.6 to 0.7 for the homogenous geological material to preserve geometric symmetry. In the study area circularity ratio ranges from 0.14 to 0.50 (Table.4.5). Sub-watershed CH-II having value 0.50 appear to be more or less circular (Fig.4.7) while all the other sub-watersheds are elongated in shape where KW-I being the most elongated.
Fig. 4.7: Circularity Ratio Map
4.3.2.3. Form Factor (Rf)

Horton (1932) proposed this parameter to predict the flow intensity of a basin having a definite area. It is defined as the ratio of basin area to the square of basin length and can be determined by the formula:

\[ Rf = \frac{A}{L_b^2} \]

Where,

- \( A \): Basin Area (Sq km)
- \( L_b \): Maximum Basin Length

Rudraiah, et al., (2008) suggested that a perfectly circular basin have form factor value >0.78. However, low form factor value in the area of interest ranging from 0.31 in sub-watershed KW-II to 0.53 in KW-I, suggest that all the sub-watershed falls in the elongated basin category. These sub-watersheds tends to be elongated with low form factor values, indicates that the basin have a flatter peak of flow for longer duration. However, flood flow for such basins is easier to manage. Sub watershed KW-II has low value of shape factor (Fig.4.8) and hence flood flow is easily managed. Further, values of sub watershed CH-III, KW-II and KW-IV fall between 0.31-0.35 (Fig.4.9) shows that these sub-watersheds are more elongated.

4.3.3. Drainage Density (Dd)

Drainage density expresses the closeness of spacing of channels introduced by Horton (1932) and is an important indicator of the linear scale of land form element in stream eroded topography. It is define as the total length of stream of all order per unit area and is a measure of how well or how poorly a watershed is drained by streams channels. It provides numerical measurement of landscape dissection and runoff potential. The drainage density can be determined by the formulae:

\[ Dd = \frac{\sum L_u}{A_u} \]

Where,

- \( \sum L_u \): Total Channel segments length cumulated from each other (Km)
- \( A_u \): Basin Area (Sq km)
Table-4.5: Shape Parameters of different Sub-watersheds

<table>
<thead>
<tr>
<th>S.No</th>
<th>Name of Sub-watersheds</th>
<th>Basin Area (km²)</th>
<th>Perimeter (km)</th>
<th>Max Basin Length (km)</th>
<th>Elongation Ratio (Re)</th>
<th>Circularity Ratio (Re)</th>
<th>Form Factor (RF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CH-I</td>
<td>130.50</td>
<td>35.57</td>
<td>8.95</td>
<td>0.20</td>
<td>0.31</td>
<td>0.39</td>
</tr>
<tr>
<td>2</td>
<td>CH-II</td>
<td>116.50</td>
<td>33.28</td>
<td>9.47</td>
<td>0.22</td>
<td>0.50</td>
<td>0.49</td>
</tr>
<tr>
<td>3</td>
<td>CH-III</td>
<td>30.00</td>
<td>25.23</td>
<td>8.65</td>
<td>0.18</td>
<td>0.48</td>
<td>0.32</td>
</tr>
<tr>
<td>4</td>
<td>KW-I</td>
<td>39.61</td>
<td>58.7</td>
<td>8.61</td>
<td>0.23</td>
<td>0.14</td>
<td>0.53</td>
</tr>
<tr>
<td>5</td>
<td>KW-II</td>
<td>34.89</td>
<td>49.07</td>
<td>10.49</td>
<td>0.18</td>
<td>0.18</td>
<td>0.31</td>
</tr>
<tr>
<td>6</td>
<td>KW-III</td>
<td>62.61</td>
<td>47.05</td>
<td>12.64</td>
<td>0.12</td>
<td>0.35</td>
<td>0.39</td>
</tr>
<tr>
<td>7</td>
<td>KW-IV</td>
<td>52.02</td>
<td>55.56</td>
<td>12.14</td>
<td>0.19</td>
<td>0.21</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Fig.4.8: Graphical Representations of Shape Parameters of Different Sub-watersheds
Form Factor

- 0.31 - 0.35
- 0.36 - 0.39
- 0.40 - 0.53

Fig. 4.9: Form Factor Map
Legend

Drainage Density

- 2.60 - 2.95
- 2.96 - 3.61
- 3.62 - 4.36

Fig. 4.10: Drainage Density Map
High drainage densities usually reduce the discharge in any single stream, more evenly distributing runoff and accelerating into secondary and tertiary streams. Areas with high drainage density signify that water goes to drain a primary stream and same time arrives to a secondary stream. Dynowska, (1976) demonstrated that drainage densities are higher in region where streams are highly loaded with alluvium. Bratsev, (1964) showed that drainage density is high in plains than in mountain since stream length in plain is more due to meandering and sinuosity. The inverse relationship between drainage density and base flow is demonstrated by Carlston, (1963) appear to be related with permeability of rock type. The large quantity of water moves on the surface of the drainage system, indicate the higher drainage density which in turn means the base flow is low (Bell, 2003). In general low drainage density is favored in the regions of highly permeable subsoil under dense vegetative cover and low relief. The low drainage density is also indicative of relatively long overland flow of surface water. High drainage density is favored in regions of weak or impermeable subsurface materials, sparse vegetation and high relief (Chow 1964). Langbein, (1947) recognized the significance of drainage density as a factor determining the time of travel by water and suggest that drainage density varying between 0.55 and 2.09 km/km² in humid region with an average density of 1.03 km/km². However, drainage density is maximum in semi-arid region (Langbein, and Schumm, 1958 and Gregorogy, and Gardiner, 1975).

The drainage density in the study area varies from 2.60 to 4.36 km/km² suggest that the area is semi-arid plain with high alluvium loaded stream due to impermeability of sub-surface lithology. High value of drainage density is found in sub-watershed CH-II and CH-III while low in sub-watershed KW-III (Fig.4.10). The low values of drainage density indicates the presence of impermeable strata in KW-III sub-watershed.

4.3.4. Channel of Constant Maintenance (C)

The reciprocal of the drainage density is constant of channel maintenance, proposed by Schumm, (1956) signifies how much drainage area is required to maintain a unit length of channel. It is illuminating and presaging the usefulness in sediment-yield to estimate the low values of this constant, i.e., a small area to maintain a given channel, is associated with weak or low-resistance soil, sparse vegetation and hilly terrain.
Legend

Constant of Channel Maintenance

- 0.22 - 0.27
- 0.28 - 0.33
- 0.34 - 0.38

Fig. 4.11: Channel of Constant Maintenance Map
Table 4.6: Drainage Density, Stream Frequency, Constant of Channel Maintenance Length of Overflow, Drainage Texture and Infiltration Number of Sub-watersheds

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of Sub-Watersheds</th>
<th>Drainage Density (Dd)</th>
<th>Stream Frequency (Fs)</th>
<th>Constant of Channel Maintenance (C)</th>
<th>Length of Overland flow (Lg)</th>
<th>Drainage Texture (Rt)</th>
<th>Infiltration Number (I)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CH-I</td>
<td>3.17</td>
<td>5.66</td>
<td>0.31</td>
<td>0.15</td>
<td>5.00</td>
<td>15.85</td>
</tr>
<tr>
<td>2</td>
<td>CH-II</td>
<td>4</td>
<td>7.47</td>
<td>0.25</td>
<td>0.12</td>
<td>10.00</td>
<td>40.00</td>
</tr>
<tr>
<td>3</td>
<td>CH-III</td>
<td>4.36</td>
<td>3.2</td>
<td>0.22</td>
<td>0.11</td>
<td>7.04</td>
<td>30.69</td>
</tr>
<tr>
<td>4</td>
<td>KW-I</td>
<td>2.95</td>
<td>4.7</td>
<td>0.33</td>
<td>0.16</td>
<td>5.12</td>
<td>15.10</td>
</tr>
<tr>
<td>5</td>
<td>KW-II</td>
<td>3.61</td>
<td>6.39</td>
<td>0.27</td>
<td>0.13</td>
<td>4.50</td>
<td>16.24</td>
</tr>
<tr>
<td>6</td>
<td>KW-III</td>
<td>2.6</td>
<td>5.1</td>
<td>0.38</td>
<td>0.19</td>
<td>6.86</td>
<td>17.83</td>
</tr>
<tr>
<td>7</td>
<td>KW-IV</td>
<td>3.4</td>
<td>6.5</td>
<td>0.29</td>
<td>0.14</td>
<td>6.17</td>
<td>20.97</td>
</tr>
</tbody>
</table>

Fig. 4.12: Log-Log Plot of Drainage Density and Stream Frequency
Lowest value is found in sub-watershed CH-III and the highest in sub-watershed KW-III (Table-4.6 and Fig.4.11) indicating low resistant soil and undulating terrain in sub-watershed CH-III, and signify high sediment yield in sub-watershed CH-III.

4.3.5. Stream Frequency (Fs)

Horton (1932) defined stream frequency as the number of stream segment per unit area and is given by the formulae:

\[ Fs = \sum \frac{Nu}{A} \]

Where,

Nu: Total number of streams in the basin
A: Basin Area (Sq km)

The high stream frequency values in the sub-watersheds of the area of interest are not corelatable with drainage density (Table-4.6) indicates the possibilities to construct drainage basin having the same drainage density but different stream frequency. High drainage density and low stream frequency in sub-watershed CH-III and positive relation of drainage density and stream frequency in other sub-watershed (Fig. 4.12 and Table 4.6) show high degree of dissection of the landscape and appear due to erodable nature of soil and rock. Further, the variable stream frequency and drainage density, lowest drainage density and high stream frequency in sub-watershed KW-III and lowest value of stream frequency in CH-III (Fig.4.13) indicates disproportionate increase in the length of streams in relation to stream number. Such exception has also been reported in Romanian Quaternary Formations (sand, silt and clay) where stream segment decreases greatly and no longer proportionate with river length (Zavoianu, 1985). Stream length also increases because of the higher sinuosity of streams, resulting in higher drainage density.
Fig. 4.13: Stream Frequency Map
4.3.6. Drainage Texture (Dt)

Horton (1945) described drainage texture is the total number of stream segments of all orders per perimeter. He recognized infiltration capacity as the single important factor which influence drainage texture and includes drainage density and stream frequency. Drainage texture can be determined by the formulae:

\[ Dt = \sum \frac{Nu}{P} \]

Where,

\[ \sum Nu = \text{total number of streams} \]
\[ P = \text{Perimeter of sub-watershed} \]

Smith (1950) classified drainage texture into five different drainage textures. The Dt less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. Present study indicates that the drainage texture of study area is moderate to very fine (Table-4.6).

Drainage texture classification map (Fig.4.14) show that sub-watersheds KW-I, KW-II and CH-I fall in moderate texture category, while KW-III, KW-IV and CH-III falls in fine and CH-II falls in very fine texture category, indicating impermeable sub-surface, soft and weak surficial lithology. Soft and weak surface unprotected with vegetation and give rise fine texture, whereas massive and resistant rock forms coarse texture. The thick unconsolidated alluvial cover produces moderate to very fine texture of drainage in the study area.

4.3.7. Infiltration Number (If)

Infiltration number plays a significant role in observing the infiltration characters of a basin. It is expressed as the product of the drainage density and stream frequency and can be given as:

\[ If = D \times Fs \]

Where,

D: Drainage density
Fs: Stream frequency
Fig. 4.14: Drainage Texture Map
High values of infiltration number in all sub-watersheds indicate low infiltration and high runoff. These values also suggest that the condition of gully erosion may be further aggravated in future due to high runoff potential of the area. All the sub-watersheds have high values of infiltration number where CH-I and CH-II having the highest values (Fig.4.15) and sub-watershed CH-II has high values of drainage density, drainage texture and infiltration number, makes together that this sub-watershed prone to severe soil erosion by water.

4.3.8. Length of Overland Flow (Lg)

Horton (1945) defined length of overland flow as the length of flow path, projected to the horizontal non channel flow from point on the drainage divide to a point on the adjacent stream channel. He further mentioned that the length of overland flow is one of the most important independent variable affecting both hydrologic and physiographic development of drainage basin. The length of overland flow is approximately equal to the half of the reciprocal of drainage density and can be given as:

\[ L_g = \frac{1}{2} \left( \frac{A_u}{L} \right) \]

Where,

- \( A_u \): Basin Area (Sq km)
- \( L \): Length of the Basin

\( L_g \) is the length of water over the ground before it gets concentrated indefinite stream channels (Horton, 1945). This factor is inversely proportional to the average slope of the channel and is synonymous with the length of sheet flow to a large degree. If the basin is well drained the value of overland flow appears to be short and the surface runoff gets concentrated quickly with high flood peak and correspondingly low flow.

The overland flow is higher in semi-arid region than in humid and humid temperate region due to lack of vegetative cover (Kale and Gupta, 2001) Table-4.6 reveals that \( L_g \) is high in all the sub-watershed and highest in KW-III (0.19) (Fig.4.16) possibly due to high drainage density.
Fig. 4.16: Length of Overland Flow Map
4.4. Relief Aspects of Drainage Network

4.4.1. Maximum Basin Relief (H)

Maximum basin relief is the elevation difference between basin mouth and the highest point within the basin perimeter. Maximum basin relief can be determined by the given formulae:

\[ H = H_{\text{max}} - H_{\text{min}} \]

Where,

\( H_{\text{max}} \) = maximum height in sub-watershed
\( H_{\text{min}} \) = height at basin mouth

In order to obtain the potential energy of drainage system, the values of maximum basin relief for drainage basins were determined and presented in the Table 4.7. Digital elevation map (Fig.4.17) generated from ASTER DEM gives elevation range of 110-175m in the drainage basin. Higher the value of maximum basin relief, greater the potential energy, results into higher rate of erosion. Sub-watershed CH-III has the highest value indicating maximum runoff potential where sub-watershed KW-I has the least runoff potential.

4.4.2. Relief Ratio (Rh)

When basin relief (H) is divided by the horizontal distance it results in a dimensionless ratio called relief ratio which is equal to the tangent of the angle formed by two plane intersecting at the mouth of the basin. Schumm (1956) measured relief ratio as the ratio of maximum basin parallel to the principal drainage line. Relief ratio measures the overall steepness of a drainage basin as an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1954). Melton (1957) used relative relief expression in percent. Relief ratio is determined by using the formulae:

\[ Rh = \frac{H}{L_{\text{bmax}}} \]

Where,

\( H \) = maximum basin relief
\( L_{\text{bmax}} \) = maximum basin length
Fig. 4.17: Digital Elevation Map of Drainage Basin
High value of relief ratio indicate steep slope and high relief though small value indicate the presence of basement rocks, exposed in the form of small ridge and mount with gentle slope. High values are characteristic of hilly region and low values are characteristic of peniplain and valley. The relief ratio generally increases with decrease of drainage area and size of the given drainage basin (Gottochlk, 1964). The values of Rh are given in Table 4.7 ranges from 0.002 (KW- IV) to 0.006 (CH-I). Relief ratio is higher in Chambal sub-watershed and lower in Kunwari sub-watershed. This can be seen in the slope map (Fig 4.18) also where slope is as high as 16°, found in all the sub-watershed of Chambal river, clearly indicate high erosion in Chambal basin.

Table-4.7: Gradient Aspect Parameters of Various Sub-watersheds

<table>
<thead>
<tr>
<th>Name of Sub-watersheds</th>
<th>Elevation</th>
<th>Max. Basin Relief (km)</th>
<th>Relief Ratio (Rh)</th>
<th>Relative Relief (Rhp)</th>
<th>Ruggedness Number (HD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH-I</td>
<td>160</td>
<td>106</td>
<td>0.054</td>
<td>0.006</td>
<td>0.15</td>
</tr>
<tr>
<td>CH-II</td>
<td>159</td>
<td>120</td>
<td>0.039</td>
<td>0.004</td>
<td>0.12</td>
</tr>
<tr>
<td>CH-III</td>
<td>160</td>
<td>112</td>
<td>0.048</td>
<td>0.005</td>
<td>0.19</td>
</tr>
<tr>
<td>KW-I</td>
<td>157</td>
<td>125</td>
<td>0.032</td>
<td>0.003</td>
<td>0.05</td>
</tr>
<tr>
<td>KW-II</td>
<td>158</td>
<td>124</td>
<td>0.034</td>
<td>0.003</td>
<td>0.07</td>
</tr>
<tr>
<td>KW-III</td>
<td>163</td>
<td>125</td>
<td>0.038</td>
<td>0.003</td>
<td>0.08</td>
</tr>
<tr>
<td>KW-IV</td>
<td>162</td>
<td>128</td>
<td>0.034</td>
<td>0.002</td>
<td>0.06</td>
</tr>
</tbody>
</table>

4.4.3. Relative Relief (Rhp)

Relative relief termed as 'amplitude of available relief' or 'local relief' is defined as the ratio of maximum basin relief and perimeter of basin. This term was used by Melton, (1957) and can be determined by using the formulae:

\[
Rhp = \frac{100 \, H}{P}
\]

Where,

\[
H = \text{Maximum basin relief}
\]

\[
P = \text{Perimeter of the basin (km)}
\]
Fig. 4.18: Slope map of Drainage Basin
The relative relief of different drainage sub-watersheds were determined and given in Table 4.7. The maximum value of relative relief is determined in CH-III sub-watershed and the minimum value in KW-I sub-watershed. The relative relief is correlatable with maximum basin relief.

4.4.4. Ruggedness Number (HD)

It is the product of maximum basin relief (H) and drainage density (Dd), where both the variables are large, generally when slope is not only steep but long as well (Strahler, 1958) and can be determine by using the formulae:

$$ HD = H \times Dd $$

Where,

- $H$ = maximum basin relief
- $Dd$ = drainage density

In the present study the value of ruggedness number ranges from 0.09 to 0.20. The higher value of ruggedness number indicates the uneven topography, lithological heterogeneity of terrain and high amount of dissection, moderate values indicate flat topped surfaces or ridges and valley topography and moderately high degree of dissection. However, lower values in the area indicate less dissection and leveled surface (Govind, 2007). High values of ruggedness number are found in all the sub-watersheds of Chambal river where sub-watershed CH-III is having the highest value. Lower values are determine in Kunwari sub-watersheds, suggesting more dissection and ruggedness in Chambal basin than Kunwari, however, both the basin have suffered high dissection which is characteristic of ravines and gullied land.