Chapter 6

QUANTITATIVE MORPHOMETRIC ANALYSIS

6.1 INTRODUCTION

The study of drainage basin provides valuable information about the geological and evolutionary history of the area. In hydrology, the morphometry of drainage basin and river networks provide clues on water discharge, maximum and minimum specific runoff and their spatial variation. A systematic study of the drainage patterns and quantitative studies like morphometric, hypsometric analysis and their statistical details aid in finding the similarities and differences between drainage basin (Horton, 1945; Strahler, 1957; Melton, 1958; Pakhmode, 2003; Gangalakunta, 2004). In recent years, several workers have been used remote sensing data and GIS technique for estimation of morphometric parameters and concluded that remote sensing technique has emerged as a powerful tool in analyzing the drainage morphometry (Agarwal, 1998; Nag, 1998; Das and Mukhrjee, 2005; Pareta and Pareta, 2012). In the present context, the various morphometric characteristic of the Thoppaiyar sub-basin is analyzed.

6.2 MORPHOMETRIC ANALYSIS

The word ‘morphometry’ is applied for the drainage basin refers to the measurement of the linear and areal aspects of the drainage basins and treating as a fundamental geomorphic unit. These quantitative approaches to the drainage basins are initiated by Horton (1945). A fully analyzed drainage map provides a reliable index for the permeability of the rocks from the drainage basin. The linear aspect of a drainage basin analysis consists of independent variables like stream order and dependent variables namely stream length and stream number (Strahler, 1957).

In the present study, morphometric analysis was carried out with the help of remote sensing and GIS techniques. In case of remote sensing, the IRS P6
LISS III and Shuttle Radar Thematic Map (SRTM) satellite data were used for preparation of various thematic maps related to morphometric analysis. The LISS III and SRTM data are having 23.5 m and 90 m resolution respectively. The ArcGIS 9.3 GIS software is effectively utilized at various stages in analysis of morphometric parameters. The various parameters and drainage characteristics of the basins are discussed in this chapter. Most of the parameters can be analyzed with respect to two main sets of properties; the topographical aspects and stream networks interconnections of the system, whereas the geometrical aspects involve length, area, shape, relief and orientation parameters. In general, the morphometric analyses were carried out and discussed under the following headings:

- Drainage network
- Basin geometry
- Drainage texture analysis and
- Relief characteristics

6.3 DRAINAGE NETWORK

The drainage network transport water and the sediments of a basin through a single outlet, which is marked as the maximum order of the basin and conventionally the highest order stream available in the basin considered as the order of the basin. The size of rivers and basins varies greatly with the order of the basin. Ordering of streams is the first stage of basin analysis.

6.3.1 Stream Order (Su)

In the drainage map of the basin, the network is divided into channel segments and has been assigned a sequence of numbers to the orders according to the hierarchy of orders of magnitude. According to Strahler's (1952) system of ordering, each fingertip channel is assigned as a segment of the first order and the number increases by one when two different order streams meet together, the order remains as that of the higher order stream. Similarly, Horton (1945) and Shreve (1967) derived stream ordering as shown in Fig. 6.1.
In Horton’s method, a first-order stream is an un-branched tributary, a second-order stream is a tributary formed by two or more first-order streams. A third-order stream is a tributary formed by two or more second-order streams and so on. In general, an $n^{th}$ order stream is a tributary formed by two or more streams of order $(n-1)$ and streams of lower order.

The Strahler method, first-order streams are the furthest upstream channels that have no tributaries. A tributary is a stream that joins another stream reach or body of water. When two first-order streams unite, they form a second order stream. In the same way, when two second-order streams unite a third-order stream is created, and so on. Where two streams of different order join, for example a first and third-order, the combined stream retains the order of the higher order stream contributing to it. The main assumption behind this ordering system is that when two similar order streams join to create the next higher order stream, mean discharge capacity is doubled.

In the Shreve method, the stream orders of the two streams contributing to a junction are added and provide the rank number of the stream below the junction. The rank of a particular stream represents the total number of the first-order streams that have contributed to it. If we assume that the contributing area of each first order stream is approximately the same and that discharge is neither lost nor gained from any source other than the tributaries (which is not always true), then the Shreve number is roughly proportional to the magnitude of discharge in the stream to which it refers. For example, a first order stream has a lower magnitude discharge than a ninth order stream. The bigger the stream order, the more water flows through it. One of the shortcomings of stream orders is that streams of the same stream order might be very different if they are located in different ecosystems or climates.

Networks can be length ratio from lower order to higher order indicating mature geomorphic stage and there is a change from one order to another order indicating the youth stage. However, the number of first, second,
third, fourth and fifth order streams, which sequentially join to form sixth order stream, varies considerably owing to different sub-surface conditions.

![Diagram of stream ordering methods](image)

**Figure 6.1 Methods of ordering streams within a drainage basin**

In the present case, the Survey of India (SOI) topographic maps on 1:50,000 scale published during 1976 was used. In addition, the IRS P6 LISS III and SRTM data acquired during 2012 and 2000 are utilized respectively to find out the modification, alteration in the drainage network. In Thoppaiyar sub-basin, the stream order and respective number of segments are shown in Fig. 6.2 and Table 6.1. The percentages of stream segments were plotted in Fig.6.3.

**Table 6.1 Stream order and distribution of stream segments**

<table>
<thead>
<tr>
<th>Stream Order</th>
<th>Number of segments</th>
<th>Percent to total stream segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1141</td>
<td>75.76</td>
</tr>
<tr>
<td>2</td>
<td>290</td>
<td>19.21</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>3.97</td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>0.93</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>0.26</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1510</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>
Figure 6.2 Stream order in Thoppaiyar sub-basin mapped and interpreted with the help of SOI topomap and SRTM satellite data.
The first order streams (Suf) those which have no tributaries and majority of the streams generally formed at higher elevation. The first order stream is illustrated as

\[ \text{Suf} = N_1 \]  

(6.1)

Where, \( N_1 \) is the first order stream.

In the study area the first order streams are 1141. The sub basin has the highest number of first order streams (75.76%) indicating less permeable formation. The development of 1st order stream of bifurcation angles are shown in Fig.6.4.

![Figure 6.4 Development of 1st order bifurcation angles](image)

The importance of the geometry of a channel bifurcation has become widely recognized (Pittaluga et al., 2003), with the bifurcation angle determining the division of sediment and water downstream and hence, the stability of the bifurcation (Bridge, 1993). Bifurcation angles between 40° and 60° are
reported as stable (Burge, 2006), with wider angles indicating instability and a high probability of channel abandonment (Federici and Paola, 2003).

6.3.2 Stream Number (Nu)

The total of order wise stream segments is known as stream number. Nu is number of streams of order u.

\[ Nu = N1+N2+...Nn \]  

(6.2)

Where,

- \( N1 = \) First order stream
- \( N2 = \) Second order stream
- \( Nn = \) Number of streams

Stream number (Nu) observed that the number of streams gradually decreases as the ordering of the streams increase. This is in accordance with the Horton’s (1945) law which states that the “number of stream segments of each order forms an inverse geometric sequence with order number”. The total stream numbers in the Thoppaiyar sub-basin is 1510 (Table 6.2).

6.3.3 Stream Length (Lu)

The total length of individual stream segments of each order is the stream length of that order.

\[ Lu = L1+L2 ......Ln \]  

(6.3)

Where,

- \( Lu = \) stream length,
- \( L1 = \) length of the first order stream,
- \( L2 = \) length of the second order stream and
- \( Ln = \) n number of the stream length.

The stream length measures the average length of a stream in each order and calculated by dividing the total length of all streams in a particular order by the number of streams in that order. The stream length in each order increases exponentially with increasing stream order. The total stream lengths of the study area have various orders, which have computed with the help of SOI topographical maps and ArcGIS 9.3 software. Horton's law of stream lengths supports the theory that geometrical similarity is preserved generally in sub-basin of increasing order (Strahler, 1964). In the study area overall stream length is 1151.05 km. This change may indicate flowing of
streams from high altitude, lithological variation and moderately steep slopes (Singh and Singh, 1997).

**Stream Length Ratio (Lur)**

The stream length ratio can be defined as the ratio of the mean stream length of the given order to the mean stream length of next lower order and has an important relationship with surface flow and discharge (Horton, 1945).

\[
Lur = \frac{Lu}{Lu - 1}
\]  (6.4)

Where,  
Lur is the stream length ratio  
Lu is the stream length of segment of order u  
Lu-1 is the stream segment length of the next lower order.

The stream length ratios (Lur) are changing haphazardly at the basin and sub-basin levels. The values of the ‘Lur’ between successive stream orders of the basin vary due to differences in slope and topographic conditions (Rakesh Kumar et al 2001 and Sreedevi et al 2005). Changes in stream length ratio from one order to another indicate the late youth to mature stage of geomorphic development (Singh and Singh, 1997). The ‘Lur’ has an important relationship with the surface flow discharge and erosional stage of the basin. Stream length ratio between the streams of different order in the sub-basin varied in the sub-basin (Table 6.2). The length ratio from lower order to higher order indicating their mature geomorphic stage whereas in remaining sub-watersheds, there is a change from one order to another order indicating their late youth stage of geomorphic development (Singh and Singh, 1997).

**Mean Stream Length (Lum)**

Mean Stream length (lum) is a dimensional property revealing the characteristic size of components of a drainage network and its contributing sub-basin surfaces (Strahler, 1964).

\[
Lum = \frac{Lu}{Nu}
\]  (6.5)
Where, \( L_u \) is stream length and 
\( N_u \) is stream number.

It is obtained by dividing the total length of stream of an order by total number of segments in the order. The mean stream length of the study area is 9 km, which might be due variations in slope and topography.

**Mean Stream Length Ratio (Lurm)**

The mean stream length ratio is calculated as total length of particular order with number of stream segment of that order. In the study area, the ‘Lurm’ is 3.30 km and ‘Lurm’ of any given order is greater than that of the lower order and less than that of its next higher order up to third order streams but for the fourth order the value is less than the lower order streams in all the basins which is possibly due to variation in the slope and topography.

**Weighted Mean Stream Length Ratio (Lurwm)**

To arrive at a more representative stream number, Strahler (1952) used a weighted mean stream length ratio obtained by multiplying the stream length 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. The weighted mean stream length ratio of the study area is 2.04 (Table 6.2).

**Table 6.2 Stream Length and Stream Length Ratio in Thoppaiyar sub-basin**

<table>
<thead>
<tr>
<th>Su</th>
<th>Lu</th>
<th>Lu/Su</th>
<th>Lur</th>
<th>Lur-r</th>
<th>Lur( r ) Lur-r</th>
<th>Lurwm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>661.27</td>
<td>0.57</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>252.48</td>
<td>0.87</td>
<td>1.52</td>
<td>913.75</td>
<td>1388.9</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>125.76</td>
<td>2.09</td>
<td>2.40</td>
<td>378.24</td>
<td>907.77</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>51.51</td>
<td>3.67</td>
<td>1.75</td>
<td>177.27</td>
<td>310.22</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>17.58</td>
<td>4.39</td>
<td>1.19</td>
<td>69.09</td>
<td>82.21</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>42.45</td>
<td>42.45</td>
<td>9.66</td>
<td>60.03</td>
<td>580.46</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1151.05</td>
<td>54.04</td>
<td>1598.38</td>
<td>3269.56</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean 3.30 2.04

(Su: Stream order, Lu: Stream length, Lur: Stream length ratio, Lur: Mean stream length ratio*, Lur-r: Stream length used in the ratio, Lurwm: Weighted mean stream length ratio)
6.3.4 Bifurcation Ratio (Rb)

The Bifurcation Ratio is the fundamental importance in drainage basin analysis as it is the foremost parameter to link the hydrological regime of a sub-basin under topological and climatic conditions. It helps to have an idea about the shape of the basin as well as in deciphering the runoff behavior.

\[ R_b = \frac{N_u}{N_u + 1} \]  \hspace{1cm} (6.6)

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) (Fig.6.5). Horton (1945) considered the bifurcation ratio as index of relief and dissection. Strahler (1957) demonstrated that bifurcation shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. It is observed from the ‘Rb’ is not same from one order to its next order. These irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler 1964). The significance of the bifurcation ratio is given in the Table 6.3 (and the example of bifurcation ratio in a basin shown in Fig.6.5).

In the present study area ‘Rb’ ranges from 3.50 to 4.83 indicates sub-basin area is not affected by major structural disturbances.

**Mean Bifurcation Ratio (Rbm)**

Mean Bifurcation Ratio (Rbm) is calculated as the Arithmetic Mean Bifurcation Ratio and the results are tabulated corresponding to sub-order basins as shown in the Table 6.4. Using Strahler's (1957) method of taking into consideration of actual number of streams that are involved in the ratio, Mean Bifurcation Ratio of different sub-basins was calculated. The mean bifurcation ratio of Thoppaiyar basin is 4.10 indicates there may not be any structural control in the basin area.
Figure 6.5 Example of bifurcation ratio

Table 6.3 Bifurcation ratio and terrain conditions

<table>
<thead>
<tr>
<th>Bifurcation ratio</th>
<th>Inferences</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td>Flat region</td>
<td>Horton (1945)</td>
</tr>
<tr>
<td>3-5</td>
<td>geological structures do not distort the drainage pattern</td>
<td>Chow (1964), Nautiyal (1994)</td>
</tr>
<tr>
<td>&gt;5</td>
<td>Lithologically and structurally control</td>
<td>Strahler (1964)</td>
</tr>
</tbody>
</table>

Weighted Mean Bifurcation Ratio (Rbwm)

To arrive at a more representative bifurcation number, Strahler (1953) used a weighted 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. Schumm (1956) has adopted this method and to determine the weighted mean bifurcation ratio of the study area is 4.10 (Table 6.4).
Table 6.4 Stream Order, Stream Number and Bifurcation Ratios in Thoppaiyar sub-basin

<table>
<thead>
<tr>
<th>Su</th>
<th>Nu</th>
<th>Rb</th>
<th>Nu-r</th>
<th>Rb*Nu-r</th>
<th>Rbwm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1141</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>290</td>
<td>3.93</td>
<td>1431</td>
<td>5623.83</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>4.83</td>
<td>350</td>
<td>1690.50</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>4.28</td>
<td>74</td>
<td>316.72</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>3.5</td>
<td>18</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1510</td>
<td>20.54</td>
<td>1878</td>
<td>7714.05</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>4.10</td>
<td>4.10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Su: Stream order, Nu: Number of streams, Rb: Bifurcation ratios, Rbm: Mean bifurcation ratio*, Nu-r: Number of stream used in the ratio, Rbwm: Weighted mean bifurcation ratios)

6.3.5 Channel Length (Cl) and Valley length (Vl)

The river channel can be divided into number of segments for determination of sinuosity parameter (Muller 1968; Friend and Sinha 1988). Channel length is the length along the longest watercourse from the outflow point of the sub-basin to the upper limit to the sub-basin boundary (Fig.6.6). The main channel length of Thoppaiyar is 65.5km, measured with the help of GIS software. The valley length referred to the number of segment length connecting upper limit to outflow point. The measured valley length of the Thoppaiyar River is 56km.

6.3.6 Minimum Aerial Distance (Adm)

The measurement of minimum aerial distance (Adm) is shortest distance between the source and mouth of the river. The minimum aerial distance in the Thoppaiyar sub-basin is 42.39km computed by using GIS software.

6.3.7 Channel index (Ci)

The channel index (Ci) is calculated (Miller, 1968) as follows

\[
Ci = \frac{Cl}{Adm}
\]  

(6.7)

Where, Cl is the main channel length and Adm is the minimum aerial distance
The measurement of channel index is the ratio between main channel length (Cl) and shortest distance between the source and mouth of the river (Adm) i.e. air length used for calculation of channel index. The measured channel index value of the Thoppaiyar sub-basin is 1.54.

6.3.8 Valley index (Vi)

The valley index (Vi) is derived for sub-basin using following formula (Miller, 1968).

\[
Vi = \frac{Vl}{Adm}
\]  

(6.8)

Where, \( Vl \) is the Valley length and \( Adm \) is the minimum aerial distance

The valley index is the ratio between valley length (Vl) and minimum aerial distance (Adm) in the basin, which is 1.32.

6.3.9 Rho Coefficient (\( \rho \))

This parameter was defined by Horton (1945) as the ratio between the stream length ratio (Lur) and the bifurcation ratio (Rb). The ‘Rho’ coefficient is an important parameter relating drainage density to physiographic development of a sub-basin which facilitate evaluation of storage capacity of drainage network and hence, a determinant of ultimate degree of drainage development in a given sub-basin (Horton 1945).

\[
\rho = \frac{Lur}{Rb}
\]  

(6.9)

Where, \( Lur \) is stream length ratio and \( Rb \) is bifurcation ratio.

The climatic, geologic, biologic, geomorphologic and anthropogenic factors determine the changes in this parameter. ‘Rho’ values of the Thoppaiyar sub-basin is 0.80. This is suggesting higher hydrologic storage during floods and shrinking of effects of erosion during elevated discharge.
6.4 BASIN GEOMETRY

Basin configuration is an important aspect in hydrological study. In order to determine the shape of the basin, a quantitative study is done using the two dimensional ratio, such as elongation ratio suggested by Horton (1952), Miller (1947) and Schumm (1956).

6.4.1 Basin Area (A)

The area of the sub-basin is an important parameter in the basin geometry. Schumm (1956) established an interesting relation between the total sub-basin area and the total stream length, which are supported by the contributing area. The computed area of Thoppaiyar sub-basin using ArcGIS 9.3 software is 462sq. km.

6.4.2 Mean Basin Width (Wb)

The mean basin width is calculated (Horton, 1932) as

\[ Wb = \frac{A}{Lb} \]  

(6.10)

Where, \( A \) = area of the basin and \( Lb \) = basin length

The calculated mean basin width of the Thoppaiyar sub-basin is 10.79 km.

6.4.3 Stream order wise mean area (Am)

The stream order wise mean area (Am) is estimated through GIS software. For this measurement, the Thoppaiyar sub-basin area is divided as first order to sixth order micro-basin (Table 6.5). The sixth order micro-basin has the highest ‘Am’ (349 sq. km) and the first order micro-basin has lowest ‘Am’ (0.18 sq. km).

6.4.4 Area ratio (Ar)

From the estimated order wise mean area (Am), the area ratio is calculated in the difference between second higher mean areas to first lower mean area
and so on. The highest ‘Ar’ value is 6.27 and lowest is 3.66 in the Thoppaiyar sub-basin (Table 6.5). The overall mean area ratio (Arm) of all in the Thoppaiyar sub-basin is 4.64.

6.4.5 Weighted Mean Area Ratio (Arwm)

In order to arrive a more representative mean area ratio a weighted mean area ratio is obtained by multiplying the mean area 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. The weighted mean area ratio of the study area is 4.42 (Table 6.5).

6.4.6 Length Area Relation (Lar)

Hack (1957) found that for a large number of basins, the stream length and basin area are related by a simple power function as follows:

\[
\text{Lar} = 1.22 \times A^{0.575} \tag{6.11}
\]

Where, A is the area of the basin in sq.km.

The exponent 0.575 is closer to Hack’s exponent and indicates that as the basins enlarge they become longer and narrower. The calculated length area relation of the study area is 41.54.

<table>
<thead>
<tr>
<th>Su</th>
<th>Nu</th>
<th>Am (sq.km)</th>
<th>Ar</th>
<th>No. of stream used in ratio</th>
<th>Product of Am</th>
<th>Arwm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1141</td>
<td>0.18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>290</td>
<td>0.82</td>
<td>4.56</td>
<td>1431</td>
<td>6519</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>3.00</td>
<td>3.66</td>
<td>350</td>
<td>1280</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>14</td>
<td>15.00</td>
<td>5.00</td>
<td>74</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>94.00</td>
<td>6.27</td>
<td>18</td>
<td>113</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>349.00</td>
<td>3.71</td>
<td>5</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1510</td>
<td><strong>462.00</strong></td>
<td></td>
<td><strong>1878</strong></td>
<td><strong>8301</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td><strong>4.64</strong></td>
<td></td>
<td><strong>4.42</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6.4.7 Basin Length (Lb)

Schumm (1956) defined the basin length as the longest dimension of the basin parallel to the principal drainage line. Gregory and Walling (1973) defined the basin length as the longest in the basin in which are end being the mouth. 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. Based on Schumm definition the basin length is measured as \( L_b = 42.80 \text{km} \).

6.4.8 Length from sub-basin center to Mouth of sub-basin (Lcm)

Length from sub-basin center to mouth of sub-basin (Lcm) is measured as per Black (1972). Using ArcGIS 9.3, the ‘Lcm’ was measured as 23.54km for Thoppaiyar sub-basin.

6.4.9 Width of the sub-basin at the Center of Mass (Wcm)

The width of the Thoppaiyar sub-basin at the center of mass (Wcm) is measured as 11.80 km (Black, 1972).

6.4.10 Basin Perimeter (P)

Basin perimeter is the outer boundary of the sub-basin that enclosed its area. It is measured along the divides between sub-basins and may be used as an indicator of sub-basin size and shape. The basin perimeter is computed by using ArcGIS-9.3 software as 148.17km.

6.4.11 Relative Perimeter (Pr)

The relative perimeter of the particular basin is as follows (Schumm, 1956);

\[ Pr = \frac{A}{P} \]  \hspace{1cm} (6.12)

Where, \( A \) = area of the basin and \( P \) = is the perimeter.
The calculated relative perimeter of the study area is 3.12.

### 6.4.12 Lemniscate's value \((k)\)

Chorely (1957), express the lemniscate's value to determine the slope of the basin as;

\[
k = \frac{Lb^2}{A}
\]  \hspace{1cm} (6.13)

Where, \(Lb\) is the basin length (km) and 
\(A\) is the area of the basin (km²).

The lemniscate's \((k)\) value for the Thoppaiyar sub-basin is 3.96, which shows that the sub-basin occupies the maximum area in its regions of inception with large number of streams of higher order.

### 6.4.13 Form Factor \((Ff)\)

The form factor \((Ff)\) is the ratio of basin area to square of the basin length and is a quantitative expression of drainage basin outline. It indicates the flow intensity of a basin of a defined area (Horton, 1945).

\[
Ff = \frac{A}{Lb^2}
\]  \hspace{1cm} (6.14)

Where, \(Lb\) is the basin length (km) and 
\(A\) is the area of the basin (km²).

The form factor \((Ff)\) value varies from 0 in highly elongated basin to 1 for perfectly circular basin. The \(Ff\) value of the sub-basin is 0.25 (Table 6.6). The value of form factor suggest that the sub-basin to be slightly elongated in shape. The sub-basin with high form factors have high peak flows of shorter duration, whereas elongated sub-basin with low form factor 0.25 indicating them to be slightly elongated in shape and lower peak flows for longer duration. Flood flows of elongated basins are easier to manage than those of the circular basin (Nautiyal, 1994).


Table 6.6 Significant of form factor

<table>
<thead>
<tr>
<th>$R_f$</th>
<th>Shape</th>
<th>Nature of Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Highly elongated</td>
<td>Low peak flow and longer duration</td>
</tr>
<tr>
<td>0 - 0.6</td>
<td>Slightly elongated</td>
<td>Flatted peak flow and longer duration</td>
</tr>
<tr>
<td>0.6 - 0.78</td>
<td>Perfectly circular</td>
<td>Moderate to high peak flow for short duration</td>
</tr>
<tr>
<td>0.78 - 1.0</td>
<td>Circular</td>
<td>High peak flow for short duration</td>
</tr>
</tbody>
</table>

### 6.4.14 Basin Shape Factor (BSF)

Basin shape can be described as circular, rectangular, triangular or pear. The latter is most common. Shape can also be quantified using equation for basin shape factor, sometimes called shape factor, not to be confused with form factor. Shape directly impacts the size of peak discharge and its arrival time at the basin outlet. Peak discharge for a circular basin will arrive sooner than that of an elongate basin of the same area because the tributary network in a circular basin is more compactly organized and tributary flows enter the mainstream at roughly the same time, thus more runoff is delivered to the outlet together, sooner (shorter duration, higher flood peak). (Morisawa (1958), Gray (1970), Wisler (1959), Bedient (1992)). The shape characteristics of the Thoppaiyar sub-basin are given in Table 6.7.

\[
BSF = \frac{L^2}{A} = \frac{L}{W}
\]  

(6.15)

Where,
- $L$ = Length of the sub-basin,
- $W$ = width of the sub-basin,
- $A$ = Area of the sub-basin

The calculated basin shape factor is 6.78.
6.4.15 Elongation Ratio (Re)

Elongation ratio is the ratio between the diameter of a circle of the same area as the drainage basin and the maximum length of the basin (Schumm, 1956). A circular basin is more efficient in runoff discharge than elongated basin (Singh and Singh, 1977).

\[
Re = \frac{2}{Lb \times (\frac{A}{\pi})^{0.5}}
\] (6.16)

Where, \( Lb \) is the length of the basin,
\( A \) is area of the basin in sq. km.

According to Strahler (1952) the elongation ratio between 0.6 and 0.8 indicates high relief and steep slope region. The elongation ratio of the Thoppaiyar sub-basin is 0.56 indicate elongated and moderate to slightly steep slope (Table 6.7).

<table>
<thead>
<tr>
<th>Basin</th>
<th>Re</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circular</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>Oval</td>
<td>0.8-0.9</td>
</tr>
<tr>
<td>Less elongated</td>
<td>0.7-0.8</td>
</tr>
<tr>
<td>Elongated</td>
<td>0.5-0.7</td>
</tr>
<tr>
<td>More elongated</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

6.4.16 Elipticity Index (Ie)

The elipticity index (Ie) provides similar insights about the relationship between morphometry and hydrology as other shape-related parameters. Elipticity index is calculated using the method of Stoddart (1965) as follows

\[
Ie = \frac{\pi \times Vl^2}{4A}
\] (6.17)

Where, \( vl \) is the valley length,
\( A \) is the area of the basin in sq.km.

Lower values indicate that the runoff from the catchment drains quickly into the channels and thereby, depending upon the total quantum of the precipitation. The value of elipticity index varies from 1 to infinity and it is
inversely proportional to form factor. The channels may swell or even overflow resulting in flooding downstream areas. The calculated elipticity index of the Thoppaiyar sub-basin is 5.32.

6.4.17 Texture Ratio (Rt)

The texture ratio (Rt) is an important factor in the drainage morphometric analysis (Schumm, 1956) which is described in

\[ Rt = \frac{N1}{P} \]  

(6.18)

The texture ratio is expressed as the ratio between the first order streams (N1) and perimeter of the basin (P), it depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. In the present study, the texture ratio of the sub-basin is 7.70 and categorized as moderate in nature.

6.4.18 Circularity Ratio (Rc)

Circulatory ratio is the ratio of the area of the basin (A) to the area of the circle having the same circumference as the perimeter (P) of the basin (Miller, 1953).

\[ Rc = 12.57 \times \frac{A}{P^2} \]  

(6.19)

‘Rc’ is also called the compactness ratio. It indicates stage of dissection in the basin. This factor is influenced more by the lithological characteristics of the basin rather than anything else. The low, medium and high values of the circulatory ratio are indications of the youth, mature and old stages of the life cycle of the tributary basins. Circular basins with low bifurcation ratio produce a sharp peak. The circulatory ratio for Thoppaiyar sub-basin is 0.26 indicate that the basin is less circular (elongated) and in youth stage.
Table 6.8 Basin geometry of the Thoppaiyar Sub Basin

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Shape Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basin Area (A) sq km</td>
<td>462 km²</td>
</tr>
<tr>
<td>2</td>
<td>Basin Length (Lb) km</td>
<td>42.8 km</td>
</tr>
<tr>
<td>3</td>
<td>Basin Perimeter (P) km</td>
<td>148.17 km</td>
</tr>
<tr>
<td>4</td>
<td>Form Factor (R)</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>Circularity Ratio (Rc)</td>
<td>0.26</td>
</tr>
<tr>
<td>6</td>
<td>Elongation Ratio (Re)</td>
<td>0.56</td>
</tr>
<tr>
<td>7</td>
<td>Elipticity index (E)</td>
<td>5.32</td>
</tr>
</tbody>
</table>

6.4.19 Circularity Ration (Rcn)

Strahler (1964) mentioned that circularity ration (Rcn) is as follows

\[ Rcn = \frac{A}{P} \]  

(6.20)

Where, \( A \) is the area of the basin and the ratio of Perimeter \( P \) is in that particular basin area.

The circularity ration of the study area is 3.12.

6.4.20 Compactness Coefficient (Cc)

The compactness coefficient of a sub-basin is the ratio of perimeter of sub-basin to circumference of circular area (Gravelius, 1914), which equals the area of the sub-basin.

\[ Cc = 0.2841 \times \frac{P}{A^{0.5}} \]  

(6.21)

The Cc is independent of size of sub-basin and dependent only on the slope. If the basin was a perfect circle, then Cc would be equal to 1 (Gravelius, 1914). The computed compactness coefficient of the Thoppaiyar sub-basin is 1.95.
6.4.21 Fitness Ratio (Rf)

The ratio of main channel length (Cl) to the length of the sub-basin perimeter (P) is fitness ratio (Melton, 1957) which is a measure of topographic fitness.

\[ Rf = \frac{Cl}{P} \]  

The fitness ratio for Thoppaiyar sub-basin is 0.43.

6.4.22 Wandering Ratio (Rw)

According to Smart and Surkan (1967), wandering ratio is defined as the ratio of the main stream length (Cl) to the basin length (Lb).

\[ Rw = \frac{Cl}{Lb} \]  

Basin length is the straight-line distance between outlet of the basin and the farthest point on the ridge. In the present study, the wandering ratio of the sub-basin is 1.53.

6.4.23 Sub-basin Eccentricity (\( \tau \))

Black (1972) has given the expression for sub-basin eccentricity as

\[ \tau = \left( \frac{Lcm^2 - Wcm^2}{Wcm} \right)^{0.5} \]  

Where,  

\( \tau \) = Sub-basin eccentricity, a dimensionless factor,  

Lcm = Straight length from the sub-basin mouth to the centre of mass of the sub-basin, and  

Wcm = Width of the sub-basin at the centre of mass and perpendicular to Lcm.

The computed sub-basin eccentricity of the study area is 1.54.
6.4.24 Centre of Gravity of the Sub-basin (Gc)

It is the length of the channel measured from the outlet of the sub-basin to a point on the stream nearest to the center of the sub-basin. The centre of the Thoppaiyar sub-basin has been determined using following steps:

- A cardboard piece was cut in the shape of Thoppaiyar sub-basin.
- The centre of gravity was located on the sub-basin shape cardboard piece using point balance standard procedure.
- The cardboard piece marked with centre of gravity was superimposed over the sub-basin plan.
- By pressing a sharp edge pin over the centre of gravity of the cardboard piece it was marked on the sub-basin.

The centre of gravity of the sub-basin computed by using ArcGIS 9.3 software, which is a point showing the latitude 11.95 N, and longitudes 78.13 E.

6.4.25 Sinuosity Index

Sinuosity deals with the pattern of channel of a drainage basin. It has been defined as 'the ratio of channel length to down valley distance'.

\[ SI = \frac{Cl}{Vl} \]  \hspace{1cm} (6.25)

In general, the value varies from 1 to 4 or more. Rivers having a sinuosity of 1.5 are called sinuous, and above 1.5 are called meandering (Wolman and Miller, 1964) (Fig.6.6). The computed value of sinuosity index of the study area is 1.16 indicates sinuous. It is a significant quantitative index for interpreting the significance of streams in the evolution of landscapes and beneficial for Geomorphologists, Hydrologists and Geologists. For the measurement of sinuosity index Mueller (1968) has suggested some important computations that deal various types of sinuosity indices. He also defines two main types i.e., topographic and hydraulic sinuosity index concerned with the flow of natural stream courses and with the development of flood plains respectively.
Figure 6.6 Channel pattern and sinuosity ratio

**Hydraulic Sinuosity Index (Hsi)**

Hydraulic sinuosity index (Mueller, 1968) is an important index of computations of sinuous as follows;

\[
Hsi = \frac{(Ci - Vi)}{(Ci - 1) \times 100} \tag{6.26}
\]

Where, ‘Ci’ is channel index and ‘Vi’ is the valley index. The computed hydraulic sinuosity index of the study area is 39.62%.

**Topographic Sinuosity Index (Tsi)**

Topographic Sinuosity Index (Tsi) is suggestive of topographic and tectonic controls. If the value of ‘Tsi’ is higher it may reflects dominant role of topography in response to tectonics (Fig.6.7). Coefficient of topographical sinuosity is obtained as the quotient between the length of the valley axis (Lv) and the straight line distance (La) between the two extreme points (Mueller, 1968). The ‘Tsi’ value is calculated as,

\[
Tsi = \frac{(Vi - 1)}{(Ci - 1) \times 100} \tag{6.27}
\]

The computed topographic sinuosity index of the study area is 60.37%. Topographical sinuosity is the result chiefly of the interaction of geological
and geomorphological factors from which the present relief makeup, and hence the undulating course of valleys, has resulted in the course of time.

Figure 6.7 Model of (A) Topographical sinuosity and (B) Hydraulic sinuosity

**Standard Sinuosity Index (Ssi)**

Standard Sinuosity Index (Ssi) which is indicative of the topographic response to the river/stream flow, the low ‘Ssi’ value being reflected by mature and middle stage of the river. The data of standard sinuosity index (Ssi) is obtained using the following formula (Mueller, 1968).

\[
Ssi = \frac{Ci}{Vi}
\]  

(6.28)

The computed standard sinuosity index of the study area is 1.15. The sinuosity indices are given in Table 6.9.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Parameter</th>
<th>Sinuosity indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Channel Length (km)</td>
<td>65.5 km</td>
</tr>
<tr>
<td>2</td>
<td>Valley Length (km)</td>
<td>56 km</td>
</tr>
<tr>
<td>3</td>
<td>Minimum Aerial Distance (km)</td>
<td>42.39 km</td>
</tr>
<tr>
<td>4</td>
<td>Channel Index (CI)</td>
<td>1.53</td>
</tr>
<tr>
<td>5</td>
<td>Valley Index (VI)</td>
<td>1.32</td>
</tr>
<tr>
<td>6</td>
<td>Hydraulic Sinuosity Index (HSI)</td>
<td>39.62</td>
</tr>
<tr>
<td>7</td>
<td>Topographic Sinuosity Index (TSI)</td>
<td>60.37</td>
</tr>
<tr>
<td>8</td>
<td>Standard Sinuosity Index (SSI)</td>
<td>1.15</td>
</tr>
</tbody>
</table>
6.4.26 Longest Dimension Parallel to the Principal Drainage Line (Clp)

The computed longest dimension parallel to the principal drainage line of the study area is 54.91 km which indicate the main channel length with fewer dimensions in the sub-basin.

6.4.27 Gravelius's shape index

The shape of a sub-basin influences the shape of its characteristic hydrograph. For example, a long shape sub-basin generates, for the same rainfall, a lower outlet flow, as the concentration time is higher. A sub-basin having a fan-shape presents a lower concentration time, and it generates higher flow. Different geomorphologic indices can be used for the analysis of a sub-basin if its shape is taken into consideration. The most frequently used index is the Gravelius's index $K_G$, which is defined as the relation between the perimeter of the sub-basin and that of a circle having a surface equal to that of a sub-basin (Musy, 2001) (Fig.6.8).

$$K_G = \frac{P}{\sqrt[2]{\pi A}} \quad (6.29)$$

Where, $K_G =$ Gravelius's shape index,
$A =$ sub-basin area [km$^2$] and
$P =$ sub-basin perimeter [km].

The computed gravelius shape index of the sub-basin is 1.10 which indicates shape as follows;

![Figure 6.8 Some $K_G$ values for different sub-basin shapes (Musy, 2001)](image-url)
6.5 DRAINAGE TEXTURE ANALYSIS

Drainage texture analysis is inferred the sub-basin frequency, density and intensity of the drainage characteristics.

6.5.1 Drainage Texture (Dt)

Drainage texture (Dt) is one of the important concept of geomorphology which means that the relative spacing of drainage lines.

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

(6.30)

Drainage texture (Dt) is total number of stream segments of all orders per perimeter of that area (Horton, 1945). Dt is a measure of closeness of the channel spacing, depending on climate, rainfall, vegetation, lithology, infiltration capacity and relief aspect of the terrain (Smith, 1950). Smith (1950) has classified drainage texture into five different classes (Table 6.10). In the present case, the drainage texture of the sub-basin is 10.19 indicates that the category is very fine drainage texture and impermeable lithology. Drainage lines are numerous over impermeable areas than permeable areas and it is measure of the total number of segments of all order per perimeter of that area. It gives an idea of the infiltration rate of the area.

Table 6.10 Classification of drainage texture

<table>
<thead>
<tr>
<th>Category</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very coarse</td>
<td>&lt;2</td>
</tr>
<tr>
<td>Coarse</td>
<td>2-4</td>
</tr>
<tr>
<td>Moderate</td>
<td>4-6</td>
</tr>
<tr>
<td>Fine</td>
<td>6-8</td>
</tr>
<tr>
<td>Very fine</td>
<td>&gt;8</td>
</tr>
</tbody>
</table>

6.5.2 Stream Frequency (Fs)

The drainage frequency introduced by Horton (1932) means stream frequency or channel frequency as the number of stream segments (Nu) per unit area (A).
In the present study, the stream frequency of the Thoppaiyar sub-basin is 3.26/km² indicates low Fs (Table 6.11). The stream frequency of the study area shows a positive correlation with the drainage density indicating that the stream population increases with the increase of drainage density. The development of the stream segments in the basin area is more or less affected by rainfall and temperature.

Table 6.11 Stream frequency for No. of stream/km²

<table>
<thead>
<tr>
<th>Stream frequency (Fs)</th>
<th>No. of Streams/km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0-5</td>
</tr>
<tr>
<td>Moderate</td>
<td>5-10</td>
</tr>
<tr>
<td>Moderate high</td>
<td>10-15</td>
</tr>
<tr>
<td>High</td>
<td>15-20</td>
</tr>
<tr>
<td>Very high</td>
<td>20-25</td>
</tr>
</tbody>
</table>

6.5.3 Drainage Density (Dd)

Drainage density is the measure of the texture of the drainage basin. Drainage density is the ratio of the total stream length (Lu) cumulated to all order in the basin to the total basin area (A).

\[
Dd = \frac{Lu}{A}
\]  

High drainage density is favored in region of weak rock or impermeable subsurface material. Low density shows highly permeable or highly resistant subsoil material under dense vegetation and low relief. The drainage density is an important indicator of the linear scale of landform element in stream eroded topography and defines 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 (Langbein, 1947). Drainage density is a better quantitative expression to the dissection and analysis of landform, although a function of climate, lithology, runoff, infiltration, structures and relief.

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

(6.31)
history of the region can finally use as an indirect indicator to explain, those variables as well as the morphogenesis of landform (Verstappen, 1983; Patton, 1988; Reddy et al 2004). The computed drainage density by using Spatial Analyst Tool in ArcGIS-9.3, of Thoppaiyar sub basin is 2.49 km/km², which indicate high drainage density (Table 6.12). It is suggested that the basin is impermeable in nature.

Table 6.12 Distribution of drainage density and category

<table>
<thead>
<tr>
<th>Range of Drainage Density (Km/Km²)</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 1.00</td>
<td>Less</td>
</tr>
<tr>
<td>1.01 - 2.00</td>
<td>Moderate</td>
</tr>
<tr>
<td>2.01 - 3.00</td>
<td>High</td>
</tr>
<tr>
<td>Above 3.00</td>
<td>Very High</td>
</tr>
</tbody>
</table>

6.5.4 Constant of Channel Maintenance (km²/km) (C)

Schumm (1956) used the inverse of drainage density or the constant (C) of channel maintenance as a property of landforms.

\[ C = \frac{1}{Dd} \] (6.33)

The constant indicates the number of km² of basin surface required to develop and sustain a channel 1 km long. The constant of channel maintenance indicates the relative size of landform units in a drainage basin and has a specific genetic connotation (Strahler, 1957). Channel maintenance constant of the study area is 0.40 km²/km (Table 6.13) and it indicates the Thoppaiyar sub basin is moderately low erodible.

Table 6.13 Constant channel maintenance (after Schumm, 1956)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>C (km²/km)</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;0.2</td>
<td>More erodible</td>
</tr>
<tr>
<td>2</td>
<td>0.2-0.3</td>
<td>Moderate erodible</td>
</tr>
<tr>
<td>3</td>
<td>0.3-0.4</td>
<td>Moderately low erodible</td>
</tr>
<tr>
<td>4</td>
<td>0.4-0.5</td>
<td>Low erodible</td>
</tr>
<tr>
<td>5</td>
<td>&gt;0.5</td>
<td>Least erodible</td>
</tr>
</tbody>
</table>
6.5.5 Drainage Intensity \((Di)\)

Faniran (1968) defines the drainage intensity, as the ratio of the stream frequency \((Fs)\) to the drainage density \((Dd)\).

\[
Di = \frac{Fs}{Dd}
\]  

(6.34)

This study shows a low drainage intensity of 1.31 for the Thoppaiyar sub-basin. The low value of drainage intensity implies that drainage density and stream frequency have little effect (if any) on the extent to which the surface has been lowered by agents of denudation.

6.5.6 Infiltration Number \((If)\)

The infiltration number of a drainage basin is the product of drainage density \((Dd)\) and stream frequency \((Fs)\) of a basin (Faniran, 1968).

\[
If = Fs \times Dd
\]  

(6.35)

It is a parameter which gives an idea of the infiltration characteristics of the basin. The Thoppaiyar sub-basin infiltration number is 8.11 and this value indicates moderate infiltration and medium runoff, the lithology of basin is hard and impermeable. The higher values of infiltration number indicate the lower infiltration and the higher runoff (Das and Mukherjee, 2005).

6.5.7 Drainage Pattern \((Dp)\)

In the sub-basin, the drainage pattern reflects the influence of slope, lithology and structure. The study of drainage pattern helps in identifying the stage in the cycle of erosion. Drainage pattern presents some characteristics of drainage basins. It is possible to deduce the geology of the basin, the strike and dip of depositional rocks, existence of faults and other information about geological structure from drainage patterns. Drainage texture reflects climate, permeability of rocks, vegetation, and relief ratio, etc. (Howard, 1967) related drainage patterns to geological information. In the study area the drainage pattern is dendritic to sub-dendritic. Dendritic
pattern is most common pattern is formed in a drainage basin composed of fairly homogeneous rock without control by the underlying geologic structure. The longer the time of formation of a drainage basin is, the more easily the dendritic pattern is formed.

6.5.8 Length of Overland Flow (Lg)

The length of overland flow is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton, 1945).

\[
Lg = \frac{A}{2 \times Lu}
\]  

(6.36)

‘Lg’ is one of the most important independent variables affecting hydrologic and physiographic development of drainage basin. The length of overland flow is approximately equal to the half of the reciprocal of drainage density (Horton, 1945). This factor is related inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree (Fig.6.9). The computed ‘Lg’ value of the Thoppaiyar sub basin is 0.20 (Table 6.14). It indicates that the channel erosion is dominant than sheet erosion.

Table 6.14 Length of overland flow (after Horton, 1945)

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Lg (Km)</th>
<th>Significant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;0.4</td>
<td>More channel erosion</td>
</tr>
<tr>
<td>2</td>
<td>0.4-0.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.5-0.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.6-0.7</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>&gt;0.7</td>
<td>More sheet erosion</td>
</tr>
</tbody>
</table>
6.6 RELIEF CHARACTERISTICS

Linear and areal features have been considered as the two dimensional aspect lie on a plan. The third dimension introduces the concept of relief. By measuring the vertical fall from the head of each stream segment to the point where it joins the higher order stream and dividing the total by the number of streams of that order, it is possible to obtain the average vertical fall. The height of the basin mouth (z) is computed as 240m amsl. The maximum height of the basin is computed as 1632m amsl. The relative height (Strahler, 1952) is difference between the minimum height and maximum height of the particular sub-basin is defined as

$$Rh = \frac{h}{H}$$  \hspace{1cm} (6.37)

The computed relative height of the study area is 0.14m. Total basin relief is the maximum vertical distance between the lowest and the highest points in a basin (Horton, 1945; Strahler, 1964).

$$H = Z - z$$  \hspace{1cm} (6.43)

Basin relief is an important factor in understanding the denudational characteristics of the basin. The maximum height of the whole basin is
1632m amsl and the lowest is 240m amsl. Therefore, the total relief of the basin is 1392m amsl.

6.6.1 Relief Ratio (Rhl)

The ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm, 1956).

\[ Rhl = \frac{H}{Lb} \]  \hspace{1cm} (6.38)

The 'Rhl' normally decreases with the increasing area and size of basin of a given drainage basin (Gottschalk, 1964). Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). High values are characteristic of hill region; low values are characteristics of pediplains and valley (Sreedevi et al 2009). The values of 'Rhl' in the basin are 0.032 indicating moderate relief and gentle slope. The relief map of the Thoppaiyar sub-basin is shown in Figure 6.10.
Figure 6.10 Relief map of the Thoppaiyar sub-basin
6.6.2 Absolute Relief (Ra)

The main objectives of absolute relief are to determine how much erosion has taken place in relation to the present summits of the area (Prasad, 1985). Absolute relief refers to the maximum elevation of any area's morphology which also provides clues to estimate the type and intensity of denudational forces at work (Thakur, 2008). Analysis of absolute relief has been made by calculating the elevation above mean sea level for delineating the heights. Considering the range of elevations, five categories of absolute relief have been identified in the present study (Fig 6.15).

The ranges vary from a minimum value of 240 m in the west and a maximum of 1632 m in southeastern part of the sub-basin. About 76% of the sub-basin has an absolute relief of 300-600 m 14% of the sub-basin is characterized by 600-900m in moderately absolute relief category and only a small portion (10%) of the area is at more than 900m and less than 300m (Fig.6.11 & Table 6.15). Hence, about 90% of the Thoppaiyar sub-basin has moderately low to moderate absolute relief which is observed in the central and western part of the sub-basin, which indicates the high runoff and low infiltration in this part of sub-basin.

<table>
<thead>
<tr>
<th>Range of Elevation(m)</th>
<th>Area (km²)</th>
<th>Area (%)</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 300</td>
<td>15</td>
<td>3</td>
<td>Low</td>
</tr>
<tr>
<td>300-600</td>
<td>351</td>
<td>76</td>
<td>Moderately Low</td>
</tr>
<tr>
<td>600-900</td>
<td>65</td>
<td>14</td>
<td>Moderate</td>
</tr>
<tr>
<td>900-1200</td>
<td>17</td>
<td>4</td>
<td>Moderately High</td>
</tr>
<tr>
<td>&gt; 1200</td>
<td>14</td>
<td>3</td>
<td>High</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>462</strong></td>
<td><strong>100</strong></td>
<td></td>
</tr>
</tbody>
</table>
Figure 6.11 Absolute relief of Thoppaiyar sub-basin
6.6.3 Relative relief (RR)

Relative relief is to ascertain the amplitude of available relief to relate the altitude of the highest and the lowest points of any particular area (Smith, 1935).

\[ RR = \text{Maximum elevation (M)} - \text{Minimum elevation (m)} \]  

(6.39)

It means that the difference between the highest and the lowest point in a spatial unit and plays an important role to understand the morphological characteristics of terrain, degree of dissection and denudational characteristics of the watershed, which together control the stream gradient, thereby influencing the flood pattern (Hadley and Schumm, 1961). Relative relief varies significantly in the watershed (Fig.6.12).

About 64% of the study area has extremely low to moderately low relative relief observed mostly in the whole southern flat land (Table 6.16). Moderate and moderately high relative relief together accounts about 29% of the total geographical area, which is found in patches in the piedmont zone. The areas of high relative relief coincide with areas of high absolute relief, thereby corresponding to steeper slopes, and high gravity of water flow and erosion rates.

Table 6.16 Distribution of Relative Relief in Thoppaiyar sub-basin

<table>
<thead>
<tr>
<th>Range of relative relief (m)</th>
<th>Area (km²)</th>
<th>Area (%)</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;70</td>
<td>159</td>
<td>34</td>
<td>Low</td>
</tr>
<tr>
<td>70-140</td>
<td>140</td>
<td>30</td>
<td>Moderately Low</td>
</tr>
<tr>
<td>140-220</td>
<td>74</td>
<td>16</td>
<td>Moderate</td>
</tr>
<tr>
<td>220-320</td>
<td>58</td>
<td>13</td>
<td>Moderately High</td>
</tr>
<tr>
<td>&gt;320</td>
<td>31</td>
<td>7</td>
<td>High</td>
</tr>
</tbody>
</table>
Figure 6.12 Relative relief of Thoppaiyar sub-basin
6.6.4 Relative Relief Ratio (Rhp)

This term relative relief ratio was used by Melton (1958). Relative relief ratio is the difference between summit level, the highest altitude for a given area (H), and base level, lowest altitude for a given area (P).

\[ Rhp = \frac{H}{P} \times 100 \]  \hspace{1cm} (6.40)

Relative relief ratio can be used as an index of the relative velocity of vertical tectonic movements. The relative relief ratio of the basin is 0.93. The low values are characteristic features of less resistant rocks (Sreedevi, 1999). Furthermore, visual study of the digital elevation model prepared from the SRTM data indicates that overall the land surface has gentle to moderate relative relief. The maximum basin relief ratio was obtained from the highest point on the sub-basin perimeter to the mouth of the stream.

6.6.5 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 sub-basin (Singh and Dubey, 1994).

\[ Dis = \frac{H}{{Ra}} \]  \hspace{1cm} (6.41)

Where H = Relative height of the basin and
Ra = absolute relief

On average, the values of ‘Dis’ vary between ‘0’ complete absence of vertical dissection/erosion and hence dominance of flat surface and ‘1’ (in exceptional cases, vertical cliffs, it may be vertical escarpment of hill slope or at seashore). The sub-basin area is divided into 1sq.km grid cell and the dissection index for each cell is worked out. The raster data is converted into dissection index map for Thoppaiyar sub-basin and categorized as low, moderately low, moderate, moderately high and high dissection index zone. The major part of the sub-basin is fall under moderately low category (Fig.6.13). The maximum ‘Dis’ of the Thoppaiyar sub-basin is 0.85.
Figure 6.13 Dissection index of Thoppaiyar sub-basin
6.6.6 Channel Gradient (Cg)

The total drops in elevation (H) from the source to the mouth were found out for the Thoppaiyar sub-basin and horizontal distances were measured along their channels.

\[ Cg = \frac{H}{(\frac{\pi}{2} * Clp)} \]  

(6.42)

Where H = Relative height of the basin and

\[ Clp = \text{longest dimension parallel to the principal drainage line} \]

The computed channel gradient of the study area is 1.6 m/km. This testifies to the validity of Horton’s Law of Stream Slopes, which states that there is a fairly definite relationship between the slope of the streams and their orders, which can be expressed by an inverse geometric series law.

**Gradient Ratio (Rg)**

Gradient ratio is an indicator of channel slope from which an assessment of the runoff volume could be made (Sreedevi, 2005).

\[ Rg = \frac{(Z - z)}{Lb} \]  

(6.43)

The ‘Rg’ of the Thoppaiyar sub-basin is 0.032, which reflects the mountainous nature of the terrain. Approximately 80% of the main stream flows through the plateau and the relatively low values of ‘Rg’ confirm the same.

6.6.7 Ruggedness Number (Rn)

Ruggedness number indicates the structural complexity of the terrain. An extreme high value of ruggedness number occurs when both variables i.e. drainage density and relief are high and slope is not only steep but long as well (Strahler, 1956).

\[ Rn = \frac{Dd}{H} * 1000 \]  

(6.44)
The ruggedness number distribution in Thoppaiyar sub-basin is given in Table 6.17. The ruggedness numbers were worked out for each sq.km and spatial distribution of ruggedness condition in the basin is generated (Fig.6.14). The sub-basin is divided into low, moderately low, moderate, moderately high and high ruggedness index zone. The low ruggedness value of sub-basin implies that area is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density (Patton and Baker, 1976).

Table 6.17 Distribution of Ruggedness number in Thoppaiyar sub-basin

<table>
<thead>
<tr>
<th>Ruggedness Number (Rn)</th>
<th>Area (km$^2$)</th>
<th>Area (%)</th>
<th>Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.18</td>
<td>162</td>
<td>35</td>
<td>Low</td>
</tr>
<tr>
<td>0.18-0.36</td>
<td>137</td>
<td>30</td>
<td>Moderately Low</td>
</tr>
<tr>
<td>0.36-0.54</td>
<td>74</td>
<td>16</td>
<td>Moderate</td>
</tr>
<tr>
<td>0.54-0.79</td>
<td>61</td>
<td>13</td>
<td>Moderately High</td>
</tr>
<tr>
<td>&gt;0.79</td>
<td>28</td>
<td>6</td>
<td>High</td>
</tr>
</tbody>
</table>

**Melton Ruggedness Number (MRn)**

Melton (1965) differentiates basins with debris flow potential from basins with bed load sediment transport. The ‘MRn’ is a slope index that provides specialized representation of relief ruggedness within the sub-basin (Melton 1965).

$$MRn = \frac{H}{A^{0.5}}$$  (6.45)

Thoppaiyar sub-basin has an ‘MRn’ of 64.76. According to the classification of Wilford et al. (2004), this sub-basin is debris flood sub-basin, where bed load component dominates sediment under transport.
Figure 6.14 Ruggedness index of Thoppaiyar sub-basin
6.6.8 Contour Geometry

The total contour length (Ctl) in the sub-basin is 7130 km. The 10 m contour interval was taken from SRTM DEM data for the analysis of relief (Fig. 6.15). The computed length of two successive contours of the study area is 245 km (Strahler, 1952), it chosen along the main channel of the river basin. The average slope width of contour represented

\[ Swc = \frac{A}{\frac{L_1 + L_2}{2}} \]  

(6.46)

Where, 
\[ A \] is area of the basin,
\[ L_1 + L_2 \] are length of two successive contours.

The computed average slope width of the contour (Swc) is 3.77.

6.6.9 Slope Analysis (Sa)

Slope is identified as “the maximum rate of change in value from each cell to its neighbours”. Slope aspect is identified as “the down-slope direction of the maximum rate of change in value from each to its neighbours”. Slope analysis is an important parameter in geomorphic studies. The slope elements are controlled by rock the climatomorphogenic processes in the area with varying resistance. An understanding of slope distribution is essential for planning, settlement, mechanization of agriculture, deforestation, planning of engineering structures and conservation practices etc. (Sreedevi et al 2005). For Thoppaiyar sub-basin slope map was prepared from SRTM data using GIS Arcview method (ESRI, 2000). In Thoppaiyar river sub basin area slope vary from 0° to 50° (Fig 6.16). A high degree of slope is noticed in the western and northwestern parts of the basin. Sub-basin slope (Sw) measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1956). The height (H) and length (Lb) of the basin were considered.

\[ Sw = \frac{H}{Lb} \]  

(6.47)

The computed value of ‘Sw’ in the basin are 0.0328 indicating gentle slope.
Figure 6.15 The geometry of contour in Thoppaiyar sub-basin
Figure 6.16 Slope distributions in Thoppaiyar sub-basin
**Average Slope \((S)\)**

The erodibility of a sub-basin can be studied and compared from its average slope (Wenthworth, 1930). More percentage of slopes accelerates erosion, if all other parameters are kept constant. The average slope of the sub-basin is determined as,

\[
S = \frac{(Z \times Ctl)}{(10 \times A)} \tag{6.48}
\]

Where,
- \(S\) is the average slope,
- \(Z\) is maximum height of the basin,
- \(Ctl\) is total contour length and
- \(A\) is area of the basin.

The computed the average slope of the Thoppaiyar sub-basin is 1.80%.

**Mean Slope of Overall Basin \((\Theta_s)\)**

Mean slope of overall basin is computed as (Chorley, 1979),

\[
\Theta_s = \frac{\sum Ctl \times Cin}{A} \tag{6.49}
\]

Where
- \(\Theta_s\) = Mean slope of overall basin,
- \(Ctl\) = Total length of contour in the sub-basin,
- \(Cin\) = Contour interval, and
- \(A\) = Area of the sub-basin.

Mean slope of the sub-basin is 0.15%.

**6.6.10 Aspect**

An aspect-slope map simultaneously shows the aspect (direction) and degree (steepness) of slope for a terrain. The aspect of slope has a very significant influence on the local climate and distribution of vegetation and biodiversity of any area (Magesh et al 2012). Figure 6.17 shows the color coded map of the Thoppaiyar sub-basin representing the compass direction of the aspect, 0 is true north; a 90 aspect is to the east, and so forth. Thus the southeast, south and southwest slopes are dominant in the Thoppaiyar sub-basin. As a result, these slopes have a high evaporation rate and are drier supporting poor vegetation cover.
Figure 6.17 Aspect map of the Thoppaiyar sub-basin
6.7 SYNTHESIS

The quantitative morphometric analyses of the sub-basin provide the hydrological behavior, basin evolutionary history and maturity of the terrain. The SOI topographic map and GIS technique were utilized for analysis of various morphometric parameters in the sub-basin, which include drainage pattern, basin geometry, drainage texture and relief characteristics. Overall 83 quantitative morphometric parameters were estimated and analyzed. The drainage network analysis provide the detailed of stream order, stream length, bifurcation ratio, valley index, etc., Basin length, area, perimeter and basin shape, elongation ratio are some of the important basin geometry parameters discussed in this chapter. The textural analysis provide valuable information on hydrology, soil erosion, etc., Relief is the one of the important characteristics highlights the relative relief, dissection index and slope aspects etc., Overall the morphometric analysis is helpful to understand the basin behavior.