CHAPTER IV
DRAINAGE BASIN MORPHOMETRY

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4.3 Hierarchical Order System
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CHAPTER IV
DRAINAGE BASIN MORPHOMETRY

4.1 Introduction:

“Morphometry means measurement of the shape or geometry, of any natural form” (Strahler, 1969).

“The measurement and mathematical analysis of the configuration of the earth surface and of the shape and dimension of its landform” (Clarke, 1970). Morphometry incorporates quantitative study of the area, altitude, volume, slope, and profiles of land and drainage basin characteristics of the area concerned (Singh, 1972). Morphometric analysis can be studied under following two contexts.

I. Spatial Morphometric analysis: The spatial morphometric analysis involves the spatial distribution of various morphometric parameters of terrain like relief, slope, dissection index, drainage frequency, drainage density, altimetric and hypsometric analysis.

II. Quantitative Morphometric or Drainage Network analysis: Quantitative drainage network analysis involves the measurements in the context of drainage network hierarchy and covers linear, aerial and relief aspect of drainage network. The hierarchical ordering is the first step in the quantitative network analysis. There is several method of hierarchical system. Usually, Horton (1945) system modified by Strahler (1952) hierarchical system is adopted. The linear aspect deals with the hierarchical order of streams, number and lengths of the streams and their associated ratios, relationships amongst them and laws of drainage compositions.
The aerial aspect covers the analysis of basin shape, basin area, slope and relief and related laws of drainage composition.

Drainage network system is a vital aspect of the drainage morphometry. Drainage network system is a topological property of drainage basin. Under normal environmental circumstances, every drainage basin obeys general laws of drainage compositions (Horton, 1945). Anomalies in drainage network properties give some interpretative potential regarding the change environmental circumstances. Hence, geomorphic study without morphometry may not be completed. Thus, the River network analysis involve the measurements of linear, aerial, shape, relief and slope properties, which are summoned under the heading river basin morphometry. The precise aim of this chapter is to understand the morphometric properties, the laws of drainage composition and degree of drainage development of Upper Girna basin.

4.2 Methodology:

The morphometric analysis based on the quantitative methods suggested by Horton R.E. (1945) Strahler A.N. (1964), Schumm S.A. (1956), Melton M.A. (1958) and Bhamare S.M. (1987). Drainage network map of the Upper Girna basin has been prepared from the Toposheets of scale 1:50,000 and the Google map of the basin. The Toposheet No. 46 L/2, 46 L/3, 46 L/6, 46 L/7, 46 L/10, 46 L/11, 46 H/10 46 H/11, 46 H/14, and 46 H/15 have been used for drainage network analysis. Horton’s system modified by Strahler (1964) has been adopted for hierarchical order system. Order wise stream numbers have been estimated and tabulated (Table no.4.1) for further estimation of the morphometric parameters like bifurcation ration, length ratio etc. The order-
number, order-length, relationships have been plotted to understand the laws of the drainage composition. The results give interpretative potentials towards the understanding of drainage network changes and the contemporary environmental conditions. Pk-Index (Bhamare, 1986) also has been worked out for the understanding of the degree of the drainage development.

To serve the above purpose ten sub-tributaries of different order of Upper Girna basin have been selected from left and right side of the main channel viz. Persul Nala, Kolthi Nala, Markandi Nala, Ojhar Nala, Girna sub Nala, Tambadi River, Aram River, Sukar Nala, Puna river, Dhardhar River, and whole Upper Girna basin.

4.3 Hierarchical Order System:

Horton’s (1945) hierarchical order system modified by Strahler (1952) has been adopted for the network organization of the Upper Girna basin. The orderwise numbers of streams have been measured from the drainage map of Upper Girna basin as shown in figure no. 4.1. Upper Girna basin is a seventh ordered composite basin. Its network has been formed from union of five sixth order tributaries. (Viz. Persul Nala, Kolthi Nala, Markandi Nala, Aram River) and 18th fifth order and 85 fourth, 384 third order, 1406 second order and 5591 first ordered tributaries. Amongst them ten tributaries have been selected for morphometric analysis.
Table No.4.1 Morphometric Parameters of selected ten sub-tributaries of different order of Upper Girna Basin

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| 2     | 46  | 24.05 | 0.523 | 1.311 | 3.538 |   |   |   |   |   |   |
| 3     | 13  | 12.38 | 0.952 | 1.821 | 1.974 | 3.250 | 3.485 | 2.180 | 1.133 | 1.039 | 0.99 |
| 4     | 4   | 8.985 | 2.246 | 2.359 | 4.000 |   |   |   |   |   |   |
| 5     | 1   | 5.4  | 5.400 | 2.404 |   |   |   |   |   |   |   |

| DHARDHAR RIVER |   |   |   |   |   |   |   |   |   |   |   |
| 1     | 224 | 70.375 | 0.314 |   | 3.246 |   |   |   |   |   |   |
| 2     | 69  | 32.73 | 0.474 | 1.510 | 4.313 |   |   |   |   |   |   |
| 3     | 16  | 16.525 | 1.033 | 2.177 | 2.668 | 5.333 | 3.973 | 2.31  | 1.063 | 1.195 | 0.44 |
| 4     | 3   | 11.97 | 3.990 | 3.863 | 3.000 |   |   |   |   |   |   |
| 5     | 1   | 12.455 | 12.455 | 3.122 |   |   |   |   |   |   |   |

(Self Generated Table)
Figure No. 4.1 The Upper Girna Drainage Network Hierarchical Order System Map
4.4 Drainage Composition:

Horton (1945) introduced the four laws of drainage composition referred as Horton’s 1st, 2nd, 3rd and 4th Laws for stream order, stream length, stream area and stream slope respectively. The laws of drainage composition have been verified to examine the morphometry of the Upper Girna basin.

4.4.1 Horton’s First Law of Stream Number:

Horton introduced first law of drainage composition as law of stream number, which relates to the definite relationship between the hierarchical order and stream numbers. The law states that the number of stream segments of successive lower order in a given basin tends to form a geometric propagation beginning with the single segment of the highest order and the bifurcation ratio between the successive segments remains constant (Horton, 1945). The law of stream number expressed in the form of exponential equation as,

\[ N_\mu = R_b^{(k-\mu)} \]

Where,

- \( N_\mu \) = Number of stream segments of given order
- \( R_b \) = Constant bifurcation ratio
- \( k \) = Highest order of the basin
- \( \mu \) = Basin order.
Table No.4.2 Relationship between Stream Order and Number of Upper Girna and Its Selected 10 Tributaries
With reference to Horton’s first law the order wise stream number, relationship of Upper Girna basin and its selected ten sub-basins have been plotted on semi-log graph as shown in the fig No. 4.2. The Fig. 4.2 manifests the following facts:

1. The relationship between stream orders versus numbers shows inverse geometric progression and hence obeys Horton’s first law of the drainage composition.

2. Majority of the regression lines coincides between lower order segments i.e. between first and second order. However curves in this segment become very steep. The steep curve itself indicates the disproportionate increase of first order streams.

3. Some of the regression lines intersect at second order segment.

4. Some of the graph reveals up-concavity in lower higher order segment and some reveals concavity in lower order segment.

5. Very few graphs are straight and parallel to main drainage network clearly indicates different size of the basin. Dixit (1976) thought that the graphs between order and number relation representing each basin has been determined by a number of factors amongst them, basin size nature and degree of tributary development are very potent. The same ordered and same sized basins may differ in degree of drainage development (Bhamare, 1986). The tendency of the interception of the graphs of the same sized and the same ordered basins result from the variations in the degree of drainage of development i.e. due to the inadequate degree of drainage development and drainage network integration. Eyles (1971) thought that the concavity in the lower order segments is attributed to the disproportionate increase of first order streams, which represents the recent rejuvenation. The rejuvenation results in the disproportionate increase in the first order streams.
tendency of the bifurcation ratio at the lower order segment is to be inversely related to the order. The straight and coincidence nature of the curves suggest the development of the drainage under normal environmental circumstances.

However during the subsequent field checks up said facts attributed to the following tributaries:

1. Ojhar Nala shows abnormal increase in 2\textsuperscript{nd} and 3\textsuperscript{rd} order segments this can be attributed with higher relief characteristics. The 2\textsuperscript{nd} and 3\textsuperscript{rd} ordered segments merge in to the small dam constructed near small settlement named Devalivani. From this dam single fourth order tributary emerged out.

2. In the case of Dhardhar, Sukar and Markandi basins convexity in the lower order segment is due to the higher proportion of first order tributaries which converged in to water bodies and no doubt high relief is also responsible for more no of lower ordered tributary.

3. The curves of all tributaries are nearly parallel. They are of different sized and ordered basins. e. g. all the different ordered and different sized tributaries are parallel to entire Upper Girna basin.

4.4. \textbf{II Bifurcation Ratio:}

The bifurcation ratio is the ratio of the number of stream of a given order (Nu) to the number of streams of the next higher order Nu+1 the order (Singh et. al., 1984) and expressed as follows.

\[
R_b = \frac{Nu}{Nu+1} \quad \text{............... (4.2)}
\]

Where,

\[R_b = \text{Bifurcation ratio.}\]
The bifurcation ratio of the successive order of stream segments has been worked for all the ten sub-basins and entire Upper Girna basin as shown in the table no. 4.2.

The bifurcation ratio of all the basins plotted for various ordered sub-basins and of the Entire Upper Girna basin (Fig No. 4.3) in order to understand the behavior of the bifurcation ratio. Which manifests the following facts.

1. The bifurcation ratio between first and second order segment shows normal behavior. The range of bifurcation ratio is well within 3 and 5 that indicate normal environmental circumstances. Similar conditions are also observed of 2nd and 3rd order segments.

2. The maximum deviation in the bifurcation ratio is observed in between segments (i.e. between thirds forth and forth fifth). The bifurcation ratio entire Upper Girna basin is well within the normal limit. However, the bifurcation ratio of Punad River is beyond the normal limit of the bifurcation ratio.
Table No.4.2 Bifurcation Ratio in Successive Orders of Streams of Upper Girna and Its Selected 10 Tributaries

<table>
<thead>
<tr>
<th>Basin No.</th>
<th>Basin</th>
<th>Ratio of stream numbers in successive orders (bifurcation ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1st/2nd</td>
</tr>
<tr>
<td>1</td>
<td>Persul nala</td>
<td>4.161</td>
</tr>
<tr>
<td>2</td>
<td>Kolthi nala</td>
<td>3.771</td>
</tr>
<tr>
<td>3</td>
<td>Markandi nala</td>
<td>3.955</td>
</tr>
<tr>
<td>4</td>
<td>Ojhar nala</td>
<td>3.813</td>
</tr>
<tr>
<td>5</td>
<td>Girna nala (5th ord seg.)</td>
<td>4.938</td>
</tr>
<tr>
<td>6</td>
<td>Tambdi River</td>
<td>4.409</td>
</tr>
</tbody>
</table>
### Table No. 4.2
Continue…

<table>
<thead>
<tr>
<th></th>
<th>Location</th>
<th>4.321</th>
<th>4.024</th>
<th>3.727</th>
<th>11.00</th>
<th>5.768</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Punad River</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Aram river</td>
<td>4.054</td>
<td>4.138</td>
<td>4.143</td>
<td>4.667</td>
<td>3.00</td>
</tr>
<tr>
<td>9</td>
<td>Sukar nala</td>
<td>3.152</td>
<td>3.538</td>
<td>3.250</td>
<td>4.00</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>Dhardhar river</td>
<td>3.246</td>
<td>4.313</td>
<td>5.333</td>
<td>3.00</td>
<td>-</td>
</tr>
</tbody>
</table>

(Self Generated Table)
Figure No. 4.3 Behavior of Bifurcation Ratio of Upper Girna and Its Selected 10 Tributaries
1. The bifurcation ratio between 3\textsuperscript{rd} and 4\textsuperscript{th} order segment of persul river indicates abnormal value i.e. 2.667 however bifurcation ratio between 3\textsuperscript{rd} and 4\textsuperscript{th} order segment for Markandi Nala, Ojhar Nala, Girna sub-basin Nala, Dhardhar river are 5.333, 5.500, 6.00, 5.33 respectively which are certainly abnormal.

2. Extremely higher bifurcation ratio of 11 observed in case of Punad basin. Behavior of Punad basin indicates abnormal circumstances.

4.4. \textit{III Horton’s law of stream length:}

Horton (1945) introduced second law of drainage composition to show the relationship between stream order and average stream length of the successive order and he found direct exponential relation between them. The order wise average stream length of the 10 tributaries of Upper Girna basin and for the entire Upper Girna River estimated from 1:50,000 scale toposheet and tabulated in table no. 4.3. The order wise average stream length also has been plotted on semi-log graph to test the Horton’s second law as shown in the figure no.4.4. The figure No.4.4 clearly indicates that average stream length increases in geometric proportion with respect to increase in a stream order. Hence Upper Girna river and its tributaries obeys Horton’s second law i.e. law of stream numbers.
Table No. 4.3. The Order Wise Average Stream Length of Upper Girna and Selected 10 Tributaries

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Basin name</th>
<th>Avg. Stream Length in Km.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1st</td>
</tr>
<tr>
<td>1</td>
<td>Persul Nala</td>
<td>0.351</td>
</tr>
<tr>
<td>2</td>
<td>Kolthi Nala</td>
<td>0.344</td>
</tr>
<tr>
<td>3</td>
<td>Markandi Nala</td>
<td>0.317</td>
</tr>
<tr>
<td>4</td>
<td>Ojhar Nala</td>
<td>0.300</td>
</tr>
<tr>
<td>5</td>
<td>Girna Nala (5th ord seg.)</td>
<td>0.286</td>
</tr>
<tr>
<td>6</td>
<td>Tambdi River</td>
<td>0.290</td>
</tr>
<tr>
<td>7</td>
<td>Punad River</td>
<td>0.350</td>
</tr>
<tr>
<td>8</td>
<td>Aram River</td>
<td>0.379</td>
</tr>
<tr>
<td>9</td>
<td>Sukar Nala</td>
<td>0.399</td>
</tr>
<tr>
<td>10</td>
<td>Dhardhar River</td>
<td>0.314</td>
</tr>
<tr>
<td>11</td>
<td>Entire Upper Girna Basin</td>
<td>0.350</td>
</tr>
</tbody>
</table>

(Self Generated Table)
Figure No. 4.4 Stream Ord. V/s Avg. St. Length Relation
• **Trends of the average stream length**

The average lengths of tributaries have been plotted on graph to understand the segment wise trend as shown in Fig. No 4.4 that depicts the following facts

1. The average stream length increases up to the fifth order segment and after fifth orders it abruptly declines.

   This fact clearly indicates that the final order stream follows straight path up to the confluence point. It means that there is an inadequate extension of length of final order. One may think that the straight path of final order streams and their stunted length are either due to sudden fall in local base level that creates steeper gradients. Stream course become straight and length is shortest.

2. The average length of second order stream segment is comparatively greater than the successive lower order segment. This fact clearly indicates the higher relief. The activeness of headward erosion might be attributed to the recent rejuvenation associated with change in local base level of the stream.

4.5. **Degree of Drainage development:**

The variations in order wise stream number and length certainly reflects on degree of drainage development. Horton (1945) attempted degree of development on first, two laws of drainage composition. Bhamare’s (1986) modified Horton’s original method of degree of drainage development.
4.5. 1. K-INDEX:

According to Bhamare (1986) the bifurcation ratio is taken as the suggestive indicator of the drainage development. Under the normal conditions, the plot of the order and the number in an exponential functional relationship represents straight line and the bifurcation ratio in successive segment remains uniform. The average bifurcation ratio is directly proportional to the inverse log of regression coefficient of the regression line.

(Bhamare 1986) Bhamare’s K-index can be expressed as-

\[ K = \frac{-b}{\log Rb} \]  \hspace{1cm} \text{(4.3)}

Where,

- \( K \) = index of bifurcation ratio  
- \( -b \) = Regression coefficient  
- \( Rb \) = Bifurcation ratio  

The K-index is the ratio between the expected (theoretical Rb) average bifurcation ratio and the observed average bifurcation ratio. It may be assumed that under the normal and ideal conditions of the drainage development the value of the K is perfect one. The deviations from this unity value of the K–index (one) suggest the inadequate development of the drainage. It might be attributed to the factors like change in climate, change of base level, deluvialistic circumstances, tectonic activities and anthropogenic activities. The value of the K-index has been estimated for ten tributaries of the Upper Girna basin and the Entire Upper Girna asin as shown in the table no.4.4.
The table no.4.4 manifests the following facts:

The K-index varies greatly and ranges between 0.703 and 1.09. This variation might be attributed variation in degree of drainage development.

Table No. 4.4. K-INdex

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Basin Name</th>
<th>Bifurcation Ratio</th>
<th>Regr. Coeff. B</th>
<th>Log Rb&lt;sup&gt;-1&lt;/sup&gt;</th>
<th>K = b / Log Rb&lt;sup&gt;-1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Persul nala</td>
<td>3.499</td>
<td>1.470</td>
<td>1.838</td>
<td>0.800</td>
</tr>
<tr>
<td>2</td>
<td>Kolthi nala</td>
<td>3.471</td>
<td>1.479</td>
<td>1.850</td>
<td>0.799</td>
</tr>
<tr>
<td>3</td>
<td>Markandi nala</td>
<td>3.689</td>
<td>1.574</td>
<td>1.764</td>
<td>0.892</td>
</tr>
<tr>
<td>4</td>
<td>Ojhar nala</td>
<td>3.919</td>
<td>1.445</td>
<td>1.686</td>
<td>0.857</td>
</tr>
<tr>
<td>5</td>
<td>Girna nala (5&lt;sup&gt;th&lt;/sup&gt; ord seg.)</td>
<td>4.610</td>
<td>1.618</td>
<td>1.507</td>
<td>1.074</td>
</tr>
<tr>
<td>6</td>
<td>Tambdi River</td>
<td>4.169</td>
<td>1.462</td>
<td>1.613</td>
<td>0.906</td>
</tr>
<tr>
<td>7</td>
<td>Punad River</td>
<td>5.768</td>
<td>1.636</td>
<td>1.314</td>
<td>1.090</td>
</tr>
<tr>
<td>8</td>
<td>Aram river</td>
<td>4.00</td>
<td>1.665</td>
<td>1.661</td>
<td>1.002</td>
</tr>
<tr>
<td>9</td>
<td>Sukar nala</td>
<td>3.485</td>
<td>1.296</td>
<td>1.844</td>
<td>0.703</td>
</tr>
<tr>
<td>10</td>
<td>Dhardhar river</td>
<td>3.973</td>
<td>1.462</td>
<td>1.669</td>
<td>0.876</td>
</tr>
<tr>
<td>11</td>
<td>Entire Upper Girna Basin</td>
<td>4.23</td>
<td>1.884</td>
<td>1.597</td>
<td>1.010</td>
</tr>
</tbody>
</table>
4.5. II $k'$ – INDEX:

Similar to K-index Bhamare’s $k'$ index expressed

$$k' = \frac{b'}{\log RL} \quad ........(4.4)$$

Where,

1. $k'$ = is Bhamare index of lagth ratio
2. $RL$ = Length ratio
3. $b'$ = Regression coefficient

$k'$ index is a dimensionless property which represents nature and degree of drainage development.

With the help of equation, $k'$—Index is computed and tabulated in the table no.4.5.
Table No. 4.5 k'- Index

<table>
<thead>
<tr>
<th>SR. NO.</th>
<th>Basin name</th>
<th>Reg.Coeff. b'</th>
<th>Log (RL)</th>
<th>k' =b / log RL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Persul nala</td>
<td>0.6978</td>
<td>4.201</td>
<td>0.166</td>
</tr>
<tr>
<td>2</td>
<td>Kolthi nala</td>
<td>0.6841</td>
<td>3.030</td>
<td>0.226</td>
</tr>
<tr>
<td>3</td>
<td>Markandi nala</td>
<td>0.5735</td>
<td>3.940</td>
<td>0.146</td>
</tr>
<tr>
<td>4</td>
<td>Ojhar nala</td>
<td>0.6930</td>
<td>2.972</td>
<td>0.233</td>
</tr>
<tr>
<td>5</td>
<td>Girna nala (5th ord seg.)</td>
<td>0.9047</td>
<td>2.017</td>
<td>0.448</td>
</tr>
<tr>
<td>6</td>
<td>Tambdi river</td>
<td>0.6725</td>
<td>1.830</td>
<td>0.368</td>
</tr>
<tr>
<td>7</td>
<td>Punad River</td>
<td>0.9523</td>
<td>1.405</td>
<td>0.678</td>
</tr>
<tr>
<td>8</td>
<td>Aram river</td>
<td>0.7801</td>
<td>3.513</td>
<td>0.222</td>
</tr>
<tr>
<td>9</td>
<td>Sukar nala</td>
<td>0.6698</td>
<td>3.386</td>
<td>0.198</td>
</tr>
<tr>
<td>10</td>
<td>Dhardhar river</td>
<td>0.9538</td>
<td>2.346</td>
<td>0.406</td>
</tr>
<tr>
<td>11</td>
<td>Entire Upper GirnaBasin</td>
<td>0.9383</td>
<td>2.420</td>
<td>0.388</td>
</tr>
</tbody>
</table>

(Self Generated Table)

The table no. 4.5 reveals the following facts:

1. The k' index shows lower values and range between 0.146 and 0.678. The lower value is of Markandi sub basin of Upper Girna basin and the highest values of Punad sub basin.

2. The lower values of k’ index are attributed to the inadequate extension of length.
4.5. III. Bhamare’s PK-Index:

Bhamare’s PK-index is expressed as follows:

\[
PK = \frac{k'}{K} \quad \text{........... (4.5)}
\]

Where,

PK—Index indicates the stages of drainage Development.

k' --------------- Index of Stream length.

K------------- Index of Bifurcation ratio.

Bhamare’s PK-index have been estimated for ten tributaries of Upper Girna basin as shown in table no 4.6

Table No 4.6 PK- Index

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Basin name</th>
<th>k'</th>
<th>K</th>
<th>PK=K'/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Persul nala</td>
<td>0.166</td>
<td>0.800</td>
<td>0.21</td>
</tr>
<tr>
<td>2</td>
<td>Kolthi nala</td>
<td>0.226</td>
<td>0.799</td>
<td>0.28</td>
</tr>
<tr>
<td>3</td>
<td>Markandi nala</td>
<td>0.146</td>
<td>0.892</td>
<td>0.16</td>
</tr>
<tr>
<td>4</td>
<td>Ojhar nala</td>
<td>0.233</td>
<td>0.857</td>
<td>0.27</td>
</tr>
<tr>
<td>5</td>
<td>Girna nala (5th ord seg.)</td>
<td>0.448</td>
<td>1.074</td>
<td>0.42</td>
</tr>
<tr>
<td>6</td>
<td>Tambdi river</td>
<td>0.368</td>
<td>0.906</td>
<td>0.41</td>
</tr>
<tr>
<td>7</td>
<td>Punad River</td>
<td>0.678</td>
<td>1.090</td>
<td>0.62</td>
</tr>
<tr>
<td>8</td>
<td>Aram river</td>
<td>0.222</td>
<td>1.002</td>
<td>0.22</td>
</tr>
<tr>
<td>9</td>
<td>Sukar nala</td>
<td>0.198</td>
<td>0.703</td>
<td>0.28</td>
</tr>
<tr>
<td>10</td>
<td>Dhardhar river</td>
<td>0.406</td>
<td>0.876</td>
<td>0.46</td>
</tr>
<tr>
<td>11</td>
<td>Entire Upper Girna Basin</td>
<td>0.388</td>
<td>1.010</td>
<td>0.38</td>
</tr>
</tbody>
</table>
Bhamare PK- index reveals degree of drainage development. The value of PK-index ranges between 0.16 and 0.62. The values are less then unity. Therefore not a single tributary is in perfect degree of drainage development. These values can be classified into categories as shown in table no 4.7.

**Table No.4.7 Drainage Development of the Upper Girna Basin**

<table>
<thead>
<tr>
<th>PK-index</th>
<th>Drainage Development</th>
<th>Name of Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00-0.20</td>
<td>Very Low</td>
<td>Markandi nala</td>
</tr>
<tr>
<td>0.21-0.40</td>
<td>Low</td>
<td>Persul nala, Kolti nala, Ojhar nala, Aram river, Sukar nala, Entire UGB.</td>
</tr>
<tr>
<td>0.41-0.60</td>
<td>Normal or Intermediate</td>
<td>Tambdi river, Girna nala, Dhardhar river</td>
</tr>
<tr>
<td>0.61-0.80</td>
<td>High</td>
<td>Punad River</td>
</tr>
<tr>
<td>0.81-1.00</td>
<td>Very High</td>
<td>Nil</td>
</tr>
</tbody>
</table>

Form the table no 4.7, it is evident that none of the tributary and entire Upper Girna basin in a perfect degree of drainage development. The Punad River shows higher degree of drainage development. Tambadi and Girna nala shows intermediate drainage development. Markandi reveals very low degree of drainage development. The remaining tributaries are in low degree of drainage development categories.

The overall degree of drainage of drainage development of Upper Girna basin reveals lower degree of drainage development. The degree of drainage development in upper reach are usually
lower. The recent rejuvenation associated with capturing of Girna by Tapi may also be related to the lower degree of drainage development.

### 4.6 Basin Geometry:

Litho-structure and the bio-climatic environment influence the basin geometry. The influence of these factors appears in the variation of their size, length and area. The basin geometry is determined by these measures. There are several parameters of basin geometry, the important amongst them are elongation ratio, circulatory ratio and shape index. All these parameters worked out and depicted in table no. 4.8.

**Table No. 4.8 Basin Geometry of Upper Girna Basin**

<table>
<thead>
<tr>
<th>No.</th>
<th>Basin name</th>
<th>Circularity Ratio</th>
<th>Elongation Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Persul nala</td>
<td>0.51</td>
<td>0.210</td>
</tr>
<tr>
<td>2</td>
<td>Kolthi nala</td>
<td>0.73</td>
<td>0.18</td>
</tr>
<tr>
<td>3</td>
<td>Markandi nala</td>
<td>0.48</td>
<td>0.39</td>
</tr>
<tr>
<td>4</td>
<td>Ojhar nala</td>
<td>0.16</td>
<td>0.29</td>
</tr>
<tr>
<td>5</td>
<td>Girna nala (5\textsuperscript{th} ord seg.)</td>
<td>0.95</td>
<td>0.52</td>
</tr>
<tr>
<td>6</td>
<td>Tambdi river</td>
<td>0.98</td>
<td>0.49</td>
</tr>
<tr>
<td>7</td>
<td>Punad River</td>
<td>0.80</td>
<td>0.27</td>
</tr>
<tr>
<td>8</td>
<td>Aram river</td>
<td>0.76</td>
<td>0.26</td>
</tr>
<tr>
<td>9</td>
<td>Sukar nala</td>
<td>0.99</td>
<td>0.255</td>
</tr>
<tr>
<td>10</td>
<td>Dhardhar river</td>
<td>0.44</td>
<td>0.11</td>
</tr>
<tr>
<td>11</td>
<td>Entire Upper Girna Basin</td>
<td>0.64</td>
<td>0.33</td>
</tr>
</tbody>
</table>
4.6. I Circularity Ratio:

The circularity ratio may be defined as the ratio of basin area to the area of circle having the same perimeter as the basin (Miller, 1953). It is a dimensionless ratio and influenced by the length of the stream of various orders.

The value of circulatory ratio always ranges between 0 and 1. Higher the value of circulatory ratio indicates more circular shape of the basin and vise versa.

Persul, Markandi, Ojhar, Dhardhar and entire Upper Girna basin having circulatory ratio less than 0.7 there for they are oval in shape. Remaining all sub-basins showing the circulatory ration more than 0.7 it indicates they are all of circular shape basins.

4.6. II Elongation Ratio:

The elongation ratio reveals the shape of a drainage basin, which is the ratio of the diameter of circle of the area as the basin to the maximum basin length (Schumm, 1956).

The value of elongation ratio also ranges between 0 and 1. the higher the value of elongation ratio, the more circular shape of the basin and vice versa. Elongation ratio runs between 0.6 and 1.0 over a wide variety of climatic and geological type. Values near 1.0 are typical of regions of very low relief, whereas values in the range of 0.6 to 0.8 are generally associated with strong relief and steep ground slopes (Strahler, 1964).

Elongation ratio for all the tributaries including Upper Girna basin ranges in between 0.11 and 0.52, which indicates towards the elongated shaped basins and very strong relief.
4.7 **Drainage pattern:**

“Drainage pattern refers to the particular plan or design which the stream courses collectively form”. Drainage pattern has close association, very delicate and intricate adjustment with structure and lithology. Hence, the knowledge of the drainage pattern of the region or a river basin may throw considerable light on the structure of the underlying rocks. It is generally recognized that drainage pattern reflects the influence of such factors as initial slopes, difference in rock hardness, structural controls, recent diastrophism and the recent tectonic activates or climatic change.

Spark (1972) has expressed his view that the arrangement of the relief is merely the pattern of the interfluves, so that in an area of well-adjusted drainage, the study of the drainage pattern is automatically the study of the relief pattern, both being dependent on structure. “The drainage pattern is one of the most informative features of landscape and casts light on the rock type geological structure, stage in drainage evolution.”

The drainage map (Fig.no.4.5) reveals the hierarchy of rivers from source to its master streams. Rills, streams and rivers unite to outline a geometrical plane. These streams, in general, do not organize at random. Their hierarchy traces their history to reflect the stage or stages of their development. Rivers cut hard and soft rocks alike over the surfaces and exhibit an organization of drainage lines over underline lithology. Over each type of lithology river alignment is guided by master and minor joints, rock characteristics and topographic expressions. Drainage patterns are closely adjusted to joints, cleavage, bedding planes and outcrops of weaker strata.
The drainage pattern of the Upper Girna basin ranges between dendritic to sub parallel drainage pattern.

The original drainage follows dendritic drainage pattern over the Deccan basaltic rocks on which drainage is formed. On the other hand sub parallel drainage pattern is secondary and recent on alluvial deposition plains and colluvial fans at foot hills.
Figure No. 4.5. The Drainage Pattern Map of Upper Girna Basin
### 4.8 Relief Analysis:

Relief can be defined as the difference between highest and lowest elevation of the unit area.

There are two way of Relief expression Viz- Absolute relief and Relative relief.

#### 4.8. I Absolute Relief:

Absolute relief is a measure of highest elevation in unit area. The Upper Girna basin area has been divided in to the grids of one square kilometer and highest elevation identified in each square grid. Further spatial absolute relief has been classified in to relief categories and the spatial absolute relief distribution map prepared as show in map (Fig no. 4.7). The areal frequencies have been measured between successive relief categories and tabulated in table no 4.9 at 200 m. relief interval.

<table>
<thead>
<tr>
<th>Relief (m.)</th>
<th>Absolute Relief (Area occupied in sq. km.)</th>
<th>Area occupied in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 - 600</td>
<td>876.7</td>
<td>33.03%</td>
</tr>
<tr>
<td>600 - 800</td>
<td>878.12</td>
<td>33.08%</td>
</tr>
<tr>
<td>800 - 1000</td>
<td>678.33</td>
<td>25.55%</td>
</tr>
<tr>
<td>1000 - 1200</td>
<td>192.12</td>
<td>7.23%</td>
</tr>
<tr>
<td>1200 - 1400</td>
<td>25.14</td>
<td>0.94%</td>
</tr>
<tr>
<td>1400 - 1600</td>
<td>3.61</td>
<td>0.13%</td>
</tr>
<tr>
<td><strong>Total Area &amp; %</strong></td>
<td><strong>2654.02</strong></td>
<td><strong>100 %</strong></td>
</tr>
</tbody>
</table>

(Self Generated Table)
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Following facts evident from the table no. 4.9

1. Absolute relief of the Upper Girna basin ranges between 419 m. (The Confluence point height of Girna with Mousam) and 1547 m. (The highest elevation at salher fort in the source region)

2. Nearly 92% area of the Upper Girna basin lies below 1000 m. elevation. Above 1000 m. area of the basin abruptly decreases.

3. The mean, median and modal values of the Upper Girna basin are 721.16, 673.89 and 660.64 respectively.

4. The standard deviation is 476.38 m. The higher value standard deviation suggests the wide variation of data. The distribution of absolute relief is unimodal.

5. The distribution of relief asymmetry also has been estimated. The skewness value for absolute relief for Upper Girna basin is -0.13. The estimated value of kurtosis for absolute relief is -0.71.

Figure No.4.6 Absolute Relief Areal Frequency Distribution
Figure No.4.7 Absolute Relief Map of Upper Girna Basin
4.8. **Relative relief:**

The relative relief is the measure of elevation of the surface above the common datum surface of the region. It is expressed in terms of surface configuration of the region Glock (1932) used the term ‘amplitude of the relief and defined it as the vertical distance from a horizontal flat upland down to the initial grade of the streams. The relative relief has been determined on the basis of the differences in the highest and lowest elevation in one km² grids of the Upper Girna basin.

The aerial frequencies of the relative relief classified in to seven categories at 100 m. relief interval table no.4.10. The measures of central tendencies worked out and a spatial distribution map of relative relief prepared Fig.No.4.9.

**Table No. 4.10 Relative relief of Upper Girna Basin**

<table>
<thead>
<tr>
<th>R.Relief (mts.)</th>
<th>Relative Relief (Area occupied in sq. km.)</th>
<th>Area occupied in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>00 – 100</td>
<td>1639.7</td>
<td>61.78</td>
</tr>
<tr>
<td>100 – 200</td>
<td>622.48</td>
<td>23.45</td>
</tr>
<tr>
<td>200 – 300</td>
<td>275.98</td>
<td>10.39</td>
</tr>
<tr>
<td>300 – 400</td>
<td>91.61</td>
<td>3.45</td>
</tr>
<tr>
<td>400 – 500</td>
<td>14.25</td>
<td>0.53</td>
</tr>
<tr>
<td>500 – 600</td>
<td>6.7</td>
<td>0.25</td>
</tr>
<tr>
<td>600-700</td>
<td>3.3</td>
<td>0.12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2654.02</strong></td>
<td><strong>100 %</strong></td>
</tr>
</tbody>
</table>

(Self Generated Table)
Nearly 61.78% of the Upper Girna basin area is occupied by lowest relative relief category i.e. 0-100 m. The area of the basin abruptly falls above 300 m. relative relief category.

The distribution of Relative relief of Upper Girna basin is further supported by worked out statistical parameters. The mean, median and modal is the measures of the central tendency. Their values in concern with relative relief are 108.76, 153.20, and 138.85 respectively. The standard deviation is 164.96 m. The measure of symmetry is skewness. The skewness value of relative relief for Upper Girna basin is 2.12 and the estimated value of kurtosis is 5.6. Kurtosis value is > 3, so that this value indicates Leptokurtic distribution. One may say that relative relief distribution of catchment of the Upper Girna basin is asymmetrical.

Figure No.4.8 Relative Relief Areal Frequency Distribution
Figure No.4.9 Relative Relief Map of Upper Girna Basin
4.9 Dissection index:

Dissection index is a ratio of relative relief and absolute relief. Dissection index worked out in each square grid of 1 km² of the Upper Girna basin. The total frequency distribution of the dissection index show unimodal and positively skewed with high degree of dispersion. Unimodality, itself indicates that dissection took place under single geomorphic process. That process can be predicted as fluvial process. The measure of central tendencies also shows variations, which depict variation in the dissection.

Table No. 4.11 Dissection Index of Upper Girna Basin

<table>
<thead>
<tr>
<th>Dissection Index</th>
<th>Area occupied in sq. km.</th>
<th>Area occupied in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 0.1</td>
<td>1436.36</td>
<td>54.12016</td>
</tr>
<tr>
<td>0.1 - 0.2</td>
<td>747.48</td>
<td>28.16407</td>
</tr>
<tr>
<td>0.2 - 0.3</td>
<td>394.2</td>
<td>14.85294</td>
</tr>
<tr>
<td>0.3 - 0.4</td>
<td>71.68</td>
<td>2.700809</td>
</tr>
<tr>
<td>0.4 - 0.5</td>
<td>4.3</td>
<td>0.162018</td>
</tr>
<tr>
<td>Total</td>
<td>2654.02</td>
<td>100 %</td>
</tr>
</tbody>
</table>

(Self Generated Table)

Maximum areal frequencies (54.12%) belong to lower dissection index category. Where minimum area of the basin belongs to highest dissection index category (0.4-0.5)

The mean, median and mode are the measures of the central tendency. Their values in concern with dissection index are 0.1166,
0.1146, and 0.1052 respectively. The skewness value of dissection index for Upper Girna basin is 1.29 and the estimated value of kurtosis is 1.04.

Figure No.4.10 Dissection Index Areal Frequency Distribution
Figure No. 4.11 Dissection Index Map

Legend
Dissection Index
- 0 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5

Dissection Index
4.10 Slope:

Slope is an angular inclination of terrain between hill tops and valley bottoms resulting from the combination of many causative factors like geological structure, climate, vegetation cover, relief and tectonic activities. Slope is one of the important factors amongst the variousgeomorphic factors playing a key role in the development of any landform.

Many Geomorphologists defines and explains the slopes: like Davis (1914), Panck (1953), King (1966), Young (1969), Singh S. (1984), R.S. Pandey(1983) and others. They have studied various aspects of processes in slope formations.

The catchment of the Upper Girna basin was divided into one square kilometer grid. The slope values were obtained by using Wentworth formula expressed as.

\[ \text{Tan } Q = \frac{N \times CI}{636.6} \]  \quad (4.6)

Where,

\[ N = \text{Average number of contour crossing in a grid.} \]

\[ CI = \text{Contour Interval} \]

The obtained values were classified in to 4 categories at 5 degree slope interval as shown in the table no. 4.12.
Table No. 4.12 Slope Category /Area in sq.km.

<table>
<thead>
<tr>
<th>SR.NO.</th>
<th>SLOPE CATEGORY (In degree)</th>
<th>AREA IN SQ.KM.</th>
<th>Area occupied in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>00 to 05</td>
<td>1802.16</td>
<td>67.90 %</td>
</tr>
<tr>
<td>2</td>
<td>05 to 10</td>
<td>309.5</td>
<td>11.66 %</td>
</tr>
<tr>
<td>3</td>
<td>10 to 20</td>
<td>357.92</td>
<td>13.47 %</td>
</tr>
<tr>
<td>4</td>
<td>Above 20</td>
<td>184.81</td>
<td>6.96 %</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td><strong>2654.02</strong></td>
<td><strong>100 %</strong></td>
</tr>
</tbody>
</table>

(Self Generated Table)

The statistical parameters of slope category also have been worked out for the basin. The mean, median and modal values are 7.09, 11.47 and 9.84 respectively. The standard deviation is 13.9. The skewness value for slope for Upper Girna basin is 2.53 and the estimated value of kurtosis for relative relief is 6.71. All these parameters are suggesting uneven distribution of the slope.
Figure 4.12 Slope Distribution of Upper Girna Basin
Figure 4.13 Slope Map of Upper Girna Basin