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Morphometric Analysis of Padmavati River Basin, Thandla Area, Jhabua Region, Madhya Pradesh, India

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Abstract

Morphometric (Quantitative) analysis of Thandla drainage basin, based on drainage map has been conducted with the help of Survey of India Toposheet no. 46 I/12, on a 2 cm = 1 km scale. Thandla Quantitative study basin has been classified into 8 (A to H) sub-basins. Morphometric parameters namely Linear, Areal, and Relief aspects have been estimated, and described. Estimation of morphometric parameters such as *Linear* (Stream order - 1st to 5th order, Stream Number 1 to 238, Bifurcation ratio - 1 to 10), *Areal* (Drainage density -2.76 to 4.91, Stream frequency - 2.799 to 6.257, Form factor - 0.348 to 2.829, Circularity ratio -0.509 to 1.143, Elongation ratio - 13.331 to 107.808, Lemniscates - 0.069 to 0.718, Length of Overland flow - 0.101 to 0.181), and *Relief variable* (Basin relief - 2 to 120 m, Relief ratio - 0.754 to 16 m, Ruggedness number - 0.008 to 0.583, Ground surface slope - 0.016 to 1.166) pertaining to eight sub-basins have been described. Inter relationship of morphometric parameters and hypsometric analysis have been determined. Morphometric data enable to locate favourable ground water potential locations in Thandla study area.

Keywords: Analysis, Quantitative, Morphometric, Hypsometric Study, Thandla Drainage Basin, Jhabua Region.

Introduction

Several workers have described the geomorphological features of different basins, drainage pattern and basin design of areas. The following workers have contributed significance geomorphological studies in different parts, namely: Horton (1932, 1945), Strahler (1952, 1957, 1964), Singh (2005), and others. The present paper deals with morphometric analysis of Thandla Drainage basin located in Jhabua district of Madhya Pradesh, India.

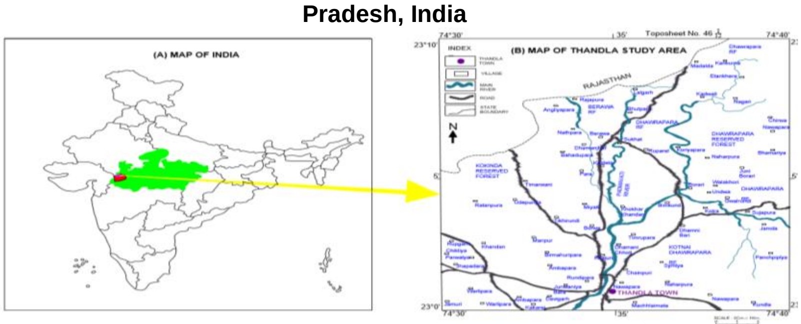
Aim of the Study

The present research investigation has been undertaken to conduct morphometric (quantitative) analysis of Padmavati River Drainage basin in Thandla area of Jhabua Region, with a view to recognize ground water potential horizons to resolve the sustained water supply problem in Thandla area.

Characteristics Features of Study Area

The study area is confined to Latitude 23^0 0' to 23^0 10 ' N and Longitude 74^0 30 ' to 74^0 40 ' E, Survey of India Toposheet No.46 I/12, (Figure 1.1) in Thandla vicinity of Jhabua Region, Madhya Pradesh, India. Study area extends over 366.58 sq. km, and it is approachable throughout the year. Geologically, study area is mainly characterized by quartzite, phyllite, basaltic lava flows having joints and fractures with black cotton, lateritic, and alluviul soils.

Figure 1.1 Location Map of study area, Jhabua district, Madhya Pradesh, India



Quantitative Morphometric Analysis

Morphometric analysis involves the measurements and mathematical study of surface landforms of earth. Computation of hydrologic parameters of drainage basin provide valuable evidence for determination of trends runoff and ground water condition. Morphometric parameters have been measured by using methods followed by Horton (1932, 1945), Strahler (1952, 1957, 1964), Marisawa (1959), Krishnamurthy *et.al.* (1996 a, b), Katara & Dev (2017), Bhuriya & Dev (2018) and others have conducted geomorphological studies in different areas. Methodology of quantitative morphometric analysis of a drainage basin as proposed by Horton (1945), and others adopted. Drainage basin analysis deals with measurements of the Linear, Areal and Relief features. Based on analysis the shape extent and channel network of the basin have been delineated. The Padmavati River basin has been classified into 8 sub-basins - A to H (Figure 1.2) on the basis of trend of streams. Morphometric analysis, deals with determination of different parameters to understand the nature of drainage basin. Computed morphometric parameters of drainage sub-basins are displayed (Table 1.1).

Figure 1.2 Drainage pattern of Thandla study area, Jhabua district, M. P.

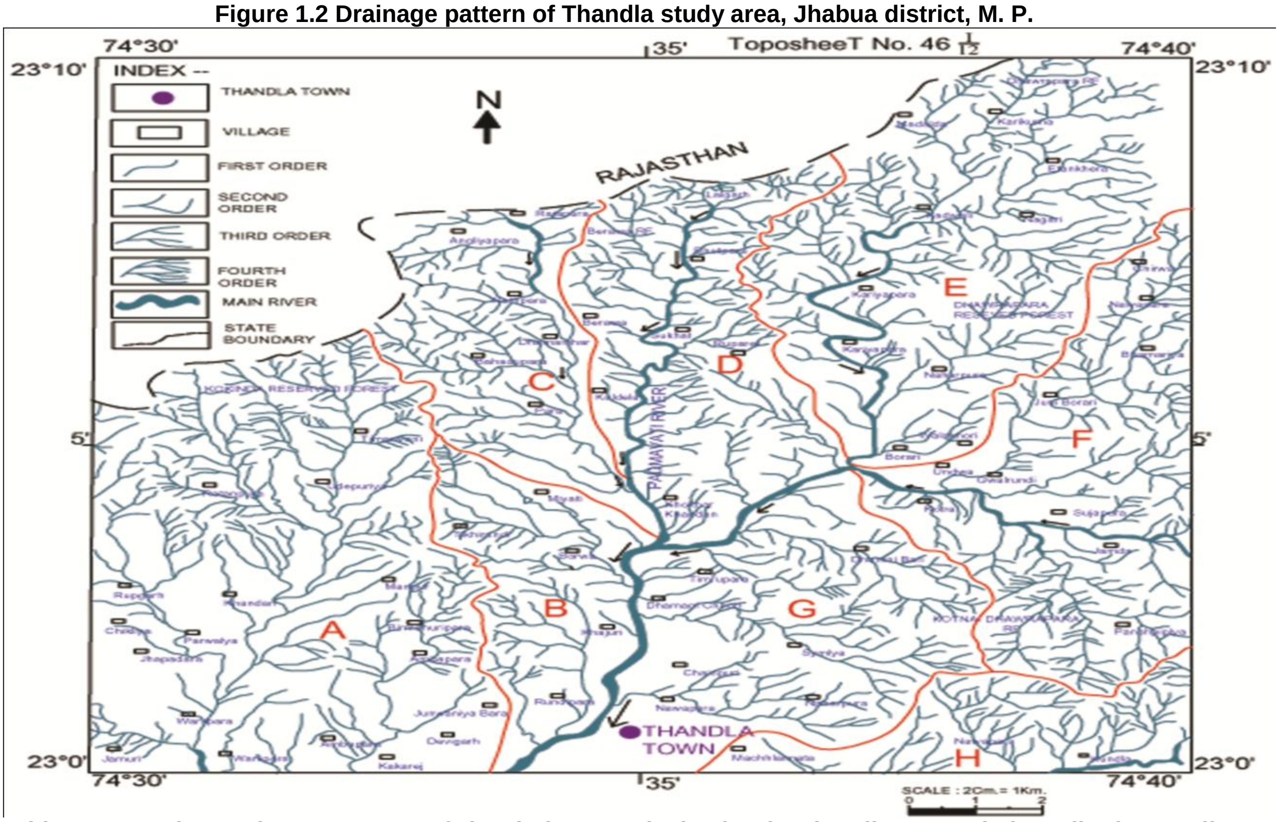


Table 1.1 Morphometric parameters of the drainage sub- basins in Thandla area, Jhabua district, Madhya Pradesh

Morphometric parameters	Drainage sub-basins of Thandla study area, Jhabua district, M. P.							
	A	B	C	D	E	F	G	H
Number of 1st order streams	238	63	98	162	223	197	118	68
Number of 2nd order streams	55	10	18	41	57	48	30	17
Number of 3rd order streams	14	4	7	10	12	11	9	5
Number of 4th order streams	3	1	2	1	4	3	3	1
Number of 5th order streams	1	0	1	0	1	1	0	0
Total number of streams	**311**	**78**	**126**	**214**	**297**	**260**	**160**	**91**
Length of 1st order streams (km.)	201	51	70	107	169	136	92	54
Length of 2nd order streams (km.)	77	23	25	41	60	47	36	18
Length of 3rd order streams (km.)	38	10	18	19	31	24	16	8
Length of 4th order streams (km.)	15	5	10	1	14	10	14	3
Length of 5th order streams (km.)	14	0	6	0	1	10	0	0
Total length of streams (km.)	**345**	**89**	**129**	**168**	**275**	**227**	**158**	**83**

Length of the sub-basin (km.)	11.35	7.9	9.25	9.5	11.7	5.25	6.35	2.65
With of the sub- basin (km.)	6.25	2.75	3.3	3.6	5.6	12.7	9	7.5
Area of the sub-basin (sq.km.)	**70.93**	**21.72**	**30.52**	**34.2**	**65.52**	**66.67**	**57.15**	**19.87**
Perimeter of the sub-basin (km.)	66	41	46	51	58	60	50	39
Highest elevation within the sub-basin (m.)	400	340	400	365	416	406	332	346
Lowest elevation within the sub-basin (m.)	280	300	330	334	335	322	300	344
Area of circle with the same perimeter as of basin (sq. km.)	66	41	46	51	58	60	50	39

Morphometric Parameters

Morphometric parameters determination and significance are described in following text:

Linear Aspects

Stream order / Stream number

Horton (1932, 1945) system has been followed for numbering streams and order. The first order streams are those which have no tributaries, when two first order streams meet form the second order and similarly the third order stream is formed by joining of two second order streams. Streams of area have been numbered in a similar manner and characterized by streams ranging from first to fifth order (Table 1.1, Figure 1.2).

Stream length

Stream length has been measured with the help of Rotometer. All identified streams are categorized to their respective orders and all the segments of orders are connected to yield number of the stream of each order in the basin. Length of the stream is indicative of the contributing area of the basin of that order (Table 1.1, Figure 1.2).

Bifurcation ratio (Rb)

Bifurcation ratio is related to the branching pattern of the drainage network, and has been defined as "a ratio of the number of streams of a given order (Nu) to the number of streams of the next higher order (Nu+1)". It is expressed by the following equation: Rb = Nu / Nu+1, where, Rb = Bifurcation ratio, Nu = Number of streams of a given order, and Nu+1= Number of streams of the next higher order.

Table 1.2 Bifurcation ratio of sub-basin of study area, Jhabua district, M. P.

Sub-basin	Stream Order	Stream Number	Bifurcation Ratio
A	1	238/55	4.32
	2	55/14	3.92
	3	14/3	4.66
	4	3/1	3
	5	1/0	1
B	1	63/10	6.3
	2	10/4	2.5
	3	4/1	4
	4	1/0	1
C	1	98/18	5.44
	2	18/7	2.57
	3	7/2	3.5
	4	2/1	2
	5	1/0	1
D	1	162/41	3.95
	2	41/10	4.1
	3	10/1	10
	4	1/0	1
E	1	223/57	3.91
	2	57/12	4.75
	3	12/4	3
	4	4/1	4
	5	1/0	1
F	1	197/48	4.10
	2	48/11	4.36
	3	11/3	3.66
	4	3/1	3
	5	1/0	1
G	1	118/30	3.93
	2	30/9	3.33
	3	9/3	3
	4	3/0	3
H	1	68/17	4
	2	17/5	3.4
	3	5/1	5
	4	1/0	1

Bifurcation ratio of drainage basin range from 1 to 10 in the sub-basins (Table 1.2). The bifurcation ratio a large number of studies suggest that trends to be constant for a particular basin and for drainage basins having a uniform climate, lithology, and stages of development. The impacts of geological structures are rather insignificant. Geological features reveal impact on the factor bifurcation ratio.

Areal Aspects

Drainage density (Dd)

Drainage density has been defined by Horton (1945) as "the ratio of total length of all stream segments in a given drainage basin to the total area". It is expressed by the formula: **Dd = L / A,** where, Dd = Drainage density, L = Total length of all stream segments of a basin, A = Total area of the basin.

Table 1.3 Drainage density of Thandla study area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km)	Total length of stream (km.)	Drainage density (1/km.)
A	70.93	345	4.86
B	21.72	89	4.09
C	30.52	129	4.22
D	34.2	168	4.91
E	65.52	275	4.19
F	66.67	227	3.40

G	57.15	158	2.76
H	19.87	83	4.17
Average = 4.075			

The drainage density ranges from 2.76 (sub-basin G) to 4.91(sub-basin D) 1/km with an average of 4.075 1/km (Table 1.3). Drainage density reflects spacing of channels, delineate a quantitative value of average stream channel length of the basin. It has been observed that a low density occurs in highly resistant regions of maximum permeable sub-soil with dense vegetative cover. High density is recorded in the weak impermeable soil (Strahler, 1964).

Stream frequency (Fs)

Horton (1932) used term stream frequency as "ratio of the total number of stream segments of all orders per unit area." factor Fs is expressed by formula: **Fs = Nu / A,** where, Fs = Stream frequency, Nu = Total number of streams, A = Area of sub-basin.

Table 1.4 Stream frequency of sub-basin of Thandla area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km)	Number of stream	Stream frequency (1/km^2)
A	70.93	310	4.370
B	21.72	78	3.591
C	30.52	126	4.128
D	34.2	214	6.257
E	65.52	297	4.532
F	66.67	260	3.899
G	57.15	160	2.799
H	19.87	91	4.579
Average = 4.269			

The stream frequency of the study area varies from 2.799 (sub-basin G) to 6.257 (sub-basin D) 1/km^2 indicating a reasonable development of streams. The average stream frequency is 4.269 1/km^2 (Table 1.4). The relationship indicates that with the increase of stream numbers, drainage density increase.

Form factor (Ff)

Horton (1932) proposed form factor as"the ratio between the basin area and square of the basin length". The form factor is determined by the formula: **Ff = A / L^2,** where, Ff = Form factor, A = Basin area, L = Basin length.

Table 1.5 Form factor of sub-basins study area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km.)	Basin length (km.)	Form factor
A	70.93	11.35	0.550
B	21.72	7.9	0.348
C	30.52	9.25	0.356
D	34.2	9.5	0.378
E	65.52	11.7	0.478
F	66.67	5.25	2.418
G	57.15	6.35	1.417
H	19.87	2.65	2.829
Average = 1.096			

The form factor of the study area varies from 0.348 (sub-basin B) to 2.829 (sub-basin H) with an average value of 1.096 (Table 1.5). The low average value indicates that the drainage basin is elongated in shape.

Circularity ratio (Cr)

Circularity ratio has been defined by Miller (1953) as "the circularity ratio of basin area with area of the circle with same perimeter as the basin." It is denoted by the formula: **Cr = Ab / Ac,** where, Cr = Circularity ratio, Ab = Area of the basin, Ac = Area of the circle with same perimeter as the basin.

Table 1.6 Circularity ratio of sub-basins of study area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km.)	Perimeter of basin (km.^{2})	Area of circle with same perimeter (km.^{2})	Circularity ratio
A	70.93	66	66	1.074
B	21.72	41	41	0.529
C	30.52	46	46	0.663
D	34.2	51	51	0.670
E	65.52	58	58	1.129
F	66.67	60	60	1.111
G	57.15	50	50	1.143
H	19.87	39	39	0.509
Average = 0.853				

The circularity ratio for the present drainage basin under investigation has been calculated to be ranging in between 0.509 (sub-basin H) to 1.143 (sub-basin G) with an average value of 0.853 indicating that the study area is comprised of a homogenous group of rocks with moderate slope (Table 1.6).

Elongation ratio (Re)

Schumm (1956) proposed the term elongation ratio as "the ratio of diameter of a circle of the same area as the basin to the maximum basin length." It can be represented by the expression: **Re =** $\sqrt{\frac{4A}{\pi}}$ **) L^2,** where, Re = Elongation ratio, A = Area of sub-basin in sq. km, L = Length of basin in km.

Table 1.7 Elongation ratio of drainage basins of study area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km.)	Basin length (km.)	Elongation ratio
A	70.93	11.35	107.808
B	21.72	7.9	41.554
C	30.52	9.25	57.675
D	34.2	9.5	62.704
E	65.52	11.7	106.889
F	66.67	5.25	48.381
G	57.15	6.35	54.140
H	19.87	2.65	13.331
Average = 61.324			

The elongation ratio of the study drainage basin ranges from 13.331 (sub-basin H) to 107.808 (sub-basin A) with an average value of 61.324 indicates that the drainage basin in nearly elongated in shape (Table 1.7). This parameter provides nature of hydrological condition.

Lemniscates Ratio (K)

Chorley (1966) suggested the term lemniscates ratio, which is based upon comparison of basin with lemniscates curves. It is expressed by the following expression: $K = L^2 / 4A$, where, K = Lemniscates ratio, L = Length of basin in km, A = Area of the sub-basin in sq. km.

Table 1.8 Lemniscates values of sub-basins of study area, Jhabua district, M. P.

Sub-basin	Area of basin (sq.km.)	Basin length (km.)	Lemniscates
A	70.93	11.35	0.454
B	21.72	7.9	0.718
C	30.52	9.25	0.700
D	34.2	9.5	0.659
E	65.52	11.7	0.522
F	66.67	5.25	0.103
G	57.15	6.35	0.176
H	19.87	2.65	0.069
Average = 0.425			

The lemniscates ratio of the study area varies from 0.069 (sub-basin H) to 0.718 (sub-basin B) with an average value of 0.425. The determined values of lemniscates ratio points out that the travel distance of water to ground water system is less (Table 1.8).

Length of Overland Flow (Lg)

Length of overland flow has been defined by Horton (1945) as "it is approximately equal to the half of the drainage density". It can be expressed as: **Lg = 1 /2 Dd,** where, Lg = Length of overland flow, Dd = Drainage density.

Table 1.9 Length of overland flow of Study Area, Jhabua District, M. P.

Sub-basin	Drainage density (1/km.)	Length of overland flow (km.)
A	4.86	0.102
B	4.09	0.122
C	4.22	0.118
D	4.91	0.101
E	4.19	0.119
F	3.40	0.147
G	2.76	0.181
H	4.17	0.119
Average = 0.126		

In the study area, the length of overland flow ranges from 0.101 (sub-basin D) to 0.181(sub-basin G) km with an average value of 0.126 suggesting that the water covers rather a small distance before entering in to the drainage pattern (Table 1.9). The maximum number of sub-basins indicate a mature stage.

Relief Aspects

Basin relief (Br)

Strahler (1952) defined basin relief as a difference between highest and lowest point in a basin. It is expressed by formula: **Br = H1 - H2,** where, Br = Basin relief, H1 = Highest elevation, H2 = Lowest elevation.

Table 1.10 Basin relief of sub-basins of Thandla study area, Jhabua district, M. P.

Sub-basin	Highest elevation (m.)	Lowest elevation (m.)	Basin relief (m.)
A	400	280	120
B	340	300	40
C	400	330	70
D	365	334	31
E	416	335	81
F	406	322	84
G	332	300	32
H	346	344	2
Average = 57.5			

Basin relief of the study drainage basin varies from 2 (sub-basin H) to 120 (sub-basin A) m with an average value of 57.5 m indicating the presence of the flat to higher elevated terrain topography (Table 1.10).

Relief Ratio (RH)

Relief ratio has been proposed by Schumm (1956) as ratio between the horizontal distance along longest dimension of a basin, dendritic to principal drainage line and maximum basin relief. It is represented by : **RH = H / L,** where, RH = Relief ratio, H = Maximum basin relief, L = Horizontal distance along longest dimension of basin.

Table 1.11 Relief ratio of sub-basin of Thandla Study Area, Jhabua District, M. P.

Sub-basin	Basin relief (m.)	Horizontal distance (m.)	Relief ratio
A	120	11.35	10.572
B	40	7.9	5.063
C	70	9.25	7.567
D	31	9.5	3.263
E	81	11.7	6.923
F	84	5.25	16
G	32	6.35	5.039
H	2	2.65	0.754
Average = 6.897			

Relief ratio for different sub-basin of study area have been calculated as ranging from 0.754 (sub-basin H) to 16 (sub-basin F) with an average value of 6.897 which is suggestive of the low slope. Hence, it can be visualized that the rate of rather eroded and low relief ratio is indicative of plain area of the drainage basin (Table 1.11).

Ruggedness number (Rn)

Ruggedness number has been defined by Strahler (1964) as product of basin relief and drainage density. It is expressed by the formula: Rn = Br × Dd, where, Rn = Ruggedness number, Br = Basin relief, Dd = Drainage density.

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Table 1.12 Ruggedness number of sub-basins of study area, Jhabua district, M. P.

Sub-basin	Basin relief		Drainage density (1/km.)	Ruggedness number
	(m.)	km.		
A	120	0.12	4.86	0.583
B	40	0.04	4.09	0.163
C	70	0.07	4.22	0.295
D	31	0.031	4.91	0.152
E	81	0.081	4.19	0.339
F	84	0.084	3.40	0.285
G	32	0.032	2.76	0.088
H	2	0.002	4.17	0.008
Average = 0.239				

The ruggedness numbers of different sub-basin range from 0.008 (sub-basin H) to 0.583 (sub-basin A) with an average value of 0.239 it indicates that the basin has the flat topography where as other basins demonstrate uneven topography (Table 1.12).

Ground Surface Slope (Gs)

Horton (1945) proposed the term ground surface slope, which is represented by "H" and "Dd" by the following equation: **Gs = H × 2 Dd,** where, Gs = Slope of ground surface, H = Basin relief, Dd = Drainage density.

Table 1.13 Ground surface slope of drainage basin of the study area, Jhabua.

Sub-basin	Basin relief		Drainage density (1/km)	Slope of ground surface
	(m.)	km.		
A	120	0.12	4.86	1.166
B	40	0.04	4.09	0.327
C	70	0.07	4.22	0.590
D	31	0.031	4.91	0.304
E	81	0.081	4.19	0.678
F	84	0.084	3.40	0.571
G	32	0.032	2.76	0.176
H	2	0.002	4.17	0.016
Average = 0.478				

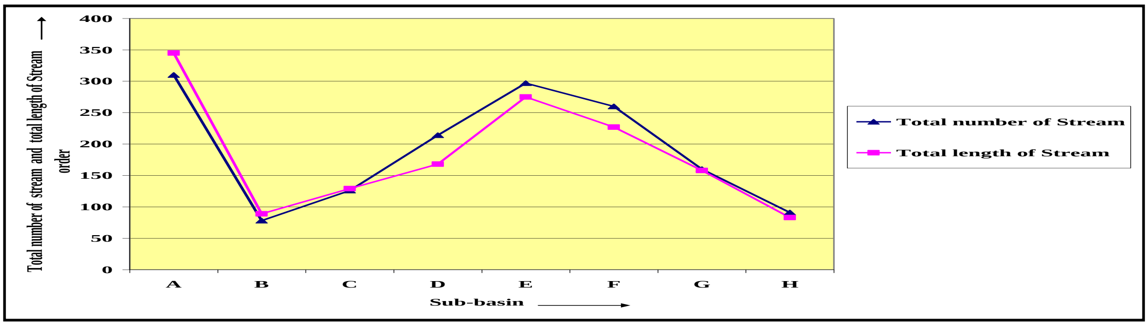
In study area, the values of ground surface slope indicate a range from 0.016 (sub-basin H) to 1.166 (sub-basin A) with an average of 0.478 indicating that the slope of ground surface is maximum in sub-basin “A” (Table 1.13).

Relationship of Morphometric Parameters

The relationship between different morphometric parameters determined in respect of Thandla drainage basin. The relationship between morphometric parameters such as stream number and stream order exhibits that with the increase of order. The number of stream decreases and shown with other parameters have been determined and described here in the following text

Relationship between Total Number of Streams and Total Length of Streams

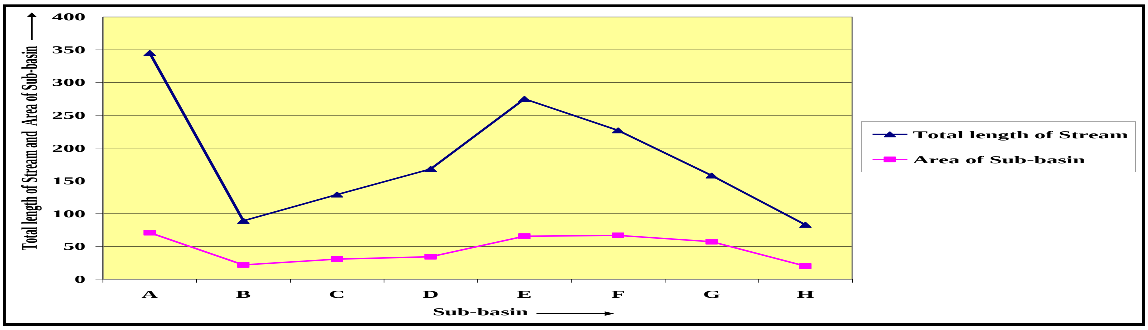
Figure 1.3 Relationship between total number of streams and total length of streams in study area, Jhabua district



The relationship points out that with the increase of total number of streams the total length of streams increase (Figure 1.3).

Relationship between total length of streams and area of the sub-basins

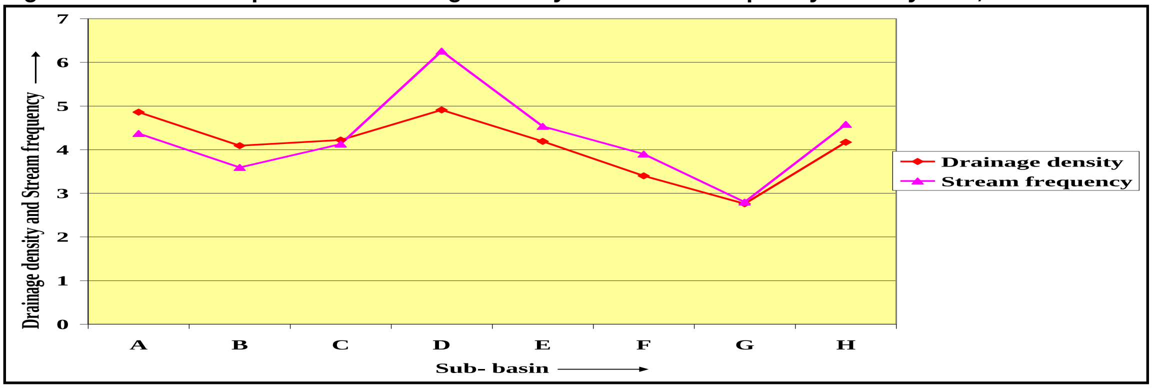
Figure 1.4 Relationship between total length of streams and area of the sub-basins in study area, Jhabua district



The relationship reflects that with the increase of total length of streams, area of the sub-basins increases (Figure 1.4).

Relationship between drainage density and stream frequency

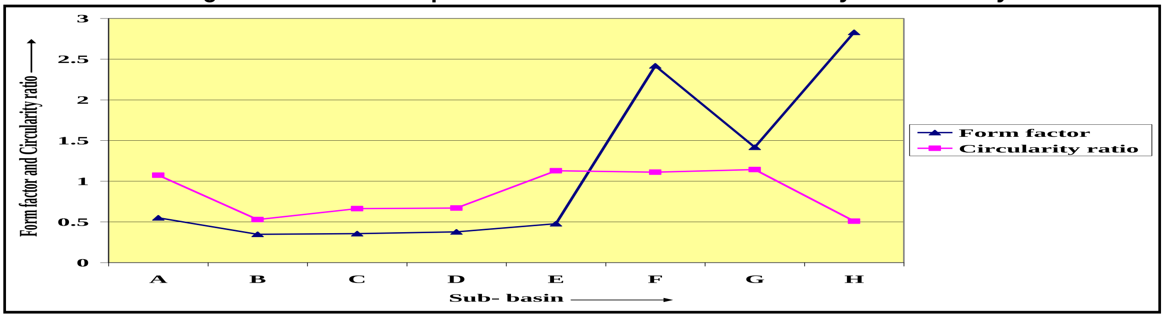
Figure 1.5 Relationship between drainage density and stream frequency in study area, Jhabua district, M. P.



The relationship exhibits that with the increase of drainage density, stream frequency also increases (Figure 1.5).

(4) Relationship between form factor and circularity ratio

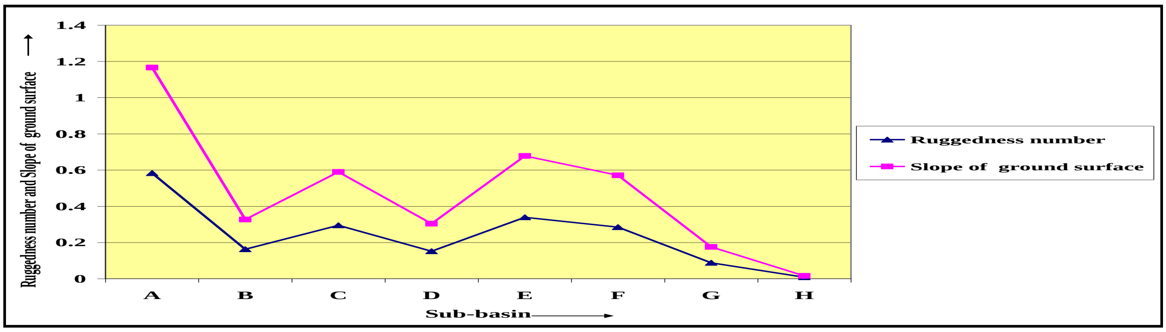
Figure 1.6 Relationship between form factor and circularity ratio in study area.



The relationship reflects the with the increase of form factor in majority of sub-basins the circularity ratio also increases (Figure 1.6).

(5) Relationship between ruggedness number and ground surface slope

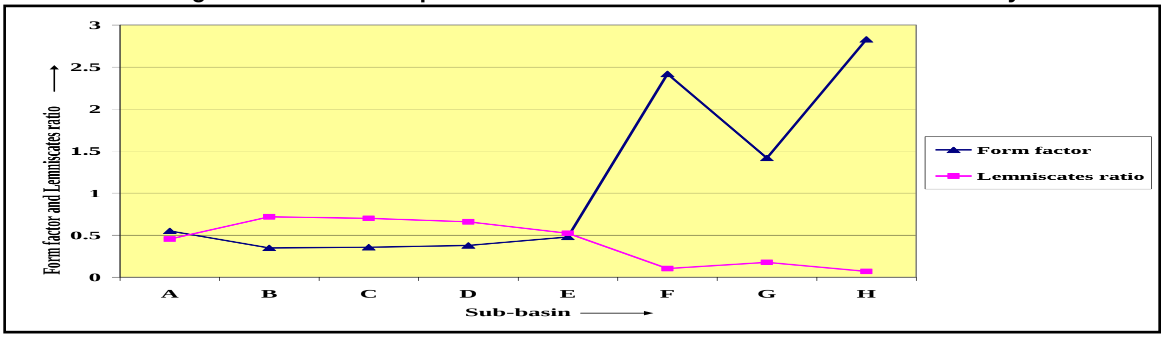
Figure 1.7 Relationship between ruggedness number and ground surface slope in study area, Jhabua district, M.P.



The relationship indicates that with increase of ruggedness number, ground surface slope also increases (Figure 1.7).

(6) Relationship between form factor and lemniscates ratio

Figure 1.8 Relationship between form factor and lemniscates ratio in study area.



Within the sub-basins A to E, with the lemniscates ratio increase of the form factor decreases. Whereas from sub-basin E to H, increase of form factor the lemniscates ratio decreases (Figure 1.8).

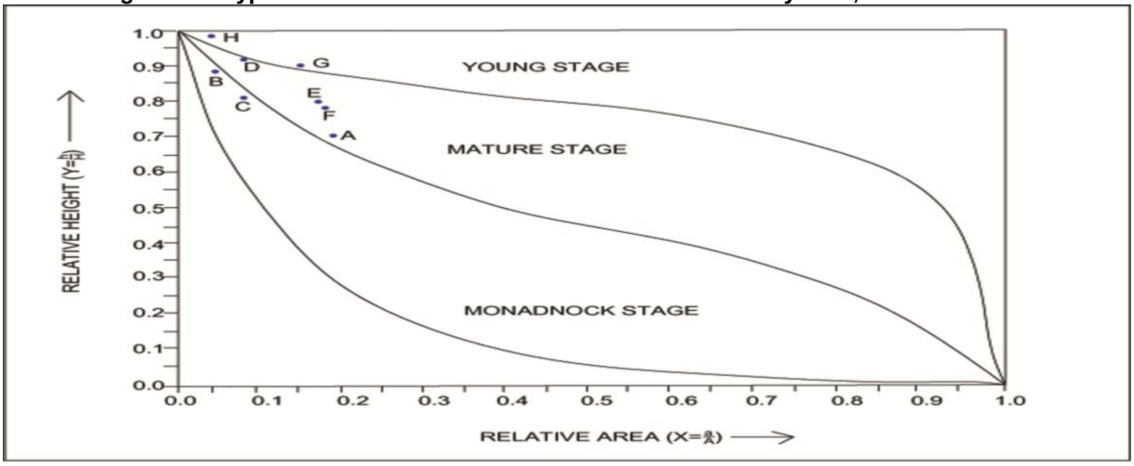
Hypsometric analysis

Hypsometric analysis of Thandla study area has been conducted by adopting procedure given by Strahler (1957, 1964). Hypsometric analysis has been elaborated as the relation of horizontal cross sectional area of drainage basin to its elevation. Following the drainage basin to be bounded by vertical sides and horizontal base plane passing through mouth, the relative height "Y" is ratio of height of a given contour "h" to total basin height "H". Ralative area "X" is the ratio of horizontal cross-sectional area "a" to the entire basin area, "A" (Table 1.14).

Table 1.14 Computed parameters of drainage basin of study area, Jhabua district.

S. No.	Sub-Basin	Lowest Elevation (h) (m.)	Highest Elevation (H) (m.)	Y = h/H (Relative Height)	Basin Area (a) (sq. km.)	X = a/A (Relative Area)
1	A	280	400	0.7	70.93	0.19
2	B	300	340	0.88	21.72	0.05
3	C	330	400	0.82	30.52	0.08
4	D	334	365	0.91	34.2	0.09
5	E	335	416	0.80	65.52	0.17
6	F	322	406	0.79	66.67	0.18
7	G	300	332	0.90	57.15	0.15
8	H	344	346	0.99	19.87	0.05
A = Total Area = 366.58 sq. km.						

Figure 1.9 Hypsometric curve Padmavati River basin of study area, Jhabua.



Hypsometric curve of the drainage basin study area reveals that the sub-basin A, B, C, D, E, F, G, and H (Figure 1.9). Plots of Sub-basins G and H indicates their locations in the Young stage, A, D, E and F belong to the Mature stage, and plots of B and C refer to the Monadnock stage. The hypsometric analysis exhibits that the major part of the Padmavati River drainage basin in Thandla area of Jhabua district, Madhya Pradesh is representing young stage of development approaching towards maturity.

Conclusion

Morphometric analysis of Thandla drainage basin in Jhabua region has been conducted based on Padmavati River drainage basin by computing Linear, Areal and Relief variables reflecting characteristic nature of the drainage basin. Morphometric data provides valuable help in the demarcation of ground water potential locations in vicinity of the Nawapara, Kundla, Panchpiplya, Jamda, Symlya, Madalda, Krikurna, Etankhera, Kadwali, Nagari, Chirwa, Bhamariya, Timarwani, Ratanpura, Udepuriya, Khokhar Khandan, Bhimkundm, Dhamni and Miyati in the Thandla study area of Jhabua district, Madhya Pradesh, India. The study infers that the hydrogeological data would immensely resolve the problem of sustained water supply to the inhabitants of Thandla area.

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