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Quantitative geomorphic analysis of Thandla area, Jhabua district, Madhya Pradesh and its application in ground water exploration: A case study

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Abstract
The paper deals with the application of quantitative geomorphic analysis in the exploration strategy of ground water resource in Thandla area of Jhabua district, Madhya Pradesh, has been carried out on the basis of Survey of India Toposheet no. 46 I/12, on a 2 cm = 1 km scale. The drainage basin has been divided into seven sub-basins A, B, C, D, E, F and G. The Linear, Areal and Relief parameters have been calculated. The determinations of morphometric variables include number and order of streams, length, width and area of the basin. The determinations of important parameters such as the Bifurcation ratio (1 to 7), Drainage density (1.33 to 2.28 1/km), Length of Overland flow (0.219 to 0.375 km), Stream frequency (1.716 to 3.302 1/km^2), Form factor (0.430 to 0.916), Circularity ratio (0.974 to1.35), Elongation ratio (10.68 to 19.18 km), Lemniscates (0.272 to 0.580), Basin relief (5 to 25 m), Relief ratio (0.588 to 3.809 m) and Ruggedness number (9.7 to 45.6) in respect of seven sub-basins of the study drainage basin have been determined. The application of morphometric parameters has been discussed. The morphometric data enables to locate favourable ground water potential locations in Thandla study area.

Keywords: application, geomorphic analysis, Thandla area, Jhabua, Madhya Pradesh

Introduction
The term "Geomorphology" has been derived from three Greek terms, "Geo" = Earth, "Morph" = Form and "Logy" = Science, i.e. referring to the science of the earth surface forms. Generally, this branch has been considered as the science of landforms. Geomorphology is the study of the origin and evolution of topographic features by physical and chemical processes operating at or near the earth's surface. The quantitative geomorphic analysis is generally known as the morphometric analysis or morphometry. It deals with study of the drainage pattern, which has been defined by Miller (1953) [6] as "the study of spatial arrangement of streams." Thornbury (1954) [11] has considered that for a particular plain the individual stream courses collectively form the pattern of drainage. In this paper the morphometric analysis of drainage basin of Thandla area of Jhabua district, Madhya Pradesh has been described.

Location of Study Area
The study area is located in the Jhabua District, Madhya Pradesh, within the latitude 23^0 0' to 23^0 5' N and longitude 74^0 30' to 74^0 40' E (Survey of India Toposheet no. 46 I / 12, on a 2 cm = 1 km scale, Figure 1). The study has been carried out in an area of 144.85 sq. km. The study area is situated in the western part of the Madhya Pradesh, and bounded by Gujarat, Maharashtra, and Rajasthan. The study area is at a distance of 5 km from the Thandla Road railway station and is approachable by both rail and road through out the year.

Physiography of Study Area
The study area is occupied by the hilly terrain, undulating country and plain country. The physiographic features of the area are developed due to the denudation brought by the water and wind as main agents. Climate of the area is tropical - monsoon type. The temperature ranges from 7^0 to 44^0 C. The rainfall ranges from 423.0 to 1655.6 mm with an average annual rainfall as 905.1 mm. In the study area, three types of soils e. g. Black cotton soil, Lateritic soil, and Red loam are observed.

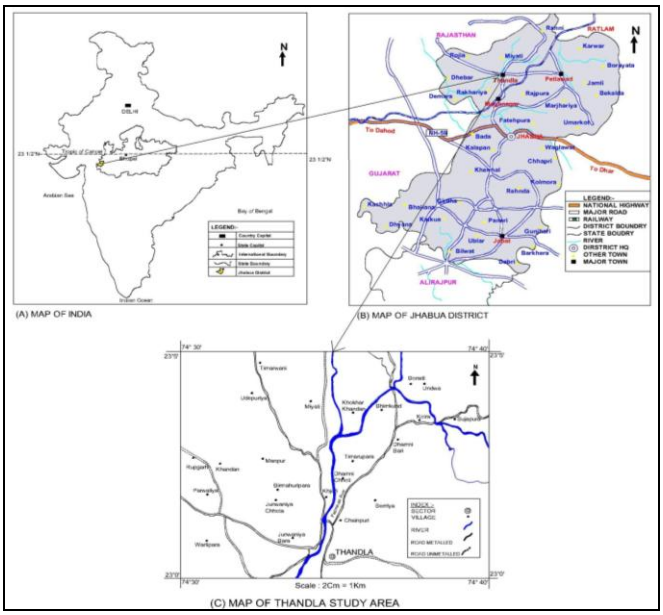

Fig 1: Location map of Thandla Study area, Jhabua district, Madhya Pradesh, India (www.Google.com).

Geology of Study Area

The study area located in Thandla sector of Jhabua district, Madhya Pradesh is predominantly occupied by lava flows of the Deccan Traps (Upper Cretaceous to Lower Eocene). In the Thandla study area following geological formations are developed (Table 1).

Table 1: Geological Succession of Thandla area, Jhabua district, Madhya Pradesh (Modified after Pandey, 2013-2014) [5].

Age	Formation	Lithology
Recent	Alluvium Plain	Sand, Silt and Clay
Upper Cretaceous to Lower Eocene	Deccan Traps	Basalts (Lava Flows)
.....Unconformity.....		
Archaean	Older Metamorphic Bundelkhand Granite	Gneiss, Granite, Quartzite
.....Unconformity.....		
Basement Not Exposed		

Geomorphic Features of Study Area

The study area constitutes a central part of Thandla area and is surrounded on east, north, west and south by the outward facing escarpment. The present study area has been exposed for a long period to denudation and resulting into residual hillocks in are plated patches. The occurrence of youth stage of drainage indicates the evidence of rejuvenation of the area. Thandla block in Khajuri and Dhamni of Thandla area represent a region of gently undulating plain country with irregular residual ridges and hillocks. Generally, limestone and some types of basalt are resistant "Valley Markers" in humid climates, whereas sandstone, quartzite and basalt are resistant ridge - markers. Other rock types generally vary in their characteristics, depending on specific composition, texture and the climatic conditions. The study area is almost flat, plateau, covered with black cotton and red soil. The valley is carried in the basalt and quantize. Nala basins have drainage pattern – parallel, dendrite and rectangular.

Morphometric Analysis of Study Area

The morphometric analysis involves the quantitative study of landforms and geomorphologic processes. It is derived from word "Morph" = form and "Metric" = number system. The morphometric analysis of the study area has been conducted by preparing a drainage map of the particular area on a scale of 2 cm = 1 Km. (Figure 2). The various Linear, Areal and Relief morphometric parameters have been determined by measurements with the help of Rotometer.

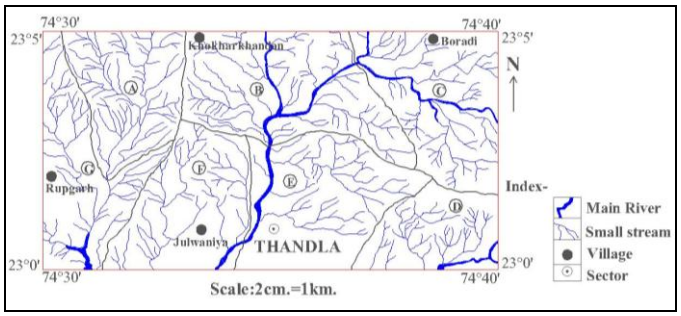

Fig 2: Drainage basin of a part of Padmavati River Thandla area, Jhabua district, Madhya Pradesh, India

Table 2: Details of the drainage basins in Thandla area, Jhabua district, M. P., India.

Morphometric Variables/ Sub-basins	Drainage basin of Thandla area, Jhabua district, M. P., India						
	A	B	C	D	E	F	G
Number of 1st order streams	59	74	68	39	43	45	42
Number of 2nd order streams	14	18	21	13	12	10	10
Number of 3rd order streams	4	4	7	3	3	2	3
Number of 4th order streams	1	0	1	0	1	0	1
Total number of streams	78	96	97	55	59	57	56
Length of 1st order streams (km.)	33	40	32	18	25	26	27
Length of 2nd order streams (km.)	10	20	15	8	12	13	7
Length of 3rd order streams (km.)	7	6	6	5	7	8	4
Length of 4th order streams (km.)	4	0	2	0	1	0	6
Total length of streams (km.)	54	66	55	31	45	47	44
Length of the sub-basin (km.)	5.25	8.5	6	5.25	6.75	5.25	8.7
Width of the sub-basin (km.)	4.5	4	5.5	3.25	5	4.75	3.75
Area of the sub-basin (sq.km.)	23.62	34	33	17.06	33.75	24.93	32.62
Perimeter of the sub-basin (km)	20	29	25	17.5	25	21.5	30
Highest elevation within the sub-basin (m.) A.M.S.L.	330	325	335	330	320	320	315
Lowest elevation within the sub-basin (m.) A.M.S.L.	310	320	325	320	310	310	290
Area of circle with the same perimeter as of basin (sq. km.)	20	29	25	17.5	25	21.5	30

1) Stream Pattern (Number, Order and Length)

The methods prepared by Horton (1932, 1945) [2, 3] and Strahler (1952, 1957) [8, 9] have been used for the ordering of streams of river basins. The first order streams are those, which have no tributaries, when two first streams meets, they from the second order stream and similarly the third and fourth order streams. The streams of the study drainage basin have been measured and computed. The stream lengths have been measured with the help of Rotometer. All the streams have been categorized to their respective orders and all the segments of orders are connected to yield the number of the streams (NU) of each order in the basin. In the study area, there are total streams ranging from 55 (sub-basin D) to 97 (sub-basin C) divisible into 1 to 4 orders in seven sub-basins and total length varies from 31 km (sub-basin D) to 66 km (sub-basin B) (Table 2).

2) Bifurcation Ratio

The bifurcation ratio has been defined by Horton (1932) [2] as "the ratio between the number of stream segments of any given order and the number of stream segments of next higher order". It is denoted by symbol 'Rb' and determined by the formula:

$$Rb = Nu / Nu+1$$

Where,
Rb = Bifurcation Ratio
Nu = Number of stream order segment of particular order
Nu + 1 = Number of stream segment of next higher order

The bifurcation ratio of sub-basins of the study area is various from 1 to 7 (Table 3).

Table 3: Bifurcation ratio of sub-basins of the Study area, Jhabua district, Madhya Pradesh, India.

S. No.	Sub-basins	Stream order	Stream number	Bifurcation ratio
1	A	1	59/14	4.21
		2	14/4	3.5
		3	4/1	4
		4	1/0	1
2	B	1	74/18	4.11
		2	18/4	4.5
		3	4/0	4
3	C	1	68/21	3.23
		2	21/7	3
		3	7/1	7
		4	1/0	1
4	D	1	39/13	3
		2	13/3	4.33
		3	3/0	3
5	E	1	43/12	3.58
		2	12/3	4
		3	3/1	3
		4	1/0	1
6	F	1	45/10	4.5
		2	10/2	5
		3	2/0	2
7	G	1	42/10	4.2
		2	10/3	3.33
		3	3/1	3
		4	1/0	1

3) Drainage Density

Drainage density is the ratio of the total length of stream of all order within basin to the basin area. It is expressed by symbol 'Dd' and commonly represented by the following formula:

$$Dd = L/A$$

Where,
Dd = Drainage density in 1/km.
L = Stream of the total length of streams of all order in km.
A = Total area of drainage basin in sq. km

Table 4: Drainage density of sub-basins of Thandla area, Jhabua district, M.P.,

Sub-basin	Area of basin (sq.km.)	Total length of stream (km.)	Drainage density (1/km.)
A	23.62	54	2.28
B	34	66	1.94
C	33	55	1.66
D	17.06	31	1.81
E	33.75	45	1.33
F	24.93	47	1.88
G	32.62	44	1.34
			Average = 1.748

The drainage densities in respect of all the sub-basin of study area have been calculated. Computed drainage density ranges from 1.33 (sub-basin E) to 2.28 (sub-basin A) 1/km with an average drainage density has of 1.748 1/km (Table 4).

4) Length of overland flow

Horton (1945) [3] has expressed length of
Overland flow, as "it is approximately equal to the half of the drainage density." Actually, it means the length or extent to which water flows over the ground before it becomes concentrated in any drainage channel. The length of overland flow is determined by the expression:

$$Lo = 1/2\ Dd \text{ in km.}$$

Where,
Lo = Length of overland flow in km.
Dd = Drainage density in 1/km.

Table 5: Length of Overland flow of study drainage basin of Thandla area, Jhabua district, Madhya Pradesh, India.

Sub-basin	Drainage density (1/km)	Length of Overland flow (km.)
A	2.28	0.219
B	1.94	0.257
C	1.66	0.301
D	1.81	0.276
E	1.33	0.375
F	1.88	0.265
G	1.34	0.373
		Average = 0.295

The length of overland flow in the area, ranges from 0.219 km (sub-basin A) to 0.375 km (sub-basin E) with an average value of 0.295 km. (Table 5) indicating that water before reaching to drainage channel, travels to a very small distance.

5) Stream Frequency

The stream frequency has been defined as "the ratio of the total number of channels of all order in a basin to the area of whole basin". The unit of stream frequency is 1/km.^{2} and it is exhibited by the formula:

$$Sf = N / A$$

Where,
Sf = Stream frequency in 1/km^2
N = Sum of all stream in basin
A = Total area of drainage basin in km^2

Table 6: Stream frequency of sub-basin of Thandla area, Jhabua district, Madhya Pradesh, India.

Sub-basin	Area of basin (sq.km)	Number of stream	Stream frequency (1/km.^{2})
A	23.62	78	3.302
B	34	96	2.823
C	33	97	2.939
D	17.06	55	3.223
E	33.75	59	1.748
F	24.93	57	2.286
G	32.62	56	1.716
			Average = 2.576

In the study area, the stream frequency ranges from 1.716 (sub-basin G) to 3.302 (sub-basin A) 1/km^2 with an average of 2.576 1/km^2 (Table 6).

6) Form Factor
Horton (1932) [2] defined the term form factor as "the ratio between the basin area and square of the basin length" It is expressed by the symbol "Ff" and calculated by formula:

$$Ff = A/L^2$$

Where,
Ff = Form factor
A = Area of the drainage basin in km^2
L = Length of basin in km.

Table 7: Form factor of sub-basins of the Study area, Jhabua district, Madhya Pradesh, India.

Sub-basin	Area of basin (sq.km)	Basin length (km)	Form Factor
A	23.62	5.25	0.856
B	34	8.5	0.470
C	33	6	0.916
D	17.06	5.25	0.618
E	33.75	6.75	0.740
F	24.93	5.25	0.904
G	32.62	8.7	0.430
			Average = 0.704

Form factor of study area ranges from 0.430 (sub-basin G) to 0.916 (sub-basin C) with an average of 0.704 **(**Table 7).

7) Circularity Ratio
The circularity ratio has been defined by Miller (1953) [6] as "the ratio of basin area with the area of circle with perimeter as of the basin". It is expressed by the formula:

$$Rc = Au / Ac$$

Where,
Rc = Circularity ratio
Au = Area of the basin in km^2
Ac = Area of circle with same perimeter as of the basin in km^2

Table 8: Circularity ratio of sub-basins Thandla area, Jhabua district, Madhya Pradesh, India.

Sub-basin	Area of basin (sq.km)	Perimeter of basin (km)	Area of circle with same perimeter (km^2)	Circularity ratio
A	23.62	20	20	1.181
B	34	29	29	1.172
C	33	25	25	1.32
D	17.06	17.5	17.5	0.974
E	33.75	25	25	1.35
F	24.93	21.5	21.5	1.159
G	32.62	30	30	1.087
				Ave. = 1.177

The circularity ratio of study area ranges from 0.074 (sub-basin D) to 1.35 (sib-basin E) with an average value of 1.177 (Table 8).

8) Elongation Ratio
The elongation ratio is also known as the basin elongation. The elongation ratio has been defined by Schumm (1956) [7] as "the ratio of diameter of a circle of the same area as the basin to the maximum basin length". The symbol "Re" or "E" generally expressed as:

$$Re = \sqrt{(4A/\pi)\,L^2}$$

Where,
Re = Elongation ratio
A = Area of basin in sq. km.
L = Length of basin in km.

Table 9: Elongation ratio of drainage basin of the Study area, Jhabua district, M.P.

Drainage sub-basin	Basin area (sq.km.)	Basin length (km.)	Elongation ratio
A	23.62	5.25	12.5
B	34	8.5	19.18
C	33	6	15.88
D	17.06	5.25	10.68
E	33.75	6.75	17.03
F	24.93	5.25	12.91
G	32.62	8.7	19.01
			Average = 15.312

Elongation ratio of drainage basin of the Thandla ranges from 10.68 (sub-basin D) to 19.18 (sub-basin B) sq.km with an average value of 15.312 km (Table 9).

9) Lemniscates
Chorley *et.al* (1957) [1] expressed the term lemniscates ratio, which is based upon the expression of the basin with lemniscates curves. It is denoted by the symbol 'K' and expressed by the formula:

$$= L^2/4A$$

Where, K = Lemniscates
L = Basin length in km.
A = Basin area in sq. km.

Table 10: Lemniscates values of sub-basins of Study area, Jhabua district, Madhya Pradesh, India.

Sub-basin	Area of basin (Sq. km.)	Length of basin (km.)	Lemniscates
A	23.62	5.25	0.291
B	34	8.5	0.531
C	33	6	0.272
D	17.06	5.25	0.403
E	33.75	6.75	0.337
F	24.93	5.25	0.276
G	32.62	8.7	0.580
			Average = 0.384

The Lemniscates values range from 0.272 (sub-basin C) to 0.580 (sub-basin G) in the study area with an average value of 0.384 (Table 10).

10) Basin Relief

Strahler (1952) [8] defined the Basin relief as "the difference between the highest and lowest point in the basin". It is expressed by symbol 'H' or 'Hb and computed by:

$$H = H1 - H2$$

Where,
H = Basin relief in meter
H1 = Highest elevation within basin (m.)
H2 = Lowest elevation within basin (m.)

Table 11: Basin relief of the drainage basin of Thandla Study area, Jhabua district, Madhya Pradesh, India.

Sub-basin	Highest elevation (m.)	Lowest elevation (m.)	Basin relief (m.)
A	330	310	20
B	325	320	5
C	335	325	10
D	330	320	10
E	320	310	10
F	320	310	10
G	315	290	25
			Average = 12.857

The Basin relief of the study area ranges from 5 m (sub-basin B) to 25 m (sub-basin G) with an average of basin relief as 12.857 m (Table 11).

11) Relief Ratio

The relief ratio has been defined by Schumm (1956) [7] as the "ratio between the horizontal distance along the longest dimension of the basin, dendrite to the principal drainage line and maximum basin relief". It can be expressed as:

$$Rh = H/L$$

Where,
Rh = Relief ratio
H = Maximum basin relief
L = Horizontal distance along longest dimension of basin

Table 12: Relief ratio of sub-basins of the Study area, Jhabua district, M. P., India

Sub-basin	Basin relief (m.)	Horizontal distance (m.)	Relief ratio
A	20	5.25	3.809
B	5	8.5	0.588
C	10	6	1.666
D	10	5.25	1.904
E	10	6.75	1.481
F	10	5.25	1.904
G	25	8.7	2.873
			Average = 2.032

The Relief ratio varies from 0.588 (sub-basin B) to 3.809 (sub-basin A) with an average relief ratio of 2.032 (Table 12)

12) Ruggedness Number

The ruggedness number is expressed by symbol 'HD' and Strahler (1964) [10] as “the product of basin relief and drainage density” has defined it. It is represented by the expression:

$$HD = H \times Dd$$

Where,
HD = Ruggedness number
H = Basin relief
Dd = Drainage density

Table 13: Ruggedness number of drainage basins of the Thandla Study area, Jhabua district, Madhya Pradesh, India.

Sub-basin	Basin relief (m.)	Drainage density (1/km.)	Ruggedness number
A	20	2.28	45.6
B	5	1.94	9.7
C	10	1.66	16.6
D	10	1.81	18.1
E	10	1.33	13.3
F	10	1.88	18.8
G	25	1.34	33.5
			Average = 22.228

The ruggedness number of drainage basin ranges from 9.7 (sub-basin B) to 45.6 (sub-basin A) with an average ruggedness number of 22.228 (Table 13).

Appplication of Geomorhic Analysis

The quantitative geomorphic analysis of Thandla drainage basin reflects that the determined parameters exhibit that the basin is characterized by dendritic drainage pattern and reveals favourable conditions for the development of ground water resource by the implementation of an appropriate plan with a view to resolve water scarcity.

Conclusion

The quantitative geomorphic analysis of Thandla drainage basin has determined the Linear, Areal and Relief parameters, which reflect the characteristic nature of the drainage basin. The morphometric analyzed data provide valuable help in delineation of ground water potential sites in the villages of the Timarwani, Udepuriya, Khokhar Khandan, Bhimkundm, Dhamni and Miyati in the Thandla study area of Jhabua district, Madhya Pradesh, India.

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