Morphometric Analysis for Evaluating Groundwater Potential Zones, In Kusangai Jor Watershed Area, Dist. Bolangir, Orissa.

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Key Words: Watershed, GIS, dendritic drainage, drought, impermeable rock, weathered zone, groundwater.

Abstract: The **'**morphometric analysis' study coupled with remote sensing and GIS techniques evaluate different valuable parameters for the watershed development plan of severely drought prone Kusangai Jor watershed of Bolangir district, Orissa. The area shows a dendritic drainage pattern, which is characteristic of a massive hard rock terrain. The elongated shape of this basin is indicated by values of form factor, circulatory ratio and elongation ratio. The higher value of mean bifurcation ratio indicates a strong structural control on drainage development. The values of drainage density and drainage texture indicate that the study area is underlain by impermeable rocks of Precambrian Age. The occurrence of groundwater in this region is restricted in the recent alluviums, top weathered zones on the hard crystalline rocks of lower relief and in the secondary porosities present as fractures and fissures in the hard crystalline rocks.

1. Introduction:

A watershed is a natural hydrological unit, which is demarcated by the topographic highs and regulates the movement and occurrence of its surface water and also the subsurface water/groundwater. It evolves over time and is important for different socio-economical studies for sustainable development of an area.

The morphometric analysis of the Kusangai Jor watershed of northern Bolangir, Orissa (Figure – 1) coupled with remote sensing and GIS techniques helps us to understand the geological and geomorphological history of drainage basin development of this region. The Kusangai Jor watershed is a chronically drought prone area. The economy of this area mainly depends on agriculture. Agriculture depends on groundwater/subsurface water because, surface water sources are scarce. Due to vagaries of monsoon rainfall and uncontrolled withdrawal of subsurface water the water levels have declined to deeper levels. As a consequence, the watershed development plan has become mandatory for developing surface and subsurface water resources of this area. For preparing a proper watershed development plan, it becomes necessary to understand about the geological and geomorphological factors, which affect on the occurrence and movement of surface and subsurface water of this region. In the present study an attempt has been made to evaluate the above said controlling factors by 'morphometric analysis' of Kusangai Jor watershed.

2. Study Area:

The Kusangai Jor drainage basin with a spread of 135.5 km^2 lie in between the longitudes 83°17?E to 83°30?E and latitudes 20° 48? N to 20° 53? N (Figure – 1). The area is moderately populated with a large number of scattered villages. The study area enjoys tropical climate with hot and dry summer. The maximum temperature even shoots up to 47 °C in the summer months. This region receives an average precipitation of about 1230 mm, but the intensity and amount of rainfall are unpredictable during the southwest monsoon period. Drought that is termed as the decrease from the normal rainfall is frequently occurring in this area. Due to unpredictable rainfall the agrarian economy of this area suffers badly and at present mostly depends on groundwater.

3. Lithology of the Study Area:

The Kusangai Jor, a tributary of Suktel River of northern Bolangir, passes through a vast tract of hard rock terrain of Precambrian Age. The study area belongs to the Eastern Ghats Granulite Belt group of rocks. The major rock types found in this area are granite gneisses, anorthosites, basic charnokites, acid charnokites, calc silicate rocks etc. The granite gneisses are the dominant rock types of this area.

4. Hydrogeomorphology:

Remote sensing data has been used to interpret the landforms (LISS-III FCC imagery on the scale of 1:50,000) to identify the potential zones of groundwater exploration. The most potential zones for groundwater are flood plains, alluvial plains and valley fills, but they spread over a small area in this region. Area dominant in aerial spread are pediments and pediplains and classified as moderately potential zones. The structural/denudational hills areas are very less potential zones of groundwater development.

5. Methodology:

The morphometric analysis of The Kusangai Jor watershed has been carried out with the help of SOI maps (64 P/5 & 64 P/9) and LISS-III FCC imagery on the scale of 1:50,000 using GIS application software and also by intensive field survey. The drainage pattern map (dendretic one for the study area, Figure-1) prepared with the help of SOI maps and LISS-III FCC imagery was used for morphometric analysis of this area. The quantitative analysis of the morphometric characteristics of a basin including stream orders, stream lengths, stream numbers, stream frequency, drainage density, drainage texture, bifurcation ratios, relief ratio form factor, circulatory ratio, elongation ratio, area, perimeter, length and width of the basin have been calculated using the formula given in the Table-1 and their results have been summarized in the Table-2.

6. Results and Discussions:

The morphometric analysis of a drainage basin provides quantitative description of the basin geometry to understand the initial slope of inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphological history of the drainage basin (Strahler, 1964). The geomorphic characteristics of a drainage basin confirms to Horton's (1932) 'Laws of stream number', which state that the number of stream segments of different order streams in a drainage basin decreases with increasing stream order.

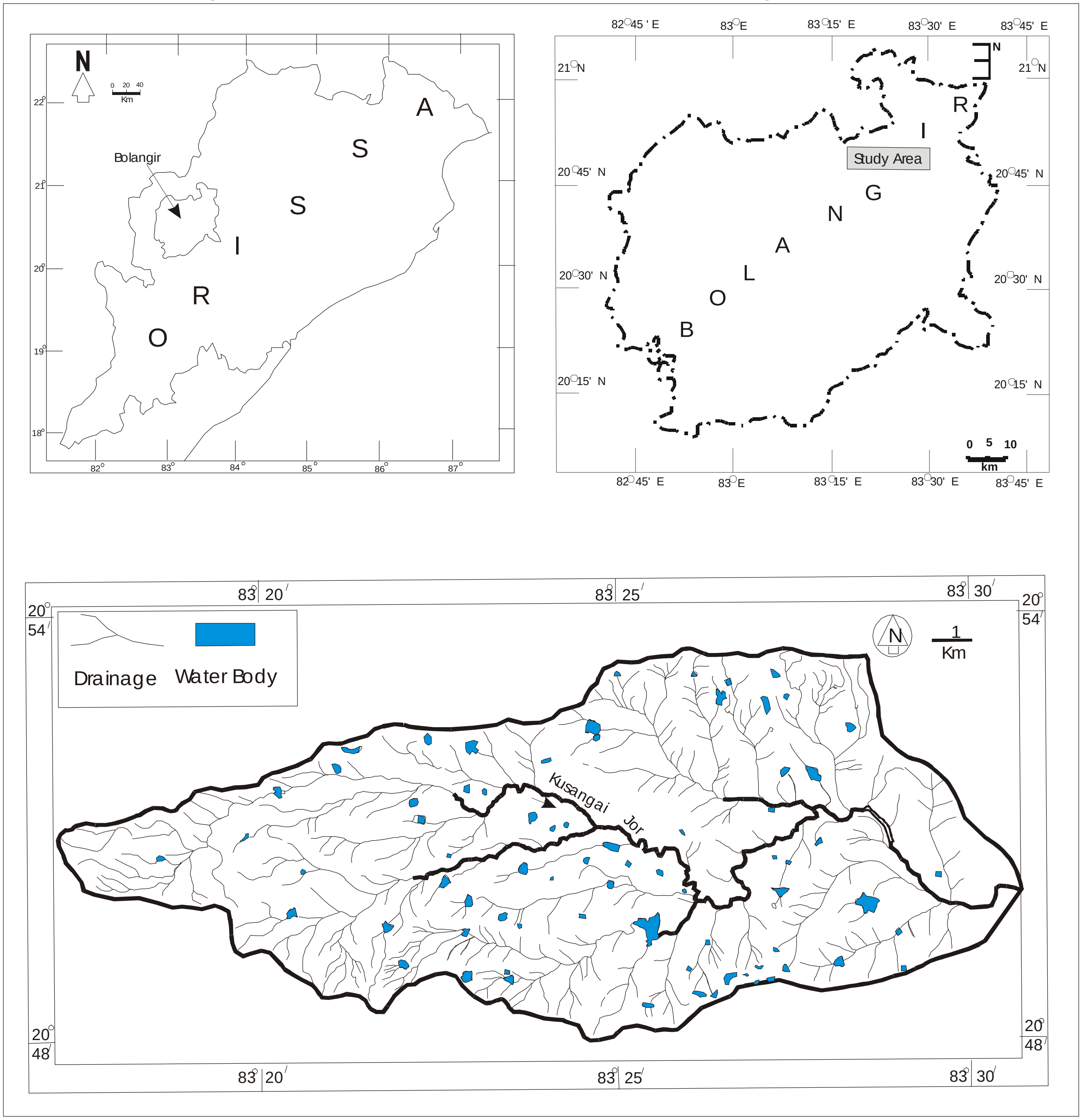

Figure-1: Location map of Kusangai Jor watershed and dendritic drainage pattern of the watershed.

Table 1:

Sl. No.	Morphometric Parameters	Formula
1	Stream Order	Hierarchical rank
2	Stream Length (Lu)	Length of the stream
3	Mean Stream Length (Lsm)	Lsm = Lu/Nu Where, Lsm = Mean Stream Length Lu = Total Stream Length of the Order ‘u’ Nu = Total no. of stream segments of the order ‘u’
4	Stream Length Ratio (RL)	RL = Lu/Lu-1 Where, RL = stream Length Ratio Lu = Total Stream Length of the Order ‘u’ Lu –1 = Total stream length its next lower order
5	Bifurcation Ratio (Rb)	Rb = Nu/Nu+1 Where, Rb = Bifurcation Ratio Nu = Total no. of stream segment of order ‘u’ Nu+1 = Total no. of stream segment of the next higher order
6	Mean Bifurcation Ratio (Rbm)	Rbm = Average of bifurcation ratios of all order
7	Relief Ratio (Rh)	Rh = H/Lb Where, Rh = Relief Ratio H = Total relief (Relative Relief) of the basin in kilometres Lb = Basin length
8	Drainage Density (Dd)	Dd = Lu/A Where, D = Drainage Density Lu = Total stream length of all Order A = Area of the basin (in km^2)
9	Stream Frequency (Fs)	Fs = Nu/A Where, Fs = Stream Frequency Nu = Total no. of stream segments of all order A = Area of the basin (km^2)
10	Drainage Texture (Rt)	Rt = Dd * Fs Where, Rt = Drainage texture Dd = Drainage density Fs = Stream Frequency
11	Form Factor (Rf)	$Rf = A/Lb^2$ Where, Rf = Form Factor A = Area of the basin (km^2) Lb^2 = Square Basin length
12	Circulatory Ratio (Rc)	$Rc = 4 * Pi * A/P^2$ Where, Rc = Circulatory Ratio Pi = ‘Pi’ value i.e., 3.14 A = Area of the basin (km^2) P^2 = Square of the perimeter (km)
13	Elongation Ratio (Re)	Re = 2 v (A/Pi)/Lb Where, Re = Elongation Ratio A = Area of the basin (km^2) Pi = ‘Pi’ value i.e., 3.14 Lb = Basin length
14	Length of Overland Flow (Lg)	Lg = 1/D * 2 Where, Lg = Length of Overland Flow D = Drainage Density

Methodology adopted for computation of morphometric parameters.

Table 2: Results of morphometric analysis of Kusangai Jor watershed in Bolangir, Orissa.

WSD Name	Stream Order	Basin Area (km^2)	No. of Stream of Different Order					Stream Length (km)					Perimeter (km)	Basin Length (Lb) (km)
			I	II	III	IV	V	I	II	III	IV	V		
Kusangai Jor Watershed	V	135.5	286	56	12	3	1	167	76	20.5	18	16	55	23

WSD Name	Mean Stream Length in km (Lsm)					Stream Length Ratio (RL)				Total Relief (m)	Relief Ratio (Rh)	Elongation Ratio (Re)	Texture Ratio (Rt)
	I	II	III	IV	V	II/I	III/II	IV/III	V/IV				
Kusangai Jor Watershed	0.58	1.36	1.71	6	16	2.34	1.26	3.50	2.66	410	0.017	0.57	5.8

WSD Name	Bifurcation Ratio (Rb)				Mean Bifurcation Ratio (Rbm)	Drainage Density (D) (km/ km^2)	Stream Frequency (Fs)	Form Factor (Rf)	Circulatory Ratio (Rc)	Length Of Overland Flow (Lg)
	I/II	II/III	III/IV	IV/V						
Kusangai Jor Watershed	5.11	4.66	4	3	4.2	2.2	2.64	0.256	0.56	0.227

It also confirms to Horton's (1932) 'Laws of stream length' which states that the average length of streams of each different order in a drainage basin increases with the increase in stream order. The results (Table-2) of the present morphometric analysis of present study area have been discussed in the subsequent subheadings.

6.1 Stream order:

Stream ordering is the first step of morphometric analysis of a drainage basin. The stream ordering of Kusangai Jor watershed has been done on the basis of Strahler's (1964) method of stream order. The first order stream has no tributaries. The second order stream has only first order streams as tributaries. Similarly, third order stream has first order and second order streams as tributaries and so on. Higher number of stream segments in a particular order indicates that the topography is still under erosion. In the present study the Kusangai Jor watershed is designated as fifth order watershed having a total number of 358 stream segments of different order spreading over an area of 135.5km^2. The lower order stream segments are dominant in number in the present study area.

6.2 Stream length (Lu):

Stream lengths of different order stream are measured by measuring the total length of stream segments of the respective order and numbers of stream segments of different order have been counted. Generally, the total length of stream segments decreases with an increase of stream order. The present study area follows this general rule. It is clear from the Table-2 that the total length of stream segments is maximum in the first order stream and minimum in the fifth order. In general the logarithms of the number of stream segments of different order when plotted against the respective order lie on a straight line (Horton's 1945). Deviation from this general trend indicates a regional upliftment across the drainage basin. In case of the present study area almost all the points lie on a straight line (Figure - 2), which indicates that there is no such regional upliftment taken place across the basin.

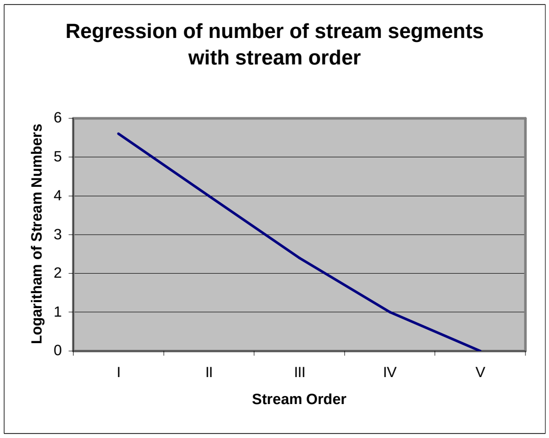

Figure- 2: Regression of number of stream segments with stream order.

6.3. Mean Stream Length (Lsm):

The mean stream lengths of different orders have been calculated dividing the total stream length of a particular order by the number of stream segments of that order. Generally Lsm of any given order is greater than that of the lower order. The Table-2 indicates that the present study area follows this general rule. Deviation from this general behaviour indicates variation in slope and topography.

6.4. Form Factor (Ff):

Form factor is measured dividing the basin area by the square of basin length (Horton, 1932). The basin length (Lb) is measured by measuring the distance from the mouth to the farthest point of the basin. The value of Ff would be always less than 0.7854 (for perfectly circular basin) because; there is no such basin that is perfectly circular in shape. The present study area has Ff value 0.256 (Table –2), which indicates the elongated shape of the basin.

6.5. Circulatory Ratio (Rc):

It is measured dividing the area of the basin by the area of a circle having the same circumference as the perimeter of the basin (Miller, 1953). This ratio is highly influenced by the length and frequency of the streams, geological structures, land use/land cover, climate, relief and slope of the basin. The low, medium and high value of Rc are indicatives of the youth, mature and old stage of the life cycle of the tributaries of a basin. The Rc value of Kusangai Jor watershed is 0.56, which indicates the dendritic stage of the tributaries of this basin. This Rc value also indicates that the drainage system of the present study area is structurally controlled and the area has moderate relief.

6.6. Elongation Ratio (Re):

Elongation ratio is the ratio between the diameter of a circle having same area as the basin and the maximum basin length (Lb). In a circular basin the run-off discharge is higher than that of an elongated basin (Singh and Singh, 1964). The value of Re generally varies from 0.6(for elongated basin) to 1.0 (for circular basin) due to variation in climate and geology. The areas of low relief show Re values close to 1.0 and Re values close to 0.6 to 0.8 indicates high relief and steep ground slope (Strahler, 1964). The different Re values can be classified as circular (>0.9), oval (0.9-0.8) and elongated (<0.7). The Re value of the present study area is 0.57, which indicates the elongated shape of the basin and also about the moderate relief.

6.7. Bifurcation Ratio (Rb):

The term bifurcation ratio was introduced by Horton (1932). It expresses the ratio of the number of stream segments of any given order to the number of stream segments in the next higher order. Strahler (1957) described that Rb values show only a small variation for different drainage basins on different environments except where a powerful geologic control dominants. The higher value of Rb indicates strong structural control, whereas, the lower Rb value is characteristics of structurally less disturbed regions (Nag, 1998). Table –2 shows that Rbm or mean bifurcation ratio of the watershed is 4.2, which indicates a strong structural control on the drainage development.

6.8. Drainage Density (Dd):

Drainage density, according to Horton (1932), is defined as the length of streams per unit area. It expresses the closeness of spacing of channel. Dd is affected by the factors that control the characteristic length of stream like resistance to weathering, permeability of rock formations, climate, vegetations etc. Langbein (1947) suggested that the Dd value varies between 0.55 and 2.09 km/km^2 in humid regions. The lower value of Dd is observed in the regions underlain by highly resistant permeable material with vegetative cover and low relief. High Dd value is observed in the regions of weak and impermeable subsurface material and sparse vegetation and mountainous relief. The Dd value of present study area is 2.2, which indicates that the region is underlain by impermeable material with moderate relief.

6.9. Stream Frequency (Fs):

It can be defined as the number of stream segments per unit area of the basin (Horton, 1945). The Fs value (2.64) of the study area has a close relationship with the Dd value (2.2). The development of stream segments is more or less affected by rainfall and temperature.

6.10. Drainage Texture (Rt):

There are different natural factors on which drainage texture depends like climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of basin development (Smith, 1950). Generally soft and weak rocks unprotected by vegetation cover produce a fine texture, whereas, massive and resistant rocks produce coarse texture. Horton recognised infiltration capacity as the single important factor, which influence the drainage texture. The drainage texture of region is directly related to Dd and Fs of that region and is expressed as the product of them. Based on Rt values Smith (1950) proposed a classification of drainage texture. For Rt value 4.0 and below, the texture is coarse; for Rt value between 4.0 to 10.0, the texture is intermediate; for Rt value above 10.0, the texture is fine and for Rt value above 15.0, the texture is ultra fine (bad land topography). The Rt value of the present study area is 5.8, which indicates the intermediate drainage texture of the study area.

6.11. Relief Ratio (Rh):

The elevation difference between the highest and lowest-points on the valley floor of a watershed is its total relief, whereas the ratio of total relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is Relief ratio (Rh) (Schumn, 1956). It measures the overall steepness of a drainage basin and is an indicator of intensity of erosion processes operating on the slopes of the basin. The Rh normally increases with decreasing drainage area and size of a given drainage basin (Gottschalk, 1964). The maximum and minimum relief of the study area are 560m and 150m respectively. Therefore, the total relief of this region is 410m. The relief ratio of the present study area is 0.017, which indicates that the study area has moderate slope.

6.12. Length of Overland Flow (Lg)

It is the length of water over the ground before it gets concentrated into definite stream channels, (Horton, 1945). This factor relates inversely to the average slope of the channel and is quite synonymous with the length of sheet flow to a large degree. It approximately equals to half of reciprocal of drainage density (Horton, 1945). Table - 2 indicates that the length of overland flow of this region is 0.227.

7. Conclusion

Morphometric analysis of Kusangai Jor Watershed of Bolangir of Orissa reveals much valuable information to set up watershed developmental plan for this area. This region is moderately populated and acutely draught prone. For mitigating the problem a proper watershed developmental plan is essential.

This watershed having moderate slope shows dendritic drainage pattern (reveals from circulatory ratio) is characteristic of a massive crystalline hard rock terrain. The plotting of the logarithms of stream number of different order against the respective order indicates that there is no such upliftment across the basin. The elongated shape of the basin is indicated by values of form factor, circulatory ratio and elongation ratio. The higher bifurcation ratios indicate strong structural control on the drainage development. The drainage density value and intermediate drainage texture indicate that the area is underlain by impermeable rocks. The occurrence of groundwater in this region is thus restricted in the recent alluviums, top weathered zones on the hard crystalline rocks of lower relief and in the secondary porosities present as fractures and fissures in the hard crystalline rocks. For sustainable development through proper groundwater exploitation should be restricted to recent alluvium, top weathered zones of hard rocks and areas with higher secondary porosities.

8. Acknowledgements

The author (A. Tantubay) acknowledges the financial assistance from CSIR New Delhi (HRD Group), Govt. of India in doing this work. The authors are grateful to A. Chakraborty, G. K. Roy, A. Kar (CGWB) for their help in providing their advices for the present study.

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