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Morphometric analysis of Pathardih catchment using remote sensing and GIS

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Abstract
Morphometric analysis is important in any hydrological investigation and it is inevitable in development and management of drainage basin. The linking of the geomorphological parameters with the hydrological characteristics of the basin provides a simple way to understand the hydrologic behavior of the different basins particularly of the ungauged basins because the hydrologic and geomorphic effects of natural and human process with in a catchment are focused at its outlet. The study has demonstrated the potential use of remotely sensed data and Geographical Information Systems (GIS) in evaluation of linear, relief and areal morphometric parameters of Pathardih Catchment. Strahler's method of stream ordering is the most commonly used method has been followed for the present study. The Pathardih Catchment a major tributary to Seonath Sub-basin in Chhattisgarh covers an area of about 2422.15 km^2 and is 5^{th} order drainage basin with mainly dendritic drainage pattern. The numbers of lower order streams are more than the higher order streams and the bifurcation ratio of the study area was low value. The low values of bifurcation ratio indicate that the drainage of the basin has suffered less structural disturbances and drainage pattern has been distorted. The basin has low drainage density of 0.53 km^{-1} and is elongated in shape. Stream length decreases with the order increases and the length of overland flow values of the basin was 0.26. These studies are significant for soil erosion prevention and land and soil management practices.

Keywords: Morphometric, surface drainage networks, GIS, linear aspects, relief aspects, Arial aspects

Introduction
Water is known as the liquid for sustenance of life. All living beings are depending on water, without which no life exists on the earth. Earth has plentiful water due to the presence of Hydrological cycle on it, but most of it is unfit for living beings use and consumption. The study of the watershed morphometric analysis provides the beneficial parameters for the assessment of the ground water potential zones, identification of sites for water harvesting structures, water resource management, runoff and geographic characteristics of the drainage system. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape, dimension of its landforms (Clarke, 1966) [1]. The Morphometric analysis consists of linear, Aerial and relief aspects. The morphometric analysis of the drainage basin and channel network play a vital role in understanding the geohydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural, etc. antecedents of the catchment. Watershed management process implies appropriate use of land and water resources for optimum production with minimum hazard to natural resources (Nag, 1998; Kanth *et al*., 2012) [10, 6].
The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at watershed level. Quantitative description of the drainage system which is an important aspect of the characterization of watersheds. The influence of drainage morphometry is very significant in understanding the landform processes, soil physical properties and erosional characteristics. Drainage characteristics of many river basins and sub basins in different parts of the globe have been studied using conventional methods (Horton, 1945; Strahler, 1957, 1964; Krishnamurthy *et al*., 1996) [3, 15, 17, 7]. To understand the evolution and behavior of drainage patterns, several methods have been developed like traditional methods such as field observations and topographic maps and advanced methods like remote sensing and Geographical Information System (GIS) (Macka, 2011; Sreedevi, 2009) [12]. In traditional methods, it is difficult to examine all drainage networks from field observations

due to their extent throughout rough terrain and or vast areas. Remote Sensing coupled with GIS technique as emerged as powerful tool in the recent years in analyzing the drainage morphometry throughout the world. These techniques have been immense utility for the analysis of morphometric parameters to arrive cost effective plans for conservation and development measures for watersheds at micro level. Many soft computing techniques were employed to estimate the water consumption under different climatic conditions (Javarayigowda, 2018) [5]. In the present study an attempt has been made to assess various morphometric parameters of Pathardih Catchment using modern geospatial tool. This study represents a better understanding of hydrologic behavior of the watershed parameters.

Materials & Methods

Description of Study Area

Pathardih Catchment a major tributary to Seonath Sub-basin in Chhattisgarh State will be selected for the Present investigate. The study area extends between latitudes 20º32'9.6" N to 21º39'25"N, and longitudes 81º12'54" E to 81º58'26" E. The total area of Pathardih Catchment is about 2422.15 km^2. The general elevation of the area ranges from 388 to 200 m above mean sea level (MSL). Location map of Pathardih Catchment was shown in the Figure 1.

Database and Methodology

Topographical maps were rectified/referenced geographically and mosaiced and entire study area was delineated in GIS environment with the help of Arc-GIS 2016 software assigning Universal Transverse Mercator (UTM), World Geodetic System (WGS dating from 1984). The Shuttle Radar Topography Mission (SRTM 30m) data were used to derive the Digital elevation model (DEM) Figure 2. Hydrology tool under Spatial Analyst Tools in ArcGIS 2016 software was used to extract drainage channels, and other parameters. The automated method for delineating streams followed a series of steps i.e. DEM, fill, flow accumulation, stream order and drainage network (Fig. 3). Extract the drainage network by using the SRTM data (Figure 2). Map creation, Scanning, Georeferencing, Spatial data and Topology creation are the steps involved in the morphometric analysis of Pathardih Catchment. The various morphometric parameters were computed using standard methodology (Table 1).

Morphometric Analysis

Morphometric analysis, which is all about exploring the mathematical relationships between various stream attributes, used to compare streams and to identify factors that may be causing differences. The term Morphometry is derived from a Greek word, where “morpho” means earth and “metry” means measurement, so together it is measurement of earth features. This is an important factor for planning any watershed development. Morphometric analysis also provides description of physical characteristics of the watershed which are useful for environmental studies, such as in the areas of land use planning, soil conservation and soil erosion.

Morphometric analysis for the present study is grouped into three classes such as linear aspects, areal aspects and relief aspects.

Linear Aspects of the Basin

Stream Order (u)

The designation of stream orders is the first step in drainage analysis and is based on hierarchic ranking of streams. In the present study, ranking of the streams is carried out based on the method proposed by Strachler (1964) [17]. The order of the basin is the order of the highest stream.

Stream Number (N_u)

Stream number is the number of stream segments of various orders. It is inversely proportional to the stream order.

Stream Length (L_u)

Total stream length is the length of all the streams having order u. It is indicative of the contributing area of the basin of that order.

Mean Stream Length (L_W)

The total stream length divided by the number of stream segments of that order gives the mean stream length of that order.

Length of Overland Flow (L_g)

It is the largest length of the flow stream from the starting point of runoff water up to that point of the catchment where runoff is not available to flow the outlet.

Maximum Basin Length (L_b)

It is the distance between watershed outlet and the farthest point of the watershed.

Stream Length Ratio (R_l)

It is defined as the total stream length of one order to the next lower order of stream segment.

$$R_l = \frac{L_u}{L_{u-1}}$$

Horton’s law (1945) of stream length states that mean stream length segments of each of the successive orders of a basin tends to appropriate a direct geometric series with streams length increasing towards higher order streams.

Bifurcation Ratio (R_b)

It 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).

$$R_b = \frac{N_u}{N_{u+1}}$$

Horton (1945) [3] considered the bifurcation ratio as an index of relief and directions. Lower value of the Rb is characteristics of basin which have suffered less structural disturbances (Strahler, 1964) [17].

Drainage Density (D_d)

Drainage density is defined as a ratio of total length of all streams to the total area of the basin. Horton (1932) [2] introduced drainage density into literature as an expression to indicate the closeness of spacing of channels.

Stream Frequency (F_s)

The stream frequency is the number of streams per unit area of the basin. It mainly depends upon the litho-logy of the basin and reflects the texture of the drainage network. It is a good indicator of drainage pattern.

Texture ratio (R_t)

It is the total number of stream segment of all orders per perimeter of that area (Horton, 1945) [4]. Horton recognized infiltration capacity as the single important factor which influences Texture ratio and considered the drainage texture to include drainage density and drainage frequency.

Aerial Aspect of Drainage Basin
Basin Area (A)
Basin area is the direct outcome of the drainage development in a particular basin. The area of Pathardih catchment is about 2422.15 km^2, which indicates that rainwater will reach the main channel more rapidly where water has not much further distance to travel.

Elongation Ratio (R_e)
Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length.

$$R_e = \frac{2R}{L_b}$$

Values close to 1.0 are typical of very low relief, where as in the range 0.6-0.8 are usually associated with the high relief and steep ground slope (Schumm, 1964) [11].

Circulatory Ratio (R_c)
It is the ratio of area of the basin to the area of circle having the same circumference as the perimeter (P) of the basin (Miller, 1953) [9].

$$R_c = \frac{A}{4\pi \times P}$$

It is influenced more by the length, frequency and gradient of streams of various orders than slope condition and drainage pattern of the basin (Strahler, 1957) [16].

Form Factor (R_f)
It is the dimensionless ratio of the basin area to the square of basin length (Horton, 1932) [2].

$$F = \frac{A}{L_{b^2}}$$

Shape factor
It is defined as the ratio of the square of the basin length to area of the basin (Horton 1945) [4] and is in inverse proportion with form factor (R_f).

Compactness coefficient (C_c)
Compactness coefficient can be represented as basin perimeter divided by the circumference of a circle to the same area of the basin and also known as the Gravelius index (GI). Lower values of this parameter indicate more elongation of the basin and less erosion, while higher values indicate less elongation and high erosion.

Relief Aspects of Drainage Basin
Maximum Watershed Relief (H)
It is the maximum vertical distance between the lowest and highest points of watershed. It is also known as total relief.

Relief Ratio (R_h)
It is the total relief (H) of watershed divided by maximum basin length (Lb). It is an indicator of potential energy available to move water and sediment down the slope.

$$R_h = \frac{H}{L_b}$$

Ruggedness Number (R_n)
Ruggedness number is the product relief of basin (H) and drainage density (Dd). It gives an idea of overall roughness of watershed.

$$R_n = H \times D_d$$

Relative Relief (Rr) It is the ratio of the maximum watershed relief to the perimeter of the watershed.

$$R_r = \frac{H}{P}$$

Morphological characteristic of a catchment were derived manually from topographic map of the watershed and Geographical Information System (GIS).

Results and Discussions
Analysis of Geo Morphologic Parameters of Watershed
The geographic parameters of the watershed have significant effects on runoff, sediment loss and erosion occurring in the watershed. It is common in hydrologic design to assume a constant depth of rainfall occurring uniformly over the watershed. The watershed area reflects the volume of water that can be generated from the rainfall. The length of watershed is usually used in computing the time parameter which is a measure of the travel time of water through the watershed. Watershed slope is an important factor in the momentum of the runoff. The watershed shape reflects the way in which runoff will concentrate at the outlet. The shape factor of the watershed is the best descriptor of the peak discharge. It is negatively correlated with peak discharge.
The morphologic parameters of Pathardih catchment under study were extracted from GIS map and also derived manually and are given in Table 1. The morphologic parameters of watershed such as area of watershed (A), perimeter of watershed (P), Stream Order, Stream Length (Lu), Mean stream length (Lsm), Stream Length ratio (R_L), Bifurcation ratio (R_b), Mean bifurcation ratio (R_{bm}), Drainage Density (D_d), Length of overland flow (L_g), Basin length (L_b), Compactness constant (C_c), Stream frequency (F_s), Circulatory ratio (R_c), Elongation ratio (R_e), Form Factor (R_f), Watershed shape factor (W_s), Drainage Texture (R_t), Total relief (H), Relief ratio (R_h), Relative relief (R_p) and Ruggedness number (R_n)etc., are extracted from GIS software. Area and perimeter of Pathardih catchment are 2422.15 km^2 and 386.54 km, respectively. The stream order and the total number of stream segments in each order for the basin are shown in Table 2. Based on the Strahler (1964) [17] system of stream ordering, the basin has been designated as a five-order basin in Figure 2. The total stream length of watershed is the sum of lengths of all streams of all orders in arable and non-arable area of Pathardih catchment. The Total Number of Streams and total stream length of Pathardih catchment are 399, 1272.64 km, respectively shows that Relation of number of streams versus stream order and Relation of Length of Stream versus Stream Order in Figure 3. The Basin Length and Stream frequency of the watershed are 109.69 km and 0.16, respectively. The Length of overland flow, Texture ratio and Circularity ratio of the watershed are 0.26, 1.03 and 0.20, respectively.

The remaining geomorphologic parameter of watershed such as, Form factor (R_f), Shape factor (B_s), elongation ratio (R_e), Compactness constant (C_c), drainage density (D_d), bifurication ratio (R_b), maximum basin relief (H), relief ratio (R_h), relative relief (R_{hp}), ruggedness number (RN) etc. are calculated manually. The shape of watershed is generally expressed by three factors i. e. form factor, Shape factor, elongation ratio and Compactness constant and these values for Pathardih catchment are 0.20, 4.97, 0.51 and 2.22, respectively. These factors are dimensionless and refer to the shape of outline of the watershed.

Drainage density obtained for Pathardih catchment is 0.53. At greater drainage density, the runoff yield at the outlet is more as rainwater enters the drainage channels immediately and reaches to outlet. The lower value of bifurcation ratio (R_b) is characteristics of the watershed which has suffered less structural distribute and the drainage patterns has not been distorted because of structural disturbances, while the higher value of R_b indicates strong structural control on the drainage pattern. The value of R_b for Pathardih catchment 3.67 derived manually and are given in Table 2. This value is lower and indicates that Pathardih catchment has suffered less structural distribute and the drainage patterns has not been distorted.

The calculated values of maximum basin relief (H), relief ratio (R_h), relative relief (R_{hp}) and ruggedness number (RN) for Pathardih catchment are 188 m, 1.71, 0.49 % and 98.78, respectively. These terms measure the steepness of the drainage basin and also considered as an indicator for the intensity of erosion processes operating at basin's slope.

Table 1: Morphologic parameter of Pathardih catchment

Morphometric parameters	Pathardih catchment
Area(km)	2422.15
Perimeter(km)	386.54
Total Stream Length (km)	1272.64
Total Number of Streams	399.00
MAX Elevation(m)	388.00
MIN Elevation(m)	200.00
Basin Length (km)	109.69
Drainage density (D_d)	0.53
Stream frequency (F_u)	0.16
Length of overland flow (L_o)	0.26
Texture ratio (T)	1.03
Circularity ratio (R_c)	0.20
Form factor (R_f)	0.20
Shape factor (B_s)	4.97
Elongation ratio (R_e)	0.51
Compactness constant (C_c)	2.22
Total relief (H)	188.00
Relief ratio (R_h)	1.71
Relative relief (R_p)	0.49
Ruggedness number (R_n)	98.78

Table 2: Stream Order, Streams Number, Total Stream length, Mean stream length, Stream Length ratio and Bifurcation Ratios in Pathardih catchment

S. No.	Stream order	Stream number	Total Stream length (Km)	Mean stream length (Lsm), Km	Stream Length ratio (RL)	Bifurcation ratio (Rb)
1	N1	312	612.64	1.964		4.333
2	N2	72	361.74	5.024	0.590	6.000
3	N3	12	178.84	14.903	0.494	6.000
4	N4	2	74.16	37.079	0.415	2.000
5	N5	1	45.27	45.270	0.610	0.000
Total		399	1272.64			
Mean						3.667

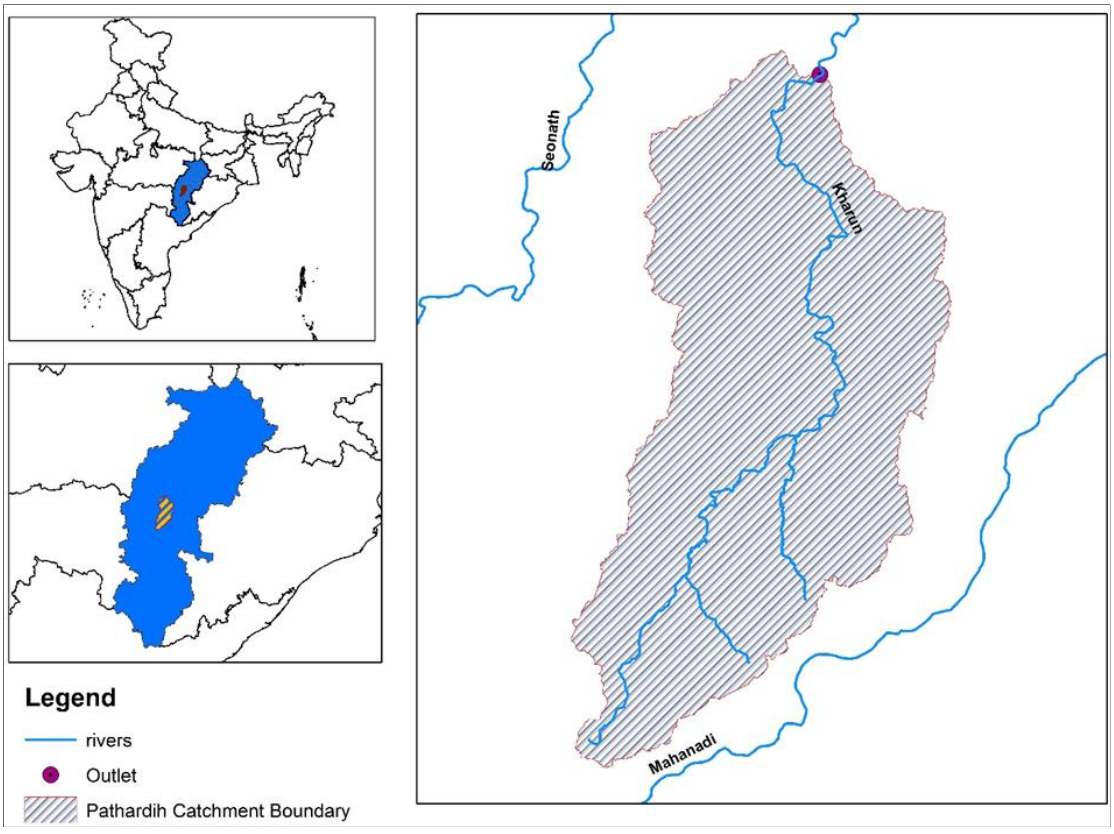

Fig 1: Location map of Pathardih Catchment

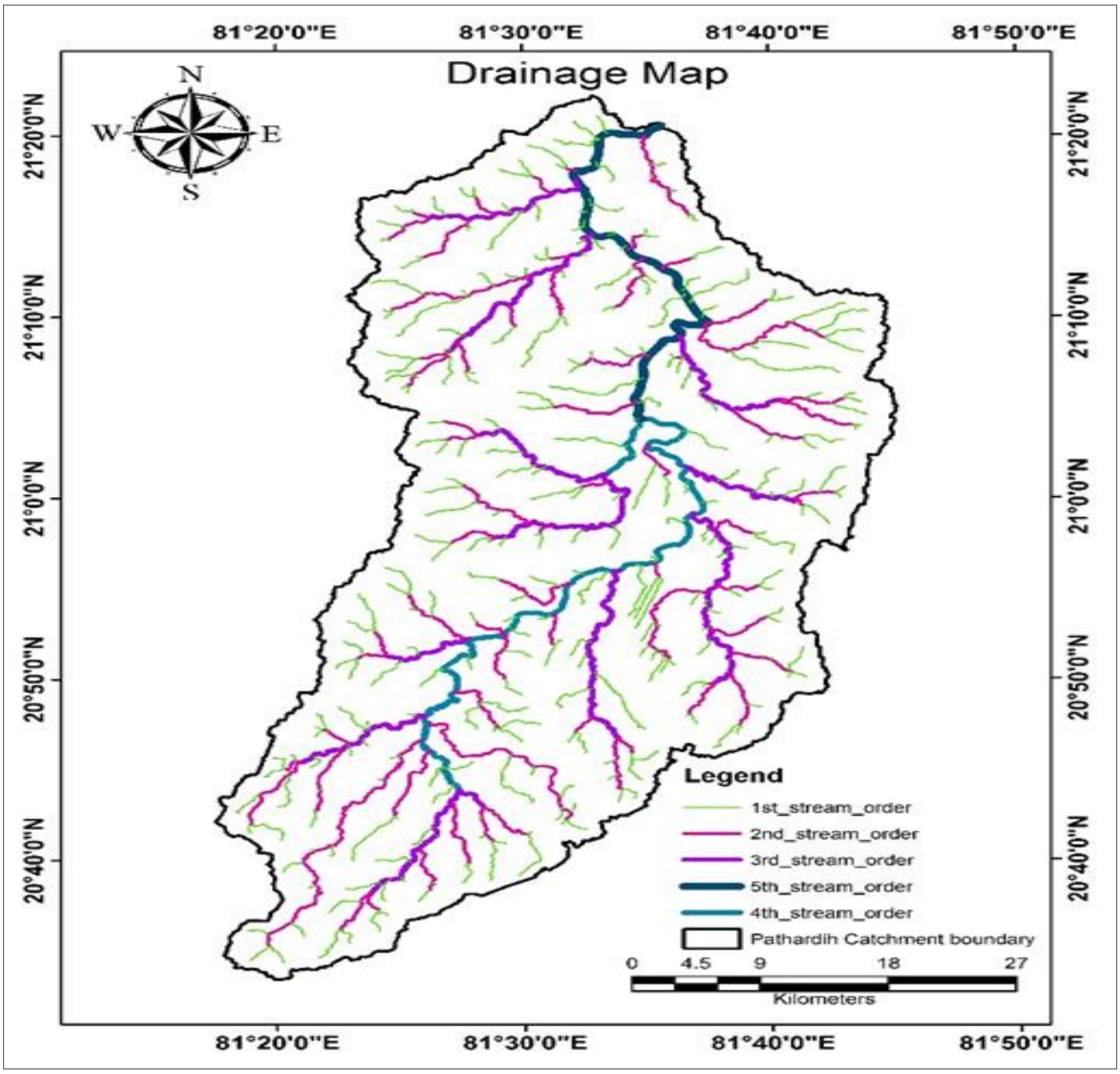

Fig 2: Drainage map of the Pathardih Catchment

Fig 2(a): Relation of number of streams versus stream order (b) Relation of Length of Stream versus Stream Order

Conclusion

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation, and natural resources management at micro level. The integrated Remote Sensing and GIS based approach is more appropriate and useful than conventional methods. The detailed quantitative morphometric analysis at the river basin enables to understand the relationships among the different aspects of the drainage patterns and their influence on landform processes, drainage, and land erosion properties. The drainage density and stream frequency are the decisive factor for the morphometric classification of drainage basins. These are controllers the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. The value of drainage density is 0.53 km^{-1} i.e below 1 km^{-1}, which shows that low drainage density nature of basin. The low values of bifurcation ratio indicate that the drainage of the basin has suffered less structural disturbances and drainage pattern has been distorted. Thus, the morphometric parameters evaluated using GIS tools helps in better understanding the nature of landforms and their processes, drainage pattern demarcations for basin area planning and management.

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