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Hydrological Inferences of Morphometric Parameters for Management of River Sub-basin in Semi-arid Tropics of India using Geospatial Technique

Benukantha Dash[1*], M. P. Tripathi[2], Dhiraj Khalkho[1], Narendra Agrawal[1] and R. K. Naik[1]

[1]*Department of Soil and Water Engineering, SVCAET&RS, FAE, IGKV, Raipur -492012*
[2]*BRSM, CAET and RS, IGKV, Mungeli-495334*

Abstract: The runoff and sediment produced from a river basin due to effective precipitation depends on the characteristics of its catchment. The catchment characteristic is site-specific and varies from basin to basin. It depends upon the topographic characteristics, climatic parameters, soil properties, geology, and human-induced activities of the catchment. Knowledge of these factors is essential for sustainable management of natural resources, *i.e.* soil and water and site-specific conservation measures of the basin or watershed. Morphometric parameters of the basin truly reflect the combination of all characteristics, and this is one of the major indicators for the hydrological behaviour of any watershed or catchment. For the present study, Pairi River sub-basin, situated between 81°51'58.7"- 82°26'16.04" E longitude to 19°55'51.9"- 20°55'6.9" N latitude, has been considered for the morphometric analysis using geospatial technique . Results of morphometric analysis revealed that the Pairi sub-basin has seventh order drainage network with a dendritic pattern. The dendritic drainage pattern of the subbasin shows that the basin has homogeneous lithology and a lack of structural control. The drainage density and stream frequency indicates that the sub-basin has a gentle slope and good permeability of sub-surface material. So, this sub-basin is suitable for constructing artificial groundwater recharge structures to improve the groundwater resource. The length of overland flow revealed that surface runoff may reach the stream more quickly within the sub-basin. The bifurcation ratio varies different successive stream orders. The mean bifurcation ratio is low, indicating that the geologic structure does not distort the drainage pattern and produces low to moderate peak flow in the sub-basin. The shape parameters such as form factor, circulatory ratioand elongation ratio indicate that the sub-basin is elongated in shape, high infiltration capacity, and flatter hydrograph with low to moderate runoff. This study can be useful for developing and managing natural resources of the Pairi sub-basin, like site-specific soil and water conservation measures such as check dam, percolation tank, water harvesting structure and development and management of groundwater, etc.

Keywords: *Geospatial technique, hydrological inference, morphometric parameters, pairi sub- basin*

Introduction

Climate and physiographic factors of a catchment/watershed are the major driving force of the hydrological process, and it reflects in the drainage network of the catchment. Therefore, it is very important to understand the basin morphology and their hydrological significance, as both are inextricably linked through the geomorphic process of soil development, erosion and deposition (Beven *et al*. 1988). The

*Corresponding author: (Email: benukantha@yahoo.co.in)

morphometric analysis provides a quantitative description of the drainage system, which is an important parameter for describing watersheds (Strahler 1964) and very useful for investigating hydrological properties. The analysis of drainage morphometry is essential for understanding the landform process, soil physical properties and erosional characteristics of a region. Several variables influence the development of drainage systems and the flowing pattern over time and space (Horton 1945; Leopold and Maddock 1953; Abrahams, 1984). Morphometric parameters of the basin,such as shape, size, slope, drainage density etc.,can be correlated (Rastogi and Sharma 1976; Magesh *et al*. 2012). The surface runoff and its intensity in a drainage system can be quantified using the geomorphic features associated with morphometric parameters (Ozdemir and Bird 2009). Topographic features such as slope and drainage network of a catchment and soil characteristics and land use cover of the area are major parameters which significantly influence the hydrological characteristics of the area. Catchment morphology is one of the sources of spatial heterogeneity (like rainfall inputs, soil characteristics and land use) and has dominant control over hydrological processes (Beven *et al*. 1988).

Quantitative correlation between morphometric and hydrological variables can be obtained by using an appropriate hydrological model and simulating the basin by considering various topographic attributes (Samal *et al*. 2014). Drainage density and time-to-hydrograph peak may relate directly or indirectly depending on environmental characteristics. Variations in climate, geology and degree of geomorphic development, in large measure, stimulate morphometric complexities (Harlin 1984). Analysis of different morphometric parameters is more convenient using a GIS-based technique to explore the correlation between drainage morphometry and hydrological characteristics (Sreedevi *et al.* 2013). The use of remote sensing and GIS technology plays an important role in finding the hydro-morphological characteristics from its morphometric parameter.The hydro-morphological characteristics of a river basin can be revealed using drainage morphometric parameters (Mahala 2020). Quantitative morphometric analysis of watershed can provide information about the hydrological nature of the rocks exposed within the watershed (Singh *et al*. 2014).

For the delineation of morphometric parameters, use of Remote Sensing (RS) and Geographical Information Systems (GIS) techniques is more convenient than conventional methods. It is a proven technique for delineating, updating and analysing the morphometric parameters of drainage basins, and effective planning and management of natural resources is more suitable than other methods. In this study, the Pairi sub-basin of Chhattisgarh state, India, is considered for interfering with the hydrological characteristics through morphometric parameters using RS and GIS technology.

Materials and Methods

Study area

The Pairi River originates from Bhatigarh hills, located near Bindranavagarh of Gariaband district, and flows southwards. It is a tributary of the Mahanadi River and joins the Mahanadi near Rajim, Gariaband district in Chhattisgarh, and drains into the Bay of Bengal. Sediment and water quality parameters are measured at Baronda, Gariaband district. The catchment area of the sub-basin upto the Baronda gauging point is 3195.0 sq km. Most of the catchment area lies in Dhamtari and Gariaband districts of Chhattisgarh state, and part of the area falls under Nabarangpur district of Odisha. The geographical extension of the sub-basin lies between 81°51'58.7"- 82°26'16.04" E latitude to 19°55'51.9"- 20°55'6.9" N longitude (Figure 1). The major landforms of the catchment area are Hills and ridges, Piedmont, pediment, upland and river valley (Ahamed and Baghel 2018). Elevation in the basin ranges from 280 to 964 m above mean sea level (MSL). In many places, the exposed bedrocks are clearly visible. The maximum and minimum of soil depth in the region varies from extremely shallow to deep. More than 85% of rainfall occurs during three to four months (June - September) during south-west monsoon period. Very meagre rainfall occurs in Northeast monsoon period. The upper catchment of the sub-basin is covered with forest, and agricultural land is predominant in the lower part of the catchment area. Open scrub land is situated in the fragmented pattern in the sub-basin, and a very small portion of the basin area is under habitation.

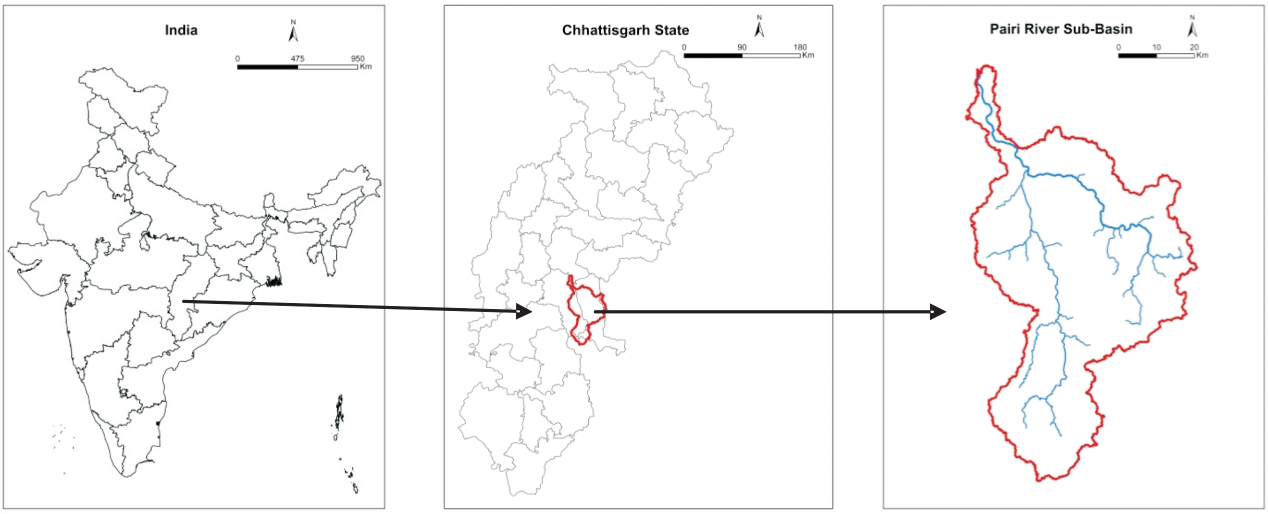

Fig.1 Location map of study area.

Morphometric Analysis

Methodology includes two parts of studies; the first part includes thematic database generation, morphometric parameter evaluation and its description; in the second part the terrain relationship between morphometric variables and their hydrological significance in the sub-basin were analysed. The Pairi sub-basin was delineated the using SRTM 30m resolution digital elevation model and the present gauging point as an outlet. Parameters such as sediment, discharge and water quality are being measured at this point. For the delineation of the drainage network of the sub-basin, the Survey of India toposheet (1:50000) was used, geo-referenced using ArcGIS and digitised the drainage line, which was updated from satellite images. The stream order of each drainage line was assigned as suggested by (Strahler 1964) *i.e.,* streams or drainage with no upstream tributaries are first order and second order is formed below the confluence of two first order streams. When two second-order streams join, they form a third-order stream and so on. Basin parameters such as area, perimeter, basin length and cumulative length of streams were measured using Geographical Information Systems (GIS). Linear, areal and relief aspects of drainage morphometry parameters were calculated using formula (Table 1). The slope map was generated using the SRTM digital elevation model (DEM). Various thematic database layers, such as sub-basin boundary, drainage network, relief and slope map, were prepared in a GIS environment.

Table 1. Formula used for computation of morphometric parameters

Sr. no	Morphometric parameters	Formula/relationship	Reference
	Linear aspects		
1	Stream order	Hierarchical rank	(Strahler 1964)
2	Stream length	Length of stream	(Horton 1945)
3	Mean stream length (Lsm)	Lsm=Lu/Nu, where Lu is the total stream length of order "u" Nu is the total number of streams of order u	(Strahler1964)

4	Stream length ratio (RL)	RL = Lu/L_{u-1}, whereLu is the total stream length of order "u" L_{u-1} is the total stream length of its next lower-order	(Horton 1945)
5	Bifurcation ratio (Rb)	Rb=Nu/(N_{u+1}) where Nu is the total number of stream order u, and N_{u+1} is the total number of streams of the next higher order.	(Schumm 1956)
6	Mean bifurcation ratio (Rbm)	Rbm is average of the bifurcation ratio of all order	(Strahler 1957)
Aerial aspects			
7	Drainage density (D)	D = Lu/A where Lu is the total stream length of all order, km and A is the a rea of the watershed, km^2	(Horton 1932)
8	Stream frequency (Fs)	Fs = Nu/A, where Nu is the total number of streams of all order and A is the area of the watershed, km^2	(Horton 1932)
9	Form factor (Ff)	Ff= A/Lb^2 where A is the area of the watershed, and L_b is the Length of the basin, km	(Horton 1932)
10	Circulatory ratio (Rc)	Rc = $4\pi A/P^2$ where A is the area of the watershed and P is the perimeter of the watershed	(Miller 1953)
11	Elongation ratio (Re)	Re= 2*sqrt(A/π)/Lb, where A is the area, km^2 and L_b length of the basin	(Schumm 1956)
12	Length of overland flow (Lg)	Lg = 1/(D*2), where D is drainage density	(Horton 1945)
13	Constant channel maintenance	C = 1/Dd Where Dd = drainage density	(Schumm 1956)
Relief aspects			
14	Basin Relief (H)	H=Elevation at the outlet of watershed Elevation at the highest point on the watershed	(Schumm 1956)
15	Relief ratio (Rh)	Rh = H/Lb Where H = maximum basin relief Lb = maximum basin length	(Schumm 1956)
16	Ruggedness number (Rn)	Rn = Bh × Dd Where Bh = vertical distance between the lowest and highest points Dd = drainage density	(Strahler 1964)

Results and Discussion

The total catchment area of the Pairi sub-basin is 3195.0 Km^2. The development of drainage networks in a watershed depends on precipitation, geology, soil characteristics and land use apart from the exogenic and endogenic forces of the area. In the limited database of any watershed/basin, analysis of morphometric parameters is ideal for identifying various hydrological behaviours of a watershed as well as characterisation of the watershed considering shape, size, relief, characteristics of the drainage network, etc., for management of water resources as well as to identify suitable sites for erosion control measures. In the present study, morphometric analysis, *i.e.,* linear aspects, areal aspects and relief aspects of the sub-basin, are considered to interfere with the hydrologic behaviour of the sub-basin. Based on the drainage network, the sub-basin is classified as a seventh-order sub-basin. The drainage pattern of the study is dendrite. Linear aspects of the sub-basin are proportionately related to stream order and reflect the geomorphologic evolution of the basin (Altin and Altin 2011, Ritter *et al*. 1995). Linear aspects morphometric parameter includes stream length, stream order, length of overland flow and bifurcation ratio, whereas areal aspect includes basin shape (circularity ratio, form factor and elongation ratio), stream frequency, drainage density, and drainage texture. The relief aspect includes basin elevation, slope and ruggedness.

Linear Parameters

Various linear parameters, such as stream order, stream number for different orders, bifurcation ratio, stream length for all stream orders and length ratio, are computed and described below.

Stream Number (Nu)

The total number of drainage lines in one segment is identified as stream number. Generally, it is observed that the number of streams gradually decreases with increasing the stream order and forms an inverse relationship (Horton 1945). A similar pattern is also observed in this sub-basin . The different stream orders (*i.e.,* first to seventh) of the drainage line and their numbers in each orderare counted with the help of the GIS environment. Total number of streams of all order in the sub-basin is 15046, including the Pairi River. Stream order-wise numbers of streams and total length are presented in the table 2. The maximum number of streams observed are of the first order (*i.e.* 7663) where as 111 streams are of the 7th order stream (Table 2 and Fig 2). Fig.3 shows the relationship between the stream order and the log of the number of streams. In the study area, more than 50% of drainage linesaand total length are first-order streams, which designate the intensity of permeability and infiltration characteristics of the area (Rai *et al.* 2018).

Table 2. Details of the drainage network of the Pairi sub-basin

Stream order	Stream segment, no	Total length, km	Stream Length, %	Maximum length, km	Mean stream length, km	Mean stream length ratio, km	Bifurcation ratio
1st	7663	4237.23	56.26	4.65	0.55	0.37	2.04
2nd	3755	1584.10	21.03	4.45	0.42	0.57	1.88
3rd	2000	898.54	11.93	4.16	0.45	0.49	2.17
4th	920	438.00	5.82	3.35	0.48	0.40	2.42
5th	380	174.00	2.31	3.22	0.46	0.62	1.75
6th	217	108.00	1.43	1.97	0.50	0.84	1.95
7th	111	91.00	1.21	6.47	0.82		
Total/Mean	15046	7530.87	100		0.501		2.03

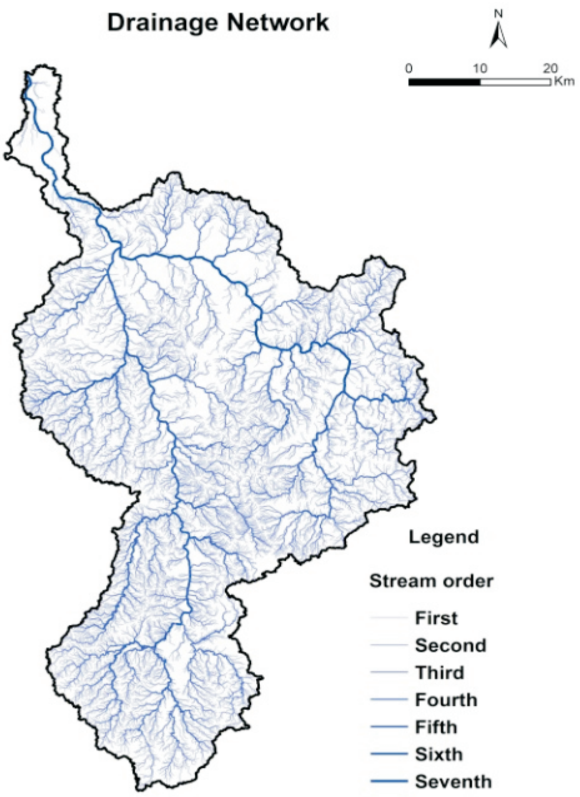

Fig.2. Drainage network with stream order of Pairi sub-basin

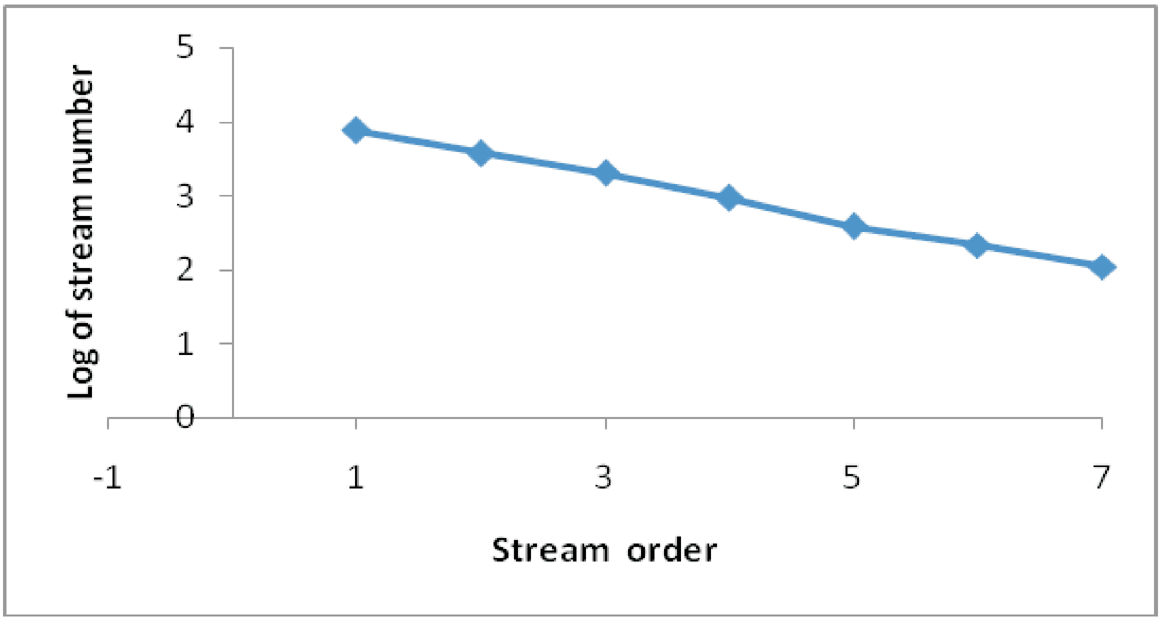

Fig. 3. Relationship between stream order and log of stream numbers of sub-basin

Stream Order

Designation of stream order of a drainage network is the first step of morphometric analysis, and (Strahler 1964) method was followed for assigning stream orderin this study area. All drainage lines were digitised using Survey of India toposheet and updated from satellite images (Figure 2). It confirms the "law of stream number" (Horton 1932), which state that the number of streams of different orders in a given drainage basin tends closely to approximate an inverse geometric ratio (Figure 3). This shows that the sub-basin has uniform underlying lithology, and geologically, there has been no probable uplift. Any deviation shows that the watershed is characterised with underlain varying lithology, high relief and/or moderately steep slopes, and probable uplift across the watershed (Singh and Singh 1997). It is observed that the first-order stream is more in forest landuse than arable lands. The drainage network of sub-basin shows that it is a seventh-order sub-basin. In total, 15046 drainage lines were observed, out of which 50.93% (7663) is first order (Table 1). Lower-order streams are considered as the primary collector of rainfall and better flood predictor (Ritter *et al*. 1995). In a basin, the stream order number is directly proportional to watershed dimension, channel size and stream discharge (Strahler 1957).

Stream Length (Lu)

The stream length of a catchment is one of the fundamental properties of a drainage network, which deals with the measurement of the channel length of a given order from the starting point. In the sub-basin, there is total of 7530.87 km length of drainage networks, including all stream orders extracted from the study area. The length of stream is one of the most important hydrological characteristics of a watershed/basin, as it indicates surface runoff characteristics. The length of first-order stream is 4237.23 km (56.26%), second order stream 1584.1 km (21.03%), third order is 898.54km (11.93%), fourth order is 438 km (5.81%), the fifth order is 174 km (2.31%), sixth order is 108 km (1.43%) and seventh order stream is 91 km (1.20%). Generally, the total length of first-order stream is more and gradually reduces as the stream order increases. A similar trend was observed in this basin also (Fig.4). This restates that the basin is underlain with uniform lithology with no probable upliftment, and movement of runoff depends only on the drainage characteristics. Streams of relatively smaller lengths are characteristics of areas with larger slopes (Sreedevi *et al.* 2013) and longer lengths of streams are generally indicative of flatter gradients.

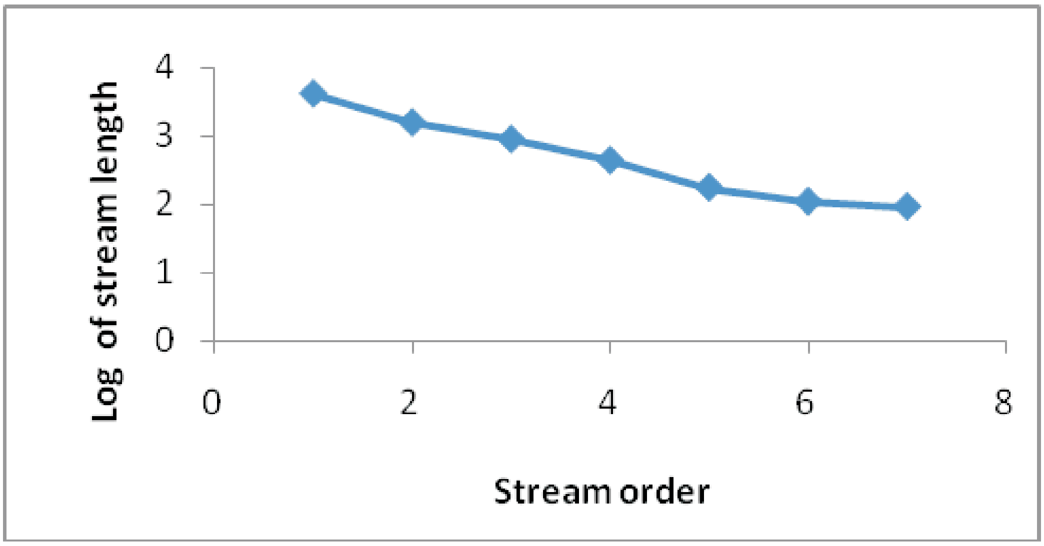

Fig.4. Relationship between stream order and log of stream length of sub-basin

Mean Stream Length (Lum)

(Strahler 1964) stated that Mean stream length (Lum) reveals the characteristics and size of stream segments and their contributing watershed surfaces. It is calculated by dividing the total stream length of an order by total number of stream segments in the subsequent order. The 'Lum' values of the sub-basin vary from 0.42 to 0.82 with mean 0.501. There is difference in the values of Lum due to variation in slope and topography of the sub-basin (Strahler 1964).

Stream Length Ratio (Lur)

The stream length ratio (Lur) is the ratio of the total length of the stream in one order to the lower order of the stream segment. It is associated with the surface runoff and erosional phase of the watershed. It is observed that in the sub-basin, the stream length ratio varies from 0.37 to 0.82 and variation between two consecutive stream orders due to differences in topographical characteristics and slope gradient (Sreedevi *et al*. 2005; Magesh and Chandrasekar 2014). Changes of 'Lur' from one order to another order indicate their late youth stage of geomorphic development (Singh *et al*. 2014).

Bifurcation Ratio (Rb)

The bifurcation ratio (Rb) is an index of reliefs and dissections, and it negatively correlates with the permeability of the watershed (Horton 1945). It ranges from about 2 for flat basins, up to 3 for rolling drainage basins and upto 4 for mountainous or highly dissected drainage basins, and it is generally higher for hilly and well-dissected drainage basins than for rolling basins (Horton 1945). (Strahler 1964) stated that Rb value characteristically ranges between 3.0 and 5.0 for watersheds where the geologic structure does not distort the drainage pattern. The lower value of Rb are characteristic of the watersheds, which have suffered less structural disturbances (Strahler 1964; Nag 1998). Higher value of Rbm indicates early peak flow with flash flooding which results more soil erosion (Rakesh *et al*. 2000). If Rbm value more, there will be more erosion susceptibility and vice versa. The sub-basin has mean bifurcation ratio of 2.03. The maximum bifurcation ratio observed in the third to fourth order, *i.e.* 2.42. It revealed that in the study area, the geologic structure do not distort the drainage pattern and it produces flatter hydrograph with delayed peak flow considering bifurcation ratio.

Drainage Density

The drainage density (Dd) of a catchment is the ratio between the total stream length of all orders and the total area of the catchment and indicates the drainage development. It is expressed as km/km^2. As per (Horton 1945), it is the expression of the closeness of spacing of channels within a basin, and it provides a numerical measurement of runoff potentiality and landscape dissection. It facilitates the selection of artificial recharge sites in a catchmentas it indicates the permeability and porosity of the basin (Krishnamurthy *et al*. 1996) and infers the relationship between climate and geology (Ritter and Major 1995). Surface runoff of a catchment is mainly influenced by rainfall characteristics, landuse pattern, slope of the area and types of soils, which directly or indirectly dictate the drainage pattern and its density.The drainage density of the study area is 2.35 km/km^2 (Table 4). It Indicates that the sub-basin comes under the coarse texture category of drainage density (Smith 1950), revealing that the sub-basin has a high vegetative cover with permeable sub-surface/resistance rock (Table 3). More than 50% area of the sub-basin has forest cover. Low drainage density generally results in areas of highly resistant rocks or permeable subsoil material, low relief and dense vegetation whereas high drainage density is observed in weak or impermeable subsurface material, sparse vegetation and mountainous relief (Nag 1998). This low value of drainage density indicates more infiltration, permeable subsoil and hence the artificial groundwater recharge may be a good option for augmentation of groundwater and wells in this region appear to possess good water potential.

Table 3.Drainage density and drainage texture classification of Pairi sub-basin

Drainage density	Drainage texture
<2	Very coarse texture
2-4	Coarse texture
4-6	Moderate
6-8	Fine
>8	Very fine

Table 4. Morphometric parameters of the sub-basin

S.No	Parameters	Value
1	Stream number (Nu)	15046
2	Stream length	7530.87 km
3	Stream order	1^{st}-7^{th}
4	Mean stream length (Lu)	0.42-0.82
5	Stream length ratio (Lur)	0.37-0.82
6	Bifurcation ratio (Rb)	1.75-2.42
7	Mean bifurcation ratio (Rbm)	2.03
8	Drainage density (Dd)	2.35 km/km^2
9	Stream frequency (Sf)	4.87/km^2
10	Form factor (Ff)	0.158
11	Circulatory ratio (Rc)	0.173
12	Elongation ratio (Re)	0.45
13	Length of overland flow (Lg)	0.21
14	Constant Channel maintenance (C)	0.42
15	Basin Relief	696 m
16	Relief ratio	0.06
17	Ruggedness number	1.64

Length of Overland Flow (Lg)

(Horton 1945) stated that the length of overland flow is an independent variable that affects the physiographic development and hydrology of the watershed. Infiltration and percolation of the soil significantly affect the length of overland flow.It has direct relationship with the average slope of the channel, and the value is less for steeper slopes and more for gentle slopes (Altaf *et al*. 2014). (Strahler 1964) stated that Lg is approximately equal to the half of the reciprocal of the drainage density, and it is the length of water flowing over the surface before it enters into a definite channel. A higher value gives favourable conditions for sheet erosion. The length of overland flow is dominates the shape of the hydrograph in a small river basin. In high-relief areas, streams of lower order rapidly join under the influence of slope, thus minimises Lg and time of concentration (Samal *et al*. 2014). In this study area, the value of Lg is 0.21 (Table 4), which indicates gentler slopes in the valley and low surface runoff, and hence, the basin is in the mature stage (Hajam *et al*. 2013). This revealed that surface runoff will reach the stream more quickly within the sub-basin.

Aerial Aspects of Sub-basin

Stream Frequency (Sf)

The stream frequency of a watershed is the ratio of the number of streams per unit area of the watershed (Horton 1932) and it is closely related to drainage density. It is the drainage network distribution over the catchment, and the high value is observed when it has very low infiltration and rocky terrain. Stream frequency is indirectly related to infiltration capacity and permeability and directly related to the relief of the watershed. Drainage density and stream frequency both quantify the texture of a drainage system, but each of which treats a distinct aspect (Samal *et al.* 2014). The stream frequency of the study area is 4.87 km^2 (Table 5), and it comes under the low category (Somashekhar *et al.* 2011). This revealed that the sub-basin has a permeable sub-surface and is good for the construction of artificial groundwater recharge structures. Similar observations were also found considering drainage density and bifurcation ratio.

Table 5.Stream frequency with no. of streams/km^2

Stream frequency (Sf)	No. of streams/km^2
Low	0–5
Moderate	5–10
Moderate high	10–15
High	15–20
Very high	20–25

*Source: Adopted from (Somashekhar *et al*. 2011)

Constant Channel Maintenance (C)

(Schumm 1956) stated the inverse of 'drainage density' or the Constant of Channel Maintenance (C) as a significant aspect of landform. It is the reciprocal of drainage density, indicating the unit area of the river basin required to sustain the one linear unit of the drainage channel. High C value indicates the basin area of lower-order drainages are relatively larger than the sub-basins which have a lower C value. A low C value minimises length of overland flow; thereby, water discharges quickly as channel flow under sparse vegetation cover (Samal *et al.* 2014). C value primarily depends on the rock form, climate regime, permeability, foliage cover and relief, along with the duration of erosion. In this sub-basin, the value of C is 0.42 (Table 4), coming under very less structural disturbances and low runoff conditions (Rai *et al*. 2018).

Form Factor (Ff)

(Horton 1945) stated that form factor (Ff) is the ratio of the area of a basin to the square of the basin length. The form factor indicates the flow intensity of a basin (Horton 1945), and it has a direct relationship between the shape of the watershed and the characteristics of the surface runoff hydrograph. The watershed will generate lower peak flows of longer duration, and the basin will be more elongated when value of Ff is small, and the watershed will experience higher peak flows with shorter duration with higher Ff (Rai *et al*. 2018). The value of the form factor would always be less than 0.7854 for all basins except for the circular basin.The Ff value of the sub-basin is 0.158 (Table 4) which revealed that there is no rapid peak flows with a flatter hydrograph and the sub-basin is elongated in nature.

Circulatory Ratio (Rc)

Circularity ratio (Rc) is defined as the ratio of the area of a basin (A) to the area of the circle having the same perimeter (P) as the basin. The circulatory ratio is influenced by many factors, such as geological structures, length and frequency of stream and land use/ land cover of the watershed (Miller 1953). The circularity ratio ranges from 0.4 to 0.5 which indicates strongly elongated and permeable homogenous geologic materials (Withanage *et al*. 2014). Higher value of the circulatory ratio indicates the circular shape of the basin. Low Rc indicates an elongated watershed with low relief (Altaf *et al*. 2014). The Rc value of the sub-basin is 0.173 (Table 4). This indicates that the sub-basin shape is elongated, has low runoff discharge with a flatter hydrograph and may have permeable sub-soil.

Elongation Ratio (Re)

(Schumm 1956) stated that the elongation ratio (Re) is defined as the ratio of the diameter of a circle having the same area as the basin to the maximum basin length (Schumm 1956). Considering the Re, the watershed can be grouped into circular (0.9– 0.10), oval (0.8– 0.9), less elongated (0.7– 0.8), elongated (0.5– 0.7), and more elongated (< 0.5) (Schumm 1956). The index ranges from zero to unity where an index of 1.0 indicates a circular basin, while elongation increases as the value of Re decreases.The Re value of the sub-basin is 0.45 (Table 4), which revealed that the sub-basin comes under the elongated shape. Hence, low peak runoff for a longer duration may be observed in this sub-basin with more infiltration. The surface runoff will take more time to travel from the most remote point to the outlet.

Relief Aspects Sub-basin

Basin Relief (H)

The elevation difference between a basin's highest and lowest point (basin outlet) is called basin relief. It is the indicator of the potential energy of the drainage system by virtue of the topographic position. It controls the slope of stream channels and, therefore, influences flood patterns and the transportation of sediment amount in the basin (Samal *et al.* 2014).When relief increases, the time concentration will decrease, which results in rapid peak runoff with less infiltration. The basin relief is an important parameter to understand the denudational characteristics of the basin. It helps to interpret geomorphic processes and landform characteristics (Pandey and Das 2016). The highest elevation in the sub-basin is 960 m, whereas the lowest elevation in the outlet is 264 m above mean sea level. The basin relief of the study area is 696 m (Table 4).

Relief Ratio (Rh)

The Relief ratio is the ratio between the basin relief and the longest horizontal distance of the basin measured parallel to the main drainage line (Schumm 1956), and it is directly related to the length of overland flow and time to peak runoff (Rai *et al.* 2018). It is closely related to the hydrological characteristics of a basin and sediment loss per unit area (Rai *et al*. 2018).It indicates the steepness of the watershed and is more susceptible to soil erosion when Rh is high. A moderate relief ratio is found in a basin where low to moderate relief and gradient exist. The Relief ratio of the sub-basin is 0.06 (Table 4), which reveals that the sub-basin may produce a flatter hydrograph. The low relief ratio value in the sub-basin revealed that it has low relief with less slope.

Ruggedness Number (Rn)

It is defined as the product of the basin relief and drainage density with the same unit (Strahler 1957) and it is a dimensionless quantity. It will be of high value when the basin has a long steep slope. A high Rn value indicates the structural complexity of a terrain that is highly susceptible to erosion and flash floods (Patton and Baker 1976). The low 'Rn' of basin suggests that area is less prone to soil erosion and has intrinsic structural intricacy in relation to relief and drainage density (Rai *et al*. 2018). The Rn value of the sub-basin is 1.64 (Table 4),which indicates that the sub-basin is less susceptible to soil erosion with a flatter hydrograph.

Hydrological inference from morphometric analysis

The quantitative analysis of morphometric indices anddrainage patterns is essential for studying the hydrological behaviour of a river basin. The morphometric parameters evaluated using geospatial technology are useful to understand various terrain parameters such as runoff characteristics, infiltration capacity, drainage network, and properties of sub-surface material, etc. The morphometric parameters such as linear, areal, and relief aspects of the Pairi sub-basin, Chhattisgarh state in the semi-arid region of India were analysed. The drainage network of the basin exhibits a seventh-order basin with dendritic type, which shows homogeneity in lithology. In the sub-basin, more than 50% of streamlines and total length are first-order streams that designate the intensity of permeability and infiltration characteristics of the area. The linear aspects indicated that the Pairi sub-basin has permeable subsurface material with less geological structural controls. The areal aspects indicate that the basin is elongated and gently sloping. The stream length ratio varies from 0.37 to 0.83. The low drainage density (2.35 km/km^2) and low stream frequency ($4.87/km^2$) of the basin indicates that the sub-basin is flat with gentle slope and has permeable sub-surface material.The sub-basin has a mean bifurcation ratio of 2.03, and the highest bifurcation ratio of 2.42 was found for the third to fourth-order streams. It revealed that in the study area, the geologic structure does not distort the drainage pattern, and it produces a flatter hydrograph with delayed peak flow considering bifurcation ratio. For groundwater augmentation, an artificial groundwater recharge structure may be one of the best options and irrigation through wells would be a viable option.The value of the Ruggedness number (Rn) of the sub-basin is 1.64, which indicates that the sub-basin is less susceptible to soil erosion with a flatter hydrograph. The elongation ratio (0.45) and circulatory ratio (0.173) revealed that the sub-basin comes under the elongated shape with low peak runoff for a longer duration may be observed in this sub-basin.

Conclusion

All morphological parameters together indicate that the basin is in the mature to an early old stage of erosional development. The present study of the Pairi sub-basin revealed that certain relationships among several morphometric parameters are correlated and useful in assessing the topography and hydrological process that occurred in the sub-basin. This information will be very much useful for site specific design and development of various water harvesting structures, soil conservation measures, and contributea basis for development and management of water resources.The results of morphometric analysis indicate that the artificial groundwater recharge can be done successfully in the sub-basin that leads to enhanced baseflow of the stream during the dry season. In the first and second-order streams, low cost gully control measures may be constructed as the runoff generation is low. Other information like land use/land cover, land form, geology, and soil properties can integrated with morphometric parameters for making decisions for site-specific soil and water conservation measures and artificial groundwater recharge structures such as check dam, water harvesting structure, percolation tank, artificial groundwater recharge structure etc. The information generated in this study will be helpful for the sustainable management of natural resources of the sub-basin.

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