



Prioritization of subwatersheds based on quantitative morphometric analysis in lower Bhavani basin, Tamil Nadu, India using DEM and GIS techniques

Anand Balasubramanian¹ · Karunanidhi Duraisamy¹ · Subramani Thirumalaisamy² · Srinivasamoorthy Krishnaraj³ · Raneesh Kolladi Yatheendradasan⁴

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Abstract

Watershed prioritization is one of the most important processes in natural resource management system especially in areas of sustainable watershed development and planning. Morphometric characteristics are the viable entity to understand the hydrological behavior of the subwatershed. For prioritization of subwatershed, morphometric analysis was utilized by using the linear, areal, and relief aspects of the drainage basin. In this context, remote sensing and GIS has been proved to be an efficient tool to identify the morphological features. The Survey of India (SOI) topographical maps, satellite data IRS-LISS III, and Cartosat DEM data were utilized to understand the drainage pattern and also for prioritization of subwatershed areas. The prioritization of subwatershed has been attempted using novel and quantitative approaches based on compound parameter ranking for soil erosion. Lower compound factors were chosen as the most feasible for soil erosion. Based on the observation, eight subwatersheds with a higher degree of the slope were severely prone to soil erosion and remaining 21 subwatersheds occur in low-lying areas that can be developed as sustainable watersheds. The identified subwatershed requires immediate soil remediation and water conservation measures for efficient watershed planning and management. The proposed study might be helpful for resource planners, government agencies, private sectors, and other stake holders to take up soil conservation measures and fixation of water-harvesting structures for better decision making.

Keywords Morphometry · DEM · Subwatershed · Compound factor · Prioritization · Lower Bhavani basin

Introduction

Land and water resource development is precisely planned based on a watershed, since it depends upon parameters like

topography, size, shape, landform, land use, vegetation cover, climate and socio-economic status. Watershed resources are interdependent, and they preserve natural resources from possible environmental damages (Adinarayana et al. 1995). Watershed management is one of the key factors for conservative planning in arid and semi-arid regions. Morphometry is the measurement and mathematical analysis of configuration of earth surface, shape, and dimension of landforms (Agarwal 1998). A varied morphometric measurement is required to evaluate the basic, linear, areal, and relief aspects of the basin. For runoff and hydrological modeling, morphometric characterization and prioritization of all hydrological units of subwatersheds are essential for development of land and water conservation measures (Aher et al. 2014). Prioritizing subwatershed and its morphometric analysis are easily observed through Remote Sensing and Geographical Information System (GIS) techniques. The uses of RS and GIS techniques in the morphometric analysis of drainage basins have emerged as a powerful tool in recent years. An attempt has been made in this study using Cartosat-1 DEM and IRS-LISS III satellite-derived data products to subbasinal

✉ Karunanidhi Duraisamy
karunasamygis@gmail.com

¹ Department of Civil Engineering (Centre for Geoinformatics and Water Technology), Sri Shakthi Institute of Engineering and Technology, L&T By-Pass, Chinniyampalayam (Post), Coimbatore 641062, India

² Department of Mining Engineering, Anna University, CEG Campus, Chennai 600025, India

³ Department of Earth Sciences, Pondicherry University, Kalapet, Puducherry 605014, India

⁴ Department of Agricultural Engineering (Centre for Geoinformatics and Water Technology), Sri Shakthi Institute of Engineering and Technology, L&T By-Pass, Chinniyampalayam (Post), Coimbatore 641062, India

and drainage features with medium spatial resolution, viz., 30 and 23.5 m, respectively. The quantitative morphometric analysis is found to be of maximum utility in watershed delineation. In earlier times, the drainage characteristics have been identified by using the conventional methods that reflect the geological and geomorphological processes over a specific time (Strahler 1957, 1964; Horton 1932, 1945; Miller 1953; Mueller 1973). Basin characteristics have been analyzed in terms of basin morphology and related parameters (Agarwal 1998) during previous times. The quantitative morphometric analysis of subwatersheds using remote sensing in the form of high spatial resolution and incorporating GIS as a spatial data management system has emerged as a powerful tool for drainage pattern studies that gives a good deal of information about the topography, subsurface material, geological structure, land use pattern, soil type, and vegetation condition of the area (Srivastava and Maitra 1995; Singh and Singh 1997; Nag 1998; Biswas et al. 1999; Nookaratnam et al. 2005; Das and Mukherjee 2005; Rudraiah et al. 2008; Javed et al. 2011; Gajbhiye et al. 2013; Withanage et al. 2014). These researchers studied the development of water resources through different morphometric parameters like stream order, stream length, stream frequency, bifurcation ratio,

drainage density, drainage texture, form factor, elongation ratio, compactness coefficient, and length of overland flow. Shuttle Radar Topographic Mission (SRTM) and GIS were used to evaluate the linear, areal, and relief aspects of the basin. The results of the analysis point out that the basin has elongated shape due to the effect of thrusting and faulting permeable sub-surface strata. So, it implies insufficient groundwater potential and concludes that morphometric analysis is an efficient tool for rainwater-harvesting and water-management plans (Sreedevi et al. 2009). Pareta and Pareta (2011) studied the drainage characteristics using Advanced Space-Borne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) and computed more than 85 parameters of all aspects, and the results suggested that the development of the area by streams evolved well beyond the maturity and the influence of lithology in controlling the drainage pattern. Stream network and other hydrological parameters have been delineated using DEM in Papanasam and Manimuthar watersheds by (Magesh et al. 2011). Hence, the combination of morphometric analysis and geovisualization will be helpful to fix water harvesting structures along with quantifying the excessive water leaving the watersheds (Patel et al. 2012).

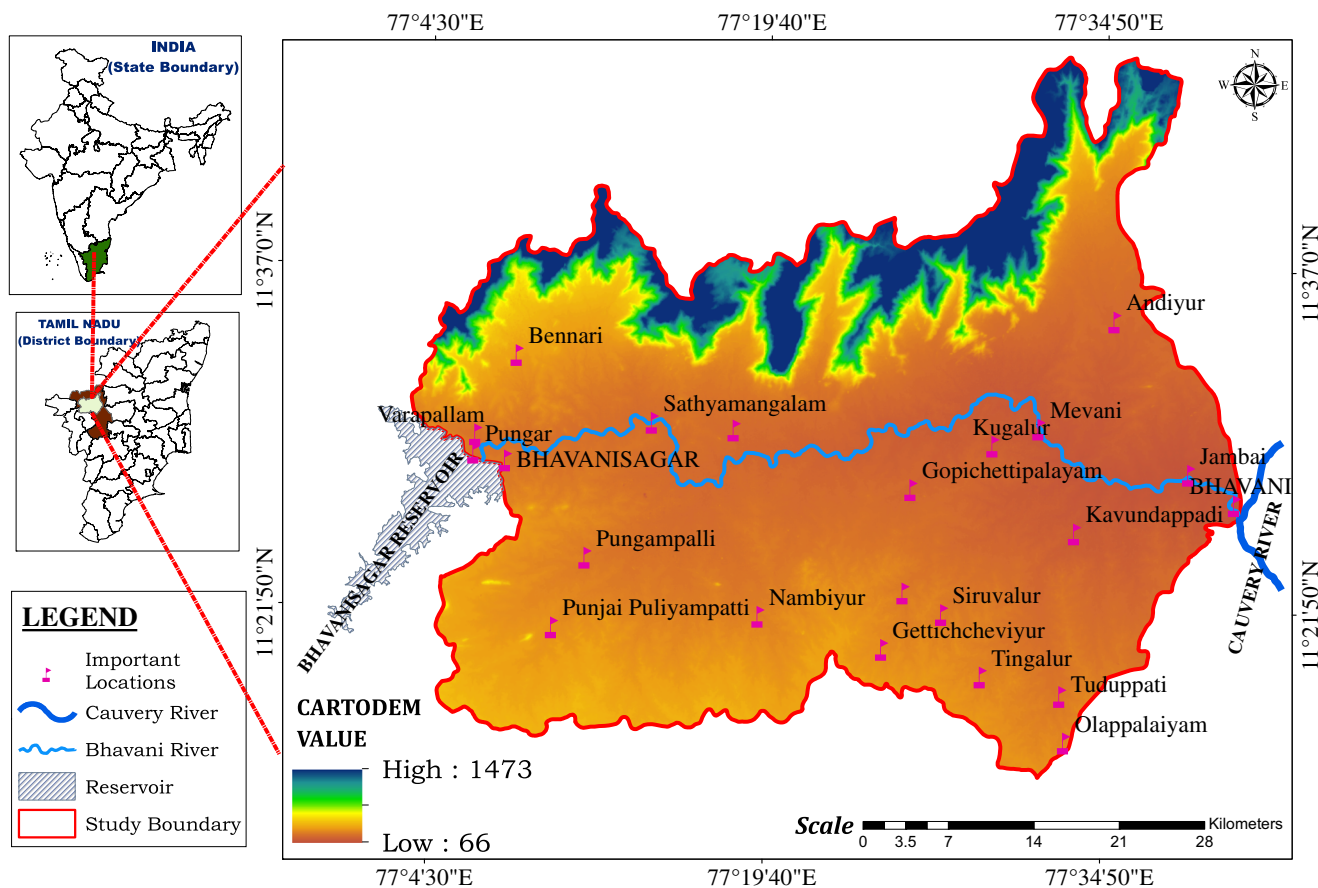


Fig. 1 Location map of the study area

In the present study, the drainage characteristics of lower Bhavani basin were studied to portray the hydrological characteristics using topographical maps and CartoDEM data. Watershed planning and development has become important for improving the surface and groundwater resources in the area. The population growth and human encroachment continue to affect the natural system of the basin. Both water shortage (drought) and overabundance (flooding) become more problematic for the agricultural activities of the study area. So, these expanding communities need an increasing water supply to carry their development activities in the watershed. Therefore, the development is essential for water-conservation practices such as drainage development, watershed evaluation, and morphometric characterization analysis to manage the drought-affected area and its agriculture practices. For the sustainable development of watershed, it is important to understand the topography, drainage pattern, and erosive areas of the region. For this purpose, detailed

morphometric analyses were attempted for 29 subwatersheds. The mathematical computations and GIS were used to evaluate the linear, areal, and relief aspects of morphometric parameters with help of CartoDEM data. Prioritization of the 29 subwatersheds of lower Bhavani basin has been attempted with the ranking of the compound parameter.

Study area

The study area, lower Bhavani basin, is located in the Erode district of Tamil Nadu, and its geographical location extends between $11^{\circ} 15'$ and $11^{\circ} 45'$ North latitude and $77^{\circ} 0'$ and $77^{\circ} 35'$ East longitude. The total geographical area of the basin is 2424 km^2 . River Bhavani which is the fourth largest tributary of river Cauvery is the major river flowing in the study area that confluences river Cauvery near Bhavani town (Fig. 1). The altitude of Bhavani basin varies between 66 and 1473 m

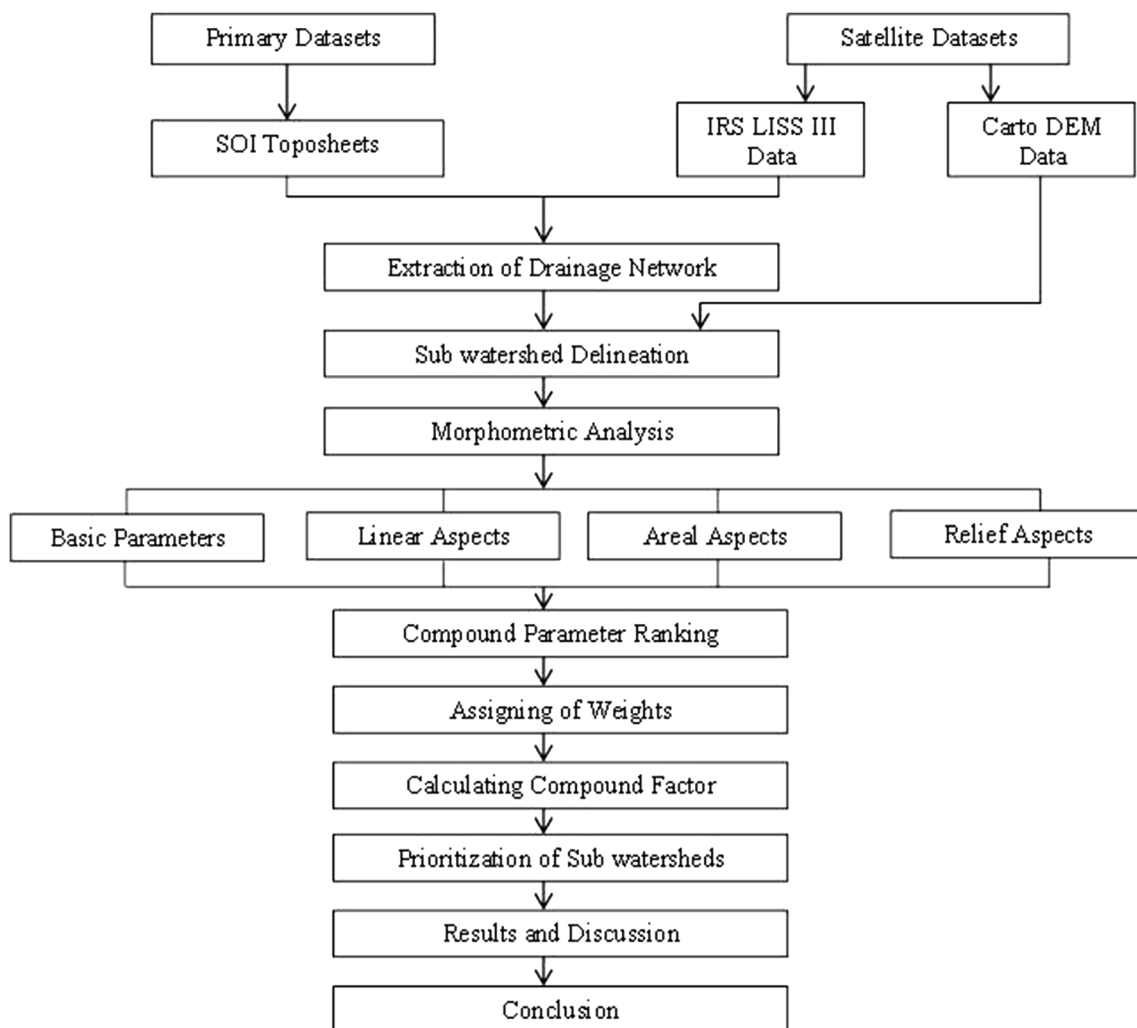


Fig. 2 Flowchart showing the methodology used in the present study

above mean sea level. The area experiences semi-arid climatic region with an average rainfall of about 666.84 mm. The temperature varies between 22 and 42 °C, and lithology of the area is dominated by Fissile Hornblende Biotite Gneiss, Hornblende Biotite Gneiss, Charnockite, Granite, Quartzites, and Amphibolites. Groundwater occurs in weathered and fractures zones. The main source of livelihood activity in the study area is agriculture. Crops like sugarcane, banana, groundnut, and paddy are cultivated throughout the study area.

Methodology

For morphometric analysis, a total of eight multi-dated subscenes are acquired from Indian Remote Sensing Satellite (IRS)-LISS III data (12 November 2008, 03 August 2009, 09 November 2011, 03 March 2013) of path 100 and rows 65 and 66 from Bhuvan Indian Geo Platform, Indian Space Research Organization (ISRO). Survey of India (SOI) topographical maps (No. 58 E/2, 3, 6, 7, 9, 10, 11) of scale 1:50,000 is used as the base map to extract the stream network and drainage map of the study area. Apart from these, CartoDEM data was processed for delineation of subwatershed with the help of pour points.

Morphometric analysis of a basin requires the delineation of basin boundary along with drainage network (Khare et al. 2014; Rai et al. 2014). For the present study, toposheets were used for digitizing the drainage network. Satellite datasets that were geometrically corrected, enhanced, and mosaicked using Erdas Imagine and Arc GIS (10.2.1) were used for digitization and computation of spatial and attribute datasets of the drainage system. The drainage network was digitized from toposheets and further updated using satellite data by visual interpretation method. The methodology followed for the study is shown in Fig. 2. The study area has been subdivided into 29 subwatersheds into (SWS-1 to SWS-29). Subwatersheds were delineated by defining pour points for each outlet of tributary streams with respect to main streams by superimposing drainage network over Cartosat digital elevation model (DEM) data.

The morphometric analysis is performed by using Strahler (1964) classification system. The parameters such as stream order, stream length, mean stream length, stream length ratio, basic bifurcation ratio, mean bifurcation ratio, relief ratio, drainage density, drainage texture, stream frequency, circularity ratio, form factor, shape factor, elongation ratio, compactness coefficient, and length of overland flow were calculated

Table 1 Formula adopted for computation of morphometric parameters

Morphometric parameters	Formula	Reference
Stream order	Hierarchical rank	Strahler (1964)
Stream length (Lu)	Length of the stream	Horton (1945)
Mean stream length (Lsm)	$Lsm = Lu/Nu$ (where Lu is the total stream length of order “u” and Nu is the total no. of stream segments of order u)	Strahler (1964)
Stream length ratio (RL)	$RL = Lu / Lu^{-1}$ (where RL is the stream length ratio, Lu is the total stream length of the order “u,” and Lu^{-1} is the total stream length of its next lower order)	Horton (1945)
Bifurcation ratio (Rb)	$Rb = Nu/Nu^{+1}$ (where Rb is the bifurcation ratio, Nu is the total no. of stream segments of order “u,” and Nu^{+1} is the number of the segments of next higher order)	Schumn (1956)
Mean bifurcation ratio (Rbm)	Rbm is the average of bifurcation ratios of all orders	Strahler (1957)
Relief ratio (Rh)	$Rh = H/Lb$ (where Rh is the relief ratio, H is the total relief (relative relief) of the basin (km), and Lb is the basin length)	Schumn (1956)
Drainage density (Dd)	$D = Lu/A$ (where D is the drainage density, Lu is the total stream length of all orders, and A is the area of the basin (km ²))	Horton (1945)
Stream frequency (Fs)	$Fs = Nu/A$ (where Fs is the stream frequency, Nu is the total no. of streams of all orders, and A is the area of the basin (km ²))	Horton (1945)
Drainage texture (Rt)	$Rt = Nu/P$ (where Rt is the drainage texture, Nu is the total no. of streams of all orders, and P is the perimeter (km))	Horton (1945)
Form factor (Rf)	$Rf = A/Lb^2$ (where Rf is the form factor, A is the area of the basin (km ²), and Lb^2 is the square of basin length)	Horton (1932)
Shape factor (Fs)	$Bs = Lb^2/A$ (where Bs is the shape factor, Lb^2 is the square of basin length, and A is the area of the basin (km ²))	Horton (1945)
Circularity ratio (Rc)	$Rc = 4*Pi * A/P^2$ (where Rc is the circularity ratio, Pi is the “Pi” value, i.e., 3.14, A is then area of the basin (km ²), and P^2 is the square of the perimeter (km))	Miller (1953)
Elongation ratio (Re)	$Re = 2\sqrt{(A/Pi)} / Lb$ (where Re is the elongation ratio, A is the area of the basin (km ²), Pi is the “Pi” value, i.e., 3.14, and Lb is the basin length)	Schumn (1956)
Compactness coefficient (Cc)	$Cc = 0.2821P/A^{0.5}$ (where A is the area of the basin (km ²) and P is the perimeter of the basin)	Horton (1945)
Length of overland flow (Lg)	$Lg = 1/D*2$ (where Lg is the length of overland flow and D is the drainage density)	Horton (1945)

using the formulas represented in Table 1. The adaptation of formulae and its interpretation can be found elsewhere (Horton 1932; Biswas et al. 1999; Rudraiah et al. 2008).

The prioritization of subwatershed was approached by parameters of linear and shape aspects. According to Biswas et al. (1999), Vittala et al. (2008), and Sharma et al. (2014), the morphometric parameters, i.e., bifurcation ratio (Rb), drainage density (Dd), stream frequency (Fs), drainage texture (Rt), form factor (Rf), shape factor (Bs), circularity ratio (Rc), elongation ratio (Re), compactness coefficient (Cc), and length of overland flow (Lg) are known as erosion risk-assessment parameters, and these parameters has been considered for prioritizing subwatersheds (Biswas et al. 1999). The linear parameters such as bifurcation ratio, drainage density, stream frequency, drainage texture, and length of overland flow have a direct association with erodibility factor where higher value signifies more erodibility (Nookaratnam et al. 2005). During prioritization of subwatersheds, highest value of linear parameters was assigned rank 1 and the next value was assigned rank 2 and so on until the least rank. Shape parameters such as form factor, shape factor, elongation ratio, compactness coefficient, and circularity ratio have an inverse relationship with erodability criteria (Patel et al. 2012). Thus, lower value of shape parameters was assigned rank 1, next higher value was assigned rank 2, and so on until the highest value. Hence, the ranking of the subwatersheds has been attempted by assigning the highest rank based on highest value in case of linear parameters and lowest value for shape parameters. Finally, the compound factor was calculated by summing up all the ranks of linear and shape parameters and dividing them by a number of parameters. From the observation, the highest prioritized rank was assigned to the subwatersheds which possess the lowest compound factor and so forth.

Results and discussions

Basic parameters

Basic parameters are one of the key parameters to achieve the morphometric analysis of subwatershed. These parameters include the area of the watershed, perimeter, basin length, and total relief and are significant for the analysis of linear, areal, and relief aspects of the basin.

Area and perimeter

Drainage area (A) is possibly an important characteristic of a watershed for hydrologic design events and replicates volume of water that can be generated from rainfall (Patel et al. 2012). In this study, the area of subwatershed varies from 455.6 km² (SWS-22) to 5.44 km² (SWS-20). The

basin perimeter is the length of line which divides the basin surface. The maximum perimeter 112.94 km is noted in subwatershed 17, and minimum 14.1 km is confined to subwatershed 10.

Basin length

The basin length (Lb) is one of the important watershed characteristics for the hydrologic process that signifies the length of the basin. Basin length for the study area has been determined in accordance with Schumn (1956) which is defined as the longest dimension of the basin parallel to the principal drainage line. Basin length has

Table 2 Identification of basic parameters for analysis of subwatersheds

Serial No.	Subwatershed name	Basic parameters			
		Area of SWS (km ²)	Perimeter (P) (km)	Basin length (Lb) (km)	Total relief (Mts)
1	SWS-1	47.08	33.34	11.98	1322
2	SWS-2	43.17	31.88	13.14	1180
3	SWS-3	93.75	53.12	17.24	1221
4	SWS-4	72.85	49.18	19.41	1433
5	SWS-5	22.03	27.09	10.4	1463
6	SWS-6	95.86	47.96	15.97	1473
7	SWS-7	13.11	19.2	5.9	1135
8	SWS-8	109.66	52.92	18.54	1428
9	SWS-9	12.01	16.11	6.96	788
10	SWS-10	9.64	14.1	6	644
11	SWS-11	7.86	20.7	8.3	851
12	SWS-12	15.05	25.8	9.88	1176
13	SWS-13	71.59	48.5	13.94	1419
14	SWS-14	8.83	17.43	5.34	486
15	SWS-15	27.23	33.74	11	1133
16	SWS-16	66.98	40.97	14.2	1377
17	SWS-17	253.2	112.94	33.19	1469
18	SWS-18	10.69	14.39	5.9	291
19	SWS-19	19.71	20	7.42	292
20	SWS-20	5.44	10.11	3.78	182
21	SWS-21	27.92	25.23	7.68	207
22	SWS-22	455.6	98.62	22.19	446
23	SWS-23	80.51	41.5	16.79	275
24	SWS-24	62	44.93	20.34	229
25	SWS-25	159.89	62.5	24.62	256
26	SWS-26	194.81	65.7	26.88	241
27	SWS-27	42.52	34.74	15	185
28	SWS-28	13.78	22.38	9.2	153
29	SWS-29	42	26.28	9.55	208

been used to calculate the relief ratio, form factor, shape factor, and elongation ratio of the basin as per the formulae suggested by Schumm (1956) and Horton (1932, 1945), respectively.

Total relief

Basin relief is the factor that reveals the denudation characteristics of landforms that show the active process of weathering, mass wasting, erosion, etc. (Sreedevi et al. 2009). Total relief is a measure of the maximum and minimum relief of the basin, and it plays a significant role in landform development, drainage development, surface and subsurface water flow, permeability, and erosional properties of the terrain (Magesh et al. 2011). In the present study, the total relief of subwatersheds varies from 1473 m (SWS-6) to 153 m (SWS-28) shown in Table 2, and the subwatersheds lying in the northern part of the basin characterized by a very steep slope were the subwatersheds responsible for low infiltration and high runoff. Similarly, the eastern part of basin indicates gentle slope category with high infiltration and low runoff

conditions and the remaining subwatersheds are liable for an intermediate rate of runoff in the basin.

Linear aspects of the basin

Stream order

Stream order is the primary process in drainage morphometric analysis of basin. The hierarchical ranking was attempted for existing streams by the proposed method of Strahler (1964). The number of streams of a given order represents the total number of all streams, which denotes the stream segments of an individual watershed. The 1st-order streams have no tributaries, 2nd-order streams are those which have 1st-order streams as tributaries, and so on (Horton 1945). The study area represents a maximum of 6th-order drainages with dendritic to subdendritic pattern (Fig. 3). Out of 29 subwatersheds, three watersheds represent 6th-order streams (subwatersheds 3, 7, and 22), 15 watershed as 5th-order streams (subwatersheds 1–6, 8, 13, 15–17, 22, 23, 25, and 26), and 20 as 4th-order streams (subwatersheds 1–6, 8, 9, 12–18, and 22–26). A total of 4646 streams have been identified in the study area (Table 3).

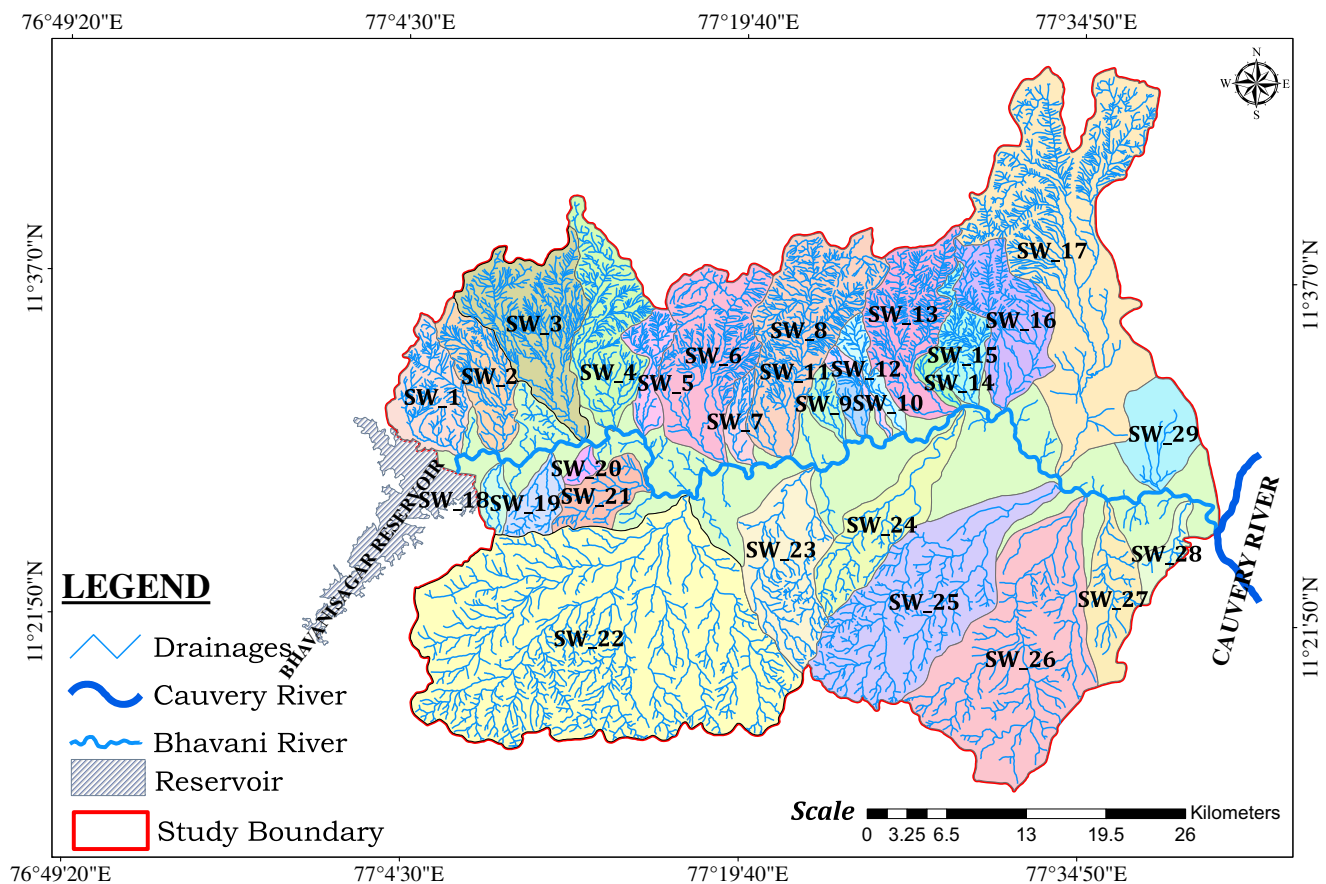


Fig. 3 Drainages with subwatersheds

Table 3 Stream order computation of subwatersheds

Serial No.	Subwatershed name	Area of SWS (km ²)	Stream order						Total No. of stream segments
			I	II	III	IV	V	VI	
1	SWS-1	47.08	133	31	9	5	1	–	179
2	SWS-2	43.17	111	29	4	5	1	–	150
3	SWS-3	93.75	251	54	26	6	2	1	340
4	SWS-4	72.85	184	47	18	5	1	–	255
5	SWS-5	22.03	82	19	4	2	1	–	108
6	SWS-6	95.86	214	58	17	6	4	–	299
7	SWS-7	13.11	26	5	1	–	–	–	32
8	SWS-8	109.66	334	99	20	5	4	–	462
9	SWS-9	12.01	17	5	2	1	–	–	25
10	SWS-10	9.64	16	4	1	–	–	–	21
11	SWS-11	7.86	13	4	2	–	–	–	19
12	SWS-12	15.05	40	10	2	1	–	–	53
13	SWS-13	71.59	259	69	12	4	1	–	345
14	SWS-14	8.83	16	5	2	1	–	–	24
15	SWS-15	27.23	95	23	9	3	1	–	131
16	SWS-16	66.98	169	31	5	3	1	–	209
17	SWS-17	253.2	468	102	24	7	2	1	604
18	SWS-18	10.69	10	4	2	1	–	–	17
19	SWS-19	19.71	27	5	1	–	–	–	33
20	SWS-20	5.44	6	2	1	–	–	–	9
21	SWS-21	27.92	34	8	1	–	–	–	43
22	SWS-22	455.6	473	119	35	9	5	1	642
23	SWS-23	80.51	89	22	6	2	1	–	120
24	SWS-24	62	42	9	4	1	–	–	56
25	SWS-25	159.89	185	54	11	3	1	–	254
26	SWS-26	194.81	113	29	6	3	1	–	152
27	SWS-27	42.52	26	5	1	–	–	–	32
28	SWS-28	13.78	12	5	1	–	–	–	18
29	SWS-29	42	9	4	1	–	–	–	14
Total		2084.77	3454	861	228	73	27	3	4646
Percentage (%)			74.34	18.53	4.9	1.58	0.59	0.06	100

Figure 4 represents about 3454 as 1st-order, 861 as 2nd-order, 228 as 3rd-order, 73 as 4th-order, 27 as 5th-order, and 3 as 6th-order streams. It may be seen that the highest stream segments are found in subwatershed 22 and the lowest stream segments in subwatershed 20. The variation in the order of streams is mainly due to the physiographic and structural conditions of the region, and these stream orders were further used in the characterization of subwatershed.

Stream length

The total length of stream network was maximum in the 1st-order streams, and it progressively decreased with increase in

stream order (Horton 1945). Stream length is one of the significant parameters in drainage morphometric studies. The hilly area are predominant with smaller-length streams (1st and 2nd order) that represent the larger slope area and longer stream lengths (3rd, 4th, 5th, and 6th order) are of a lesser slope with gentle and flat terrain (Khare et al. 2014). In the present study, the stream lengths were measured using GIS techniques and order-wise stream length for 29 subwatersheds are shown in Table 4, and the total length of 1st- and 2nd-order streams contributes 75.94% of total stream length and remaining orders constitute 24.06%, which obviously indicates that the basin stream length is higher in the 1st-order streams and decreases where the stream order increases.

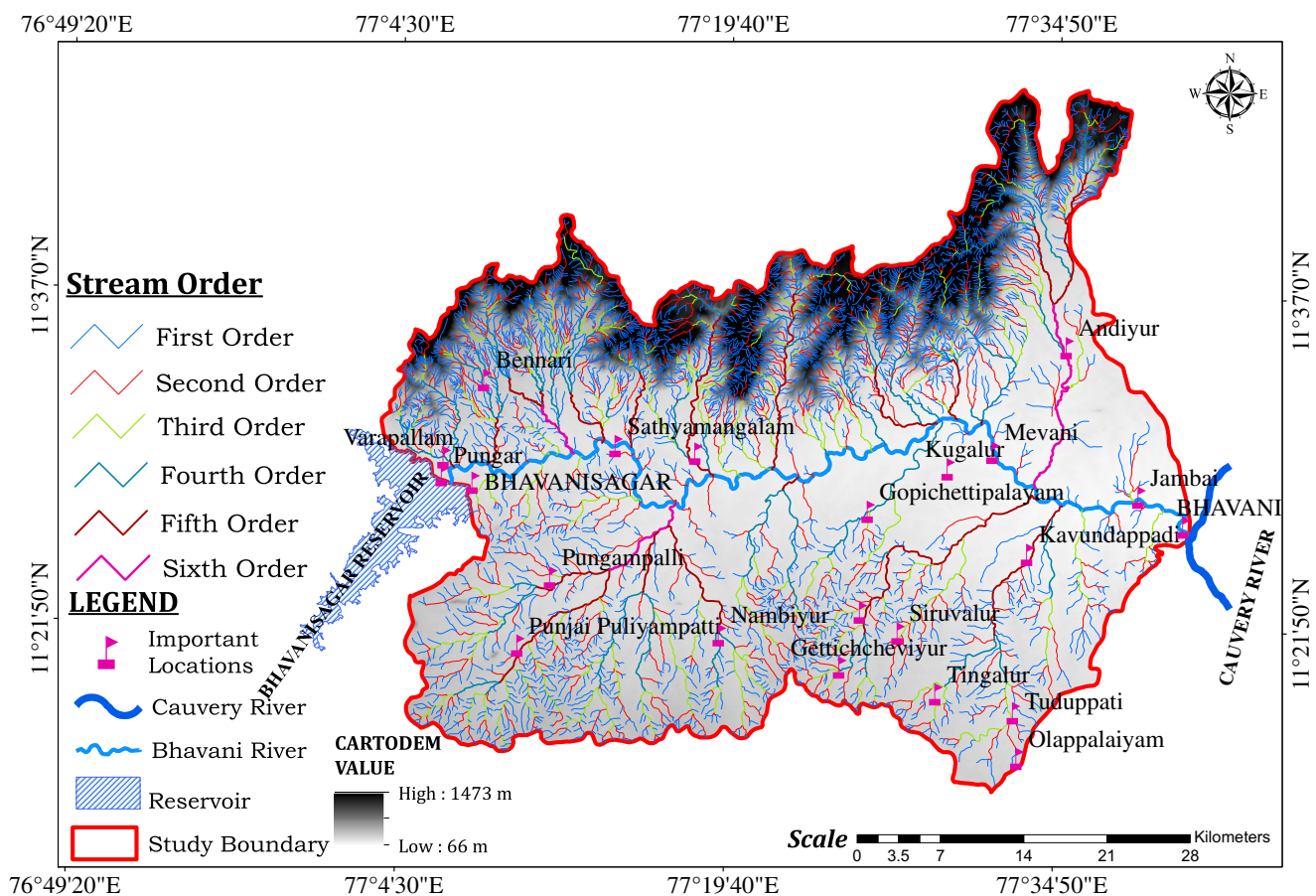


Fig. 4 Stream order map of lower Bhavani basin

Mean stream length

The stream length is a distinctive property of the drainage network. It is well associated with a basin of the watershed (Strahler 1964). Mean stream length reveals the characteristic property related to the size of drainage network components and its contributing basin surfaces (Khare et al. 2014). The drainage basin denotes that the mean stream length of a given order is greater than the lower order and lesser than the higher order. Stream length is obtained by dividing the stream length by the number of stream-order segments. The mean stream length is shown in Table 5. The range of stream length varies between 0.23 and 19.254 km. Subwatersheds 2–8, 10, 13, 17, 19, 21, 22, 24, and 26–28 indicate the mean stream length with higher-order streams. Such mean stream length is greater than that of lower order and less than that of its next higher order (Rudraiah et al. 2008). This significant variation of subwatersheds indicates a change in topographic elevation and slope for the basin.

Stream length ratio [R1]

Stream length ratio may be defined as the higher order of stream length divided by the next lower order stream segments as presented in Table 6. The stream length variation is attributed to the change in slope and topography which stand for the late youthful stage of geomorphic development of streams in the vicinity (Vitalla et al. 2008).

Bifurcation ratio

Bifurcation ratio is defined as the ratio of a number of stream segments of a given order to the number of segments of the next higher order (Schumn 1956). The bifurcation ratio varies with reference to region, environment, and lithology of an area (Strahler 1957). When the Rb value ranges from 3 to 5, the geology of the area does not have any control over the drainage pattern (Suresh 2007). The bifurcation ratio is also an indicator for the shape of the basin, where the elongated basin will have a high Rb value and circulatory basin will have a low Rb

Table 4 Stream length computation of subwatersheds

Serial No.	Subwatershed name	Area of SWS (km ²)	Stream length (km)						Total of stream length
			I	II	III	IV	V	VI	
1	SWS-1	47.08	77.35	25.97	8.56	16.76	0.65	–	129.29
2	SWS-2	43.17	78.04	29.96	7.52	15.07	5.08	–	135.67
3	SWS-3	93.75	183.96	53.98	28.22	24.78	6.22	5.87	303.03
4	SWS-4	72.85	127.25	37.11	28.83	17.64	6.37	–	217.2
5	SWS-5	22.03	45.41	14.13	4.49	2.65	7.33	–	74.01
6	SWS-6	95.86	154.52	44.85	34.57	16.18	17.42	–	267.54
7	SWS-7	13.11	15.72	12.46	6.26	–	–	–	34.44
8	SWS-8	109.66	226.19	78.73	36.36	10.94	17.08	–	369.3
9	SWS-9	12.01	11.98	8.17	7.94	0.72	–	–	28.81
10	SWS-10	9.64	14.28	7.67	4	–	–	–	25.95
11	SWS-11	7.86	7.2	7.3	8.17	–	–	–	22.67
12	SWS-12	15.05	21.79	9.31	0.86	8.98	–	–	40.94
13	SWS-13	71.59	158.15	50.5	36	21.34	10	–	275.99
14	SWS-14	8.83	8.53	10	3.12	4	–	–	25.65
15	SWS-15	27.23	56.13	22	8.24	4.43	6.29	–	97.09
16	SWS-16	66.98	108.95	34.35	24.69	13.36	0.37	–	181.72
17	SWS-17	253.2	284	92.15	51.42	34.41	20.26	19.254	501.494
18	SWS-18	10.69	6.38	5.56	5.88	0.23	–	–	18.05
19	SWS-19	19.71	15.39	15.11	6.03	–	–	–	36.53
20	SWS-20	5.44	3.09	2.99	1.2	–	–	–	7.28
21	SWS-21	27.92	27.45	15.47	8.7	–	–	–	51.62
22	SWS-22	455.6	377.81	164.67	107.06	41.9	39.25	9.17	739.86
23	SWS-23	80.51	57.82	34.06	14.44	22	1.68	–	130
24	SWS-24	62	32.53	14.81	15.19	18.51	–	–	81.04
25	SWS-25	159.89	109	66.26	36.04	9.1	25.37	–	245.77
26	SWS-26	194.81	119.71	55.54	25.19	19.37	14	–	233.81
27	SWS-27	42.52	29.06	9.55	9.24	–	–	–	47.85
28	SWS-28	13.78	5.89	4.45	5.26	–	–	–	15.6
29	SWS-29	42	14.67	6.21	1.34	–	–	–	22.22
Total		2084.77	2378.25	933.32	534.82	302.37	177.37	34.294	4360.424
Percentage (%)			54.54	21.4	12.27	6.93	4.07	0.79	100

value (Khare et al. 2014). Table 7 shows the Rb values for the study area. In the present study, the Rb values of the basin indicate a uniform decrease in (SWS-6, SWS-7, SWS-9, SWS-11, SWS-14, SS-17, 19, 20, SWS-23, and SWS-27) from one order to the next order; whereas, in other subwatersheds, the Rb values are not the same from one order to the next. This variation may be attributed to the geological and lithological developments of the basin, and further, the higher value 6.2 is noted in subwatershed 16, indicating a strong structural control over the subwatershed and lower value of 0.8 is noted in

subwatershed 2, indicating that the watershed is prone to less structural disturbances (Vittala et al. 2008).

Mean bifurcation ratio

Mean bifurcation is defined as the average of bifurcation ratio of all orders. The mean bifurcation ratio (Rbm) ranges between 3.0 and 5.0 for a basin, and the influence of geological structures is significant on the drainage network that is negligible (Strahler 1964). The values are shown in Table 7. The

Table 5 Mean stream length computation of subwatersheds

Serial No.	Subwatershed name	Area of SWS (km ²)	Mean stream length (km)					
			I	II	III	IV	V	VI
1	SWS-1	47.08	0.581	0.838	0.951	3.352	0.65	–
2	SWS-2	43.17	0.703	1.033	1.89	3.014	5.08	–
3	SWS-3	93.75	0.732	0.999	1.086	4.13	3.11	5.87
4	SWS-4	72.85	0.691	0.79	1.601	3.528	6.37	–
5	SWS-5	22.03	0.553	0.743	1.122	1.325	7.33	–
6	SWS-6	95.86	0.722	0.773	2.033	2.697	4.356	–
7	SWS-7	13.11	0.604	2.492	6.26	–	–	–
8	SWS-8	109.66	0.678	0.796	1.819	2.189	4.28	–
9	SWS-9	12.01	0.704	1.634	3.98	0.72	–	–
10	SWS-10	9.64	0.8925	1.918	4	–	–	–
11	SWS-11	7.86	0.553	1.826	4.086	–	–	–
12	SWS-12	15.05	0.544	0.931	0.43	8.99	–	–
13	SWS-13	71.59	0.61	0.731	3	5.336	10	–
14	SWS-14	8.83	0.533	2	1.57	4	–	–
15	SWS-15	27.23	0.59	0.957	0.916	1.477	6.3	–
16	SWS-16	66.98	0.644	1.109	4.939	4.453	0.38	–
17	SWS-17	253.2	0.609	0.903	2.142	4.916	10.13	19.254
18	SWS-18	10.69	0.638	1.39	2.94	0.23	–	–
19	SWS-19	19.71	0.57	3.022	6.03	–	–	–
20	SWS-20	5.44	0.516	1.496	1.2	–	–	–
21	SWS-21	27.92	0.808	1.933	8.7	–	–	–
22	SWS-22	455.6	0.799	1.383	3.059	4.656	7.86	9.17
23	SWS-23	80.51	0.65	1.549	2.407	11	1.69	–
24	SWS-24	62	0.774	1.646	3.798	18.51	–	–
25	SWS-25	159.89	0.59	1.228	3.277	3.033	25.37	–
26	SWS-26	194.81	1.06	1.916	4.199	6.457	14	–
27	SWS-27	42.52	1.118	1.91	9.24	–	–	–
28	SWS-28	13.78	0.49	0.89	5.26	–	–	–
29	SWS-29	42	1.63	1.552	1.34	–	–	–
Mean stream length			0.709	1.392	3.217	3.241	3.687	1.182

range of values varies from 6.125 to 2.167 for subwatersheds 21 and 18, respectively.

Areal aspects of the basin

Drainage density

Drainage density is the ratio of total length of all stream orders of a basin to the total area of the drainage basin (Horton 1932). The Dd gives the closeness of the spacing of the streams, and it depends upon the permeability of a subsurface material, vegetation types, and relief. The less Dd has normally ensued in highly permeable earth surface material and land covered with dense vegetation of low relief. Higher Dd is confined to impermeable subsurface material with sparse vegetation and high relief (Suresh 2007). In the

present study, the subwatersheds of Dd varies from 0.52 to 3.85 km/km² which represents that subwatersheds 29, 27, 28, 24, and 20 have low drainage density because of the presence of fractured, resistant permeable rocks in southern side of the basin and subwatersheds 13, 15, 8, 5, 2, and 3 have higher drainage density which indicates the subsurface strata is impermeable with high relief of coarse drainage pattern. Then, the rest of all subwatersheds lies in moderate drainage density category.

Stream frequency

The total number of stream segments for all stream order per unit area is referred as a stream frequency, and it is also known as channel frequency (Horton 1932). The stream frequency mainly depends on the lithology of

Table 6 Stream length ratio computation of subwatersheds

Serial No.	Subwatershed name	Area of SWS (km ²)	Stream length ratio (Rl)					
			II/I	III/II	IV/III	V/IV	VI/V	VII/VI
1	SWS-1	47.08	0.336	0.33	1.958	0.039	–	–
2	SWS-2	43.17	0.383	0.251	2.003	0.338	–	–
3	SWS-3	93.75	0.293	0.522	0.879	0.251	0.943	–
4	SWS-4	72.85	0.291	0.777	0.611	0.361	–	–
5	SWS-5	22.03	0.3111	0.318	0.59	2.767	–	–
6	SWS-6	95.86	0.29	0.77	0.469	1.077	–	–
7	SWS-7	13.11	0.792	0.502	–	–	–	–
8	SWS-8	109.66	0.349	0.461	0.3	1.561	–	–
9	SWS-9	12.01	0.681	0.971	0.09	–	–	–
10	SWS-10	9.64	0.538	0.521	–	–	–	–
11	SWS-11	7.86	1.013	1.12	–	–	–	–
12	SWS-12	15.05	0.428	0.092	10.441	–	–	–
13	SWS-13	71.59	0.32	0.712	0.592	0.469	–	–
14	SWS-14	8.83	1.172	0.312	1.282	–	–	–
15	SWS-15	27.23	0.391	0.374	0.537	1.419	–	–
16	SWS-16	66.98	0.315	0.719	0.541	0.028	–	–
17	SWS-17	253.2	0.324	0.559	0.67	0.589	0.96	–
18	SWS-18	10.69	0.871	1.058	0.04	–	–	–
19	SWS-19	19.71	0.981	0.4	–	–	–	–
20	SWS-20	5.44	0.968	0.401	–	–	–	–
21	SWS-21	27.92	0.563	0.562	–	–	–	–
22	SWS-22	455.6	0.436	0.65	0.391	0.937	0.233	–
23	SWS-23	80.51	0.59	0.423	1.523	0.077	–	–
24	SWS-24	62	0.456	1.026	1.219	–	–	–
25	SWS-25	159.89	0.608	0.543	0.252	2.788	–	–
26	SWS-26	194.81	0.463	0.453	0.769	0.722	–	–
27	SWS-27	42.52	0.329	0.968	–	–	–	–
28	SWS-28	13.78	0.756	1.182	–	–	–	–
29	SWS-29	42	0.423	0.216	–	–	–	–

the basin and reflects the texture of the drainage network. In the present study, the value of stream frequency (Fs) varies from 0.33 (SWS-29) to 4.9 km/km² (SWS-9), as shown in Table 8 which indicates that both low and high values of the drainage density and stream frequency of subwatersheds are positively correlated. A low value of stream frequency (0–2 km/km²) indicates low runoff and higher value (2–5 km/km²) indicates more runoff in the region.

Drainage texture

Texture ratio is the equal spacing of drainage lines of all orders of the stream segment. Drainage texture is measured by the number of stream segments of all orders existing as perimeter of the area. The Rt involves in natural factors are climate,

rainfall, vegetation, rock types, soil types, infiltration capacity, relief, and stage of development (Smith 1950). Following Smith (1950), the drainage density has been classified into five different classes of textures, very coarse (< 2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (> 8). In the present study, the drainage texture varies from 0.53 (SWS-29) to 8.73 (SWS-8) shown in Table 8, which indicates that subwatersheds are very coarse to coarse drainage texture. Therefore, Dd of subwatersheds 29, 26, 24, 27, 28, 20, 25, 23, 22, 18, 21, 19, and 17 are of very coarse drainages lying towards the southern side with less relief, are permeable in nature, and with high infiltration capacity; whereas, subwatersheds 13, 15, 8, 5, 3, 4, 14, 11, 6, 1, 12, 16, 10, 7, and 9 are of coarse drainage network lying in the northern side of the basin with high relief, are impermeable in nature, and of low infiltration capacity.

Table 7 Bifurcation and mean bifurcation ratio computation of subwatersheds

Serial No.	Subwatershed name	Bifurcation ratio (Rb)					Mean bifurcation ratio (Rbm)
		I/II	II/III	III/IV	IV/V	V/VI	
1	SWS-1	4.29	3.444	1.8	5	–	3.633
2	SWS-2	3.827	7.25	0.8	5	–	4.219
3	SWS-3	4.648	2.076	4.333	3	2	3.211
4	SWS-4	3.914	2.611	3.6	5	–	3.781
5	SWS-5	4.315	4.75	2	2	–	3.266
6	SWS-6	3.689	3.411	2.833	1.5	–	2.858
7	SWS-7	5.2	5	–	–	–	5.1
8	SWS-8	3.373	4.95	4	1.25	–	3.393
9	SWS-9	3.4	2.5	2	–	–	2.633
10	SWS-10	4	4	–	–	–	4
11	SWS-11	3.25	2	–	–	–	2.625
12	SWS-12	4	5	2	–	–	3.667
13	SWS-13	3.753	5.75	3	4	–	4.125
14	SWS-14	3.2	2.5	2	–	–	2.566
15	SWS-15	4.13	2.555	3	3	–	3.171
16	SWS-16	5.451	6.2	1.666	3	–	4.079
17	SWS-17	4.588	4.25	3.428	1.698	1.052	3.003
18	SWS-18	2.5	2	2	–	–	2.167
19	SWS-19	5.4	5	–	–	–	5.2
20	SWS-20	3	2	–	–	–	2.5
21	SWS-21	4.25	8	–	–	–	6.125
22	SWS-22	3.974	3.4	3.888	1.8	5	3.612
23	SWS-23	4.045	3.666	3	2	–	3.178
24	SWS-24	4.666	2.25	4	–	–	3.638
25	SWS-25	3.425	4.909	3.666	3	–	3.75
26	SWS-26	3.896	4.833	2	3	–	3.432
27	SWS-27	5.2	5	–	–	–	5.1
28	SWS-28	2.4	5	–	–	–	3.7
29	SWS-29	2.25	4	–	–	–	3.125

Form factor

Form factor was calculated by the ratio of the basin area to the square of the basin length and is defined as the shape of the basin (Schumn 1956). The value of form factor should be always greater than 0.7854, indicating that the basin is perfectly circular (Rai et al. 2014) and whereas lower values of form factor indicates elongated subwatersheds. In the present study, the Ff values varies from 0.11 to 0.92, as shown in Table 8, suggesting that 28 subwatersheds represented the elongated shape with lower peak flows for the longer duration. Whereas, SWS-22 is of higher Ff values which indicates a nearly circular watershed with a higher peak flow of shorter duration.

Shape factor

Shape factor is the ratio of the square of the basin length to the area of the basin (Horton 1945). The parameters such as basin

shape, form factor, circularity ratio, elongation ratio, and compactness coefficient have a correlation with the shape factor. The Fs for the study area (Table 8) ranges between 1.07 for subwatershed 22 and 6.67 for subwatershed 24. The present study demonstrates the shape of subwatersheds shown in Fig. 5 where subwatersheds vary from circular to elongate in shape.

Circularity ratio

Circularity ratio is the ratio of the basin area to the area of a circle that has the same perimeter as the basin (Miller 1953). The parameter mainly considers that the variation of circularity ratio mainly depends on length and frequency of stream, geological structures, land use/land cover, climate, relief, and slope of the basin. The subwatersheds with less than 0.5 will have an elongated basin while values greater than 0.5 will be more or less a circular shape indicative of a structurally

Table 8 Areal and relief aspects of morphometric parameters

Serial No.	Subwatershed name	Drainage density (Dd)	Stream frequency (Fs)	Drainage texture (Rt)	Form factor (Rf)	Shape factor (Fs)	Elongation ratio (Re)	Compactness coefficient (Cc)	Length of overland flow (Lg)	Relief ratio (Rh)
1	SWS-1	2.74	3.8	5.36	0.32	3.04	0.53	0.64	1.37	110.35
2	SWS-2	3.14	3.47	4.7	0.25	3.99	0.53	0.56	1.36	89.8
3	SWS-3	3.03	3.47	6.4	0.32	3.04	0.43	0.64	1.51	70.82
4	SWS-4	2.98	3.5	5.18	0.19	5.17	0.37	0.49	1.62	73.82
5	SWS-5	3.35	4.9	3.98	0.2	4.9	0.37	0.5	1.62	140.67
6	SWS-6	2.79	3.11	6.23	0.37	2.67	0.52	0.6	1.38	92.23
7	SWS-7	2.62	2.44	1.66	0.37	2.66	0.44	0.69	1.49	192.37
8	SWS-8	3.36	4.21	8.73	0.31	3.13	0.49	0.63	1.42	77.02
9	SWS-9	2.39	2.08	1.55	0.24	4.03	0.58	0.56	1.31	113.21
10	SWS-10	2.69	2.17	1.48	0.26	3.73	0.6	1.83	1.28	107.33
11	SWS-11	2.88	2.41	0.91	0.11	8.76	0.23	1.19	2.08	102.53
12	SWS-12	2.72	3.52	2.05	0.15	6.48	0.28	1.39	1.87	119.02
13	SWS-13	3.85	4.81	7.11	0.36	2.71	0.38	2.15	1.61	101.79
14	SWS-14	2.9	2.71	1.37	0.3	3.22	0.36	1.97	1.65	91.01
15	SWS-15	3.56	4.81	3.88	0.22	4.44	0.3	1.68	1.82	103
16	SWS-16	2.71	3.12	5.1	0.33	3.01	0.5	2.04	1.41	96.97
17	SWS-17	1.98	2.38	5.34	0.22	4.35	0.24	1.69	2	44.26
18	SWS-18	1.68	1.59	1.18	0.3	3.26	0.64	1.96	1.24	49.32
19	SWS-19	1.85	1.67	1.65	0.35	2.79	0.61	2.12	1.27	39.35
20	SWS-20	1.33	1.65	0.89	0.38	2.62	0.66	0.69	1.22	48.14
21	SWS-21	1.84	1.54	1.7	0.47	2.11	0.55	2.43	1.34	26.95
22	SWS-22	1.62	1.4	6.5	0.92	1.08	0.58	1.08	1.31	20.09
23	SWS-23	1.61	1.49	2.89	0.28	3.5	0.58	1.89	1.3	16.37
24	SWS-24	1.3	0.9	1.24	0.14	6.67	0.38	1.37	1.6	11.25
25	SWS-25	1.53	1.58	4.06	0.26	3.79	0.51	1.82	1.39	10.39
26	SWS-26	1.2	0.78	2.31	0.26	3.7	0.56	1.84	1.32	8.96
27	SWS-27	1.12	0.75	0.92	0.18	5.29	0.44	1.54	1.5	12.33
28	SWS-28	1.13	1.3	0.8	0.16	6.14	0.34	1.42	1.7	16.63
29	SWS-29	0.52	0.33	0.53	0.46	2.17	0.76	2.4	1.14	21.78

controlled basin. In this study, the values of Rc ranges from 0.23 to 0.76. Table 8 indicates that subwatersheds 3, 4, 5, 7, 8, 11, 12, 13, 14, 15, 16, 17, 24, 27, and 28 are elongated in shape; the remaining subwatersheds (1, 2, 6, 9, 10, 18, 19, 20, 21, 22, and 23) are more or less circular in shape. The circular subwatershed indicates high infiltration over the area, where it takes a longer time to reach the basin outlet.

Elongation ratio

Elongation ratio is the ratio of the diameter of the circle which represents the area of the basin to its length (Schumm 1956). The value of elongation ratio normally differs from 0.6 to 1.0 over a wide variety of climatic and geological conditions. The elongation ratio that is greater than 1.0 indicates low relief whereas 0.6 to 0.9

indicate high relief and steep ground slope (Strahler 1964). These values are grouped in three categories: circular (> 0.9), oval ($0.9-0.8$), and less elongated (< 0.7). Elongation ratio for the study area varies from 0.49 to 2.43. Therefore, the higher elongation ratio shows high infiltration rate and low runoff whereas lower values were characterized by low infiltration and high runoff where the basin experiences the semi-arid climatic conditions with an impervious geological nature.

Compactness coefficient

Compactness coefficient was calculated as a ratio of basin perimeter divided by the circumference of the circle of the area of a particular subwatershed. The compactness ratio is also known as Gravelius Index (GI).

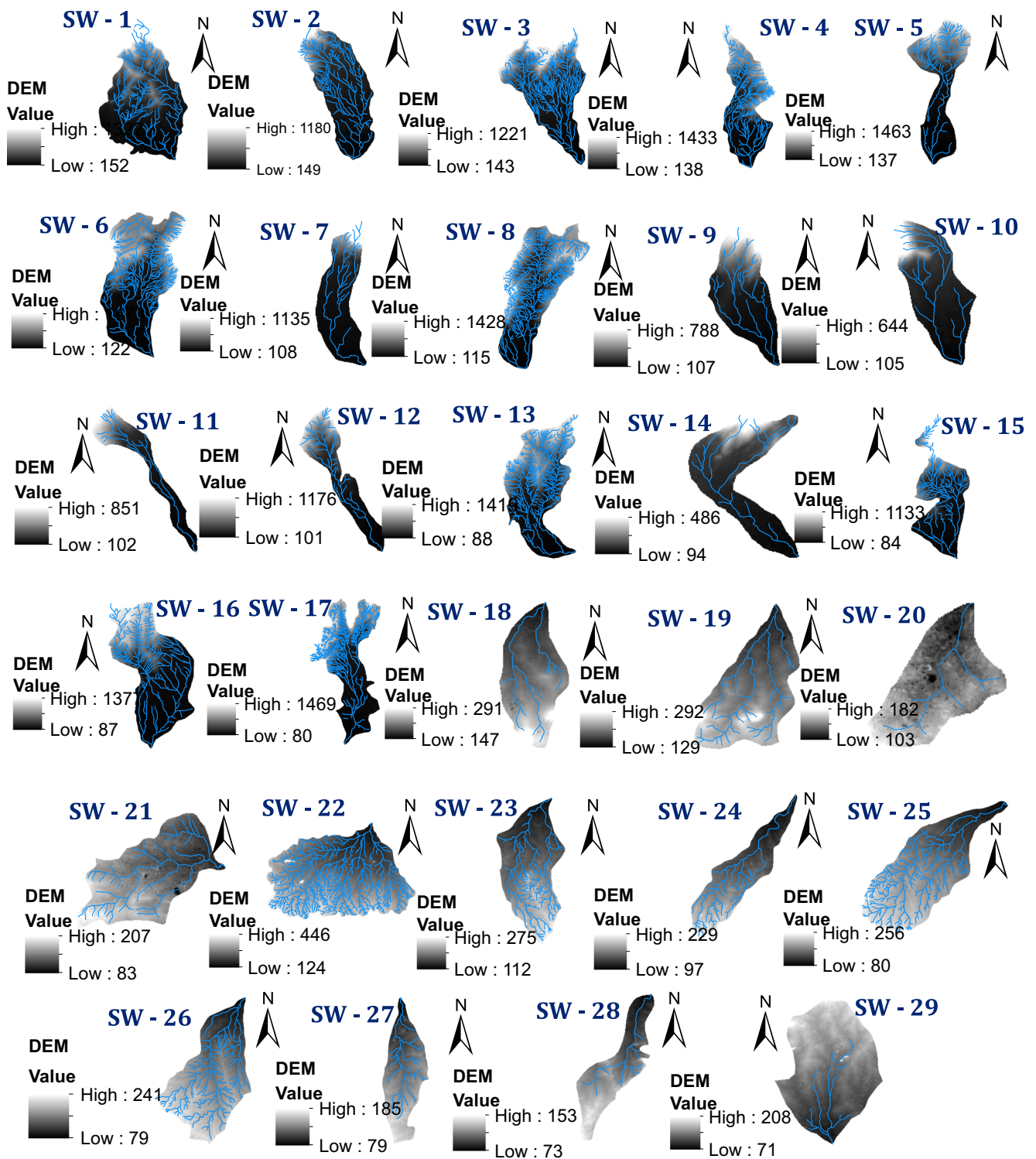


Fig. 5 Subwatershed of Carto DEM with drainages

Compactness coefficient equals 1 indicates basin as circular and greater than 1 indicates more deviation from circular and considered an elongated basin. The value of Cc ranges from 2.08 to 1.14 shown in Table 8, which indicates all the subwatersheds, belongs low to high elongated subwatersheds.

Length of overland flow

The water that flows in the ground before it gets concentrated into a definite stream channel is termed as length of overland flow (Horton 1945). Length of overland flow indirectly relates to the average channel slope. It is an important independent

factor which affects the hydrologic and physiographic developments of the drainage basin. The overland flow of the study area ranges from 0.51 to 3.78, as shown in Table 8. The values are higher in the southern region, which indicates the low relief whereas lower values are observed in the northern side of a basin with high relief and rapid runoff process for subwatersheds 13, 5, 8, and 10.

Relief aspects of the basin

Relief ratio

The relief ratio is the total relief of the basin divided by the length of the basin. According to Schumn (1956), relief and gradient of channels have a direct relationship with the hydrological characteristics of the drainage basin. The relief ratio generally increases with decreasing drainage area and size of the watersheds of a drainage basin (Gottschalk 1964). In the present study, the value of relief ratio varies from 192.37 to 8.96, as shown in Table 8. The northern side of the basin replicates a higher relief ratio of a steep slope, and the southern side of the basin replicates a lower relief ratio of gentle slope areas. The higher steepness of slope is

an indicator of intense soil erosion of the watersheds, and lower relief indicates the resistant basement rocks. From this observation, subwatershed 7 was identified as having a very high relief and 26 with a low relief, while the rest of the subwatersheds indicate a high to moderate relief of the basin.

Prioritization of subwatershed

Compound parameter

Prioritization of subwatershed was attempted from the compound parameter. The compound factor can be calculated by summing the ranks of linear and shape parameters and then dividing by the number of parameters (Patel et al. 2012). During subwatershed prioritization, higher ranks were assigned to subwatershed with the lowest compound factor and vice versa. In the present study, subwatershed 4 gets prioritized with rank 1 whose compound factor is 11.4 and the subwatershed with the highest compound factor value at 19.8 (subwatershed 29) was assigned with the lowest rank. The lower value of the compound factor was probably possible for soil erosion. Based on the observation, the prioritization

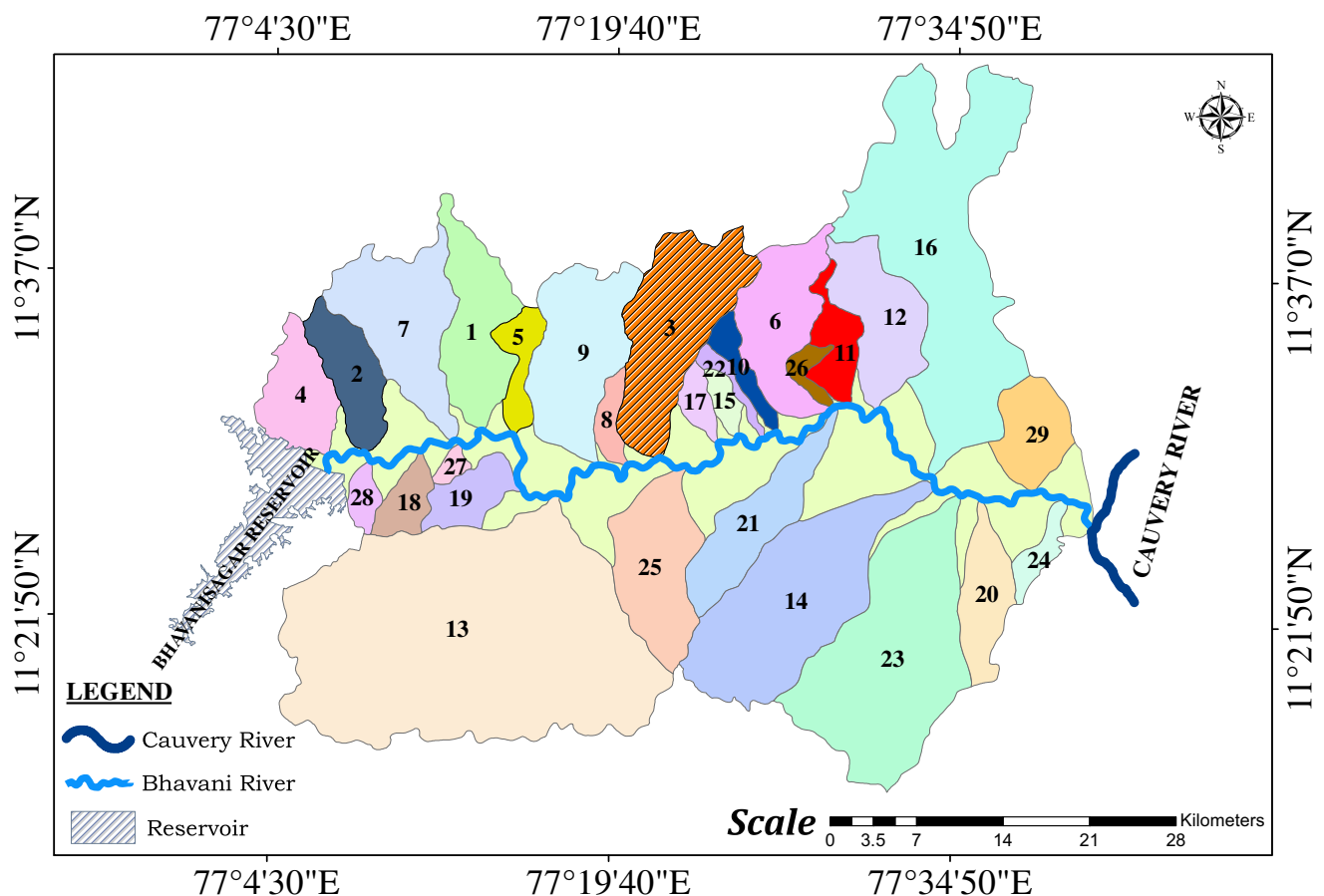


Fig. 6 Prioritized subwatershed and its priority rank

Table 9 Estimation of compound factor with priority ranking

Serial No.	Subwatershed name	Rbm	Dd	Fs	Rt	Lg	Ff	Fs	Re	Cc	Rc	Compound factor	Prioritized ranks
1	SWS-1	14	11	5	6	19	19	10	7	12	18	12.1	4
2	SWS-2	5	5	8	10	25	11	19	3	11	19	11.6	2
3	SWS-3	19	6	9	4	24	20	11	8	19	11	13.1	7
4	SWS-4	9	7	7	8	23	6	24	1	22	7	11.4	1
5	SWS-5	18	4	1	12	26	7	23	2	23	8	12.4	5
6	SWS-6	24	10	11	5	20	24	6	5	13	17	13.5	9
7	SWS-7	3	15	13	18	15	25	5	9	17	12	13.2	8
8	SWS-8	17	3	4	1	28	18	12	6	16	14	11.9	3
9	SWS-9	25	16	17	20	14	10	20	4	7	22	15.5	17
10	SWS-10	7	14	16	21	16	12	17	20	5	25	15.3	15
11	SWS-11	26	9	14	26	21	1	29	12	29	1	16.8	22
12	SWS-12	12	12	6	16	17	3	27	14	27	3	13.7	10
13	SWS-13	6	1	2	2	29	23	7	27	21	9	12.7	6
14	SWS-14	27	8	12	22	22	16	13	24	24	6	17.4	26
15	SWS-15	21	2	3	13	27	8	22	17	26	4	14.3	11
16	SWS-16	8	13	10	9	18	21	9	25	15	15	14.3	12
17	SWS-17	23	17	15	7	13	9	21	18	28	2	15.3	16
18	SWS-18	29	20	20	24	10	17	14	23	3	27	18.7	28
19	SWS-19	2	18	18	19	12	22	8	26	4	26	15.5	18
20	SWS-20	28	24	19	27	6	26	4	10	2	28	17.4	27
21	SWS-21	1	19	22	17	11	28	2	29	10	20	15.9	19
22	SWS-22	15	21	24	3	8	29	1	11	8	23	14.3	13
23	SWS-23	20	22	23	14	9	15	15	22	6	24	17	25
24	SWS-24	13	25	26	23	5	2	28	13	20	10	16.5	21
25	SWS-25	10	23	21	11	7	13	18	19	14	16	15.2	14
26	SWS-26	16	26	27	15	4	14	16	21	9	21	16.9	23
27	SWS-27	4	28	28	25	2	5	25	16	18	13	16.4	20
28	SWS-28	11	27	25	28	3	4	26	15	25	5	16.9	24
29	SWS-29	22	29	29	29	1	27	3	28	1	29	19.8	29

of eight subwatersheds with higher degree of slope was severely prone to soil erosion (SWS-4, SWS-2, SWS-8, SWS-1, SWS-5, SWS-13, SWS-3, SWS-7), and the remaining 21 subwatersheds were taking place in the low-lying area that could be developed as sustainable watersheds. Even though the compactness coefficient for SWS-11 is high, it is not prone to erosion because of the least number of stream network, low drainage density, and basin relief. The graphical representation of prioritization and compound factor are depicted in Fig. 6, and Table 9 explored the quantitative results.

Conclusion

In this research, the quantitative morphometric analysis was done with the help of a topographical maps, CartoDEM

data, and IRS-LISS III data. Therefore, the remote sensing and GIS techniques were more efficient to understand the morphological characteristics of the individual subwatershed. The linear, areal, and relief aspects demonstrated the hydrologic behavior of the watershed, and their characteristics were very useful to illustrate the prioritization of each subwatersheds. In the present study, 29 subwatersheds have been considered for the analysis. The stream ordering of subwatersheds went up to 6th order. The relief and slope aspects of morphometric parameters affected the development of stream segments. The total number of 4646 stream segments was identified, and they are categorized as 1st order (74.34%), 2nd order (18.53%), 3rd order (4.9%), 4th order (1.58%), 5th order

(0.59%), and 6th order (0.06%). Incidentally, the 1st order recorded 54.54% of the stream length whereas the 6th order had only 0.79% of the stream segments. The bifurcation results showed that the basin has a good structural control. Most of the watersheds are elongated in shape. The drainage density varies from 0.52 to 3.85 km². This suggests that the soil is low to medium permeable and the texture is coarse (Patel et al. 2012). Furthermore, the novel and quantitative approach were done for prioritization of subwatersheds most possible for soil erosion conservative measures. The identified subwatersheds need to be ensued immediate remediation for soil and water conservation for the purpose of efficient watershed management planning. This subwatershed prioritization study was quiet useful as a resource planner, decision maker, or any government, private agency who attempt to take up soil conservation measures or fixation of water harvesting structures in the Lower Bhavani region of Erode district in Tamil Nadu.

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