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Watershed prioritization using morphometric parameters in some part of Painganga River sub-basin, Maharashtra, India

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Abstract
The study area is a part of Painganga River basin in the Chandrapur district of Maharashtra. It extends between 19°48'56"N and 79°03'43"E, 19⁰48'21"N and 79°0'2"E & 19°44'43"N and 78°52'59"E. It falls on the Survey of India toposheet no. 56 M/1, 56 M/2, 56 I/13 and 56 I/14on 1:50,000 scale. Geologically, the study area is covered by Limestone/shale with limestone bands towards northern part and Deccan lava flows towards southern part. Geomorphologically study area is covered by alluvial plain on the northern part, pediplain on the central part, plateau and denudational hills on the southern part. The whole catchment is divided into five smaller units, as sub-watersheds SW-1, SW-2, SW-3, SW-4 and SW-5. Based on the morphometry, the sub-watersheds have been grouped into three categories, as per priority needs, high priority, medium priority and low priority. SW-1 shows medium priority and remaining SW-2, SW-3, SW-4 and SW-5 shows low priority respectively.

Keywords: prioritization, Painganga River, remote sensing and GIS

Introduction

According to (Desta *et al*., 2005) [7], any surface area from which runoff resulting from rainfall is collected and drained through a common confluence point is termed as watershed. Watershed characteristics such drainage, landforms, slope, soils, and land use land cover along with rainfall effect the status of soil erosion and which need to be evaluated for prioritization of sub basin and to execute water and soil conservation measures (Reddy et. al., 2004; Manjare, *et al*., 2018; Shrivatra *et al*., 2021a) [31, 22, 35]. Since, land and water resources are limited and their wide utilisation is imperative, especially for countries like India, where the population pressure is increasing continuously. The resource development programmes are applied generally on watershed basis and thus prioritization is essential for proper planning and management of natural resources for sustainable development (Manjare et. al., 2020; Shrivatra *et al*., 2021b) [23, 36]. Therefore, watershed management is aimed to protect the environment and enhancing food security (Kumar and Palanisami, 2009) [13].

The morphometric assessment helps to elaborate a primary hydrological diagnosis in order to predict approximate behaviour of a watershed if correctly coupled with geomorphology and geology (Esper, 2008) [9]. Watershed prioritization is the ranking of different critical sub watersheds according to the order in which they have to be taken up for the treatment by soil and water conservation measures. A particular sub-watershed may get top priority due to various reasons but often the intensity of land degradation is taken as the basis. In the absence of sediment yield data or ungauged watershed situations, geomorphologic parameters along with the satellite based land use / land cover information of watershed may be helpful in prioritization of the sub watersheds. Morphometric analysis and prioritization of watersheds are very important for water resource modeller and flood management (Youssef *et al*., 2011; Miller and Craig Kochel, 2010; Bali *et al*. 2012; Manjare et. al., 2014) [47, 25, 4, 16]. The morphometric analysis is very much useful in dealing with where information accessibility is limited data and other resources, and high soil variety (Meshram *et al*. 2020; Sangma and Guru 2020; Rahmati *et al*. 2019; Manjare *et al*. 2019) [24, 32, 29, 19].

The proper management needs utilization of lands, water and soil resources of a watershed for optimum production with minimum hazard to natural resources. Morphometric analysis can be used for prioritization of sub watersheds by studying different linear, areal and relief aspects of the watershed (Biswas et. al., 1999) [5]. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Agarwal CS, 1998; Reddy et. al., 2002; Iqbal M, Sajjad H, 2014) [2, 31, 12]. The morphometric characteristics at the watershed scale may contain important information regarding its formation and development because all hydrologic and geomorphic processes occur within the watershed (Singh, S., 2007) [38]. It is also found to be of immense utility in watershed prioritization and conservation of natural resources at watershed level (Manjare et. al., 2017; Manjare, *et al*., 2018) [17, 19]. Remote sensing and GIS techniques are now a day used for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as they provide a flexible environment and a powerful tool for the manipulation and analysis of spatial information (Iqbal M, Sajjad H, 2014; B.S. Manjare et. al., 2016) [12, 18].

Study Area

The study area falls in Chandrapur district of Maharashtra which is located in Survey of India 1:50,000 scale toposheet no. 56 M/1, 56 M/2, 56 I/13 and 56 I/14 bounded by latitude and longitude 19°48'56"N and 79°03'43"E, 19⁰48'21"N and

79°0'2"E and 19°44'43"N and 78°52'59"E is in the Korpana taluka in Chandrapur district, Maharashtra. The Painganga River originates from Ajantha ranges in Aurangabad district in Maharashtra. The river enters in Korpana taluka at Kodsi village and it converging into Wardha River near a small village called Wadha in Chandrapur taluka of Chandrapur district and forms the small sub watershed (Fig. 1).

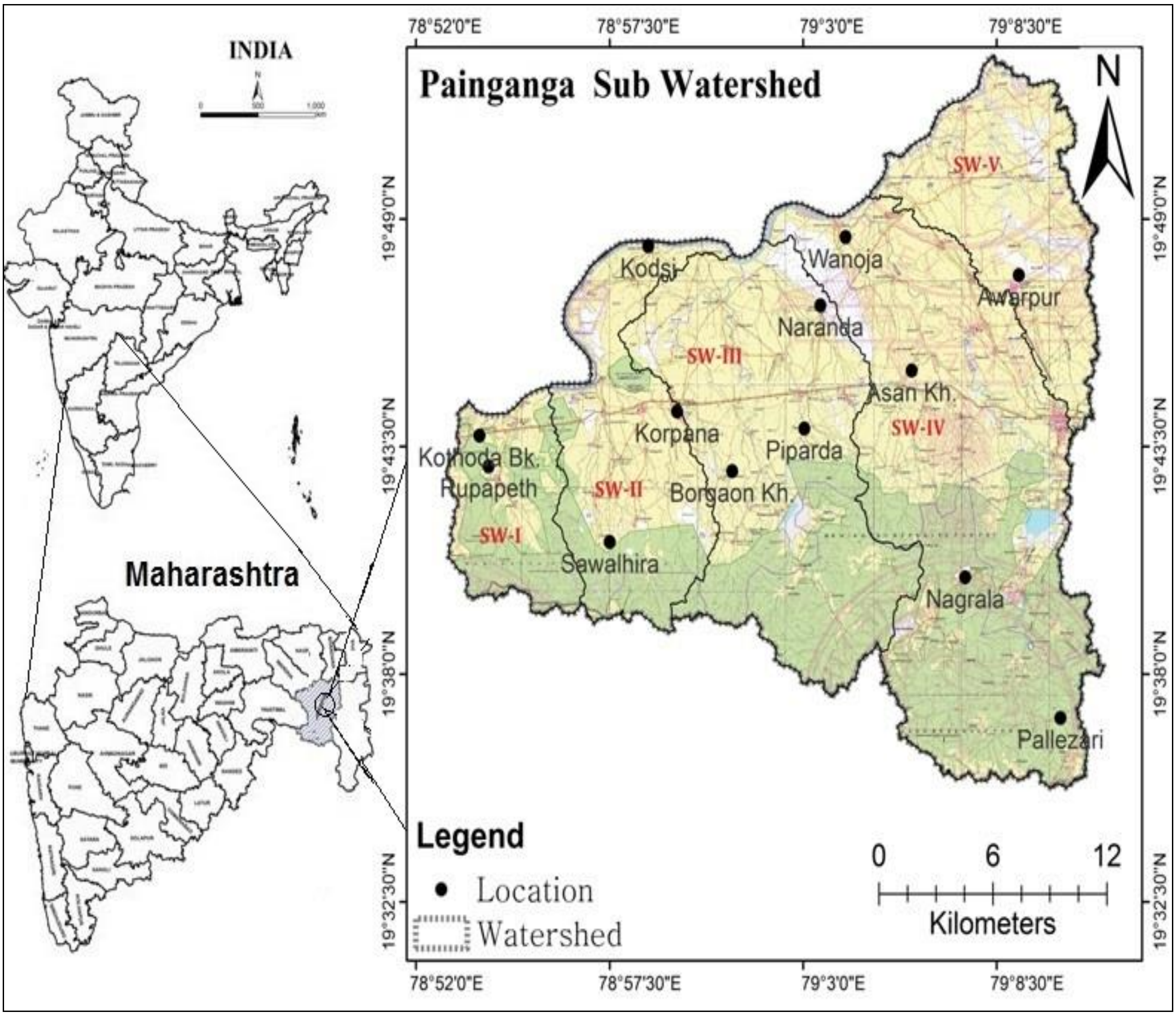

Fig 1: Topomosaic and location map of the study area

General Geology

The Vindhyan sediments, Lower Gondwana sediments, Deccan Traps, Alluvium and soil mainly constitute the geology of the area. The Geological map is been prepared from satellite data and DRM followed by field checks (Fig. 2). Geologically, the study area is underlain by Limestones of Penganga Group along the western extremity of the study area with dissected out crops along central, northern and eastern parts of watershed. Limestone-Shale sequence of Penganga Group is noticed in the remaining parts of watershed unconformably followed by Deccan basalts (A.P. Dharashivkar *et al*., 2014) [15].

Geology of the study area

Laterite

Laterite is rich in iron and aluminium oxides, formed by weathering. Laterites are commonly seen as over Deccan Traps. It is generally Reddish brown in colour and hard, thickness varies from a few cm. to 8 m. Laterite in the study area are seen in small patches towards southern part (Fig. 2).

Basaltic lava flow

The igneous activity during upper cretaceous period released tremendous outburst of volcanic energy resulting in the eruption of thick series of lava and associated pyroclastic materials. The basalt rock is solidified lava flow of upper Cretaceous to Eocean period. The Penganga group of rocks are overlain by the Deccan trap basaltic lava flows of Sahyadri Group with some patches of laterite (Upper Cretaceous to Paleogene age), which cover Nagrala and southern part of the study area. The Basaltic rock in the study area shows porphyretic to sub porphyretic in texture, compact and weathered (Fig. 2).

Sandstone/ shale

Sandstone is a sedimentary rock mainly made of sand or quartz grains while shale is a finely stratified sedimentary rock of silt and clay-size mineral particles. The colour of sandstone varies depending on its composition. Sandstone usually has a light colour since they are made of light-coloured minerals. Like sandstone, shale is also a very common type of sedimentary rock. It's typically grey in colour, but this colour can change depending on the presence of other minerals. In study area sandstone/shale can be seen in northern part (Fig. 2). In some area feldspathic arenites are sandstones are also observed which contain less than 90% quartz, and more feldspar than unstable lithic fragments, and minor accessory minerals. Feldspathic sandstones are commonly immature or sub-mature. In study area felspathic sandstone can be seen in northern part (Fig. 2).

Limestone/ shale

Limestone and shale with bands of limestone and shale are seen in the study area. In the study area the Penganga Limestone is greyish black, fine-grained, non-crystalline and moderate to highly indurated in nature. The shales are of white to grey in colour and soft in nature and can be seen northern, western and small portion of eastern part of the study area. Limestone is exposed around Sawalhira, Awarpur and Kodsi etc. villages. Limestone-Shale with Limestone Bands, which is exposed in Piparda, Korpana, Borgaon Kh. villages of the study area (Fig. 2).

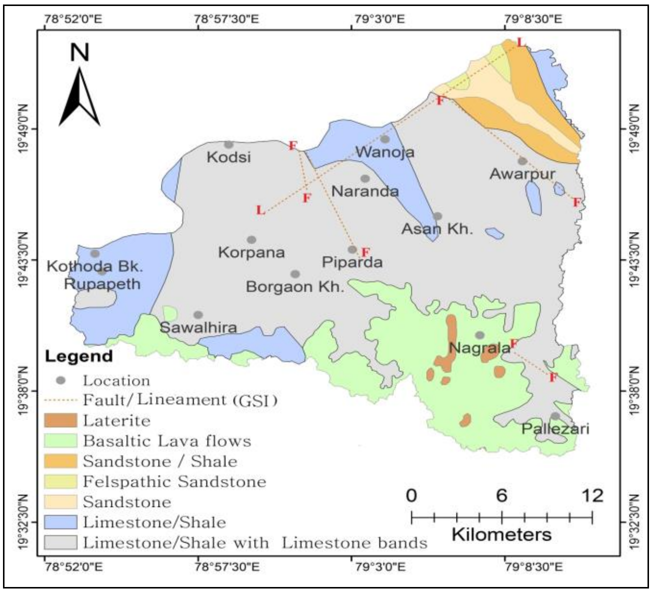

Fig 2: Geological map of study area (modified after GSI, 2000)

Geomorphology

The geomorphology map has been prepared by visual interpretation and field studies. In the study area, five major geomorphic units are present *viz*., denudational hills, plateau, pediments, pediplain, and alluvial plain.

Denudational hills

Denudational landforms are formed as a result of active processes of weathering, mass wasting and erosion due to the action of exogenic agents upon the exposed rocks. During these processes, the rocks on the land surface are worn away and the result is an overall lowering of the land surface. In the study area it covers southern and western part of watershed. It covers the area near Pallezari and Nagrala village (Fig. 3).

Plateau

A plateau is a flat, elevated landform that rises sharply above the surrounding area on at least one side. Plateaus occur on every continent and take up a third of the Earths land. They are one of the four major landforms, along with mountains, plains, and hills. In the study area it covers southern and western part of watershed. It is located in the area near Kusumbi, Dhanakdevi and Jiwati village (Fig. 3).

Pediments

A pediment is a gently sloping erosion surface or plain of low relief formed by running water in arid or semiarid region at the base of a receding mountain front. A pediment is underlain by bedrock that is typically covered by a thin, discontinuous veneer of soil and alluvium derived from upland areas. In the study area it is situated between hilly terrain/plateau and plains. It is located in the area near Nokari Bk., Sawalhira village (Fig. 3).

Pediplain

Pediplain is the broad, relatively flat rock surface formed by the joining of several pediments. Pediplains are usually formed in arid or semi-arid climates and may have a thin veneer of sediments. It is postulated that the pediplain may be the last stage of landform evolution, the final result of the processes of erosion. It covers central part of watershed and it is located in the near Borgaon Kh., Piparda village (Fig. 3).

Alluvial Plain

An alluvial plain is a largely flat landform created by the deposition of sediment over a long period of time by one or more rivers coming from highland regions, from which alluvial soil forms. As the highlands erode due to weathering and water flow, the sediment from the hills is transported to the lower plain. In the study area it covers northern part of watershed. It is located in the area near Kodsi, Wanoja, Awarpur village (Fig. 3).

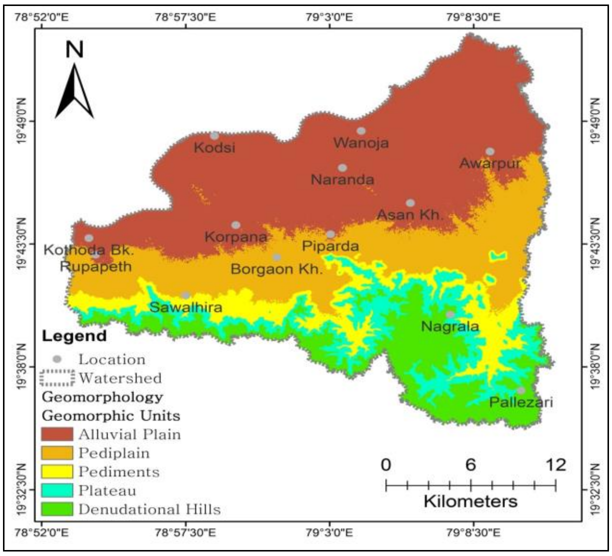

Fig 3: Geomorphological map of the study area

Data Used

The study area falls in Chandrapur district of Maharashtra which is located in Survey of India 1:50,000 scale toposheet no. 56 M/1, 56 M/2, 56 I/13 and 56 I/14 which were rectified through the software Arc-GIS 10.3.1 version. The Indian Remote Sensing Satellite IRS 1C Linear Imaging Self Scanner (LISS-III) image with 23.5m spatial resolution down loaded from the website BHUVAN (Fig. 4) and the Shuttle Radar Topography Mission (SRTM) digital data taken from the website United States Geological Survey (USGS) (Fig 5). The District Resource Map (DRM) have been procured from Geological Survey of India are used to delineate geology and geomorphology of the study area.

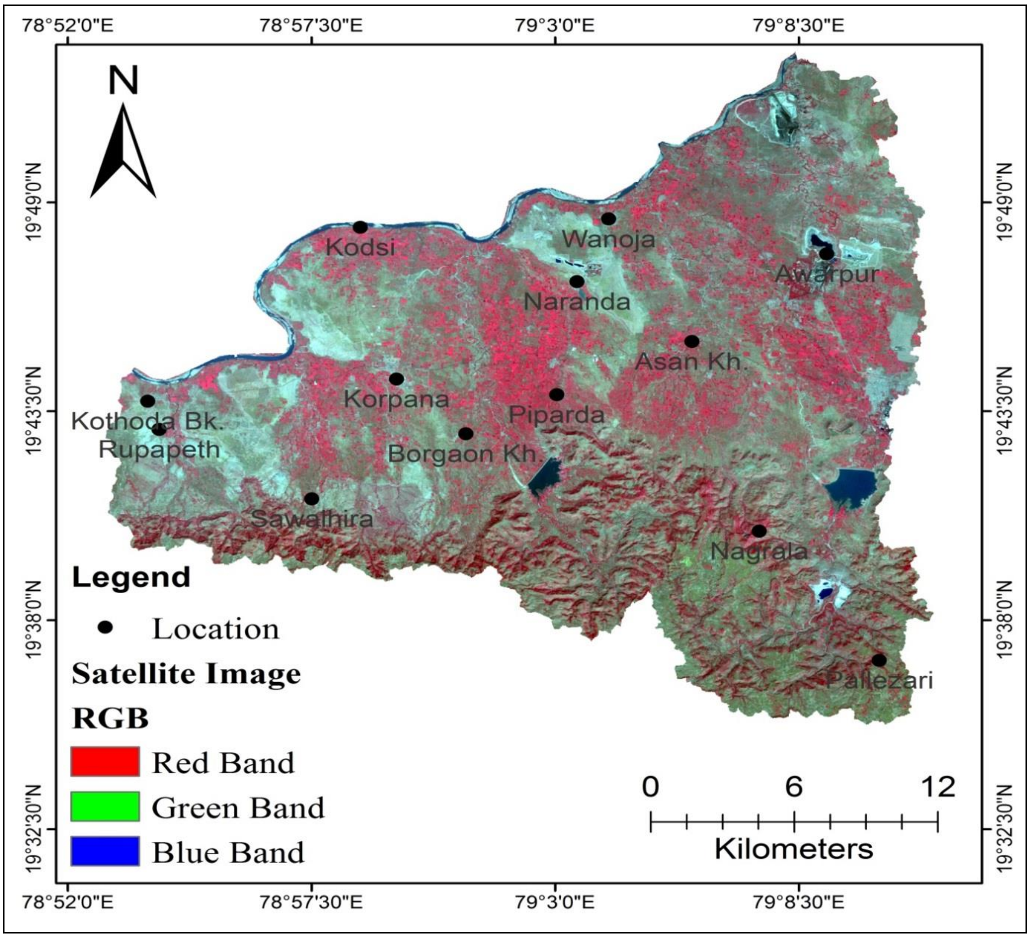

Fig 4: IRS LISS III satellite image of 23.5.mt. spatial resolution of the study area

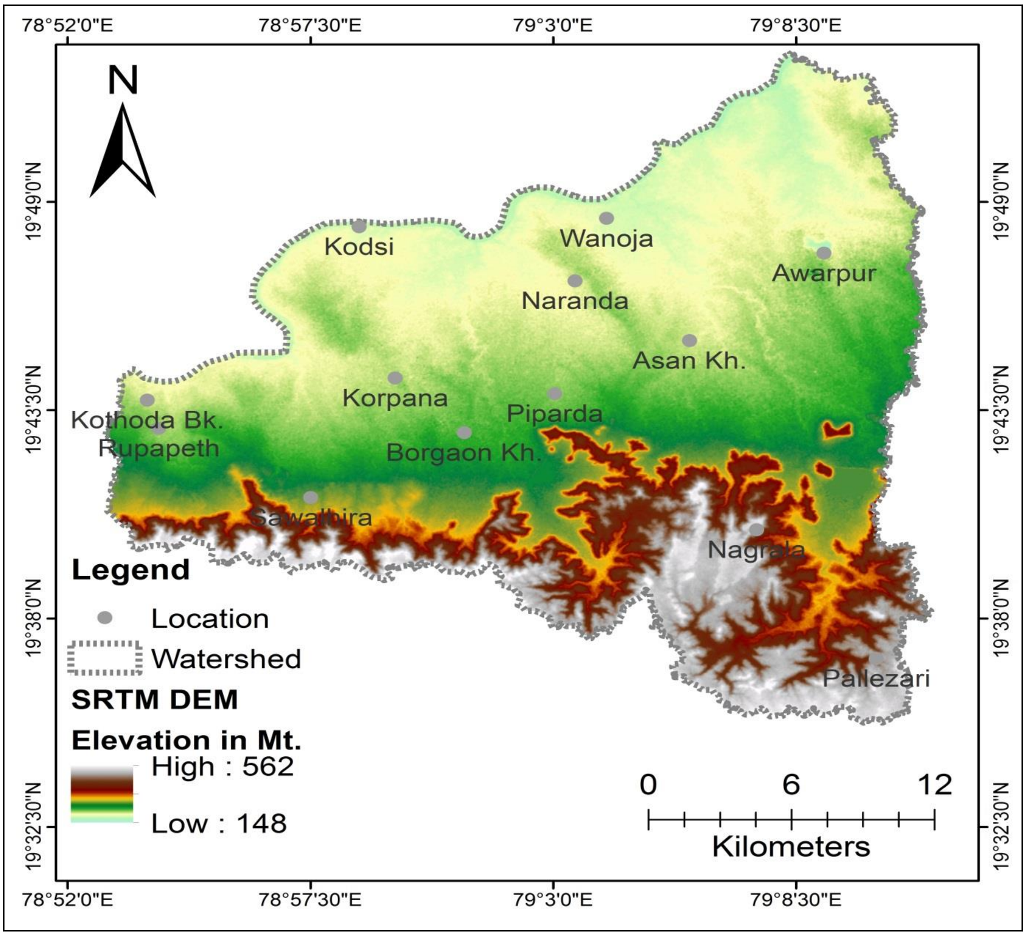

Fig 5: SRTM DEM of 30 mt. resolution map of the study area

Methodology

The toposheet taken from SOI has been rectified and mosaic using the software Arc GIS 10.3.1 version. IRS LISS -3 satellite data of 19 January 2019, and SOI toposheets were used to delineate geomorphic maps and geomorphic units were extracted from the satellite image by Digital Elevation Model (DEM) and incorporated into GIS database. The geological map was then used to delineate different types of rocks present in the area. The final layout of drainage and lithological map was prepared using the software Arc-GIS 10.3.1 version. The prioritization of all the five sub watersheds was carried out by calculating compound value (C_p) (Table 8). Sub watersheds with highest C_p were of low priority while those with lowest Cp were of high priority.

Morphometry

Table 1: Formulae adopted for computations of morphometric parameters

	Sr. no	Parameter	Symbol	Formula	Reference
Linear	1.	Stream Order	S_u	Hierarchical rank	Strahler (1952) [40]
	2.	Stream number	N_u	N_u=S1+S2+S3…Ln	Horton (1945) [11]
	3.	Stream Length	L_u	Length of the stream (kilometres)	Strahler (1964) [42]
	4.	Mean stream length	L_{sm}	$L_{sm}= L_u/N_u$ where, L_u= Total stream length of order 'u' N_u= Total no. of stream segments of order 'u'	Strahler (1964) [42]
	5.	Stream length Ratio	R_L	R_L= Lsm/Lsm-1 L_{sm}= Mean stream length of a given order and L_{sm}- 1 = Mean stream length of next lower order	Strahler (1964) [42]
	6.	Bifurcation Ratio	R_b	$R_b=N_u/N_u+1$ where, N_u=Total no. of stream segments of order 'u' N_u+1=Number of stream segments of the next higher order	Schumm (1956) [33]
	7.	Mean bifurcation ratio	R_{bm}	R_{bm}= Average of bifurcation ratio of all orders	Strahler (1964) [42]
	8.	Rho coefficient	ρ	$\rho = L_{ur}/R_b$	Horton (1945) [11]
Areal	9.	Basin perimeter (km)	P	P= Outer boundary of drainage basin measured in kilometres	Schumm (1956) [33]
	10.	Basin length (km)	L_b	$L_b = 1.312 \times A^{0.568}$ where, A = Area of the basin	Schumm (1956) [33]
	11.	Basin area (km2)	A	Area from which water drains to a common stream and boundary is determined by opposite ridges	Schumm (1956) [33]
	12.	Form factor (R_f< 1)	R_f	$R_f = A/L_b^2$ where, A= area of the basin (km^2) and L_b= basin length, km	Horton (1932) [10]
	14.	Drainage density	D_d	$D_d= L_u/A$ measured in (km/ km2) where, L_u = Total length of the stream (km) and A = Area of the basin in (km^2)	Horton (1932) [10]
	15.	Stream frequency	F_s	$F_s = N_u/A$ where, N_u = Total no. of stream segments of all orders and A = area of the basin (km^2)	Horton (1945) [11]
	16.	Drainage texture	D_t	$D_t= N_u/P$ where, N_u= Total no. of stream of all orders and P= basin perimeter measured in km	Horton (1945) [11]
	17.	Circulatory ratio (R_c≤ 1)	R_c	$R_C= 4\pi A/P^2$ where, A = area of the basin (km^2) and P= basin perimeter measured in km	Miller (1953) [25]
	18.	Elongation ratio	R_e	$R_e=2\sqrt{(A/\pi)}/Lb$, Where, A= Basin area, L= Basin length	Bull & Mc Fadden (1977) [6]
	19.	Constant of channel maintenance (km2/km)	CCM	CCM=1/D_d Where, D_d= drainage density	Schumm (1956) [33]
Relief	20.	Maximum height of the basin	Z	GIS analysis/DEM	
	21.	Height of basin mouth	z	GIS analysis/DEM	
	22.	Basin relief/ Relative relief (m)	H	H= Z-z where, Z= Maximum elevation of the basin (m) and Z= Minimum elevation of the basin (m)	Strahler (1952) [40]
	22.	Relief ratio	R_r	$R_r= H/L_b$ where, H = Basin relief and L_b= Length of basin	Schumm (1956) [33]
	23.	Ruggedness number	R_n	$R_n=D_d$*H where D_d= Drainage density and H= Basin relief (m)	Patton & Baker (1976) [27]

Linear Aspect

The linear aspects of morphometric analysis of basin include stream order, stream number, stream length, mean stream length, stream length ratio, rho coefficient and bifurcation ratio.

Stream Order (N_u)

Based on the hierarchic making of streams, the designation of stream order is the first step in morphometric analysis of a drainage basin (Strahler, 1957) [41]. Painganga River is allocated as 5th order stream. The stream order and stream number is presented in (Table 2). Out of five sub watersheds, SW-2 and SW-4 have 5th order stream, SW-1 have 3rd order stream while remaining SW-3 and SW-4 have 4th order stream.

Stream Length (L_u)

Stream length was calculated on the basis of the law proposed by (Horton, 1945) [11] for all five sub watersheds. Relatively, shorter the stream length is at area of steep slopes and finer texture, whereas longer the stream length is at area of gentle slope (Strahler, 1964) [42]. The stream length for all the five sub watersheds has been calculated (Table 2). In SW-3, 120.06 km length of 1st order, 87.48 km length of 2nd order, 17.22 km length of 3rd order, 27.58 km of 4th order and in SW-4, 158.02 km length of 1st order, 106.10 km length of 2nd order, 36.53 km of 3rd order, 12.82 km length of 4th order and 29.80 km length of 5th order. The irregularities of stream length in SW-3 between 3rd order and 4th order same for SW-4 between 4th order and 5th order indicates geological and morphological controls on river basin.

Table 2: Calculation of different Linear Morphometric Parameters of all five Sub Watersheds from the Study Area

Sr. No.	Sub Watershed Code	Basin Area (km^2)	Stream Order (S_u)	Stream Number (N_u)	Stream Length (L_u) (km)	Log N_u	Log L_u
1.	SW1	47.35	I II III IV V	38 9 2	41.45 21.22 5.77	1.57 0.95 0.30	1.61 1.32 0.76
2.	SW2	91.77	I II III IV V	97 22 8 4 1	66.99 46.79 21.08 5.60 4.15	1.98 1.34 0.90 0.60 0	1.82 1.67 1.32 0.74 0.61
3.	SW3	165.15	I II III IV V	315 38 7 2	120.06 87.48 17.22 27.58	2.49 1.57 0.84 0.30	2.07 1.94 1.23 1.44
4.	SW4	230.15	I II III IV V	199 53 10 3 1	158.02 106.10 36.53 12.82 29.80	2.29 1.72 1 0.47 0	2.19 2.02 1.56 1.10 1.47
5.	SW5	85.28	I II III IV V	153 20 7 2	71.92 28.49 11.35 9.95	2.18 1.30 0.84 0.30	1.85 1.45 1.05 0.99

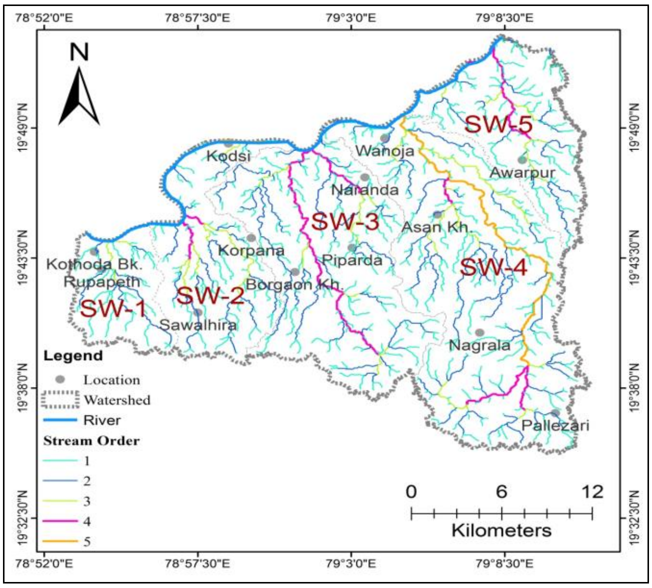

Fig 6: Drainage map of the study area

Mean Stream Length (L_{sm})

According to (Strahler, 1964) [42], mean stream length is the characteristic property of drainage network and associated surface. It is calculated by dividing the total length of streams of given order (L_u) to the total number of streams (N_u) (Mahala A, 2019) [14].

The mean stream length for all five sub watersheds has been calculated (Table 3). Low values in the upper reaches of sub watershed indicate young morphological development and high erosion potentiality.

The L_{sm} in the study area for SW-1 vary from 1.09 km to 2.88 km, SW-2 varies from 0.69 km to 4.15 km, SW-3 varies from 0.38 km to 13.79 km, SW-4 varies from 0.79 km to 29.80 km, and SW-5 varies from 0.47 km to 4.97 km. In SW-2, 1st order (0.69 km), 2nd order (2.12 km), 3rd order (2.63 km), 4th order (1.4 km), 5th order (4.15 km). The low value of L_{sm} for high order stream i.e., 1.4 km for 4th order in SW-2 is due to the fact that the streams fall within this order has stopped their channel lengthening much before than the lower order streams.

Stream Length Ratio (R_L)

According to (Horton, 1945) [11], stream length ratio is the ratio between mean stream length of one order to next lower order of the stream. Areas having mountain–plain front river basin have irregular tendency of stream-length ratio than regular plateau fringe river basin (Magesh and Chandrasekhar, 2014) [15]. The R_L value is calculated for all five sub watersheds (Table 3). The R_L in the study area for SW-1 starts with 2.15 for 1st to 2nd order and 1.22 for 2nd to 3rd order, for SW-2 starts with 3.07 for 1st to 2nd order, 1.24 for 2nd to 3rd order, 0.53 for 3rd to 4th order and 2.96 for 4th to 5th order, for SW-3 starts with 6.05 for 1st to 2nd order, 1.06 for 2nd to 3rd order and 5.60 for 3rd to 4th order, for SW-4 starts with 2.53 for 1st to 2nd order, 1.82 for 2nd to 3rd order, 1.16 for 3rd to 4th order and 6.97 for 4th to 5th order, for SW-5 starts with 3.02 for 1st to 2nd order, 1.14 for 2nd to 3rd order and 3.06 for 3rd to 4th order. The changes in the R_L between successive stream orders of the basin varies due to the differences in slope and topographic conditions (Adhikari S, 2020).

Table 3: Calculations of Mean Stream Length (L_{sm}) and Stream Length Ratio (R_L) for all five Sub Watersheds from the Study Area

Sr. No.	Sub Watershed Code	Mean Stream Length (L_{sm}) (km)					Stream Length Ratio (R_L)			
		I	II	III	IV	V	II/I	III/II	IV/III	V/IV
1.	SW1	1.09	2.35	2.88			2.15	1.22		
2.	SW2	0.69	2.12	2.63	1.4	4.15	3.07	1.24	0.53	2.96
3.	SW3	0.38	2.30	2.46	13.79		6.05	1.06	5.60	

4.	SW4	0.79	2.00	3.65	4.27	29.80	2.53	1.82	1.16	6.97
5.	SW5	0.47	1.42	1.62	4.97		3.02	1.14	3.06	

Bifurcation Ratio (R_b)

Bifurcation ratio is the ratio between total numbers of streams in a given order (N_u) to the number of next higher order (N_u+1) (Horton, 1945) [11]. The lower value of R_b show structurally less disturbed watersheds without any distortion in drainage pattern (Suji *et al*., 2015) [44]. The bifurcation ratio is calculated for all five sub watersheds (Table 4). The R_b value for SW-1 is 4.22 for 1st to 2nd order and 4.5 for 2nd to 3rd order, for SW-2 is 4.40 for 1st to 2nd order, 2.75 for 2nd to 3rd order, 2.00 for 3rd to 4th order and 4.00 for 4th to 5th order, for SW-3 is 8.28 for 1st to 2nd order, 5.42 for 2nd to 3rd order and 3.5 for 3rd to 4th order, for SW-4 is 3.75 for 1st to 2nd order, 5.3 for 2nd to 3rd order, 3.33 for 3rd to 4th order and 3.00 for 4th to 5th order, for SW-5 is 7.65 for 1st to 2nd order, 2.85 for 2nd to 3rd order and 3.5 for 3rd to 4th order. Based on R_b values, SW-3 and SW-5 have high values whereas remaining SW-1, SW-2 and SW-4 have low values. This implied that SW-3 and SW-5 are relatively more disturbed sub watersheds whereas SW-1, SW-2 and SW-4 are relatively sustainable sub watersheds.

Table 4: Calculations of Bifurcation Ratio (R_b) and Mean Bifurcation Ratio (Rb_m) for all five Sub Watersheds from the Study Area

Sr. No.	Sub Watershed Code	Bifurcation Ratio (R_b)				Mean Bifurcation Ratio (Rb_m)
		I/II	II/III	III/IV	IV/V	
1.	SW1	4.22	4.5			4.36
2.	SW2	4.40	2.75	2.00	4.00	3.28
3.	SW3	8.28	5.42	3.5		5.73
4.	SW4	3.75	5.3	3.33	3.00	3.84
5.	SW5	7.65	2.85	3.5		4.67

Rho Coefficient (ρ)

Rho coefficient (ρ) is the ratio between stream length ratio and bifurcation ratio and it is an important parameter to relate drainage density and the physiographic development of the basin, and allows the evaluation of the storage capacity of the drainage network (Horton 1945) [11]. The ρ is calculated for all five sub watersheds (Table 5), for SW-1 the ρ for 1st order is 0.50 and 0.27 for 2nd order, for SW-2 the ρ for 1st order is 0.69, 0.45 for 2nd order, 0.26 for 3rd order and 0.74 for 4th order, for SW-3 the ρ for 1st order is 0.73, 0.19 for 2nd order and 1.6 for 3rd order, for SW-4 the ρ for 1st order is 0.67, 0.34 for 2nd order and 3rd order, 2.32 for 4th order, for SW-5 the ρ for 1st order is 0.39, 0.4 for 2nd order and 0.87 for 3rd order. Here, ρ is higher at SW-2, SW-3, SW-4, SW-5, while lower at SW-1. This suggests that SW-2, SW-3, SW-4 and SW-5 have the highest storage capacity during floods and attenuation effects of erosion during elevated discharge.

Table 5: Calculations of Rho Coefficient (ρ) for all five Sub Watersheds from the Study Area

Sr. No.	Sub Watershed Code	Rho Coefficient (ρ)			
		I	II	III	IV
1.	SW1	0.50	0.27		
2.	SW2	0.69	0.45	0.26	0.74
3.	SW3	0.73	0.19	1.6	
4.	SW4	0.67	0.34	0.34	2.32
5.	SW5	0.39	0.4	0.87	

Areal Aspect

It deals with 2D parameters like basin shape and area, drainage density, drainage texture, stream frequency, elongation ratio, circularity ratio, and form factor.

Drainage Density (D_d)

Drainage density (D_d) is the total stream length in a given basin to the total area of the basin (Strahler, 1964) [42]. Over a wide range of geologic and climatic types, the low drainage density is more likely to occur in regions of highly permeable sub soil material under dense vegetative cover and where relief is low. In contrast high D_d is favoured in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief (Iqbal M, Sajjad H, 2014) [12]. The D_d is calculated for all five sub watersheds (Table 6) and it varies between 1.42 km/km^2 to 1.57 km/km^2. For SW-1 the D_d is 1.44 km/km^2, for SW-2 the D_d is 1.57 km/km^2, for SW-3 the D_d is 1.52 km/km^2, for SW-4 the D_d is 1.49 km/km^2 and for SW-5 the D_d is 1.42 km/km^2. Based on the D_d values, the study area mostly falls under low drainage density zone (<2 km/km^2) which indicates low relief, low slope, high infiltration capacity and low water regimes throughout the basin.

Stream Frequency (F_s)

According to (Horton, 1945) [11], stream frequency is the total number of streams per unit area. Stream frequency exhibits a positive correlation with drainage density in the watershed indicating an increment in stream population with respect to increase in drainage density. The stream frequency is calculated for all five sub watersheds (Table 6) and it ranges from 1.03 to 2.19 streams/km^2. For SW-1 the F_s is 1.03 streams/km^2, for SW-2 the F_s is 1.43 streams/km^2, for SW-3 F_s is 2.19 streams/km^2, for SW-4 the F_s is 1.15 streams/km^2 and for SW-5 the F_s is 2.13 streams/km^2. Based on the F_s value the SW-1 and SW-4 show low F_s due to low relief whereas remaining SW-2, SW-3 and SW-5 show moderate to low $F_{s,}$ moderate relief, balanced infiltration capacity which might be attributable to less pervious sub-surface in the study area.

Drainage Texture (D_t)

Drainage texture is the total number of stream segments per perimeter of the basin as per (Horton, 1945) [11]. The soft or weak rock unprotected by vegetation produce a fine texture whereas massive and resistant rocks cause coarse texture (Iqbal M, Sajjad H, 2014) [12].

(Smith, 1950) [37] Classified drainage texture into five different classes i.e., very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine drainage texture (>8). The D_t is calculated for all five sub watersheds (Table 6) and it varies between 1.36 to 4.62 indicating very coarse to moderate drainage texture.

Form Factor (R_f)

Form factor is the ratio of the area of the basin to the square of basin length (Horton, 1932) [10]. The value of form factor would always be greater than 0.78 for a perfectly circular basin. Smaller the value of form factor more elongated will be the basin. The R_f value is calculated for all the five sub watersheds (Table 6) and the value ranges from 0.26 to 0.50. For SW-1 the R_f value is 0.50, for SW-2 the R_f value is 0.30, for SW-3 the R_f value is 0.42, for SW-4 the R_f value is 0.26 and for SW-5 the R_f value is 0.31. The R_f value of all five sub watersheds are less than 0.78 which indicates all the five sub watersheds are elongated in nature.

Circulatory Ratio (R_c)

Circulatory ratio (R_c) is the ratio of watershed area to the area of a circle having the same circumference as the perimeter of the basin (Miller, 1953) [25]. The R_c value is calculated for all five sub watersheds (Table 6) and the value varies between 0.25 to 0.45. For SW-1 the R_c value is 0.45, for SW-2 R_c value is 0.26, for SW-3 the R_c value is 0.33, for SW-4 the R_c is 0.26 and for SW-5 the R_c value is 0.25. The R_c value of all five sub watersheds show elongated basin. The elongation is due to diversity of slope, relief and structural conditions prevailing in the watersheds.

Elongation Ratio (R_e)

Elongation Ratio (R_e) is defined as the ratio between the diameter of the circle of the same area as the drainage basin to the maximum length of the basin (Schumm, 1956) [33]. Areas with higher elongation ratio values have high infiltration capacity and low runoff. A circular basin is more efficient in discharge to runoff than an elongated basin (Iqbal M, Sajjad H, 2014) [12]. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are usually associated with high relief and steep ground slope. The R_e value is calculated for all five sub watersheds (Table 6) which varies between 0.58 to 0.79 i.e., for SW-1 the R_e value is 0.79, for SW-2 the R_e value is 0.61, for SW-3 the R_e value is 0.73, for SW-4 the R_e value is 0.58 and for SW-5 the R_e value is 0.63. Based on R_e value of all five sub watersheds, the basin is usually associated with high relief and steep ground slope.

Constant of Channel Maintenance (CCM)

Constant of channel maintenance is calculated as the reciprocal of drainage density (Schumm, 1956) [33]. It can also be expressed as a required minimum area for the maintenance and development of a channel (Dutta and Roy, 2012) [8]. Low value of CCM indicates the area is under the influence of high structural disturbance, low permeability, steep to very steep slopes and high surface runoff whereas high values of CCM indicates the area is under very less structural disturbances and less runoff conditions (G.P.O. Reddy *et al*, 2004) [31]. The CCM value is calculated for all five sub watersheds (Table 6) and it ranges from 0.63 to 0.70. For SW-1 the CCM value is 0.69, for SW-2 the value is 0.63, for SW-3 the value is 0.65, for SW-4 the value is 0.67 and for SW-5 the value is 0.70. CCM value of SW-1 and SW-5 has higher value while remaining SW-2, SW-3 and SW-4 have lower value.

Table 6: Calculations of Areal Aspects for all the five Sub watersheds from the Study Area

Sr. No.	Sub Watershed Code	A (sq.km)	P (km)	L_b (km)	D_d	F_s	D_t	R_f	R_c	R_e	CCM
1.	SW1	47.35	36.01	9.72	1.44	1.03	1.36	0.50	0.45	0.79	0.69
2.	SW2	91.77	65.59	17.49	1.57	1.43	2.01	0.30	0.26	0.61	0.63
3.	SW3	165.15	78.19	19.79	1.52	2.19	4.62	0.42	0.33	0.73	0.65
4.	SW4	230.15	103.81	29.29	1.49	1.15	2.56	0.26	0.26	0.58	0.67
5.	SW5	85.28	64.59	16.54	1.42	2.13	2.81	0.31	0.25	0.63	0.70

Relief Aspect

Basin Relief (H)

Basin relief (H) plays an important role in drainage development, surface and sub surface water flow, permeability, landforms development and erosion properties of the terrain (G.P.O. Reddy *et al*, 2004) [31]. It is the general morphometric parameters used to understand the morphological characteristics of basin (Raux *et al*., 2011) [28]. It depends upon the underlain geology, geomorphology and drainage characteristics of the region and it is the best indicator of erosional stages of any river basin (Thomas *et al*. 2010) [45]. The basin relief is calculated for all the five sub watersheds (Table 7) and it varies between 125 to 399 m. For SW-1 the H is 374m, 378 m for SW-2, 385 m for SW-3, 399 m for SW-4 and 125 m for SW-5. Except SW-5, the remaining four sub watersheds i.e., SW-1, SW-2, SW-3 and SW-4 are having high relief greater than 150 m which indicates the gravity of water flow, low infiltration and high runoff conditions.

Relief Ratio (R_r)

Relief ratio is defined as ratio of basin relief to basin length (Schumm, 1956) [33]. Higher value of R_r indicates steep slope and high relief and low value of R_r indicates gentle slope and low relief (Adhikari, S., 2020). The relief ratio is calculated for all five sub watersheds (Table 7) and it ranges from 0.007 to 0.038. For SW-1 the R_r is 0.038, for SW-2 the R_r is 0.021, for SW-3 the R_r is 0.019, for SW-4 the R_r is 0.013 and for SW-5 the R_r is 0.007. Except SW-5, the remaining four sub watersheds i.e., SW-1, SW-2, SW-3 and SW-4 are having high relief ratio indicates steeper slope and high relief.

Ruggedness Number (R_n)

Ruggedness number is defined as the product of drainage density and relative relief. The R_n is high when both drainage density and relative relief are high (Ansari *et al*. 2012) [3]. It depends upon sharpness of native relief, amplitude of available drainage density and other environmental factors such as slope, rainfall, weathering, soil texture, natural vegetation etc. (Shankar & Dhaniranjan, 2014) [34]. The R_n is calculated for all five sub watersheds (Table 7) and it ranges from 0.17 to 0.59. For SW-1 the R_n value is 0.53, for SW-2 the R_n value is 0.59, for SW-3 the R_n value is 0.58, for SW-4 the R_n value is 0.59 and for SW-5 the R_n value is 0.17. Based on the R_n value SW-5 have low R_n value which indicates less susceptibility to erosion whereas SW-1, SW-2, SW-3 and SW-4 have high R_n value which indicates high susceptibility to erosion.

Table 7: Calculations of Relief Aspects for all the five Sub watersheds from the Study Area

Sr. No.	Sub Watershed Code	Z (m)	Z (m)	H (m)	R_r	R_n
1.	SW1	556	182	374	0.038	0.53
2.	SW2	554	176	378	0.021	0.59
3.	SW3	562	177	385	0.019	0.58
4.	SW4	553	154	399	0.013	0.59
5.	SW5	273	148	125	0.007	0.17

Sub-Watershed Prioritization

Prioritization process is a tool for the watershed manager to identify the priority pollutants, potential priority sources and targeted areas within the basin. The prioritization process begins with the identification of the priority water quality problems. Basin prioritization is the ranking of different sub watersheds according to the order in which they have to be taken up for treatment and conservation measures. (Manjare *et al*., 2017) [17]. Morphometric analysis and prioritization of watersheds are very important for water resource modeller and flood management (Youssef *et al.* 2011; Bali *et al.* 2012) [47, 4]. The resource development programs are applied generally on watershed basis and thus prioritization is essential for proper planning and management of the natural resources for sustainable development (Vittala *et al*., 2008) [46]. Linear parameters have direct relationship with soil erodibility whereas shape parameters have inverse relationship with erodibility, lower the value of this parameters more is the erodibility (Nookaratnam *et al*. 2005; Singh and Singh 2014; Sujatha *et al*. 2015; Manjare *et al*., 2019) [26, 39, 43, 21], the highest their value shows the most erodible soil in a watershed. The morphometric parameters such as bifurcation ratio (R_b), constant of channel maintenance (CCM), drainage density (D_d), stream frequency (F_s), drainage texture (D_t), form factor (R_f), circularity ratio (R_c), and elongation ratio (R_e) are also termed as erosion risk assessment parameters and have been used for prioritizing watersheds (Biswas et. al., 1999) [5]. So for the prioritization of sub watershed, the highest value of linear parameter was rated as 1, second highest value was rated as rank 2 and so on, and least value was rated as last rank. In the shape parameters, the lowest value was given as rank 1; next lower value was rated as rank 2 and so on. After the rating has been done based on every single parameter, the rating values all the five sub-watersheds were averaged so as to arrive at a compound value (C_p). The prioritization was carried out by assigning ranks to the individual indicator and a compound value (C_p) was calculated (Table 8). Sub watersheds with highest C_p were of low priority while those with lowest Cp were of high priority (Table 8.). Thus an index of high, medium and low priority was produced. Sub watersheds have been broadly classified into three priority zones according to their compound value (Cp): High (<8.0), Medium (8.0-10) and Low (10 and above).

Table 8: Computed Parameters used for Ranking and Prioritization of Sub-Watersheds

Sr. No.	Parameters	Computed Parametric Values and Ranks				
		SW-1	SW-2	SW-3	SW-4	SW-5
1.	P	36.01	65.59	78.19	103.81	64.59
2.	L_b	9.72	17.49	19.79	29.29	16.54
3.	A	47.35	91.77	165.15	230.15	85.28
4.	R_f	0.50	0.30	0.42	0.26	0.31
5.	D_d	1.44	1.57	1.52	1.49	1.42
6.	F_s	1.03	1.43	2.19	1.15	2.13
7.	D_t	1.36	2.01	4.62	2.56	2.81
8.	R_c	0.45	0.26	0.33	0.26	0.25
9.	R_e	0.79	0.61	0.73	0.58	0.63
10	CCM	0.69	0.63	0.65	0.67	0.70
Compound Value (C_p)		9.934	18.166	27.359	37.022	17.466
Rank		1	3	4	5	2
Final Priority		Medium	Low	Low	Low	Low

High Priority

Higher the priority, greater will be the degree of soil erosion in the particular sub watershed and it became potential area for applying soil conservation measures. If the sub watershed falls under high priority class then it should be provided immediate soil and water conservation measures as they are likely to be subjected to maximum soil erosion.

Medium Priority

Only one sub watershed i.e., SW-1 falls under medium priority class and should be provided with soil and water conservation measures as they are subjected to soil erosion, but less erosion compared to high priority class.

Low Priority

Remaining four sub watersheds i.e., SW-2, SW-3, SW-4 and SW-5 falls under low priority class and have slight erosion susceptibility zone and may need agronomical measure to protect sheet and rill erosion. Low priority sub watersheds have low risk of land degradation.

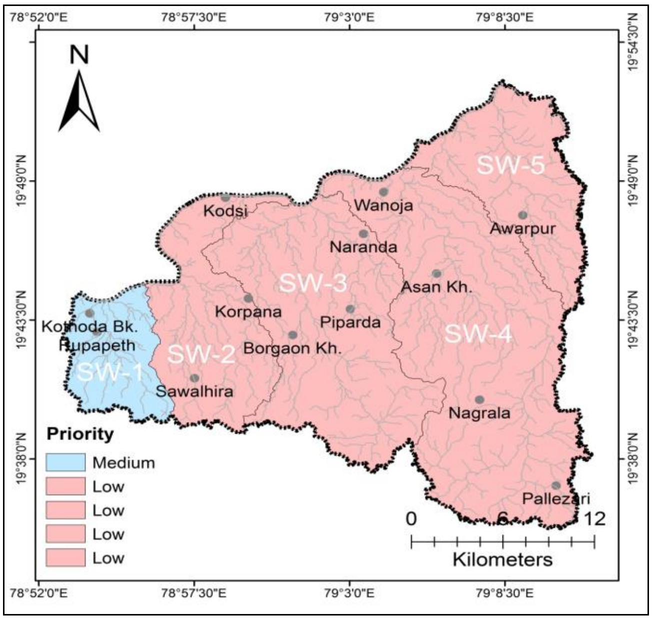

Fig 7: Map of prioritized sub watersheds of the study area through morphometric parameters

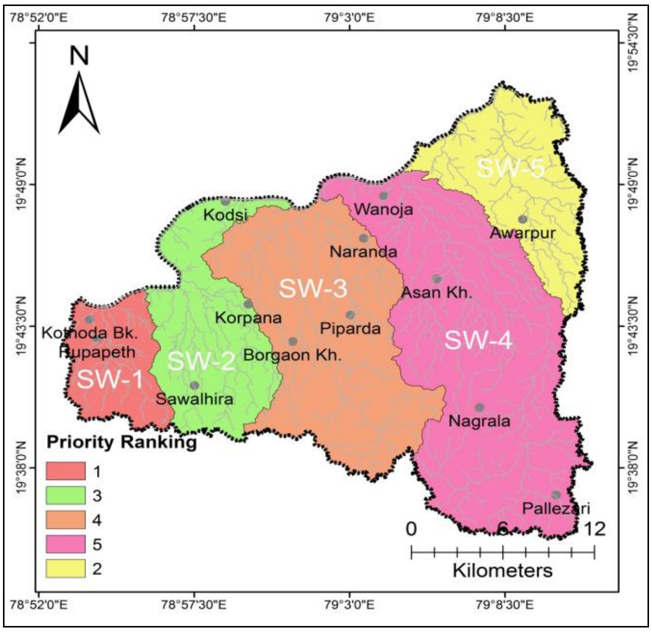

Fig 8: Ranking of the sub watersheds of the study area

Conclusion

Remote sensing and GIS is a powerful tool in prioritization of sub watershed based on morphometric analysis which is helpful in management and planning at sub watershed level. The entire study area is divided into five sub watersheds namely SW-1, SW-2, SW-3, SW-4 and SW-5 and the prioritization of all the five sub watersheds has been explained with the help of morphometric parameters. Considering the massive investment in the watershed development program, it is now become very important to plan the activities on priority basis for achieving profitable results. Therefore, this work will help the planners to address the problematic areas with minimal cost. The study area is allocated as 5th order drainage basin. Study area shows dendritic to sub dendritic pattern. The irregularities of stream length in SW-3 and SW-4 show geological and morphological control on river basin. Form factor and circulatory ratio of all five sub watersheds indicates elongated nature of basin. SW-1, SW-2, SW-3 and SW-4 are having high relief which indicates the gravity of water flow, low infiltration and high runoff conditions whereas SW-5 are having low relief indicates low runoff. SW-1, SW-2, SW-3 and SW-4 have high R_n value which indicates high susceptibility to erosion whereas SW-5 is having low R_n value which indicates less susceptibility to erosion. By the complete analysis of drainage basin parameters the sub watersheds are classified into 3 priority zones; high priority, medium priority and low priority. The result of prioritization analysis revealed that the sub watersheds, such as SW-1 fall under medium priority zone due to moderate compound value having very coarse drainage texture, steep slopes which indicates less erosion compared to high priority class while remaining four sub watersheds i.e., SW-2, SW-3, SW-4 and SW-5 falls under low priority zone due to high compound value which indicates low risk of land degradation.

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