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Prioritization of Sub-Watersheds based on Morphometric parameters in Pare watershed, Arunachal Pradesh, India

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ABSTRACT

Mountainous watersheds are constantly under pressure of huge amount of soil loss due to soil erosion. Pare watershed is situated in the eastern Himalayan ranges of Arunachal Pradesh, India, which is subjected to such soil losses and its sub-watersheds are being degraded in many places. Watershed management programs are required in the area in which prioritization of sub-watersheds is one of the first steps. A study has been carried out to address this issue in the area to prioritize 26 sub-watersheds of Pare through morphometric analysis. The study used digital elevation model (DEM) to determine several morphometric parameters of the watershed. The analysis revealed that Pare river is of the 7th order comprising of 6127 stream segments running over the watersheds for about 2448 km. Based on the results obtained, the study area is an elongated well dissected watersheds with high relief and great presence of streams all over the watershed indicating faster runoff peak attainment which is synonymous to rapid transportation of sediment load. The analysis also revealed that SW25 required the top priority in dealing with soil, land and water management measures while least priority could be given to SW7 among all the sub-watersheds in the Pare basin. We suggest various stakeholders who are involved in watershed development programs in the region to take cues from the results obtained in this paper. The results of this study are quite satisfactory in understanding the various morphological aspects of the watershed. Nonetheless, efforts to improve the results can always be made through incorporation of land-use and soil information to enhance the prioritization process so that purpose utilization of the watershed may be reflected in the results.

Keywords : Soil Loss, Prioritization of Sub-Watersheds, Morphometric Analysis, DEM

I. INTRODUCTION

Topography plays a very crucial role in controlling the pathways of water after precipitation reaches the ground. Many researchers had analysed to represent topography quantitatively at various scale, and acknowledged that watershed is the most appropriate unit of landscape analysis for planning and management of land and water resources. A watershed generates runoff as a result of precipitation, then the fate of the water majorly depends on the watershed, soil, land use and geological characteristics. Yadav et al. [1] acknowledged that several watersheds are being degraded due to anthropogenic activities and human induces climate change. Soil erosion is one of the major issues, particularly in hilly regions, leading to degradation of its landscape. Therefore, it has become essential to manage the landscapes at the watershed scale. However, managing large size watersheds is always going to be difficult and also may results in inefficiency of the measures implemented for reducing soil erosion. A feasible solution to this will be the adoption of management strategies at the sub-watershed level which brings the need for decision making and prioritization of sub-watersheds to give priority to those sub-watersheds which have been degraded more or have the potential to be degraded faster. In the developing countries such as India where both the human and financial resources are limited, decision making for planning and management of watersheds and its implementations are often very difficult, expensive and time consuming [2]. Sub-watershed prioritization helps in identifying critically endangered sub-watersheds so that management strategies can be implemented to achieve sustainable development in controlling soil erosion, floods, and sediment loads [3].

In the past, several researchers had carried out different kind of approaches to prioritize sub-watersheds. Such notable studies include Wang et al. [4], Rahaman et al. [5] and Arabameri et al. [6] based on multi criteria decision analysis; Aher et al. [7] based on weighted sum analysis; Ayele et al. [8] based on sediment yield index; Meshram and Sharma [9] based on principle component analysis; Tyagi et al. [10] based on Soil and Water Assessment Tool (SWAT) model; Katiyar et al. [11] based on area weighted vegetation and Gashaw et al. [12] based on modelling of soil erosion. The weighted sum analysis technique considered morphometric parameters in the prioritization of sub-watershed determined from digital elevation models (DEM) only. In the ungauged and data scarce remote places such as hilly regions, this kind of approach can be considered efficient to prioritize sub-watershed. Adhami and Sadeghi [13] mentioned that topo-hydrological and geomorphometric factors influenced the site selection and implementation of land and water conservation measures in sub-watersheds and a well-planned watershed management practices can overcome poor watershed conditions of excessive runoff, low productive yield, accelerated soil erosion, poor infiltration, flooding and droughts [14].

Morphometry may be defined as the mathematical analysis of the Earth's surface that describes its topographic reliefs [15]. A quantitative description of the drainage system, which is an important aspect of a watershed can be obtained from morphometric analysis [16]. Morphometric characteristics of a watershed contains crucial information on the hydrologic and geomorphic processes which could be used as decisive tool in land and water resource management [17]. The conventional techniques of morphometric analysis such as digitization of stream network, delineation of watershed and assigning attributes to them from toposheets is a laborious job and time consuming. However, with the advent of geographic information systems (GIS) and availability of remotely sensed elevation model such as the DEM, extraction of morphometric parameters become easier and more importantly save time in the quantitative characterization of landforms [18]. The capability of GIS allows data manipulation and analysis with ease in assessing various morphometric parameters of the drainage basins and watersheds. Unlike contours in topographic maps, DEM data provide continuous data, which is an added advantage over easy integration with GIS and further data manipulation. Few prominent scientific studies regarding morphometric analysis using DEM in the last few decades are Nag [19]; Chopra et al. [20], Kale and Shejwalkar [21], Rudraiah et al. [22], Patel and Sarkar [23], Wang et al. [24], Pareta and Pareta [25], Altaf et al. [26], Magesh et al. [27] and Jacques et al. [28].

In this study, we attempted to prioritize various sub-watersheds of Pare watershed in relation to soil erosion problems prevalent in the study area through determination of morphometric parameters. The study area, in the recent past, has been under the pressure of agricultural as well as human habitation expansion involving lots of landscape transformation. A great number of changes in hydrological aspects is expected to occur in the study area due to this change in landscapes. Therefore, prioritization of sub-watersheds in Pare has been carried out in order to aid in decision making process such as distribution of project cost, type of projects and various soil and water conservation measures.

II. METHODS AND MATERIAL

A. Study Area and Data

The Pare watershed is one of the eastern Himalayan watersheds formed on a sub-tributary river of Brahmaputra river. It is situated in Papumpare district of Arunachal Pradesh, India lying between 93°13'15" E and 93°47'07" E longitudes and 27°09'36" N and 27°22'08" N latitudes covering a geographical area of 773 sq. km. The study area is shown in Figure 1 wherein the outlet is situated at Hoj (93°47'7.92" E and 27°15'18.24" N). Pare watershed is a mountainous watershed where the hill ridges run haphazardly either parallel or in opposite direction as soon as one hill ridges end. Usually in the study area, very high orographic precipitation causes landslides and huge amount of soil has been transported towards downstream.

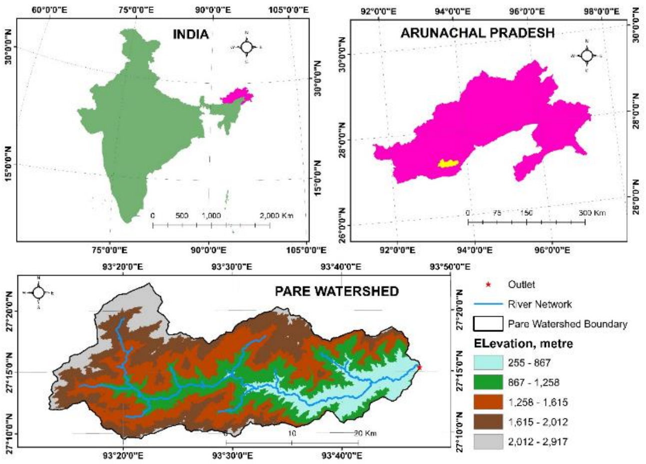

Figure 1 : Map of the study area, Pare watershed

In the present study, digital elevation model (DEM) of Shuttle Rada Topography Mission (SRTM) with a spatial resolution of approximately 30 m, downloaded from the website https://earthexplorer.usgs.gov/ was used to carry out morphometric analysis in the study area. Also, a total of 8 toposheets with toposheet no.: 83E_3, 83E_4, 83E_7, 83E_8, 83E_11, 83E_12, 83E_15, and 83E_16 with a scale of 1:50,000 were downloaded from Manchitra, Nakshe Portal which is under Survey of India (SOI) (http://soinakshe.uk.gov.in/).

B. Methodology

The SRTM DEM with 30 m resolution used in the present study contains voids which has no data; therefore, filling of such voids was performed using raster calculator while toposheets were georeferenced in ArcGIS. Delineation of drainage networks, watershed, sub-watersheds and determination of watershed and stream characteristics were performed using Arc Hydro toolbar in ArcGIS. Stream order for the watershed as well as sub-watersheds were computed using Hydrology toolbar in ArcGIS. Number of streams generated depends on the stream threshold provided while delineation. Higher threshold value results in lesser number of streams and vice versa. Visual comparison of stream network in the toposheets with the delineated stream network from DEM was made in order to setup a suitable stream threshold. In the present study, a threshold value of 50 cells was found suitable as it agrees with toposheets to large extent regarding number of streams and their origin. A flow diagram of the methodology carried out in this study is presented in Figure 2. The watershed and sub-watersheds characteristics determined in this study include area, perimeter, highest and lowest [outlet(s)] elevation values, and length of the basin. For stream network, characteristics such as order, length and number were determined. Finally, bifurcation ratio, form factor, drainage texture, compactness coefficient, circulatory ratio, elongation ratio, drainage density, stream frequency, length of overland flow, relief ratio, and ruggedness number were determined with the help of standard formulae illustrated in Table I.

Stream order: Stream order proposed by Strahler [16] is a hierarchical relationship between stream segments and their connectivity to each other. First order streams are non-branching fingertip stream segments, second order streams are those streams which receive water only from first ordered streams, third order streams are those where two second ordered streams join together and so on. It is to be noted that higher order number is formed only when two streams of the same order meet.

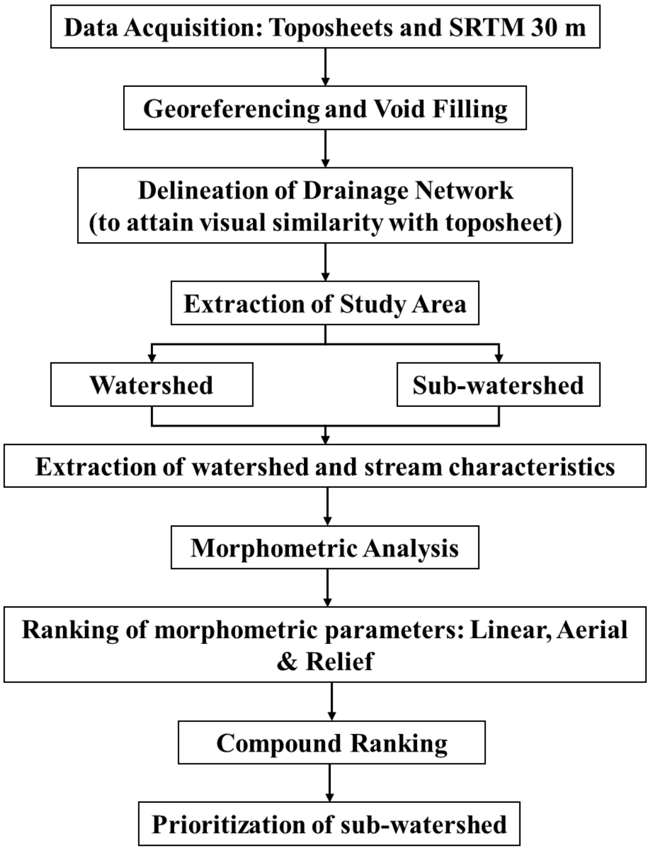

Figure 2: Methodology used in the study

Stream number (N_u): Stream number is the total counts of stream segments of different order separately and is inversely proportional to the stream order [16].

$$N_u = N1 + N2 + \cdots + Nn \quad (1)$$

Where, N_u is number of streams of the u^{th} order and N1, N2, …, Nn are the number of streams of 1^{st}, 2^{nd}, …, n^{th} order.

Length of stream (L_u): Stream length of the u^{th} order is calculated as measuring and totalling the length of all the u^{th} order streams within the watershed area [16].

$$L_u = L1 + L2 + \cdots + Ln \quad (2)$$

TABLE I

MORPHOMETRIC PARAMETERS AND THEIR FORMULAE

Morphometric Parameter	Formula	Author
Mean bifurcation ratio (Rb_m)	$R_{b_m} = \dfrac{\frac{N1}{N2} + \frac{N2}{N3} + \cdots + \frac{Nn-1}{Nn}}{n-1}$	[29]
Form factor (F_f)	$F_f = {}^{A}/_{L_b{}^2}$	[30]
Drainage Texture (D_t) (number/km)	$D_t = {}^{N_u}/_{P}$	[31]
Compactness Coefficient (C_c)	$C_c = 0.282 \times P/\sqrt{A}$	[31]
Circularity ratio (R_c)	$R_c = 4 \pi A / P^2$	[32]
Elongation ratio (R_e)	$R_e = \dfrac{D_c}{L_b} = 1.129 \times \dfrac{\sqrt{A}}{L_b}$	[33]
Drainage density (D_d) (km/km^2)	$D_d = {}^{L_u}/_{A}$	[16]; [30]
Stream frequency (F) (number/km)	$F = {}^{N_u}/_{A}$	[30]
Average Length of Overland Flow (L_g) (km)	$L_g = 0.5 \times \dfrac{1}{D_d}$	[31]
Relief Ratio (Rhl)	$Rhl = {}^{H}/_{L_b}$	[33]; [34]
Ruggedness Number (R_n)	$R_n = D_d \times H$	[16]

Where, L_u is number of streams of the uth order and L1, L2, …, Ln are the number of streams of 1st, 2nd, …, nth order. They are generally represented in unit of kilometres (km).

In the Table I, A denotes area (km^2); L_b denotes basin length (km) which is the distance from the outlet to the farthest point on the drainage divide; P denotes basin perimeter (km) and H denotes the elevation difference between the highest and lowest points (km) of the watershed/sub-watersheds. After determination of theses morphometric parameters, all the sub-watersheds are given a rank depending on its value keeping in mind the importance of each parameter on soil erosion. Higher rank (low in numerical value) indicating higher priority should be given to the sub-watershed which is at higher risk of being eroded due to greater runoff or faster movement of water. The risk of being eroded in a sub-watershed, faster than the other sub-watersheds are conceptualized from the morphometric parameters. Further, compound scores are determined for each sub-watershed by averaging the ranks obtained from various morphometric parameters. Finally, the sub-watersheds are ranked and assigned a priority value with its lowest value indicating sub-watershed which required the most priority in terms of soil conservation needs.

III.RESULTS AND DISCUSSION

Watershed and stream characteristics viz. shape, pattern, stage, health, permeability of bed rocks and its relation with lithological characteristics could be identified from morphometric parameters [35]. The results of the morphometric analysis of Pare watershed and its sub-watersheds are presented in Table II and Table III. In the Table II, the length and number of streams of various order and their totals are shown while Table III presented the various morphometric parameters listed in Table I. The drainage network delineation of Pare watershed with a stream threshold value of 50 cells results in 7th order stream network as shown in Figure 3. Also, we divided the whole watershed into 26 sub-watersheds (Figure 3) to cover the major tributaries as well as looking at the importance of sub-watersheds to the inhabitants.

A. Morphometric Parameters in Pare Watershed

Determination of stream order is the primary step of morphometric analysis. Table II indicates that Pare watershed is a 7th order watershed, in which, SW7 and SW15 also are of the same order. In total there are ten 6th order sub-watersheds (SW4, SW10, SW13, SW16, SW18, SW19, SW20, SW22, SW24 and SW25), eleven 5th order sub-watersheds (SW1, SW2, SW3, SW5, SW6, SW8, SW11, SW12, SW21, SW23 and SW26) and the rest three sub-watersheds (SW9, SW14 and SW17) are of 4th order. The stream lengths of various order for Pare watershed and its sub-watersheds are presented in Table II. Pare has a total stream length of 2448.22 km constituting total lengths of 1308.96, 568.77, 298.55, 142.26, 58.92, 61.59 and 9.17 km respectively for 1st, 2nd, 3rd, 4th, 5th, 6th and 7th order. The usual nature of stream length in a watershed decreases with stream order and any departures will indicate terrain characteristics of high relief, underlain by varying lithology and probable uplift across the basin [36]. In the present study, sub-watersheds viz. SW4, SW7, SW10, SW13, SW15, SW16, SW18, SW19, SW20, SW22, SW24 and SW25 do not exactly fulfil the definition of watershed, instead, they received runoff from one or more sub-watersheds lying upstream. The geological and tectonic characteristics of a watershed are reflected in bifurcation ratio of the watershed [35] [37]. A bifurcation ratio between 3 and 5 indicates a watershed of natural drainage system within a homogenous rock [38]. Watershed having high bifurcation ratio have less chance of being flooded and eroded [39] as higher bifurcation ratio indicates well-dissected drainage basins [31]. The mean bifurcation ratio of Pare watershed was found as 4.29 (Table III) indicating well dissected drainage basin. A perfectly circular watershed will have a form factor value of 0.785 [25] and any deviation from it indicates elongated watershed. The form factor of Pare watershed was found as 0.24 (Table III) indicating highly elongated watershed. According to Pareta and Pareta [25], drainage textures are categorised into five different classes viz. very coarse texture (<2), coarse texture (2 to 4), moderate texture (4 to 6), fine texture (6 to 8) and very fine texture (>8). In the present study, the drainage texture of Pare watershed was found as 38.31 (number/km) indicating very fine texture.

TABLE II

STREAM ORDER, NUMBER OF STREAMS AND THEIR LENGTHS IN PARE AND ITS SUB-WATERSHEDS

Name	Number of Streams								Length of Streams							
	N1	*N2*	*N3*	*N4*	*N5*	*N6*	*N7*	*Nu*	*L1*	*L2*	*L3*	*L4*	*L5*	*L6*	*L7*	*Lu*
SW1	354	82	18	2	1	-	-	457	103.42	40.98	25.00	9.60	7.32	-	-	186.32
SW2	311	74	16	4	1	-	-	406	86.37	42.82	21.35	5.48	11.41	-	-	167.42
SW3	173	44	7	2	1	-	-	227	52.34	25.31	6.04	8.89	1.55	-	-	94.14
SW4	26	14	-	-	2	13	-	55	8.74	2.52	-	-	0.89	2.69	-	14.84
SW5	197	45	11	2	1	-	-	256	51.44	24.23	13.30	6.09	5.28	-	-	100.33
SW6	148	34	7	2	1	-	-	192	45.79	15.71	9.28	2.44	3.68	-	-	76.90
SW7	192	86	29	25	-	-	44	376	51.38	22.64	7.38	6.25	-	-	8.07	95.72
SW8	173	47	10	3	1	-	-	234	56.05	20.02	9.06	6.39	3.89	-	-	95.40
SW9	108	29	7	1	-	-	-	145	31.56	16.70	7.16	6.02	-	-	-	61.44
SW10	107	42	19	21	-	25	-	214	28.05	10.01	4.51	4.35	-	4.84	-	51.75
SW11	213	51	8	2	1	-	-	275	54.96	23.68	18.10	7.21	1.34	-	-	108.28
SW12	101	23	5	2	1	-	-	132	30.50	16.48	10.09	3.48	1.29	-	-	61.85
SW13	81	33	17	4	-	28	-	163	22.30	10.47	5.14	1.29	-	5.00	-	44.20
SW14	132	27	4	1	-	-	-	164	35.34	12.63	5.07	8.19	-	-	-	61.23
SW15	51	21	19	-	-	2	9	102	14.46	3.91	5.28	-	-	0.56	1.83	26.04
SW16	95	36	24	2	2	26	-	185	23.61	6.41	7.43	0.41	0.93	6.06	-	44.85
SW17	110	28	6	1	-	-	-	145	34.33	11.14	6.09	6.47	-	-	-	58.03
SW18	77	33	19	5	1	18	-	153	21.80	9.36	5.33	1.59	0.04	4.55	-	42.66
SW19	84	45	9	7	1	22	-	168	21.45	13.85	1.98	2.79	0.66	5.16	-	45.87
SW20	60	17	18	5	1	19	-	120	17.27	3.62	3.57	1.33	0.35	4.11	-	30.25
SW21	373	87	20	4	1	-	-	485	103.05	46.17	28.15	9.17	9.26	-	-	195.80
SW22	187	85	43	14	1	37	-	367	48.87	33.47	15.90	3.61	0.59	6.66	-	109.10
SW23	299	69	18	4	1	-	-	391	87.36	41.10	18.09	9.62	8.86	-	-	165.04
SW24	95	40	27	10	1	18	-	191	30.12	10.67	6.33	1.55	0.43	4.28	-	53.38
SW25	747	314	195	92	1	111	-	1460	186.26	77.31	46.60	20.10	0.29	20.14	-	350.70
SW26	217	49	9	3	1	-	-	279	61.49	27.43	12.35	10.83	5.03	-	-	117.12
Pare	4718	1113	233	49	11	2	1	6127	1308.96	568.77	298.55	142.26	58.92	61.59	9.17	2448.22

TABLE III
MORPHOMETRIC PARAMETERS OF PARE AND ITS SUB-WATERSHEDS

Name	Rb_m	F_f	D_t	C_c	R_c	R_e	D_d	F	L_g	Rhl	R_n
SW1	4.97	0.50	9.28	1.86	0.29	0.79	3.29	8.07	0.15	0.15	5.24
SW2	4.21	0.33	7.88	2.05	0.24	0.64	3.28	7.95	0.15	0.11	4.42
SW3	3.93	0.48	7.24	1.67	0.36	0.78	3.31	7.97	0.15	0.16	4.18
SW4	3.00	0.47	4.42	1.74	0.33	0.77	3.64	13.47	0.14	0.24	2.56
SW5	3.99	0.25	6.18	2.04	0.24	0.56	3.00	7.67	0.17	0.13	4.43
SW6	3.68	0.57	6.93	1.60	0.40	0.85	3.17	7.93	0.16	0.21	4.38
SW7	1.73	5.67	9.32	0.64	2.41	2.69	0.31	1.20	1.63	0.23	0.53
SW8	3.68	0.43	7.10	1.75	0.33	0.74	3.34	8.20	0.15	0.16	4.31
SW9	4.96	0.32	5.56	1.72	0.34	0.64	3.30	7.79	0.15	0.18	4.45
SW10	1.63	0.45	8.28	1.85	0.29	0.76	3.32	13.71	0.15	0.17	3.25
SW11	4.14	0.49	8.26	1.66	0.37	0.79	3.25	8.49	0.15	0.17	4.44
SW12	3.37	0.49	5.35	1.65	0.37	0.79	3.44	7.33	0.15	0.19	4.01
SW13	2.20	0.46	7.62	1.73	0.33	0.77	3.63	13.38	0.14	0.19	3.50
SW14	5.21	0.29	5.61	1.93	0.27	0.61	3.31	8.87	0.15	0.23	6.01
SW15	3.31	0.38	4.85	2.13	0.22	0.70	3.35	13.11	0.15	0.28	4.30
SW16	3.44	0.27	7.16	1.91	0.27	0.58	3.07	12.67	0.16	0.18	4.13
SW17	4.87	0.26	4.88	2.00	0.25	0.58	3.25	8.11	0.15	0.15	4.04
SW18	2.59	0.85	6.61	1.83	0.30	1.04	3.35	12.02	0.15	0.28	3.68
SW19	3.04	0.79	8.30	1.52	0.43	1.00	3.24	11.88	0.15	0.25	3.40
SW20	2.63	0.39	5.75	2.01	0.25	0.70	3.54	14.05	0.14	0.24	3.95
SW21	4.41	0.38	9.14	1.88	0.29	0.70	3.05	7.55	0.16	0.12	4.63
SW22	4.26	0.58	10.55	1.66	0.36	0.86	3.13	10.54	0.16	0.17	4.18
SW23	4.17	0.32	8.81	1.77	0.32	0.64	3.27	7.75	0.15	0.13	5.49
SW24	3.32	0.56	7.04	1.88	0.28	0.85	3.23	11.55	0.15	0.15	2.62
SW25	19.62	0.31	18.25	2.11	0.22	0.63	3.07	12.76	0.16	0.10	5.68
SW26	3.97	0.41	6.60	1.98	0.26	0.72	3.19	7.61	0.16	0.13	4.01
Pare	4.29	0.24	38.31	1.64	0.38	0.56	3.18	7.95	0.16	0.05	8.46

The high value of drainage texture indicate that the basin is crowded with numerous stream segments with higher degree of slopes. As presented in Table III, the compactness coefficient of Pare watershed is 1.64 indicating compact watershed. For a perfectly circular watershed, the compactness coefficient is 1, and is the most hazardous condition, since it will yield the shortest time of peak flow in the watershed. Circularity ratio is one of the morphometric parameters which reflects the nature of elongation and stages of watershed development. Circulatory ratio with low, medium and high values are indicative of youth, mature and old stages of the watershed development respectively. In the present study, the circulatory ratio of Pare watershed was found as 0.38 indicating elongated watershed and in youth stage. The elongation ratio of Pare watershed was found as 0.56 indicating elongated watershed. An elongation value of close to unity indicates circular watershed. Drainage density is one of the most important morphometric parameters in a watershed since it provides a rough idea of how the fate of precipitation will turn once it reaches the ground. Higher the drainage density lesser will be the time of peak runoff, also indicating quicker transportation of sediment load given the condition that soils are being eroded. The drainage density in Pare watershed was found as 3.18 km/km^2 and the values ranges from 0.31 to 3.64 km/km^2 in the sub-watersheds. Stream frequency of a watershed is directly proportionate to the number of streams indicating close correlation with drainage density. The stream frequency in Pare was found as 7.95 per square kilometre of area and it ranges from 1.2 to 14.05 per square kilometre area across the sub-watersheds. According to Horton [31], a watershed has a pronounced channel erosion if the average length of overland flow is less than 0.4, otherwise, sheet erosion is prominent in the watershed. As per the result as presented in Table III, Pare watershed has a characteristics of strong channel erosion as indicated by a value of Lg = 0.16 km. Schumm [33] mentioned that relief ratio of a watershed signifies intensity of erosion occurring on the slopes of the watershed. It indicates the overall steepness of the watershed. The relief ratio in Pare watershed was found as 0.05. The ruggedness number is a combined index of drainage density and total basin relief with higher value indicating higher risk of soil erosion. As per the results of morphometric analysis in Pare watershed, a very high value of ruggedness number was obtained for the watershed indicating very high risk of soil erosion occurring on the steep watershed slopes.

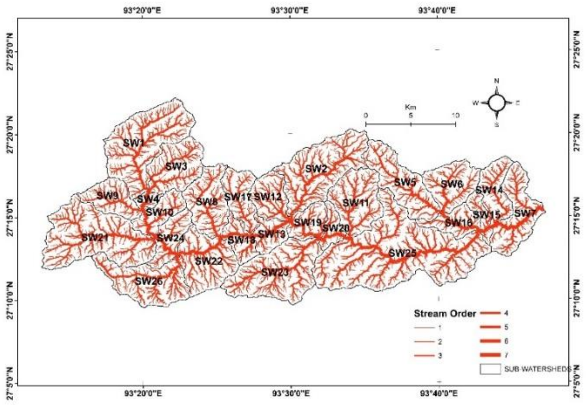

Figure 3: Sub-watershed and stream order of Pare watershed

B. Prioritization of sub-watersheds

The main objective of this study is to prioritize sub-watersheds of Pare through analysis of morphometric parameters. Eleven morphometric parameters listed in Table I were considered while prioritizing sub-watersheds. The definitions of all the parameters are correlated with various hydrological aspects such as topography, potentiality of runoff volume generation and time of peak attainment in order to develop relationships regarding whether higher or lower values of these morphometric parameters will cause higher or lower soil erosion. The results of the prioritization of sub-watersheds in Pare are illustrated in Table IV and the final priority map is shown in Figure 4.

TABLE IV
PRIORITY RANKS OF SUB-WATERSHEDS IN PARE WATERSHED IN RELATION TO SOIL EROSION PROBLEMS

Name	Rb_m	F_f	D_t	C_c	R_c	R_e	D_d	F	L_g	Rhl	R_n	Compound Score	Final Priority
SW1	3	20	4	12	12	18	12	16	19	19	4	12.64	11
SW2	8	8	10	3	3	8	13	18	14	25	9	10.82	5
SW3	13	17	12	20	21	17	10	17	16	16	14	15.73	20
SW4	21	16	26	17	17	16	1	3	26	4	25	15.64	19
SW5	11	1	19	4	4	1	25	22	2	23	8	10.91	6
SW6	15	22	16	24	24	22	20	19	7	8	10	17.00	24
SW7	25	26	3	26	26	26	26	26	1	6	26	19.73	26
SW8	14	13	14	16	16	13	7	14	20	17	11	14.09	14
SW9	4	6	22	19	19	6	11	20	15	12	6	12.73	12
SW10	26	14	8	13	13	14	8	2	18	15	23	14.00	13
SW11	10	18	9	22	22	19	15	13	12	14	7	14.64	17
SW12	17	19	23	23	23	20	4	25	23	9	17	18.45	25
SW13	24	15	11	18	18	15	2	4	25	10	21	14.82	18
SW14	2	4	21	8	8	4	9	12	17	7	1	8.45	2
SW15	19	10	25	1	1	10	6	5	21	1	12	10.09	3
SW16	16	3	13	9	9	3	22	7	5	11	15	10.27	4
SW17	5	2	24	6	6	2	16	15	11	18	16	11.00	7
SW18	23	25	17	14	14	25	5	8	22	2	20	15.91	21
SW19	20	24	7	25	25	24	17	9	10	3	22	16.91	23
SW20	22	11	20	5	5	11	3	1	24	5	19	11.45	8
SW21	6	9	5	11	11	9	24	24	3	24	5	11.91	9
SW22	7	23	2	21	20	23	21	11	6	13	13	14.55	16
SW23	9	7	6	15	15	7	14	21	13	21	3	11.91	9
SW24	18	21	15	10	10	21	18	10	9	20	24	16.00	22
SW25	1	5	1	2	2	5	23	6	4	26	2	7.00	1
SW26	12	12	18	7	7	12	19	23	8	22	18	14.36	15

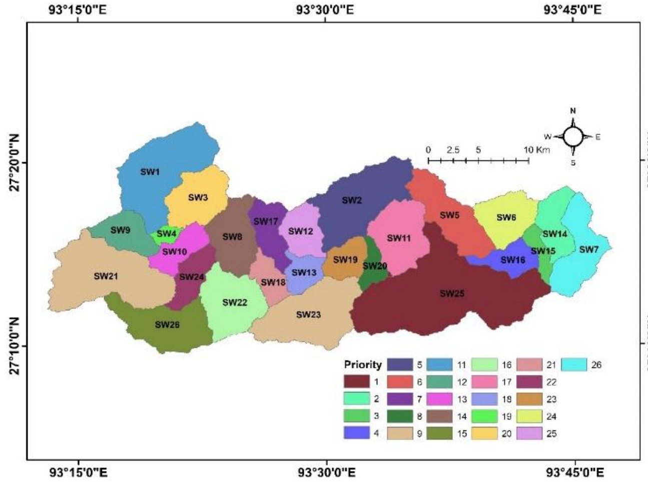

Figure 4 : Priority map of sub-watersheds in Pare basin

Linear morphometric parameters such as bifurcation ratio, drainage texture, drainage density, stream frequency and length of overland flow have direct relationship with soil erodibility while shape morphometric parameters such as form factor, compactness coefficient, circulatory ratio and elongation ratio are inversely proportional to soil erodibility [35] [40]. The two relief morphometric parameters i.e. relief ratio and ruggedness number, considered in the study are directly proportional to soil erodibility. The maximum value in linear and relief parameters among the sub-watersheds has been assigned as rank 1 and the least value as rank 26. On the opposite, the maximum value in shape parameters among the sub-watersheds has been assigned as rank 26 and the least as rank 1. Compound scores are determined by averaging all over the linear, shape and relief parameters for each sub-watershed, as illustrated in Table IV. The maximum and minimum compound prioritized score of the sub-watersheds are 7 (SW25) and 19.73 (SW7) respectively indicating SW25 has the priority rank of 1 while SW7 has the lowest priority rank of 26. This can be interpreted in a way that SW25 has been found to be the most vulnerable to soil erosion requiring highest priority for carrying out soil, land and water conservation measures while such mitigation and intervention measures could be taken up at last for SW7. As mentioned in Chandniha and Kansal [35], morphometric study is one of the most appropriate techniques to address issues related to water distribution and erosion problems over the watershed, we suggest various decision makers and stakeholders to get interest in this paper in order to manage various sub-watersheds in the Pare catchment.

IV.CONCLUSION

Soil erosion is one of the most hazardous phenomena that occurred naturally and accelerated due to human interventions. A lot of mountainous watershed are under high pressure of soil loss inhibited by heavy rainfall as well as steep topography. Identification of critically degraded watersheds are one of the first steps in watershed management programmes to provide necessary mitigations and interventions. Morphometric analysis not only allows to identify such critically degraded watersheds, but helped in understanding various terrain parameters such as nature of bedrock, infiltration capacity, surface runoff, etc. In this study, prioritization of sub-watersheds using morphometric characteristics was carried out in Pare watershed using SRTM DEM. The morphometrics parameters determined in this study are linear parameters: stream order, stream length, mean bifurcation ratio, drainage texture, drainage density, stream frequency and length of overland flow; shape parameters: form factor, compactness coefficient, circulatory ratio and elongation ratio; and relief parameters: relief ratio and ruggedness number. The results obtained in the study indicated that Pare is a 7th order river comprising of 6127 stream segments running over the watersheds for about 2448 kilometres. The mean bifurcation ratio, form factor, drainage texture, compactness coefficient, circulatory ratio, elongation ratio, drainage density, stream frequency, length of overland flow, relief ratio and ruggedness number of Pare watershed are found as 4.29, 0.24, 38.31 per km, 1.64, 0.38, 0.56, 3.18 km/km2, 7.95 per km2, 0.16 km, 0.05 and 8.46 respectively. The results of the prioritization of the sub-watersheds showed that SW25 has the highest probability to be affected by soil erosion while SW7 the least chance of being affected. So, the authors recommended various decision makers, watershed managers and other associated stakeholders to take up watershed management plans according to the priority's ranks obtained in this study. However, improvement could be made by incorporating land-use and soil information since watershed management programmes always will depend on the purpose utilization of the watershed thereby the results of priority may differ.

V. REFERENCES

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