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Sub-watersheds wise slope instability analysis and prioritization of the Balason River Basin of Darjeeling Himalaya, India using compound ranking method

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ABSTRACT

To balance between the demand and supply and ever increasing demand, it is necessary to conserve natural resources like watersheds, with proper prioritization. In that sense, morphometric analysis of any drainage basin is considered of high importance in hydrological investigation. Morphometric parameters describe the topology, the structure, the platform and the relief of basin, applied for the prioritization of watersheds. Some pre-information such as runoff, stages of its development and soil loss etc. are also provided by the analysis of morphometric parameters. In the present study, an attempt has been made to prioritize sub-watersheds based on morphometric analysis in relation to slope instability. The base map of stream network were digitized from toposheets no. 78A/4, 78A/8, 78B/1, 78B/5 and 78B/6 (Scale 1:50000) and then updated on Google earth. Arc GIS 9.3 software and MS excel-2007 was used to assess 13 morphometric parameters i.e. bifurcation ratio (Rb), length of overland flow (Lof), drainage density (Dd), stream frequency (Fs), texture ratio (Rt), drainage texture (Td), compactness coefficient (Cc), constant of channel maintenance (Ccm), shape factor/ basin shape (Sf), form factor (Ff), circularity ratio (Rc), elongation ratio (Re) and relief ratio (Rr). The results showed that SW 4, SW 5 and SW 8 fall under very high priority class in respect of soil erosion and soil loss or simply instability, having Rb of 3.532 – 4.002, Dd of 5.986 – 6.538, Fs of 14.934 – 29.447, Td of 9.765 – 23.158, Rt of 7.055 – 16.958, Lof of 0.069 – 0.084, Rr of 0.209 – 0.302, Cc of 1.265 – 1.554, Ccm of 0.139 – 0.167, Sb of 2.969 – 5.556, Ff of 0.180 – 0.337, Rc of 0.420 – 0.634 and Re of 0.479 – 0.655. Sub-watershed wise highest priority was obtained by SW 5 followed by SW 8, SW 4, SW3, SW 9, SW 1, SW 6, SW 16, SW 2, SW 17, SW 15, SW 13, SW 7, SW 10, SW 11, SW 12, SW 14, and SW 18.

Keywords: Sub-watersheds, Morphometric parameters, GIS, Compound Ranking Method, Prioritization.

INTRODUCTION

Drainage basin or watershed is the basic or ideal areal unit of the earth surface in geomorphological study of fluvially eroded landscapes (Chorley, 1969), for the management and sustainable development of natural resources (Patel et al. 2013). Keeping in view of the increasing population demand and food security for the future generation, it is realized that the water and land resources need to be developed and used and managed comprehensively in an integrated way (Biswas et al., 1999). Morphometric analysis is very much important in analyzing the changing quality of water and soil of a small hilly micro watershed. In addition, it is very useful in regional flood frequency analysis, hydrological modeling, watershed prioritization, natural resources conservation and management, drainage basin evaluation, etc. For that, it requires measurement of linear, areal and relief aspects of the basin (Nautiyal, 1994). The estimation of morphometric parameters of a hilly catchment gains more importance in spite of the difficulty in collection and measurement of hydrologic data (National Institute of Hydrology 1998). Hence, GIS is an effective tool, not only for collection, storage, management and retrieval of spatial and non-spatial data, but also for the derivation of the useful results and modeling (Gupta and Srivastava, 2010; Srivastava et al., 2011). Pioneering work on the drainage basin morphometry has earlier been carried out by Horton (1932, 1945), Smith (1950), Stahler (1952, 1964), Miller (1953), Schumm (1956), Melton (1958) and Chorley (1969). Prioritization of sub-watersheds based on morphometric analysis were also attempted by Biswas et al. (1999), Chopra et al. (2005), Patel et al. (2013), Rekha et al. (2011), Panhalkar et al. (2011), Vandana (2012), Patil and Mali (2013), Panda and Nagarajan (2013), Tolessa and Rao (2013), Ali and Ali (2014), Amani and Safaviyan (2015) etc. Shrimali et al. (2011) delineated and prioritized of soil erosion areas in Sukhana lake catchment in the Shiwalik hills by using RS and GIS. Nookaratnam et al. (2005) carried out check dam positioning by prioritization of micro-watersheds using Sediment Yield Index (SYI) model and morphometric analysis using GIS. Similarly, Javed et al. (2009) and Javed et al. (2011) studied on prioritization of sub-watersheds of Kanera watershed in Guna district of Madhya Pradesh and Jaggar watershed in the Karauli district of Rajasthan respectively, based on morphometric and land use analysis using RS and GIS techniques.

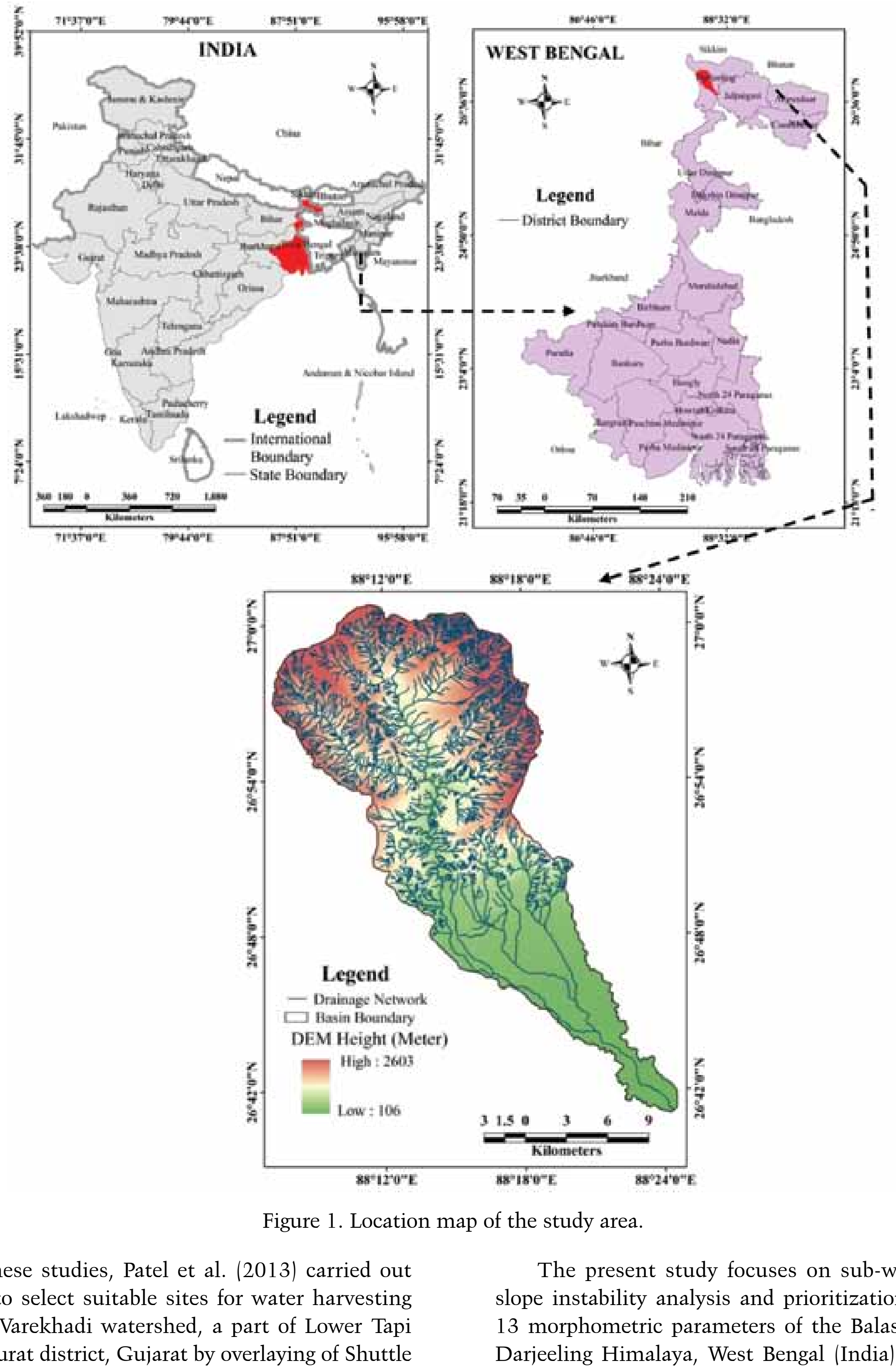

Figure 1. Location map of the study area.

Apart from these studies, Patel et al. (2013) carried out a case study to select suitable sites for water harvesting structures in Varekhadi watershed, a part of Lower Tapi Basin (LTB), Surat district, Gujarat by overlaying of Shuttle Radar Topography Mission DEM, soil map and slope map using RS and GIS approach. Chirala et al. (2015) worked on Meghadrigedda catchment in Visakhapatnam, India for mapping of soil erosion zones using RS and GIS techniques.

The present study focuses on sub-watersheds wise slope instability analysis and prioritization based on the 13 morphometric parameters of the Balason river basin, Darjeeling Himalaya, West Bengal (India), using RS and GIS techniques. Prioritization rating of 18 sub-watersheds is carried out through compound ranking method. The sub-watershed with the lowest rank is given the highest priority in terms of erosion and suggested for conservation measures urgently.

Table 1. Empirical formula for calculating of morphometric parameters

Sl. No.	Morphometric Parameters	Types/ Aspects	Methods/ Formulae	References	Units	Results
1	Bifurcation Ratio (Rb)	Linear aspect	Rb =Nu/Nu+1 Nu= Total number of stream segment of order 'u', Nu+1= Number of stream segment of next higher order	Schumm, 1956	Unit less	1.6-4.103
2	Length of Overland Flow (Lof)	Linear aspect	Lof= 1/2Dd Dd= Drainage density	Horton, 1945	Km/sq.km	0.069-0.857
3	Drainage Density (Dd)	Areal aspect	Dd= L/A L= Total length of streams, A= Area of watershed	Horton, 1945	Km/sq.km	0.583-7.207
4	Stream Frequency (Fs)	Areal aspect	Fs= N/A N= Total number of streams, A= Area of watershed	Horton, 1945	No. of stream/ sq.km	0.069-29.447
5	Texture Ratio (Rt)	Areal aspect	Rt= N1/P N1=Total number of first order streams, P= Perimeter of watershed	Horton, 1945, Schumm, 1956	No. of first order stream/km	0-16.958
6	Drainage Texture (Td)	Areal aspect	Td= Nu/P Nu= Total number of streams, P= Perimeter of watershed	Horton, 1945	No. of stream/km	0.069-23.158
7	Compactness Coefficient (Cc)	Areal aspect	$Cc= 0.2841*P/A^{0.5}$ P= Perimeter of watershed, A= Area of watershed	Gravelius, 1914	Unit less	1.198-2.156
8	Constant of Channel Maintenance (Ccm)	Areal aspect	Ccm= 1/Dd Dd= Drainage density	Horton, 1945	Sq. km/km	0.139-18.714
9	Shape Factor/ Basin Shape (Sf)	Areal aspect	$Sf= Lb^2/A$ Lb= Length of watershed, A= Area of watershed	Horton, 1932	Unit less	1.780-5.804
10	Form factor(Ff)	Areal aspect	$Ff= A/ Lb^2$ A= Area of watershed, Lb= Length of watershed	Horton, 1932	Unit less	0.172-0.562
11	Circulatory ratio(Rc)	Areal aspect	$Rc= 4\pi A/P^2$ A= Area of watershed, π=3.14, P= Perimeter of watershed	Miller, 1953	Unit less	0.218-0.707
12	Elongation ratio (Re)	Areal aspect	$2\sqrt{(A/\pi)}/Lb$ A= Area of watershed, π=3.14, Lb= Length of watershed	Schumm, 1956	Unit less	0.468-0.846
13	Relief Ratio (Rr)	Relief aspect	Rr= Bh/Lb Bh= Basin relief, Lb= Basin length	Schumm, 1956	Enumer-ative	0.023-0.302

STUDY AREA

The Balason river basin which is located in the western part of Darjeeling district, confronted frequent destructive landslide events, was chosen as a study area (Figure 1). The major right bank tributary of the Mahananda River, the Balason River originates from Lepchajagat (2361 m) located on the Ghum-Simana ridge. Balason river basin coversparts of Rangli Rangliot, Naxalbari, Matigara, Jorebunglow Sukiapokhri, Mirik and Kurseong block of Darjeeling district in West Bengal, having an area of 378.45 km^2. It is located in between 26° 40´ N to 27° 01´ N and 88°7´E to 88°25´ E. The main Balason River flows north to south-east having length of about 51.92 km and joins Mahananda River at 26°41´28´´ N and 88°24´15´´ E . The highest and lowest elevations are 2613 m found in southeastern corner and 105 m in Southern part of the basin respectively. About 83% of basin area falls within the slope 0°-30° revealing the activeness of the total erosional agents in its upper reaches. The area having above 30° slope have mostly been deforested and affected by weathering processes. The average rainfall of the basin is 2300 mm (range 2000-5000 mm) which is primarily dependent on southwest monsoon and occurs mostly in the months of June to September. The mean annual temperature is about 20.94°C. The northern upper hill tract and southern alluvial zone have a mean annual temperature of 12°C and 24.70°C respectively (Lama, 2003).

The study area is predominately represented by very shallow to deep soils. A vast portion of the basin is consisted of wide open gently sloping southern alluvial plain. Just immediately north of this rolling plain, a foothill zone is situated which associated with active exogenetic processes and various geological disturbances. Above this zone, comparatively less dissected and lower relative relief but rugged northern highland is located. The river basin is characterized by complex geological formation. The major portion of the basin is consisting of Darjeeling

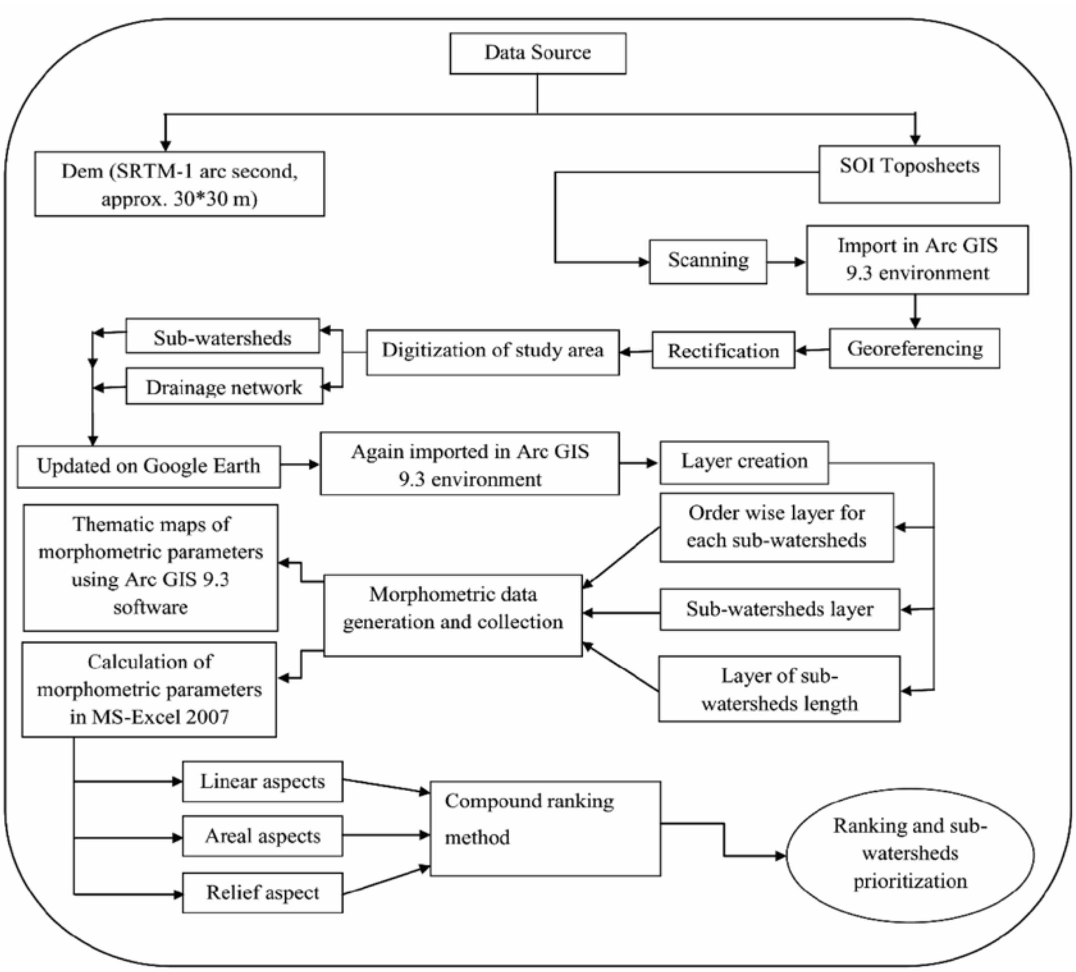

Figure 2. Methodology followed in the present study.

group, Daling series rock type and Permian Damuda series that rests along a thin belt, mostly extending in an E-W direction. The Darjeeling group of metamorphic rocks consists of carbonaceous mica-schists, granetiferous mica-schists, golden-silvery mica schists and coarse grained gneiss of various resistances. These rocks are deeply weathered and having high density of fractures. During rainy season water percolates through the exposed fractures which reduce the cohesive strength of the soil.

METHODOLOGY

The present study is basically based on morphometric analysis of Balason river basin. To assess the morphometric conditions, SRTM Dem (30m resolution), Survey of India (SOI) toposheets and geological maps were used. The drainage network was initially derived from SOI toposheets78A/4, 78A/8, 78B/1, 78B/5 and 78B/6 (Scale 1:50000) and later updated using Google Earth. The sub-watersheds boundaries were demarcated on the basis of slope, elevation, 3D view and drainage flow directions and then the basin was divided into 18 sub-watersheds. To find out the sub-watersheds which are more unstable on the basis of slope instability, two major steps have been considered i.e. morphometric parameters calculation and preparation of spatial data layers and sub-watersheds wise slope instability analysis and prioritization using compound ranking method (Figure 2).

Morphometric parameters calculation and preparation of spatial data layers

The morphometric parameters, such as bifurcation ratio (Rb), length of overland flow (Lof), drainage density (Dd), stream frequency (Fs), texture ratio (Rt), drainage texture (Td), compactness coefficient (Cc), constant of channel maintenance (Ccm), shape factor/ basin shape (Sf), form factor (Ff), circularity ratio (Rc), elongation ratio (Re) and relief ratio (Rr), were computed using standard methods and formulae and prepared data layers in GIS (Table 1).

Table 2. Results of some of the morphometric parameters.

Watershed no.	Basin area(A) in km^2	Basin Perimeter (P) in km	No. of first order stream	Total stream length	Total number of stream	Drainage density in km/ km^2	Drainage frequency in no. of stream/ km^2	Texture ratio in no. of first order stream/km	Drainage texture in no. of stream/km	Constant channel maintenance	Length of overland flow
SW 1	54.21	36.40	442	264.95	592	4.887	10.920	12.143	16.264	0.205	0.102
SW 2	13.28	16.55	82	52.88	110	3.982	8.283	4.955	6.647	0.251	0.126
SW 3	10.47	14.19	117	52.27	155	4.992	14.804	8.245	10.923	0.200	0.100
SW 4	5.69	10.62	94	37.20	131	6.538	23.023	8.851	12.335	0.153	0.076
SW 5	14.84	18.87	320	106.95	437	7.207	29.447	16.958	23.158	0.139	0.069
SW 6	28.96	24.17	264	143.06	373	4.940	12.880	10.923	15.432	0.202	0.101
SW 7	24.44	37.52	138	93.23	186	3.815	7.610	3.678	4.957	0.262	0.131
SW 8	12.79	19.56	138	76.56	191	5.986	14.934	7.055	9.765	0.167	0.084
SW 9	29.86	27.00	431	188.60	597	6.316	19.993	15.963	22.111	0.158	0.079
SW 10	11.25	16.77	60	39.31	84	3.494	7.467	3.578	5.009	0.286	0.143
SW 11	20.50	25.63	109	74.34	152	3.626	7.415	4.253	5.931	0.276	0.138
SW 12	7.69	11.69	43	28.04	59	3.646	7.672	3.678	5.047	0.274	0.137
SW 13	18.67	29.18	129	64.93	183	3.478	9.802	4.421	6.271	0.288	0.144
SW 14	19.31	18.60	32	37.04	44	1.918	2.279	1.720	2.366	0.521	0.261
SW 15	27.57	29.96	185	100.93	258	3.661	9.358	6.175	8.611	0.273	0.137
SW 16	14.00	19.70	101	53.93	151	3.852	10.786	5.127	7.665	0.260	0.130
SW 17	6.74	12.35	59	28.59	83	4.242	12.315	4.777	6.721	0.236	0.118
SW 18	58.18	57.65	0	33.94	4	0.583	0.069	0.000	0.069	1.714	0.857

Bifurcation ratio (Rb)

Rb is an index of reliefs and dissections (Horton, 1945). It is a dimensionless property that expresses the ratio of the number of streams of a given order to the number of streams of the next higher order (Horton, 1932, 1945; Schumm, 1956). In different environmental condition, as well as different regions, Rb values shows only a little variation, except where very strong geological control dominates (Stahler, 1957) and morphometric control of the basin itself (Singh et al., 1984). Lower Rb values are the results of structurally less disturbed watershed without any distortion in drainage pattern (Javed et al., 2009; Magesh et al., 2012) and are the attributed to the relatively gentle slope (Panda and Nagarajan 2013). In this study, Weighted Mean Bifurcation Ratio (Rbwm) was considered which obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values.

Length of overland flow (Lof)

Lof is one of the most independent variables affecting both the hydrologic and physiographic development of drainage basin (Sharma and Padmaja, 1982). It refers to the length of the run-of the rainwater on the ground surface, before it localized into definite channels and considered length of overland flow to be about half the distance between stream channels and taken it to be roughly half the reciprocal of the drainage density (Horton, 1945). Length of overland flow is inversely relates with the average channel slope (Patel et al., 2013).

Drainage density (Dd)

It indicates the closeness of spacing between channels (Javed et al., 2009) and is a measure of the stream length per unit area in a region of watershed (Horton, 1932 and 1945; Stahler 1952; Melton, 1958); thus 'Dd' has units of the reciprocal of length (Patel et al., 2013). Structures, relief history (Pareta and Pareta, 2012), resistance to weathering, permeability of rock formation, climate, and vegetation etc. are the important controlling factors of drainage density (Javed et al., 2009). 'Dd' is helpful to study hydrologic response to rainfall events (Melton, 1957; Gupta and Srivastava, 2010), landscape dissection, runoff potential, infiltration capacity, climatic condition and vegetation cover of the basin (Patil and Mali, 2013). Singh (2010) divided drainage density into five categories i.e. (i) very low (ii) low (iii) moderate (iv) high (v) very high.

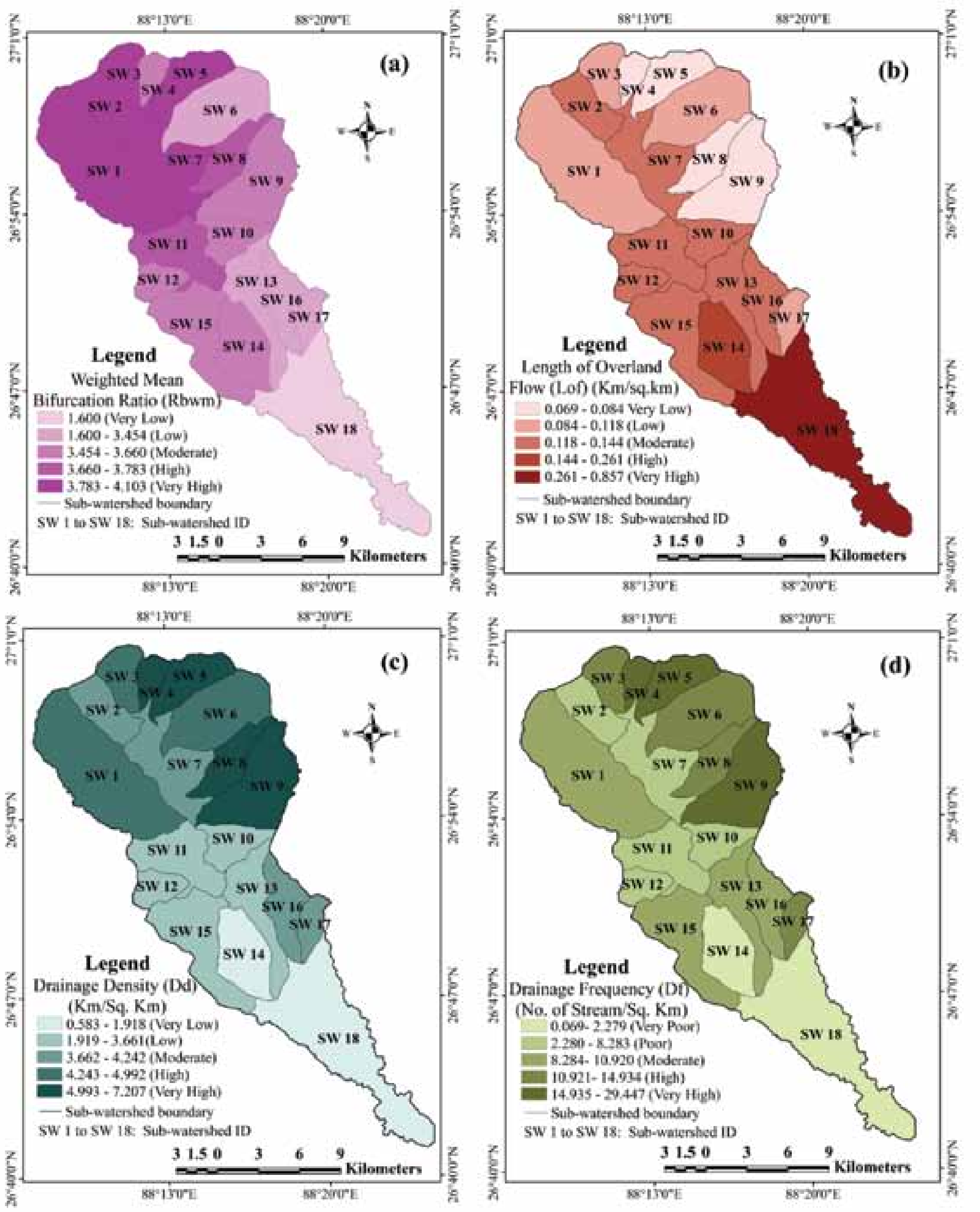

Figure 3. Sub-watershed-wise data layers of (a) weighted mean bifurcation ratio. (b) length of overland flow, (c) drainage density, and (d) drainage frequency.

Stream frequency (Fs)

The word 'stream frequency' introduced by Horton refers to the total number of stream segments of all orders per unit area (Horton, 1932, 1945). It has the positive correlation with 'Dd', indicating the increase in stream frequency with respect to increase density (Javed et al., 2009; Patel et al., 2013; Parveen, 2012). 'Fs' too can be classified into five categories i.e. very poor, poor, moderate, high and very high (Singh 2010).

Texture ratio (Rt)

Texture ratio is an important factor in the drainage morphometric analysis, which depends on the underlying lithology, infiltration capacity and relief aspects of the

Table 3. Calculation table for relative relief and relief ratio

Compactness Coefficient (Cc)	Basin Shape (Sb)	Longest Axis in km	Highest Elevation (m)	Lowest Elevation (m)	Relative Relief (rr)	Relief Ratio (Rr)
1.40	3.28	13.33	2300	580	1720	0.129
1.29	2.83	6.13	2300	1020	1280	0.209
1.25	2.31	4.92	2300	1080	1220	0.248
1.26	2.97	4.11	2320	1080	1240	0.302
1.39	3.47	7.18	2460	940	1520	0.212
1.28	2.94	9.22	2613	820	1793	0.194
2.16	3.43	9.16	1720	540	1180	0.129
1.55	5.56	8.43	2420	660	1760	0.209
1.40	2.84	9.21	2420	540	1880	0.204
1.42	2.95	5.76	2000	520	1480	0.257
1.61	1.78	6.04	1680	400	1280	0.212
1.20	2.55	4.43	1400	420	980	0.221
1.92	5.80	10.41	1920	200	1720	0.165
1.20	3.00	7.61	980	200	780	0.102
1.62	4.01	10.52	1240	200	1040	0.099
1.50	4.94	8.32	1820	220	1600	0.192
1.35	3.97	5.17	1120	220	900	0.174
2.15	5.03	17.10	500	105	395	0.023

terrain and can be defined as the ratio between first order stream streams and perimeter of the basin (Schumm, 1956).

Drainage texture (Td)

Drainage texture is an important geomorphic concept which means that the relative spacing of drainage lines (Smith, 1950). Horton (1945) defined drainage texture as the total number of stream segments of all orders per perimeter of the area. The drainage density and drainage frequency have been collectively defined as drainage texture (Tolessa and Rao, 2013). According to Singh (2010), drainage texture refers to the relative spacing of streams per unit length in grid squares. It depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. Smith (1950) and Singh (2010) classified drainage texture into five different textures i.e. very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8).

Compactness coefficient (Cc)

Cc can be defined as the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed (Gravelius, 1914) and also known as Gravelius Index (GI). A circular basin will yield the shortest time of concentration before peak flow occurs in the basin, thus it is most hazardous from a drainage point of view (Javed et al., 2009; NookaRatnam et al., 2005). It is dependent only on slope. This parameter is inversely related with the elongation ratio.

Constant of channel maintenance (Ccm)

Constant of channel maintenance is an important property of landforms and it can be defined as the inverse of drainage density (Schumm, 1956). It means that the number of square km or kms of basin surface required developing and sustaining of a channel of 1 km long. According to Strahler (1957) it indicates the relative size of landforms units in a drainage basin and has a specific genetic connotation. The values of Ccm are divided into five classes i.e. very high, high, moderate, low and very low.

Shape factor/ basin shape (Sf)

Sf is the ratio of the square of the basin length to area of the basin (Horton, 1945) and inversely related with form factor. Lower value of Sf reveals peaked flood discharge, while higher value indicates weaker flood discharge periods.

Form factor (Ff)

According to Horton (1932, 1945) form factor may be defined as the ratio of basin area to square of the basin length. For a perfectly circular watershed, the value of form factor would always be less than .754 (Chopra et al., 2005; Javed et al., 2009). Smaller the value of form factor, more elongated will be the basin.

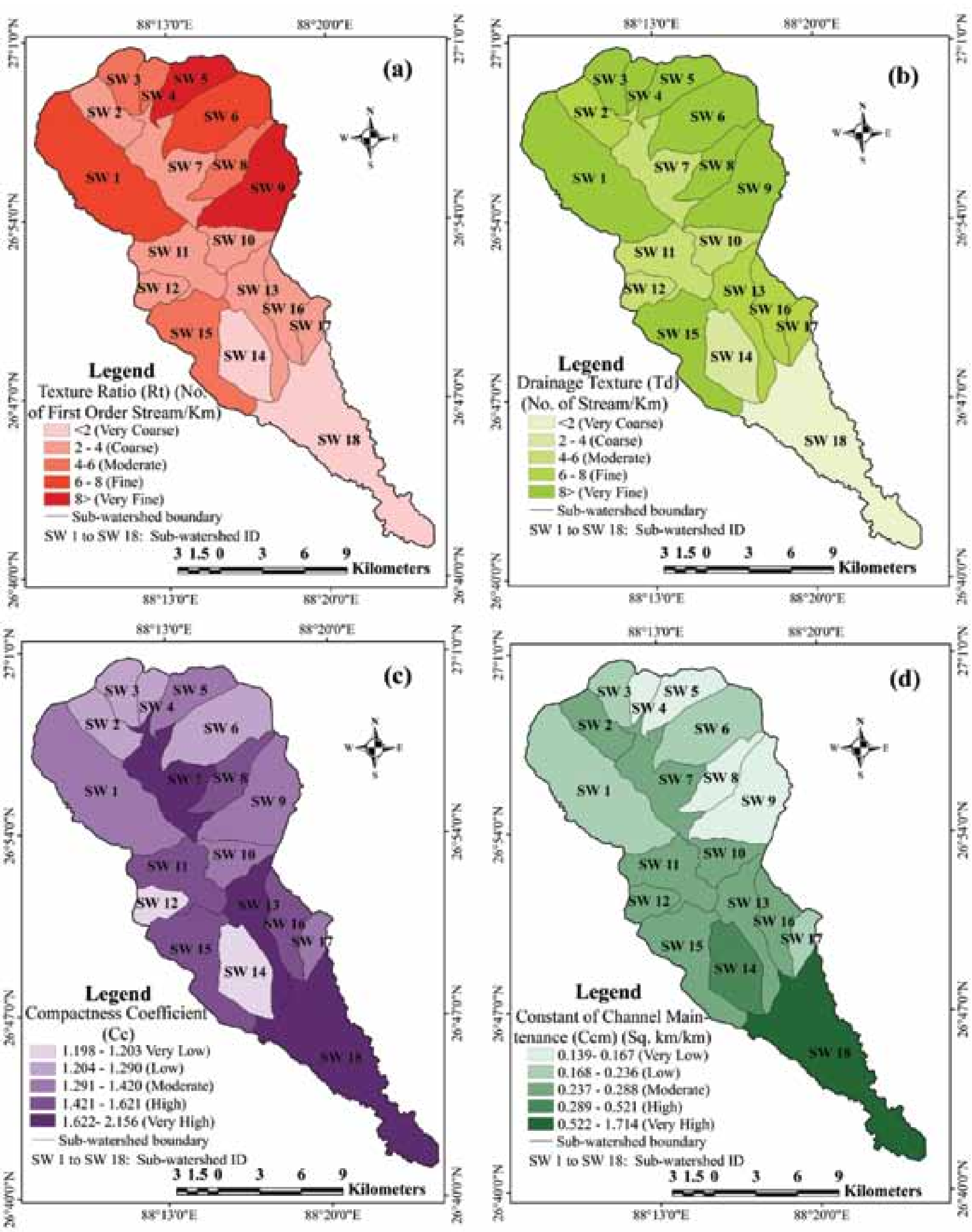

Figure 4. Sub-watershed wise data layers of (a) texture ratio, (b) drainage texture, (c) compactness coefficient, and (d) constant of channel maintenance.

Circularity ratio (Rc)

Quantitative dimensionless circularity ratio is used for the outline form of a watershed (Miller, 1953; Stahler, 1964). It can be defined as the ratio of the area of a basin to the area of a circle, having the same circumference as the perimeter of the basin (Miller, 1953). It depends on the length and frequency of streams, geological structures, land use/land cover, climate and slope of the basin. Rc varies from 0 (a line) to 1 (a circle).

Elongation ratio (Re)

Elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length (Schumm, 1956). This ratio runs between 0.6 and

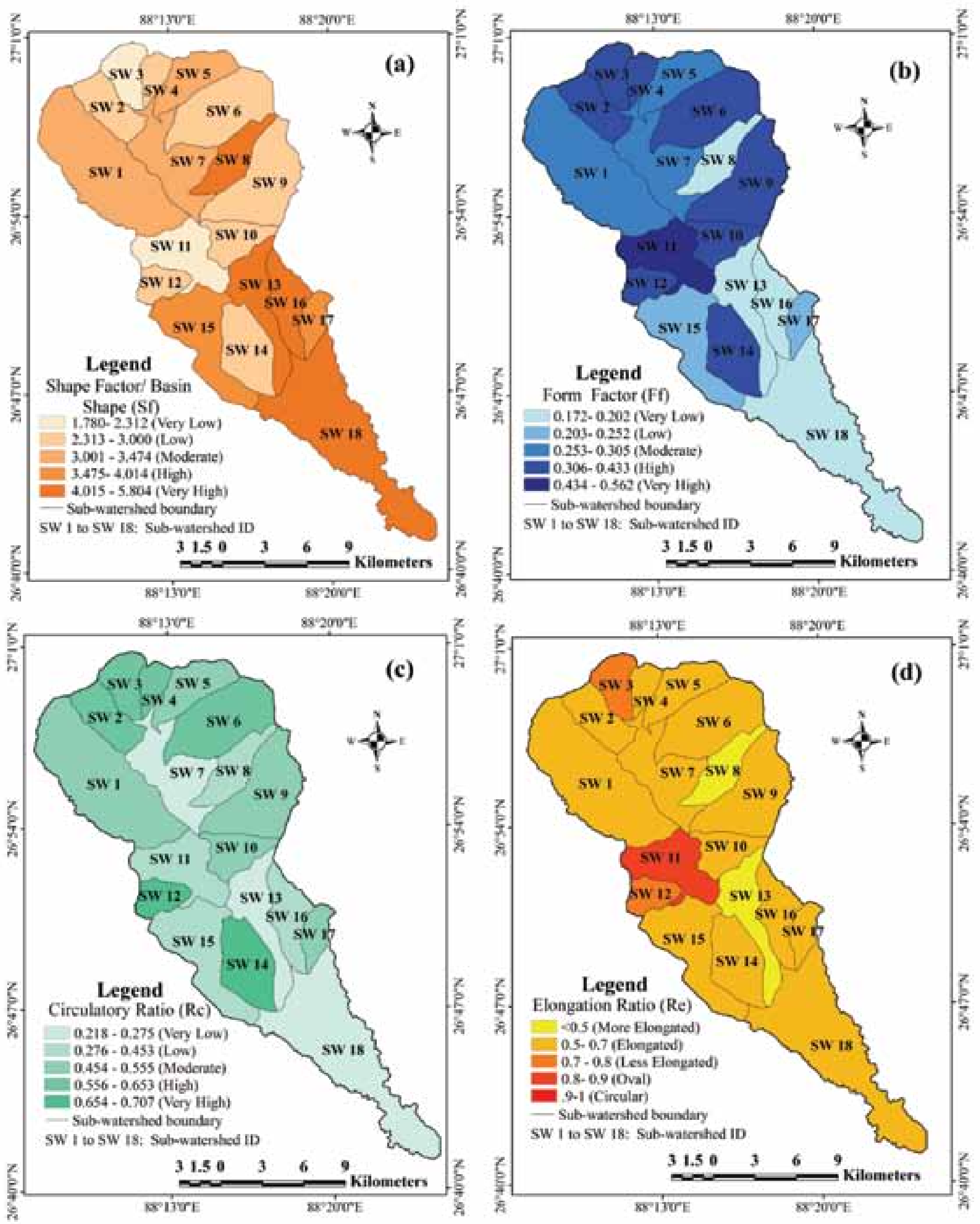

Figure 5. Sub-watershed wise data layers of (a) shape factor, (b) form factor, (c) circulatory ratio, and (d) elongation ratio.

1.0 over a wide variety of climatic and geologic types and it can be classified into five categories i.e. circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7) and more elongated (<0.5) (Strahler, 1964). The value of Re varies from 0 (highly elongated shape) to 1 (circular shape).

Relief ratio (Rr)

The relief ratio may be defined as the ratio between the total relief of a basin and the longest dimension of the basin parallel to the main drainage line (Schumm, 1956). Total relief is the difference in the elevation between the highest point of a watershed and the lowest point on the valley floor (Pareta and Pareta, 2012).

Sub-watersheds wise slope instability analysis and prioritization using compound ranking method

The morphometric parameters i.e. bifurcation ratio (Rb), drainage density (Dd), stream frequency (Fs), texture ratio

Table 4. Calculation table for form factor, circulatory ratio and elongation ratio

Watershed no.	Area(A) in km^2	Length in km (Lb)	Perimeter (P) in km	Form factor(A/ Lb^2)	Circulatory ratio($4\pi A/P^2$)	Elongation ratio $2\sqrt{(A/\pi)}/Lb$
1	54.21	13.33	36.40	0.305	0.514	0.623
2	13.28	6.13	16.55	0.353	0.609	0.671
3	10.47	4.92	14.19	0.433	0.653	0.742
4	5.69	4.11	10.62	0.337	0.634	0.655
5	14.84	7.18	18.87	0.288	0.523	0.605
6	28.96	9.22	24.17	0.341	0.623	0.659
7	24.44	9.16	37.52	0.291	0.218	0.609
8	12.79	8.43	19.56	0.180	0.420	0.479
9	29.86	9.21	27.00	0.352	0.514	0.669
10	11.25	5.76	16.77	0.339	0.502	0.657
11	20.50	6.04	25.63	0.562	0.392	0.846
12	7.69	4.43	11.69	0.392	0.707	0.706
13	18.67	10.41	29.18	0.172	0.275	0.468
14	19.31	7.61	18.60	0.333	0.701	0.652
15	27.57	10.52	29.96	0.249	0.386	0.563
16	14.00	8.32	19.70	0.202	0.453	0.507
17	6.74	5.17	12.35	0.252	0.555	0.567
18	58.18	17.10	57.65	0.199	0.220	0.503

(Rt), drainage texture (Td), length of overland flow (Lof), compactness coefficient (Cc), basin shape/shape factor (Sb), form factor (Ff), circularity ratio (Rc) and elongation ratio (Re) are termed as erosion risk assessment parameters (Biswas et al., 1999). In this study, two extra parameters were added for prioritization of sub-watersheds, i.e. constant of channel maintenance (Ccm) and relief ratio (Rr). The linear aspects like bifurcation ratio and length of overland flow, areal aspects like drainage density, stream frequency, texture ratio, drainage texture and relief aspects like relief ratio, have a direct correlation with erodibility that means higher the value, more is the erodibility or simply instability. Thus for prioritization of 18 sub-watersheds, the highest value was rated as 1, second highest value was rated as 2 and so on, and the lowest value was rated as 18 (Table 5). On the other hand, the areal aspects such as compactness coefficient, constant of channel maintenance, basin shape, form factor, circularity ratio, elongation ratio have an inverse relationship with erodibility, lower the value, more is the erodibility (Nooka Ratnam et al., 2005). Hence the lowest value was rated as 1, next lower value was rated as 2 and so on, and the highest value was rated as 18 (Table 5). After assigning the rank to every single parameter in relation to slope instability, the ranking values of each sub-watershed were summed up for each of the 18 sub-watersheds to arrive at compound score. Based on the compound score, the sub-watersheds having least value was assigned highest priority, next higher value was assigned second highest priority and so on.

RESULT AND DISCUSSION

Linear aspects

The detailed results of linear aspects like weighted mean bifurcatin ratio (Rbwm) and length of overland flow (Lof) is shown in Table 6. The values of Rbwm was used to classify the watershed into five categories i.e. very low, low, moderate, high and very high. SW 1, SW 2, SW 3, SW 5, and SW 7, are dominated by very high Rbwm value ranging from 3.78-4.10 due to low permeability and the presence of joints/fractures, observed in the exposed rocks helping first order streams, while SW 18 registered with very low Rbwm of 1.60, indicating less disturbed watersheds (Figure 3a). Low value of Lof indicates the basin was structurally complex and vice versa (Table 2). The calculated values of Lof are classified into five classes i.e. very high, high, moderate, low and very low. Very high (0.262 - 0.857) and very low (0.069 - 0.084) Lof were found for SW 18 and SW 4, SW 5, SW 8, SW9 respectively (Figure 3b).

Areal aspects

The results of areal aspects like drainage density (Dd), drainage frequency (Fs), texture ratio (Rt), drainage texture (Td), compactness coefficient (Cc), constant of channel maintenance (Ccm), shape factor (Sf), form factor (Ff), circularity ratio (Rc) and elongation ratio (Re) were given in Table 6. Dd in all the sub-watersheds range from 0.58

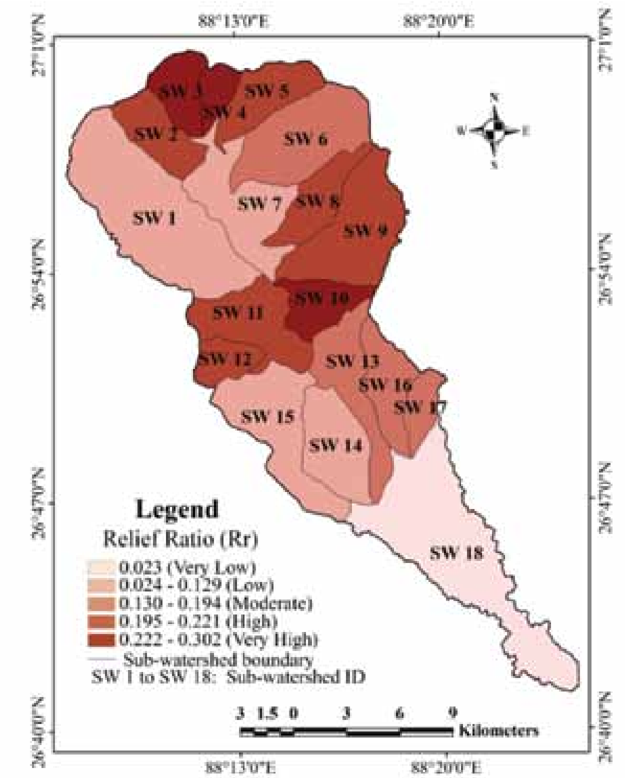

Figure 6. Sub-watershed-wise data layer of relief ratio.

Table 5. Logic behind ranking of 18 sub-watersheds in relation to slope instability, based on morphometric parameters

Morphometric parameters	Rank at 18 point scale	Logic applied
Bifurcation Ratio (Rb)	1 rank to sub-watershed which has the highest Bifurcation Ratio	Higher the Bifurcation Ratio value greater the slope instability
Length of Overland Flow (Lof)	1 rank at the highest Length of Overland Flow	Higher the Length of Overland value, the sub-watershed become more instable
Drainage Density (Dd)	1 rank at the sub-watershed having highest Drainage Density	The sub-watershed become more instable where the Drainage Density value is maximum
Stream Frequency (Fs)	1 rank at the highest Stream Frequency	Higher Stream Frequency value leads more instability
Texture Ratio (Rt)	1 rank at the maximum Texture Ratio	Texture Ratio value directly related to slope instability
Drainage Texture (Td)	1 rank at the largest drainage texture	Slope become More instable where Drainage Texture value is higher
Compactness Coefficient (Cc)	1 rank at the lowest Compactness Coefficient	Slope instability is negatively correlated with Compactness Coefficient value
Constant of Channel Maintenance (Ccm)	1 rank at the lowest Constant of Channel Maintenance	Higher the Constant of Channel Maintenance value lower the slope instability
Shape Factor/ Basin Shape (Sf)	1 rank at the lowest Shape Factor	Higher Shape Factor value represents lesser slope instability
Form Factor (Ff)	1 rank at the lowest Form Factor	Slope instability is more in lesser Form Factor value area.
Circularity Ratio (Rc)	1 rank at the lowest Circularity Ratio	Basin Circularity Ratio value negatively related to slope instability
Elongation Ratio (Re)	1 rank at the lowest elongation ratio	Lower the value of elongation ratio indicates greater slope instability
Relief Ratio (Rr)	1 rank at the highest Relief Ratio	Higher value indicates more slope instability

Table 6. Morphometric parameter wise sub-watersheds that fall in different categories

Parameters	Sub-Watersheds fall in different category				
	Very Low	Low	Moderate	High	Very High
Drainage Density	SW 14, SW 18	SW 10, SW 11, SW 12, SW 15	SW 2, SW 7, SW 16, SW 17	SW 1, SW 3, SW 6	SW 4, SW5, SW8, SW 9
Stream Frequency	SW 14, SW 18	SW 2, SW 7, SW 10, SW 11, SW 12	SW 1, SW 13, SW 15, SW 16	SW 3, SW6, SW8, SW17	SW 4, SW 5, SW 9
Bifurcation Ratio	SW 18	SW 6, SW 13, SW 16, SW 17	SW 4, SW 9, SW 10, SW 12, SW14, SW 15	SW 8, SW 11	SW 1, SW 2, SW 3, SW 5, SW 7
Length of Overland Flow	SW 4, SW 5, SW 8, SW 9	SW 1, SW 3, SW 6, SW 17	SW 2, SW 7, SW 10, SW 11, SW 12, SW 13, SW 15, SW 16	SW 14	SW 18
Constant of Channel Maintenance	SW 4, SW 5, SW 8, SW 9	SW 1, SW 3, SW 6, SW 17	SW 2, SW 7, SW 10, SW 11, SW 12, SW 15, SW 16	SW 14	SW 18
Form Factor	SW 8, SW 13, SW 16, SW 18	SW 15, SW 17	SW 1, SW 5, SW 7	SW 2, SW 3, SW 4, SW 6, SW 9, SW 10, SW 12, SW 14	SW 11
Circularity Ratio	SW 7, SW 13, SW 18	SW 8, SW 11, SW 15, SW 16	SW 1, SW 5, SW 9, SW 10, SW 17	SW 2, SW 3, SW 4, SW 6	SW 12, SW 14
Shape Factor	SW 3, SW 11	SW 2, SW 4, SW 6, SW 9, SW 10, SW 12, SW 14	SW 1, SW 5, SW 7	SW 15, SW 17	SW 8, SW 13, SW 16, SW 18
Compactness Coefficient	SW 12, SW 14	SW 2, SW 3, SW 4, SW 6	SW 1, SW 5, SW 9, SW 10, SW 12, SW 14, SW 17	SW 8, SW 11, SW 15, SW 16	SW 7, SW 13, SW 18
Relief Ratio	SW 18	SW 1, SW 7, SW 14, SW 15	SW 6, SW 13, SW 16, SW 17	SW 2, SW 5, SW 8, SW 9, SW 11, SW 12	SW 3, SW 4, SW 10
	Very Coarse	Coarse	Moderate	Fine	Very Fine
Texture Ratio	SW 14, SW 18	-	SW 7, SW 10, SW 11, SW 12	SW 2, SW 13, SW 15, SW 16	SW 1, SW 3, SW4, SW 5, SW 6, SW 8, SW 9, SW 17
Drainage Texture	SW 18	SW 14	SW 7, SW 10, SW 11, SW 12	SW 2, SW 13, SW 16, SW 17	SW 1, SW 3, SW4, SW 5, SW 6, SW 8, SW 9, SW 15
	More Elongated	Elongated	Less Elongated	Oval	Circular
Elongation Ratio	SW 8, SW 13	SW 1, SW 2, SW 4, SW 5, SW 6, SW 7, SW 9, SW 10, SW 15, SW 16, SW 17, SW 18	SW 3, SW 12	SW 11	-

to 7.21 Km/Sq. km. (Table 2). The low values of Dd are associated with regions, having highly permeable sub-soil materials under dense vegetation cover and low relief while high values of Dd indicate regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief. In the Balason river basin, very low Dd were found in SW14 and SW18 (0.583 - 1.918) and on the other hand, very high Dd regions were found in SW 4, SW 5, SW 8 and SW 9 (4.993 - 7.207), because of impermeable subsurface materials and high relief (Figure 3c). SW 4, SW 5 and SW 9 (14.935 - 29.447) have very high Fs, because of the presence of ridges on both sides of the valley, high relief resistant/ low conducting sub surface material and indicate large number of stream availability, high runoff value, low infiltration capacity while, very poor was found in SW 14, SW 18 (0.069- 2.279), indicating low relief, highly permeable subsurface material, low runoff value and small number of stream availability (Table 2 and Figure 3d). The Rt were calculated for the 18 sub-watersheds (Table 2) and classified into five classes i.e. very coarse, coarse, moderate, fine and very fine (Figure 4a).Very coarse texture ratio was found in SW 14and SW 18 (<2) indicating permeable subsurface while very fine was in SW 1, SW 3, SW 4, SW 5, SW 6 and SW 9 (>8), representing impermeable subsurface. In the same way, the Td was very coarse in SW 18(<2) revealing permeable surface, while very fine in SW 1, SW 3, SW 4, SW 5, SW 6, SW 8, SW 9 and SW15 (>8), indicating impermeable subsurface material (Table 2 and Figure 4b). Lower value of Cc reveals less erosion while higher value indicates high erosion (Table 3). SW12 and SW 14 are associated with very low Cc (1.198 - 1.203), and on the other hand, SW 7, SW 13, SW 18 were depicted with high

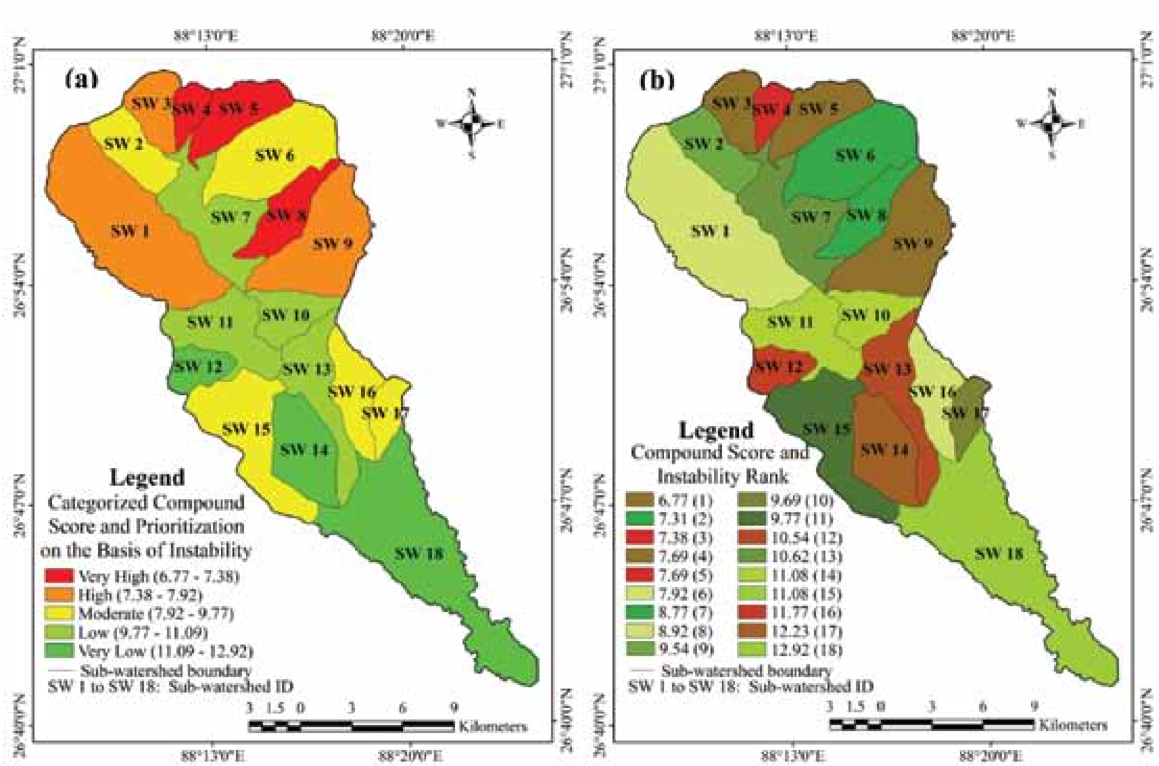

Figure 7. Sub-watershed prioritization. (a) Categorized compound score and prioritization, (b) Individual sub-watershed prioritization.

Table 7. Details of prioritized zones of Balason river basin

Prioritized zone	Sub-basins fall in this category
Very high	SW 4, SW 5, SW 8
High	SW 1, SW 3, SW 9
Moderate	SW 2, SW 6, SW 15, SW 16, SW 17
Low	SW 7, SW 10, SW 11, SW 13
Very low	SW 12, SW 14, SW 18

Cc (1.622- 2.156) (Figure 4c).The lower value of Ccm indicates that the area is under the influence of structural disturbances, having high runoff and low permeability. In this study, the value of Ccm was very high in SW 18 (0.522 - 1.714) and very low in SW4, SW 5, SW 8 and SW 9 (0.139- 0.167) (Table 2 and Figure 4d). SW 3, SW 11 fall in the category of very low Sf (1.780- 2.312) that would indicate peaked flood discharge, while SW 8, SW 13, SW 16 and SW 18 have the very high shape factor (4.015 - 5.804), revealing weaker flood discharge periods (Table 3 and Figure 5a).The watershed with high Ff has high peak flows of shorter duration and vice versa (Table 4). In present study, the Basin was classified into five parts based on form factors i.e. very high, high, moderate, low and very low. Value of form factor obtained very low for watershed SW 8, SW13, SW 16 and SW 18 (0.172- 0.202) while very high for watershed SW 11 (0.434 - 0.562) (Figure 5b).

Based on Rc value, the Balason River basin can be classified into five category i.e. very high, high, moderate, low and very low. If the value was low then the discharge will be slow as compared to the others and so the possibility of erosion will be less. Very high value of Rc was found in SW 12 and SW 14 (0.654 - 0.707), while very low value observed in SW 7, SW 13 and SW 18 (0.218 - 0.275) (Table 4 and Figure 5c). The oval shape sub-watershed was found in SW 11(0.8- 0.9) and more elongated shape in SW8 and SW13 (<0.5) (Table 4 and Figure 5d).

Relief aspects

It measures the overall steepness of the watershed. Low values of Rr indicates lower slope and minimum intensity of erosion process while high value reveals high slope, hilly region and maximum intensity of erosion process (Table 3).

Table 8. Instability rank of Balason river basin, based on composite ranking coefficient value

Watershed Id.	Rbwm	Dd	Fs	Td	Rt	Lof	Rr	Cc	Ccm	Sb	Ff	Rc	Re	Composite score	Compound score	Instability rank
SW 1	4.016 (2)	4.887 (7)	10.92 (8)	16.264 (3)	12.143 (3)	0.102 (12)	0.129 (14)	1.405 (10)	0.205 (7)	3.278 (10)	0.305 (9)	0.514 (9)	0.623 (9)	103	7.92	6
SW 2	4.012 (3)	3.982 (9)	8.283 (12)	6.647 (11)	4.955 (10)	0.126 (10)	0.209 (7)	1.290 (6)	0.251 (9)	2.830 (4)	0.353 (15)	0.609 (13)	0.671 (15)	124	9.54	9
SW 3	4.103 (1)	4.992 (5)	14.804 (5)	10.923 (6)	8.245 (6)	0.100 (14)	0.248 (3)	1.246 (3)	0.200 (5)	2.312 (2)	0.433 (17)	0.653 (16)	0.742 (17)	100	7.69	4
SW 4	3.532 (13)	6.538 (2)	23.023 (2)	12.335 (5)	8.851 (5)	0.076 (17)	0.302 (1)	1.265 (4)	0.153 (2)	2.969 (8)	0.337 (11)	0.634 (15)	0.655 (11)	96	7.38	3
SW 5	4.002 (4)	7.207 (1)	29.447 (1)	23.158 (1)	16.958 (1)	0.069 (18)	0.212 (15)	1.392 (8)	0.139 (1)	3.474 (12)	0.288 (7)	0.523 (11)	0.605 (7)	88	6.77	1
SW 6	3.454 (14)	4.94 (6)	12.88 (6)	15.432 (4)	10.923 (4)	0.101 (13)	0.194 (10)	1.276 (5)	0.202 (6)	2.935 (6)	0.341 (13)	0.623 (14)	0.659 (13)	114	8.77	7
SW 7	3.969 (5)	3.815 (11)	7.61 (14)	4.957 (16)	3.678 (14)	0.131 (8)	0.129 (15)	2.156 (18)	0.262 (11)	3.433 (11)	0.291 (8)	0.218 (1)	0.609 (8)	138	10.62	13
SW 8	3.783 (6)	5.986 (4)	14.934 (4)	9.765 (7)	7.055 (7)	0.084 (15)	0.209 (8)	1.554 (13)	0.167 (4)	5.556 (17)	0.180 (2)	0.420 (6)	0.479 (2)	95	7.31	2
SW 9	3.639 (10)	6.316 (3)	19.993 (3)	22.111 (2)	15.963 (2)	0.079 (16)	0.204 (9)	1.404 (9)	0.158 (3)	2.841 (5)	0.352 (14)	0.514 (10)	0.669 (14)	100	7.69	5
SW 10	3.539 (12)	3.494 (15)	7.467 (15)	5.009 (15)	3.578 (16)	0.143 (4)	0.257 (2)	1.420 (11)	0.286 (15)	2.949 (7)	0.339 (12)	0.502 (8)	0.657 (12)	144	11.08	14
SW 11	3.771 (7)	3.626 (14)	7.415 (16)	5.931 (13)	4.253 (13)	0.138 (5)	0.212 (6)	1.608 (14)	0.276 (14)	1.780 (1)	0.562 (18)	0.392 (5)	0.846 (18)	144	11.08	15
SW 12	3.636 (11)	3.646 (13)	7.672 (13)	5.047 (14)	3.678 (15)	0.137 (6)	0.221 (4)	1.198 (1)	0.274 (13)	2.552 (13)	0.392 (16)	0.707 (18)	0.706 (16)	153	11.77	16
SW 13	3.432 (16)	3.478 (16)	9.802 (10)	6.271 (12)	4.421 (12)	0.144 (3)	0.165 (13)	1.919 (16)	0.288 (16)	5.804 (18)	0.172 (1)	0.275 (3)	0.468 (1)	137	10.54	12
SW 14	3.66 (8)	1.918 (17)	2.279 (17)	2.366 (17)	1.72 (17)	0.261 (2)	0.102 (16)	1.203 (2)	0.521 (17)	2.999 (9)	0.333 (10)	0.701 (17)	0.652 (10)	159	12.23	17
SW 15	3.647 (9)	3.661 (12)	9.358 (11)	8.611 (8)	6.175 (8)	0.137 (7)	0.099 (17)	1.621 (15)	0.273 (12)	4.014 (14)	0.249 (5)	0.386 (4)	0.563 (5)	127	9.77	11
SW 16	3.011 (17)	3.852 (10)	10.786 (9)	7.665 (9)	5.127 (9)	0.130 (9)	0.192 (11)	1.496 (12)	0.260 (10)	4.944 (15)	0.202 (4)	0.453 (7)	0.507 (4)	116	8.92	8
SW 17	3.445 (15)	4.242 (8)	12.315 (7)	6.721 (10)	4.777 (11)	0.118 (11)	0.174 (12)	1.351 (7)	0.236 (8)	3.966 (13)	0.252 (6)	0.555 (12)	0.567 (6)	126	9.69	10
SW 18	1.6 (18)	0.583 (18)	0.069 (18)	0.069 (18)	0 (18)	0.857 (1)	0.023 (18)	2.147 (17)	1.714 (18)	5.026 (16)	0.199 (3)	0.220 (2)	0.503 (3)	168	12.92	18

The Rr for watersheds varies from 0.023-0.302. Very low Rr was found in SW 18 and very high Rr for SW 3, SW 4 and SW 10 (Table 6 and Figure 6).

Prioritization of sub-watersheds

On the basis of morphometric analysis, SW 4, SW 5 and SW 8 fall in the high priority zone, while SW 12, SW 14 and SW 18 fall in the very low category (Table 7 and Figure 7a). Sub-watershed wise highest priority obtained by SW 5 followed by SW 8, SW 4, SW3, SW 9, SW 1, SW 6, SW 16, SW 2, SW 17, SW 15, SW 13, SW 7, SW 10, SW 11, SW 12, SW 14, and SW 18 (Table 8 and Figure 7b).

CONCLUSION

Watershed prioritization is considered as one of the most important aspects of planning, development and management programmes for the developing countries like India. The morphometric parameters, evaluated using GIS, have helped to understand the existing geomorphic process, operating within the framework of drainage basin which helps prioritization of watershed development. Balason is a seventh order basin. The 13 morphometric were used for this study. It can realistically be assumed that watersheds which attained low priority for soil conservation, are likely to have a high level of environment quality and hence, the high priority watersheds should be considered for protection. Therefore, immediate attention towards soil conservation measures is required in these sub-watersheds, to conserve land for future erosion. These sub-watersheds may also be applicable in land use planning, in conservation of biodiversity, natural resources and locating water harvesting structure.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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