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Prioritization of Sub-Watersheds Using Morphometry and Land Cover Based Multi-Criteria Analysis in Basaltic Terrain of Central India

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Abstract: The geomorphological characteristics are more commonly used for characterization and prioritization of watersheds/basin. Morphometric and land cover analysis using Remote sensing (RS) and Geographic Information System (GIS) with multi criteria analytical (MCA) is most effective, time saving and accurate technique for prioritization of watersheds and helps in identification of suitable sites for conservation measures. Morphometric analysis revealed that SW8 is more susceptible to erosion followed by SW2. The land cover analysis shows that SW6 is more prone to soil erosion. Combined influence of both the parameters revealed that SW8 is more susceptible and SW1 is least susceptible to soil erosion. This study helps in planning various soil and water conservation measures to arrest soil erosion and improve the productivity of the soils.

Key words: *GIS, Remote sensing, Morphometric parameters, Land cover classes, Soil erosion susceptibility, Watershed*

Introduction

Sustainable use of natural resources is a major concern for the stake holders. Soil and water are the two major natural resources which directly or indirectly affect the livelihood of the people. Planning and management of these two natural resources is need of the hour which is mostly affected by the growing population, industrialization, deforestation, overgrazing, change of land use *etc*. Soil erosion is a major problem worldwide and it not only erode the top fertile soil from the agricultural field but also reduce the storage capacity of the reservoir. Various parameters like topographic position, landform, land use /land cover, rainfall intensity and its amount and soil properties play a significant role in soil erosion (Romshoo *et al*. 2012; Kavian *et al*. 2013). Watershed is an ideal unit for sustainable management of natural resources *i.e.* land and water to mitigate the adverse effect of exploitation and it involves judicious use of land, water and forest. Quality and quantity of data base are required for management of any watershed or drainage basin. As it is very difficult to get all the information, morphometric analysis along with land use/land cover classes are commonly done for solving the various hydrological problems of the watershed, planning and implementation of soil and water conservation measures, water resource development, ground water development and management, erosion control measures and many more. Satellite-based remote sensing integration with GIS provides a platform for quick and efficient watershed management (Altaf *et al*. 2014).

It is very difficult to treat the all the area of catchment at a once. Thus, it is necessary to divide the whole basin into smaller units considering its drainage pattern (Meshram and Sharma 2015) and first erosion

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control measures should be done in that area which is more susceptible to soil erosion. Morphometric analysis is one of the suitable methods to divide the area according to drainage pattern. In general, morphomometric analysis was done to categorize the relatively more erosion prone area within a region. Morphometry is the measurement and the mathematical analysis of the earth surface, shape and dimension of its landform (Strahler 1964; Clarke 1966; Agarwal 1998) and can be achieved through measurement of linear, aerial and relief aspects of the basin and slope contribution (Nag and Chakraborty 2003; Magesh *et al*. 2012; Sahu *et al*. 2016). Many researchers studied morphometric analysis at various levels *i.e.* watershed to catchment for planning, management and modeling of natural resources. Quantitative morphometric analysis of watershed can provide information about the hydrological nature of the rocks exposed within the watershed (Singh *et al*. 2014). Morphometric analysis is a significant tool for prioritization of sub-watersheds even without considering the soil map (Biswas *et al*. 1999).

Morphometric analysis provides a quantitative description of the drainage system, which is an important parameter for description of watersheds (Strahler 1964) and useful for hydrological investigation. The influence of drainage morphometry is very significant in understanding the landform process, soil physical properties and erosional characteristics A numbers of variables influenced the development of drainage system and the flowing pattern over space and time (Horton 1945; Leopold and Maddock 1953; Abrahams 1984). Various hydrological parameters can be correlated with shape, size, slope, drainage density *etc.* of the basin (Rastogi and Sharma 1976; Magesh *et al*. 2012).The surface runoff and flow intensity of the drainage system can be estimated using the geomorphic features associated with morphometric parameters (Ozdemir and Bird 2009). Various researchers used conventional methods to study the drainage characteristics of many river basins and sub-basins in different parts of the globe (Horton 1945; Strahler 1957; Krishnamurthy *et al*. 1996). Integration of Remote Sensing (RS) and Geographical Information Systems (GIS) techniques are more convenient for prioritization of watersheds using morphometric parameters and land cover classes as compared to conventional method. It is a proven technique for delineating, updating and analyzing the morphometric parameters of drainage basin and effective planning and management of natural resources and more suitable than other methods. Prioritization of sub-watersheds has been carried out by using RS and GIS in different basin and sub-basin to identify the erosion prone area of watersheds in various river basin (Javed *et al.* 2009, Gajbhiye *et al*. 2014; Chandniha and Kansal 2014).

In the present study, integration of morphometirc parameters with land cover classes have been used to prioritize erosion susceptibility of the major sub-watersheds of Dhanora block in basaltic region of central India using remote sensing and GIS (Bhat and Ramshoo 2009).

Materials and methods

The study area lies between 22^0 21' to 22^0 36' N latitudes and 79^0 37' to 79^0 59' E longitudes in Seoni district, Madhya Pradesh, India with an area of 550.3 km^2. It is one of the eight blocks of Seoni district of Madhya Pradesh, India. The elevation varies from 370 m to 599 m from mean sea level (MSL). The block comes under the catchment area of Wainganga river, a tributary of Godavari river. It is situated in the Agro-ecological sub-region (AESR) 10.4 which is Central Highlands (Malwa and Bundelkhand), Hot Sub-humid (Dry) Eco-sub-region. The soil temperature regime is hyperthermic and soil moisture regime is ustic. The average rainfall of the watershed is 1384mm with mean annual temperature of 28 ± 2^0C. The drainage pattern of the study area is dendritic in nature. The major crops in kharif season are soybean, paddy, maize, pigeon pea, gram and wheat and chick pea in rabi season. The location map of the study area is shown in fig.1

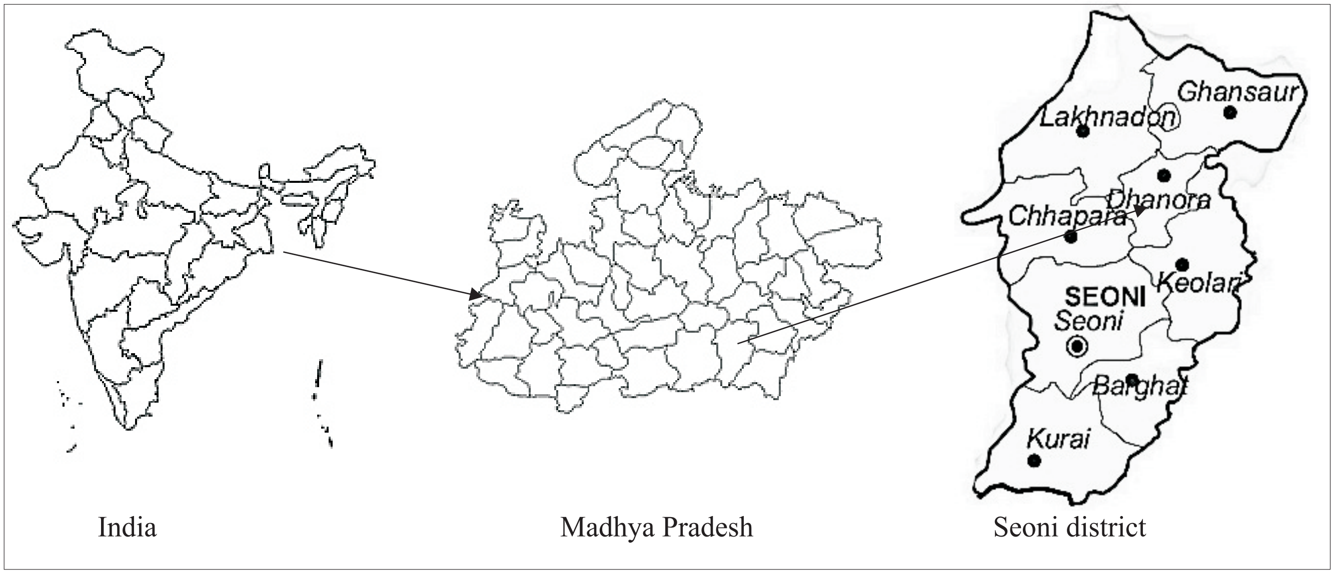

Fig. 1 Location map of study area

The Dhanora block was divided into number of sub-watersheds using ArcGIS software. Eight major sub-watersheds were identified for prioritization considering erosion susceptibility (Fig 2). Different data set like Cartosat-1DEM (30m spatial resolution) for drainage generation, Indian Remote Sensing LISS-IV data with 5.8 m spatial resolution used for classification of land cover classes. The morphometric parameters were estimated using drainage thematic layer extracted from Cartosat-1 30 m digital elevation model (DEM) using ArcGIS (Altaf *et al*. 2014). The drainage systems of all the sub-watersheds are shown in figure 3 a-h. Morphometric parameters are calculated based on the formula shown in table 1 and grouped into three categories *i.e* linear, shape and relief aspects. For prioritization of sub-watersheds, linear parameters like drainage density, stream frequency, mean bifurcation ratio, drainage texture, length of overland flow and areal parameters like basin relief directly related to susceptibility to erosion of the watershed are considered and greater value of these parameters has higher degree of soil erosion due to runoff water in the region and *vice-versa*. Hence, for prioritization of sub-watersheds, linear parameters having highest value was assigned rank 1, second highest value was assigned rank 2 and so on. Shape parameters such as circularity ratio, elongation ratio, compactness coefficient and form factor have an inverse relationship with erosion, lower the value, more is the soil erosion. Thus shape parameters with lowest value was assigned rank 1, second lower value as rank 2 and so on. Hence, the ranking of the sub watersheds has been determined by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters.

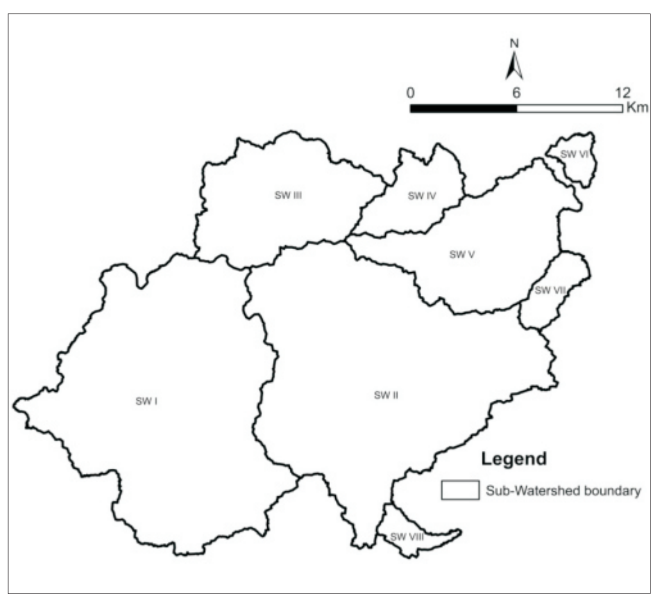

Fig. 2 Map of sub-watersheds of Dhanora block

Table 1: Methodology used for computation of morphometric parameters

S. no	Morphometric parameters	Formula/relationship	Reference
Linear aspects			
1	Stream order	Hierarchical rank	Strahler (1964)
2	Stream length	Length of stream	Horton (1945)
3	Mean stream length (Lsm)	Lsm=Lu/Nu, where Lu is total stream length of order "u" Nu is total number of stream of order u	Strahler(1964)
4	Stream length ratio (RL)	RL = Lu/L_{u-1}, whereLu is total stream length of order "u" L_{u-1} is total stream length of its next lower order	Horton (1945)
5	Bifurcation ratio (Rb)	Rb=Nu/(N_{u+1}) where, Nu is total number of stream order u and N_{u+1} is total number of stream of the next higher order	Schumms(1956)
6	Mean bifurcation ratio (Rbm)	Rbm is average of the bifurcation ratio of all order	Strahler (1957)
Aerial aspects			
7	Drainage texture (Dt)	Dt = Nu/p, where Nu is the total number of stream of all order and P is the perimeter of the basin in km	Horton (1945)
8	Drainage density (D)	D = Lu/A where Lu is total stream length of all order, km and A is the area of the watershed (km^2)	Horton (1932)
9	Stream frequency (Fs)	Fs = Nu/A, where Nu is the total number of stream of all order and A is the area of the watershed	Horton (1932)
10	Form factor (Ff)	Ff= A/Lb^2 where A is the area of the watershed and L_b Length of the basin, (km)	Horton (1932)
11	Circulatory ratio (Rc)	Rc = $4\pi A/P^2$ where A is the area of the watershed and P is the perimeter of the watershed	Miller(1953)
12	Elongation ratio (Re)	Re= 2*sqrt(A/π)/Lb, where A is the area, km^2 and L_b length of the basin	Schumms(1956)
13	Length of overland flow (Lg)	Lg = 1/(D*2), where D is drainage density	Horton(1945)
Relief aspects			
14	Relief	Elevation at outlet of watershed – Elevation at highest point on the watershed	Schumms(1956)

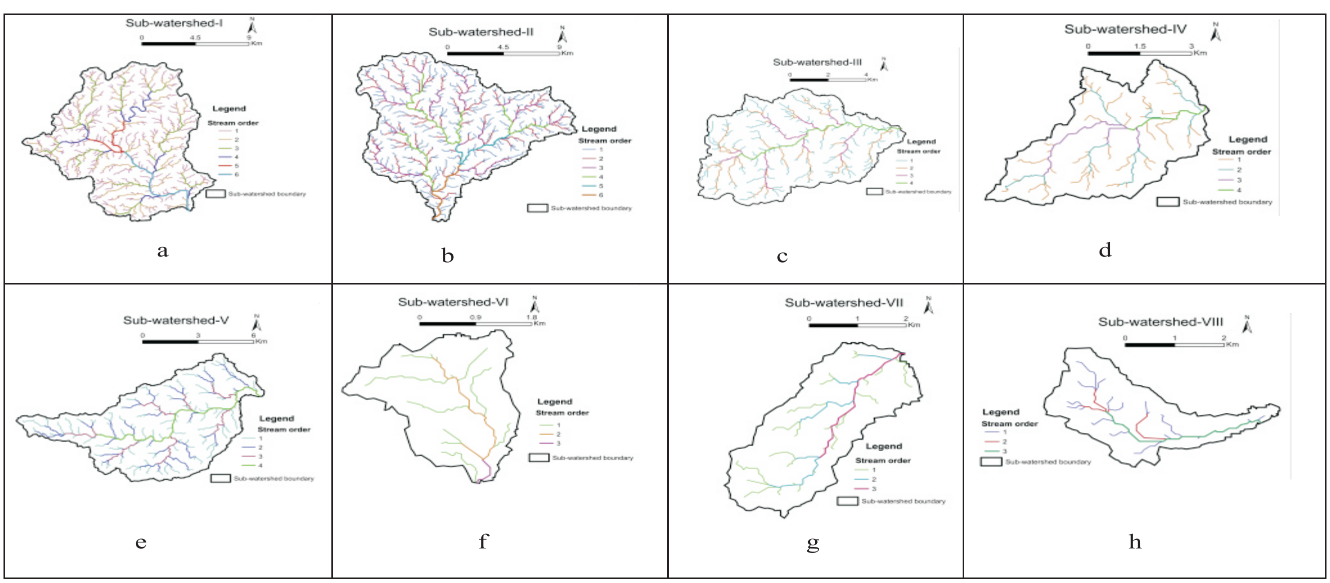

Fig. 3 (a-h) Drainage map of sub-watersheds SW I(a) – SW VIII(h) with stream order of Dhanora block

Multispectral Indian Remote Sensing (IRS) satellite, Linear Imaging Self Scanner (LISS)-IV data with 5.8m spatial resolution acquired on 23rd November, 2013 was used for classification of land use/land cover (LULC). Before start of LULC classification, the study site was visited and gathered information on different type of land use, landform, crop, other land cover classes *etc*. The LULC classified into agriculture, wasteland, forest, water bodies (river, canal and water harvesting structure) and impervious surface.

Compounded value method for prioritization on erosion susceptibility of sub-watershed was done using multi-criteria analysis and this is the one of the best methods to compare between similar entities like watersheds (Altaf *et al*. 2014). This is based on principles of knowledge driven modeling (Todorovski and Dzeroski 2006).

Here, the prioritization was done based on degree of erosion susceptibility of various sub-watersheds using morphometric parameters and land cover classes. The ranks of various sub-watersheds were assigned between 1 to 8, as the total numbers of sub-watersheds are 8. Rank 1 was given to the both morphometric and land cover classes, (parameters having maximum contribution to the soil erosion) whereas rank 8 represents minimum contribution. Compound value (Cp) of the sub-watershed was calculated considering the average value of assigned rank of the all parameters and it represents the cumulative impact of all the parameters to erosion susceptibility of a sub-watershed. The Cp was calculated using the formula

$$Cp = \frac{1}{n}\sum_{i=1}^{n} R$$

Where,

Cp- Compound value of a particular sub-watershed,

Ri- Assigned rank of a particular sub-watershed for a parameter,

n- Number of parameters,

The sub-watershed having least average value was given highest priority for soil and water conservation measures to arrest the soil erosion and sub-watershed having highest average value was given least priority among all sub-watersheds.

Results and discussion

Morphometric parameters

The morphometric analysis of the parameters, such as drainage density, mean bifurcation ratio, stream frequency, drainage texture, length of overland flow, form factor, circulatory ratio, elongation ratio, compactness coefficient, relief, stream order, number of stream and total length of stream of all the eight sub-watersheds are carried out and results are presented in table 2 and 3.

Stream order

The stream order designation is the first step of morphometric analysis and Strahler (1964) method is used for designation of stream order of sub-watersheds and it defined the position of streams in the hierarchy of tributaries. The highest stream order for SW1 and SW2

Table 2 : Sub-watersheds wise information of Dhanora block

Sub-watershed	Basin area (km^2)	Perimeter (km)	Basin length (km)	Number of streams						Stream length (km)					
				I	II	III	IV	V	VI	I	II	III	IV	V	VI
WS1	163.30	72.77	17.44	423	197	111	51	26	34	185.98	91.81	43.66	19.98	8.68	11.3
WS2	166.93	73.34	17.30	448	199	113	82	24	22	185.61	873.21	44.23	32.15	8.52	8.18
WS3	55.18	38.37	11.53	153	74	42	34			62.27	33.26	15.22	10.78		
WS4	19.21	24.19	7.272	49	28	12	8			21.28	11.06	5.90	2.94		
WS5	57.35	42.53	13.28	144	68	38	36			47.64	30.82	17.15	13.42		
WS6	5.15	11.54	3.15	12	9	3				8.10	3.22	0.65			
WS7	9.11	15.51	5.24	24	11	12				10.38	4.97	3.66			
WS8	6.02	14.87	4.36	18	6	11				6.78	2.58	3.82			

6th order, whereas, 4th order for SW3 to SW5 and 3rd order SW6 to SW8. Details of stream order with its length presented in table 2. It is observed from table 2 that number of streams decreased with increase in stream order except for stream order 6th for SW1 and for 3rd for SW7 and SW8 and r^2 value is more than 0.9 which is quite satisfactory except in SW7 and SW8. More deviation in SW7 and SW8 indicates that the sub-watershed terrain is characterized with high relief and/or moderately steep slopes, underlain by varying lithology and probable uplift across the basin (Singh and Singh 1997). The relationship between stream order and log of stream numbers of sub-watersheds is presented in figure 4.

The mean length of stream decreased as stream order increased except in SW8 for 3rd order stream which indicates basin evolution follows the erosion laws acting on geological material with homogenous weathering erosion characteristics.

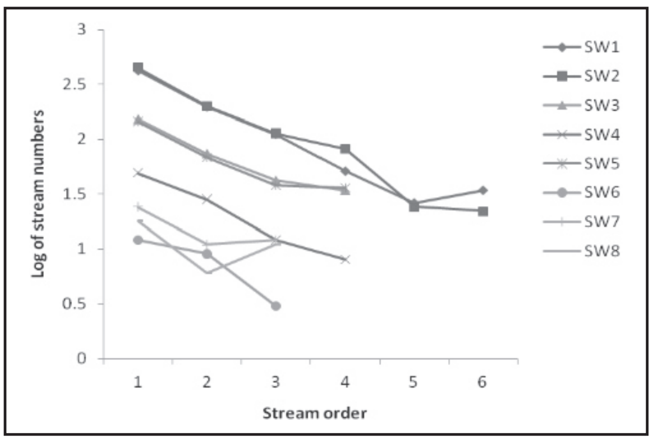

Fig. 4 Relationship between stream order and log of stream numbers of sub-watersheds

Drainage density (Dd)

Drainage density is one of the major characteristics of the watershed for selection of artificial recharge site as it indicates the permeability and porosity of the basin (Krishnamurty *et al*. 1996) and interpreted the relationship between climate and geology (Ritter and Major 1995). The rainfall characteristics influence the quantity of surface runoff. Nag (1998) found that low drainage density generally results in areas of highly resistant rocks or permeable sub-soil material, dense vegetation and low relief, where as high drainage density results due to weak or impermeable sub-surface material, sparse vegetation and mountainous relief. Density of vegetation and rainfall absorption capacity of soils influence the rate of surface run-off and affects the drainage density of an area. Lower drainage density was observed in the SW5 (1.9 km/sqkm) indicates that it has higher permeability than other sub-watersheds. If drainage density is considered alone it has lowest susceptibility to erosion than other sub-watershed. With lowest erosion susceptibility in SW5, it is ranked as 8. SW6 has the highest drainage density (2.32 sq/sqkm) indicating lowest permeability and highest erosion susceptibility with respect to drainage density and hence ranked lowest *i.e.* 1. Other sub-watersheds have ranked between 2 to 7 (Table 3 and 4).

Table 3 Sub-watershed-wise morphometric parameters of the Dhanora block

Sub-watershed	Drainage density	Mean Bifurcation ratio	Stream frequency	Drainage texture	Length of overland flow	Form factor	Circulatory ratio	Elongation ratio	Compactness coefficient	Relief (m)
SW1	2.21	1.76	5.15	5.81	0.22	0.53	0.38	0.82	1.629	209
SW2	2.19	1.97	5.31	6.10	0.22	0.55	0.39	0.84	1.624	202
SW3	2.20	1.68	5.49	3.98	0.22	0.41	0.47	0.72	1.478	128
SW4	2.14	1.86	5.04	2.02	0.23	0.36	0.41	0.68	1.579	72
SW5	1.90	1.65	4.98	3.38	0.26	0.32	0.39	0.64	1.606	137
SW6	2.32	2.16	4.66	1.03	0.21	0.51	0.48	0.81	1.455	79
SW7	2.08	1.54	5.15	1.54	0.23	0.33	0.47	0.64	1.470	109
SW8	2.19	1.77	5.81	1.21	0.22	0.31	0.34	0.63	1.734	96

Table 4 : Morphometry based prioritization of sub-watersheds

Sub-watershed	Drainage density	Mean Bifurcation ratio	Stream frequency	Drainage texture	Length of overland flow	Form factor	Circulatory ratio	Elongation ratio	Compactness coefficient	Relief (m)	Cp value	Erosion susceptibility rank
SW1	2.21	1.76	5.15	11.56	0.225	0.53	0.38	0.82	1.629	209	4.5	4
Rank	2	5	5	2	7	7	2	7	7	1		
SW2	2.19	1.97	5.31	12.10	0.228	0.55	0.39	0.84	1.624	202	4.2	2
Rank	4	2	3	1	5	8	3	8	6	2		
SW3	2.20	1.68	5.49	7.89	0.226	0.41	0.47	0.72	1.478	128	4.3	3
Rank	3	6	2	3	6	5	6	5	3	4		
SW4	2.14	1.86	5.04	4.00	0.233	0.36	0.41	0.68	1.579	72	4.8	6
Rank	6	3	6	5	3	4	5	4	4	8		
SW5	1.90	1.65	4.98	6.72	0.263	0.32	0.39	0.64	1.606	137	4.3	5
Rank	8	7	7	4	1	2	4	2	5	3		
SW6	2.32	2.16	4.66	2.07	0.214	0.51	0.48	0.81	1.455	79	5.4	8
Rank	1	1	8	8	8	6	8	6	1	7		
SW7	2.08	1.54	5.15	3.02	0.239	0.33	0.47	0.65	1.470	109	4.7	7
Rank	7	8	4	6	2	3	7	3	2	5		
SW8	2.19	1.77	5.81	2.35	0.228	0.31	0.34	0.63	1.734	96	3.8	1
	5	4	1	7	4	1	1	1	8	6		

Mean bifurcation ratio (Rbm)

Horton (1945) considered bifurcation ratio (Rb) as an index of reliefs and dissections and it negatively correlated with the permeability of watershed. In the present study, mean Rb of all the sub-watershed varies from 1.54 to 2.16. The lower value of Rb are characteristics of the watersheds, which have suffered less structural disturbances (Strahle 1964; Nag 1998). Higher value of Rbm indicates early peak flow with flash flooding which results more soil erosion (Rakesh *et al*. 2000). There is direct relationship between Rbm and erosion susceptibility *i.e* higher the value, more the erosion and *vice versa.* The mean bifurcation ratio of all the sub-watersheds in lower side indicates less structurally complex and high permeability. The SW7 has low Rbm as compared to other sub-watersheds and less susceptibility to erosion and it ranked as 8. The SW6 has highest mean bifurcation ratio (2.16) and it posses the low permeability among all the sub-watersheds and assigned rank 1 with highest erosion susceptibility. Similarly, other sub-watersheds are assigned ranks between 2 to 7 considering the mean bifurcation ratio among them (Table 3 and 4).

Stream frequency (Fs)

Stream frequency or channel frequency is directly related to number of stream per unit area of the watershed (Horton 1932). It indicates close correlation with drainage density value of the sub-watershed. Stream frequency is indirectly related to infiltration capacity, permeability and direct relationship with relief of the watershed. It indicates the stream network distribution over the watershed and high value results when the watershed has rocky terrain and very low infiltration which results more susceptible to erosion. Among all the sub-watersheds, SW8 has maximum value of stream frequency of 5.81/km^2 indicating lowest infiltration capacity with more susceptible to erosion among all the sub watersheds and ranked as 1. Lowest stream frequency was observed in SW6 *i.e* 4.66/km^2 which shows less susceptible to erosion among all the sub-watersheds and thus assigned ranked 8. All the other sub-watersheds were ranked between 2 to 7 considering the stream frequency value (Table 3 and 4).

Drainage texture

Drainage texture is one of the important parameters of morphometric study of the drainage basin and shows relative spacing of drainage lines, which are more prominent in impermeable material as compared to permeable ones (Ali and Khan 2013). Infiltration capacity of soil is the dominant factor influencing drainage texture which includes drainage density and stream frequency as well (Horton 1945). It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, relief and stage of development. Sub-watershed of low infiltration capacity will have higher drainage texture and was assigned rank 1 which indicating that it has more prone to erosion. The SW2 has highest value (12.1) and ranked as 1 which indicates more susceptibility towards erosion with low infiltration capacity among all the sub-watersheds whereas, SW6 was assigned rank 8 (2.07) as it has lowest drainage texture value with least susceptible to erosion among sub-watersheds.

Similarly, other sub-watershed were ranked from 2 to 7 considering the relative drainage texture value among them (Table 3 and 4).

Length of overland flow (Lg)

Length of overland flow is independent variables affecting hydrological and physiographic development of watershed (Horton 1945). It is significantly affected by infiltration and percolation through the soil. Lg is directly related with average slope of the channel and less for steeper slope and longer for gentle slopes (Altaf *et al*. 2014). It is synonymous with length of sheet flow as quite commonly used to a large degree. The SW5 has highest Lg (0.263) and assigned with rank 1 indicating highest potential of erosion within the sub-watersheds. The lowest Lg found in SW6 (0.214) and assigned rank 8 which has least susceptible to erosion among all the sub-watersheds considering the length of overland flow parameters. Other sub-watersheds were assigned ranks between 2 to 7 (Table 3 and 4).

Form factor (Rf)

The form factor indicates the flow intensity of a basin (Horton 1945) and has direct relationship between stream flow and shape of the watershed (Sahu *et al.* 2016). Value of form factor would be always less than 0.7854 for all basins except for circular basin. Smaller value of form factor indicates the elongated basin. Watershed with high value of form factor has high peak flow of shorter duration, whereas, those with low value of form factor have lower peak flow of longer duration. The SW8 has smaller value of form factor as compared to other sub-watersheds and hence assigned rank 1, whereas, SW2 has higher value of form factor and thus ranked 8. Similarly, other sub-watersheds are assigned ranks between 2 to 7 considering the form factor value (Table 3 and 4).

Circulatory ratio (Rc)

The circulatory ratio is influenced by many factors like geological structures, land use/ land cover, length and frequency of stream and describe as a significant ratio that indicates the dendritic pattern of a watershed (Miller 1953). Circularity ratio ranges from 0.4 to 0.5 that indicates strongly elongated and permeable homogenous geologic materials (Withanage 2014). Higher value of circulatory ratio, greater the circular shape of the basin and *vice-versa.* Low Rc indicates elongated watershed with low relief and less permeable (Altaf *et al*. 2014). Lowest Rc was observed in SW8 and ranked 1 due to low infiltration rate and more prone to soil erosion among the sub-watersheds. Similarly, SW6 shows highest Rc *i.e*. 0.48 and assigned rank 8 with least susceptible to soil erosion among all the sub-watersheds considering the circulatory ratio. Other sub-watershed were ranked between 2 to 7 considering the value of circulatory ratio (Table 3 and 4).

Elongation ratio (Re)

Elongation ratio represents the shape of the watershed and gives information about hydrological characteristics of a watershed. This value generally varies from 0.6 to 1.0 over wide climatic and geologic types (Strahler 1964). Values near to one correspond to low relief, whereas, values ranges between 0.6 to 0.8 represents the high relief and steep ground slope (Strahler 1964). Highest Re (0.84) was observed in SW2 and thus assigned rank 8 and this sub-watershed indicates least susceptibility to soil erosion due to runoff water. Lowest Re was observed in SW8 and hence assigned rank 1 which is more prone to erosion among all the sub-watersheds. Other sub-watersheds were assigned rank in between 2 to 7 considering elongation ratio value. The SW1, SW2 and SW6 are oval in shape, SW4, SW5, SW7 and SW8 has elongated shape and SW3 is less elongated in shape (Table 3 and 4).

Compactness coefficient (Cc)

Compactness coefficient of a watershed has direct relationship to the infiltration capacity of the watershed. Lower value of the Cc signifies more prone to soil erosion. The lowest Cc value found in SW6 and thus assigned rank 1 whereas, highest Cc value was observed in SW8 and has highest infiltration capacity among all the sub-watersheds and less susceptible to erosion. Similarly, ranks have been assigned between 2 to 7 to other sub-watersheds according to the Cc value (Table 3 and 4).

Basin relief (H)

Relief of the watershed is an important morphometric variable used for the assessment of morphological characteristics of topography (Gayen *et al*. 2013). There is a strong correlation between hydrological characteristics and the relief of a drainage basin (Schumms 1956). Relief aspects are related with three dimensional features *i.e* area, volume and altitude of landform to analyze different geo-hydrological characteristics (Withanage *et al*. 2014; Sahu *et al*. 2016). Relief parameters of the watershed are presented in table 3. It is an index of overall steepness of a drainage basin as well as of the intensity of erosion process operating on the slopes of a basin (Altif *et al.* 2014). The ranking system adopted in sub-watersheds considering basin relief is similar to D, Rbm and Fs as they impart same erosional characteristics. Lower value of basin relief indicates less susceptibility to erosion. The SW4 has lowest basin relief among all the sub-watersheds and assigned rank 8. Highest basin relief was observed in SW1 and more susceptible to erosion in relation to other sub-watersheds (Table 3 and 4).

It is observed that, no single parameters can be used to rank the sub-watersheds on susceptibility of erosion. Hence, after assigning the rank in each morphometric parameter, a compound value (Cp) was calculated by averaging all the values. Lowest rank has high susceptibility erosion, whereas, higher rank has lowest susceptibility of erosion among themselves.

Effect of land cover on soil erosion susceptibility and its relationship

Land Cover

Degree and type of vegetation or land cover (LC) plays a vital role in drainage pattern as well as soil erosion. Vegetation reduces the impact of rain drop, intercept the rainfall, reduces the runoff velocity, root system bind the soil and increase the infiltration capacity of soil which directly or indirectly reduce soil erosion. Remote sensing can be a very good tool for studying the changes because of its synoptic view capability and repetitive coverage (Luque 2000). Difference in vegetation coverage significantly affects erosion susceptibility of sub-watersheds (Rosenqvist and Brikett 2002). Contribution of runoff increases sharply due to impervious nature of the land either by natural composition or by human settlement due to the obstruction of infiltration process (Dams *et al*, 2013) which influence the soil erosion.

Before the start of mapping of land cover, the study area was traversed with IRS LISS-IV image and toposheet of Survey of India. After that, Visual image interpretation method based on tone, texture, association, size, shape, pattern of satellite image, topographic location and field knowledge was followed to delineate various land use/land cover categories using the IRS LISS-IV data. After mapping land cover, it was again verified with extensive field survey before finalization of land cover map. The land cover has been classified into 5 classes on the basis of image interpretation of the study area which influence the soil erosion. The classes are agriculture, forest, wasteland, impervious surface and water bodies (Table 5).

The ranking of sub-watershed was given on the basis of influence of land cover towards the soil erosion. Here per cent of area of a particular class is taken as criteria for ranking the sub-watersheds. The sub-watersheds was assigned rank 1 having maximum percentage of land cover class which directly cause soil erosion and rank 8 was assigned to sub-watersheds having minimum percentage of land cover of same class which have indirect relationship with soil erosion.

Among all the sub-watersheds, area having maximum percentage of forest land cover which directly reduces erosion is assigned rank 8 and sub-watershed having minimum area of forest assigned rank 1. Similarly, wasteland which directly causes erosion, sub-watershed having maximum area was assigned rank 1 and minimum area was assigned rank 8. Accordingly, for all land cover classes, rank was assigned for all the sub-watersheds in between 1 to 8 based on contribution to erosion. Finally a single compounded value was generated by averaging the assigned rank for each sub-watershed.

Impervious surface: Impervious surface is that land where, the soil is either absent like exposed rock or the area where, maximum land is covered with impervious material like habitation. The amount of soil erosion from this area is assumed to be zero or negligible as there is no soil to be eroded. This type of area is less susceptibile to erosion. The sub-watershed having maximum percentage of such type of area has lowest contribution towards soil erosion, whereas, sub-watershed having minimum percentage of area

Table 5 : Area with percentage of various land cover classes of sub-watersheds

Sub-watershed	Area	Categories				
		Agriculture	Forest	Wasteland	Impervious surface	Waterbodies
SW1	ha	8710.99	4651.24	2327.7	321.9	318.17
	%	53.34	28.48	14.25	1.97	1.94
SW2	ha	9161.25	2368.59	4492.33	471.02	199.81
	%	54.88	14.18	26.91	2.82	1.19
SW3	ha	2959.79	479.83	1758.61	129.31	190.46
	%	53.63	8.69	31.87	2.34	3.45
SW4	ha	984.18	34.84	801.34	77.06	23.58
	%	51.23	1.81	41.71	4.01	1.22
SW5	ha	3149.32	504.97	1832.4	149.38	98.93
	%	54.9	8.8	31.95	2.6	1.72
SW6	ha	219.07	72.04	211.19	11.18	1.52
	%	42.53	13.98	41.00	2.17	0.29
SW7	ha	582.28	29.2	267.21	32.05	0.26
	%	63.91	3.20	29.33	3.51	0.02
SW8	ha	559.95	0	18.43	23.62	0
	%	93.01	0	3.06	3.92	0

contributes highest towards susceptibility to erosion. The rank 1 was assigned to the sub- watershed having minimum percentage of such type of land cover, whereas, rank 8 was assigned to the sub-watershed, where, maximum area of impervious surface occur. In the present study SW1 was assigned rank 1 as it has minimum impervious surface (1.97%) indicating it has more susceptibility to erosion and rank 8 was assigned to SW4 as it has maximum impervious surface area (4.01%). Other sub-watersheds area were ranked in between 2 to 7 with respect to the percentage of impervious area.

Agriculture: Area under agricultural crops is more than 50% in the all the sub-watersheds except SW6 and it is the first dominating land cover. An average of 54.59% area under agriculture land use present in all sub-watersheds. Generally, agricultural land present in the relatively less slope area and more runoff water gets infiltrate into the soil which reduces both volume and peak runoff. The root systems of the crop strongly bind the surface soil and reduces the impact of rainfall on surface soil and reduces the runoff velocity. All these cumulative effects reduce the soil erosion. Hence, the sub-watershed having more area under agriculture is less susceptibility to erosion and assigned rank 8 and *vice-versa*. It is found that SW8 (93.01%) has maximum percentage of area under agriculture and thus assigned rank 8 and SW6 (42.53%) was assigned rank 1 as it has minimum percentage agricultural land among all the sub-watersheds. Other sub-watersheds are ranked between 2 to 7 considering the percentage of agriculture land.

Forest: The total percentage of forest area under all the sub-watershed varies from 0 to 28.48%. It comprises mainly moderately dense and dense forest. Forest land cover work against the soil erosion and SW having more percentage of area under forest was least susceptible to erosion and assigned rank 8. The SW having less percentage area under forest was assigned rank 1 as it is more susceptible to erosion. The lowest forest area is found in SW 8 (0%) and assigned rank 1, whereas, in SW1 maximum percentage of forest area (28.48%) was found and hence assigned rank 8. Other sub-watersheds are assigned rank in between 2 to 7 with respect to the percentage of forest area.

Wasteland: Wasteland is the second dominating land cover and its consists of 24.28% of area of all the sub-watersheds. Wastelands are the unutilized land and have no agricultural activities. This type of land are kept fallow throughout the year. Due to less vegetative cover, these types of land are highly susceptible to erosion. The SW having more area under this type of land cover are more prone to erosion and assigned rank 1, whereas, the SW has less area among all the sub-watersheds was assigned rank 8 as it is less susceptible to erosion. Among all, SW4 has maximum percentage of area and assigned rank 1 whereas, SW8 has minimum percentage of area and assigned rank 8. Other sub-watersheds are assigned rank between 2 to 7.

Water bodies: Water bodies included 1.72 % of total area of all the sub-watersheds. Similar ranking has been adopted as done in impervious surface. The maximum coverage was observed in SW3 (3.45%) and assigned rank 8, whereas, in SW8 (0%) no area under water bodies and thus assigned rank 1. Similarly, rank was assigned in other sub-watersheds considering the percentage of water bodies.

After assigning the ranks to all land cove classes, a compound value (Cp) was calculated by averaging the rank value of individual land cover classes for each sub-watershed. Using the compound value, all the sub-watersheds are ranked from 1 to 8 with respect to erosion susceptibility. The lowest rank has high susceptibility erosion, whereas, higher rank has lowest susceptibility of erosion among themselves (Table 6).

Influence of combined effect land cover classes and morphometry parameters towards erosion susceptibility of sub-watersheds

After ranking the land cover classes and morphometry parameters individually, both the parameters were integrated to get a cumulative impact on susceptibility of erosion. The individual ranking obtained were averaged for each watershed to get a compound value for prioritization of sub-watersheds with respect to erosion susceptibility. Compound value (Cp) of each sub-watershed is presented in table 7. If we consider morphometric parameters, SW8 is more vulnerable to soil erosion but SW6 least susceptible to erosion, whereas, SW6 is most prone to erosion considering land cover classes and SW2 is less vulnerable among sub-watersheds. When we combined the both parameters, the result indicated shows that SW8 is more susceptible to erosion and also shows that forest cover is nil and stream frequency is maximum in the sub-watershed.

Table 6. Land cover based prioritization of sub-watersheds for erosion susceptibility

Sub-watershed	Area	Categories					Cp Value	Erosion susceptibility rank
		Agriculture	Forest	Wasteland	Impervious surface	Waterbodies		
SW1	ha	53.34	28.48	14.25	1.97	1.94		
	%	3	8	7	1	7	5.2	7
SW2	ha	54.88	14.18	26.91	2.82	1.19		
	%	5	7	6	5	4	5.4	8
SW3	ha	53.63	8.69	31.87	2.34	3.45		
	%	4	4	4	3	8	4.6	3
SW4	ha	51.23	1.81	41.71	4.01	1.22		
	%	2	2	1	8	5	3.6	2
SW5	ha	54.90	8.8	31.95	2.6	1.72		
	%	6	5	3	4	6	4.8	5
SW6	ha	42.53	13.98	41.00	2.17	0.29		
	%	1	6	2	2	3	2.8	1
SW7	ha	63.91	3.20	29.33	3.51	0.02		
	%	7	3	5	6	2	4.6	4
SW8	ha	93.01	0	3.06	3.92	0		
	%	8	1	8	7	1	5	6

Table 7. Prioritization of sub-watersheds for erosion susceptibility based on combined influence of morphometry and land cover

Subwatershed	Morphometric parameters										Land cover					Cp value	Erosion susceptibility rank
	Linear parameters					Shape parameters				Relief parameters	Agriculture	Forest	Waste land	Impervious surface	Water bodies		
	Drainage density	Mean Bifurcation ratio	Stream frequency	Drainage texture	Length of overland flow	Form factor	Circulatory ratio	Elongation ratio	Compactness coefficient	Relief (m)							
	D	Rbm	Fs	Rt	Lg	Rf	Rc	Re	Cc	H							
SW1	2.21	1.76	5.15	5.81	0.225	0.53	0.38	0.82	1.629	209	53.34	28.48	14.25	1.97	1.94		
Rank	2	5	5	2	7	7	2	7	7	1	3	8	7	1	7	4.73	8
SW2	2.19	1.97	5.31	6.10	0.228	0.55	0.39	0.84	1.624	202	54.88	14.18	26.91	2.82	1.19		
Rank	4	2	3	1	4	8	3	8	6	2	5	7	6	5	4	4.53	5
SW3	2.20	1.68	5.49	3.98	0.226	0.41	0.47	0.72	1.478	128	53.63	8.69	31.87	2.34	3.45		
Rank	3	6	2	3	6	5	6	5	3	4	4	4	4	3	8	4.40	2
SW4	2.14	1.86	5.04	2.02	0.233	0.36	0.41	0.68	1.579	72	51.23	1.81	41.71	4.01	1.22		
Rank	6	3	6	5	3	4	5	4	4	8	2	2	1	8	5	4.40	3
SW5	1.90	1.65	4.98	3.38	0.263	0.32	0.39	0.64	1.606	137	54.90	8.8	31.95	2.6	1.72		
Rank	8	7	7	4	1	2	4	2	5	3	6	5	3	4	6	4.47	4
SW6	2.32	2.16	4.66	1.03	0.214	0.51	0.48	0.81	1.455	79	42.53	13.98	41.00	2.17	0.29		
Rank	1	1	8	8	8	6	8	6	1	7	1	6	2	2	3	4.53	6
SW7	2.08	1.54	5.15	1.54	0.239	0.33	0.47	0.65	1.470	109	63.91	3.20	29.33	3.51	0.02		
Rank	7	8	4	6	2	3	7	3	2	5	7	3	5	6	2	4.67	7
SW8	2.19	1.77	5.81	1.21	0.228	0.31	0.34	0.63	1.734	96	93.01	0	3.06	3.92	0		
	5	4	1	7	5	1	1	1	8	6	8	1	8	7	1	4.27	1

Hence, SW8 should be given highest priority for land treatment among sub-watersheds followed by SW3. It also revealed that least priority should be given to SW1 among the sub-watersheds as it has maximum percentage area covered by forest.

Conclusions

Identification of erosion prone area is first foremost assignment for development and management of watersheds. Morphometric parameters as well as land use/land cover information helps to identity the erosion susceptibility areas and for the identification of suitable soil and water conservation measure to control soil erosion, artificial recharge site and water harvesting structures which are the major objectives of watershed development. Application RS and GIS for analyzing the morphometric parameters and land use/land cover class helps in prioritization sub-watershed in drainage basin is more appropriate methodology as compared to conventional approaches. Here, the major eight sub-watersheds of Dhanora block were prioritized for identification of most susceptible to erosion. The results of prioritization considering morphometric analysis revealed that SW8 is more susceptible to erosion followed by SW2, whereas, land cover analysis shows that SW6 is more prone to soil erosion followed by SW4. But the combined influence of morphometry parameters and land cover classes revealed that SW8 is most susceptible to soil erosion whereas, SW1 is least susceptible to soil erosion. The study can be used for site suitability analysis of various soil and water conservation structures and can be helpful for planning and management of the watershed. Various soil and water conservation measures like contour bunding, vegetative strips, contour farming in agricultural field, staggered contour trench in waste land, siltation traps in just below the forest area as well as in escarpment, stone bunding in higher slopes area, permanent check dam in 3rd and above stream order and temporary and semi permanent check dam on 1st and 2nd order stream, afforestation *etc.* should be done to reduce the soil erosion. These measures also helps in ground water recharge and extend the base flow in the stream in the post monsoon period.

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