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ORIGINAL ARTICLE

An Integrated Approach for the Prioritization of Subwatersheds in the Urmodi River Catchment (India) for Soil Conservation using Morphometric and Land Use Land Cover (LULC) factors

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Abstract
The present investigation intends to prioritize the sub-watersheds of the Urmodi River watershed (Maharashtra State, India) for Soil Conservation, which is based on the integrated approach consisting of geomorphometric and Land Use Land Cover (LULC) factors. Prioritization based on Geographic Information Science (GIS) platform, allows us to take informed decisions for managing and safeguarding resources from degradation. Quantitative morphometric analysis of three aspects, namely linearity, shape and relief, were carried out for sub-watersheds encompassing the entire study area. In addition, Remote Sensing (RS) based on high-resolution multispectral data with 10 m spatial resolution captured by Sentinel 2 satellite was analysed to infer the land cover condition. In water-induced soil erosion, morphometric parameters have crucial role in understanding the geo-environmental characteristics of the terrain. Moreover, rainfall effects depend on the pattern of LULC change and each land cover responds differently to the raindrop energy it receives. Therefore, it requires integration of the geomorphological and hydrological characteristics of the sub-watersheds derived from their morphometric parameters with the LULC to generate compounded ranking-based prioritization of the sub-watersheds. During the prioritization analysis, the lower compound value is considered with higher priority for appropriate soil conservation measures. It was found that the integration of morphometric and LULC factors changed the prioritization ranking considerably. Incidentally, Sub-watershed 4 which was having moderate raking based on morphomertic analysis, got highest rank and compound value of 2.38 due to integrated approach. It was evident that the use of an integrated prioritization approach helps us to arrive at better decision-making related to soil conservation.

Keywords Morphometric parameters · Land use land cover (LULC) · Prioritization · Soil erosion

1 Introduction

Watershed is a geographical unit and natural boundary where it is a logical choice to practice morphometric analysis to understand the hydrological cycle (Ahmed et al. 2018).

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Watershed deterioration is one of the common issues in India and it also influences at global scale (Prabhakar et al. 2019). Therefore, prioritization of the watershed is necessary for comprehensive watershed management and planning to reduce soil loss (Ahirwar et al. 2019). In watershed management, its prioritization has attracted scientific attention, which helps for the better and protective measures for the natural resource management (Sarma and Saikia 2012). Soil erosion is one of the detrimental processes for land resource and it leads to uncertainty related to water availability in the watershed area. Erosion (soil loss) not only destroys the land but also creates the other environmental issues like reservoir sedimentation, channel siltation, deposition of unfertile material on agricultural land and posing infertility due to erosion (Vemu and Udayabhaskar 2010). Drainage basin refers to the whole area providing runoff and sustaining parts or all stream-flow including main channels with its tributaries (Prabhakaran and Jawahar Raj 2018). Analysis of morphometric parameters of a drainage basin and its associated stream network show its hydrological behaviour (Pophare and Balpande 2014). Quantitative parameters of drainage network of the basin have a very helpful function in the hydrological model, watershed prioritization, natural resource management and its rehabilitation (Choudhari et al. 2018). Remote Sensing (RS) and Geographical Information System (GIS) is a widely used tool in prioritization of watershed, which also helps in planning and development (Sarma and Saikia 2012). In the watershed development plan, it is essential to understand the terrain conditions, erosion status and drainage pattern of an area (Sreedevi et al. 2005). Rainfall and wind are the main factors that cause erosion and soil degradation, which cause changes in river morphology and problems related to the water reservoir and other environmental issues. Integration of RS and GIS methods can be successfully used in soil erosion assessment and subwatershed prioritization (Thakkar and Dhiman 2007; Javed et al. 2011; Chandniha and Kansal 2017).

The joint application of the RS and GIS methodology has been found to be a promising and powerful tool in the morphometric analysis of drainage network in recent years (Pandey and Das 2016). It is essential for prioritizing subbasins as part of the integrated assessment of river basin degradation. Many researchers have used the GIS and RS approach in studies related to the watershed management including its prioritization for better management of natural resources (Nooka Ratnam et al. 2005; Malik and Bhat 2014; Khadse et al. 2015; Meshram and Sharma 2017).

A study was carried out in 2020 by the National Institute of Soil Bureau and Land Use Planning (NBSS and LUP 2002) employing the Universal Soil Loss Equation (USLE) to show soil erosion risk zones in the Maharashtra state (India). This study showed that soil degradation triggered by soil erosion is quite prominent in this area. Other recent study, performed by Bagwan and Gavali (2020a) revealed that very severe erosion zone (> 80 ton/ha^{-1} year^{-1}) was expanding with the annual incremental rate of 14.87% in the study area. In addition to this aspect, it was also found that the rainfall erosivity is high in Urmodi River watershed having values around 1014.7 MJ mm ha^{-1} h^{-1} year^{-1} in the plateau region (Bagwan and Gavali 2020b). Therefore, due to soil erosion susceptibility, there is a pertinent need to prioritize regions for soil conservation and to protect the land from deterioration. As a part of watershed management and better resource utilization, factors, such as basin drainage characteristics, soil condition and land cover, play a crucial role (Bhattacharya et al. 2019). In the current study, an attempt is made to derive ranking based on morphometric parameters and Land Use Land Cover (LULC) using RS and GIS tools for prioritization of soil erosion measures in the Urmodi River watershed (Satara district, Maharashtra State, India) as a part of sustainable development plan for this region.

2 Study area

The Urmodi River watershed (Satara district, Maharashtra, India; Fig. 1) is located between: longitudes 73° 47′ 38.432″ E–74° 6′ 58.267″ E and latitudes 17° 28′ 36.893″ N–17° 44′ 35.072″ N. The Urmodi river basin covers 414.27 km^2. It is spread in three toposheets viz. 47 K/2, 47K3 and 47 G/14. From the toposheets, with the elevation difference of 685 m. Urmodi River originates at the Kaas Lake located in Jaoli block (administrative boundaries) and meets with the Krishna River at Kashil village, in Satara block. The study region is situated on the right bank of the Krishna River. The world heritage site Kaas plateau (IUCN 2012) is located in the upper catchment of the River Urmodi, which is a source of attraction for tourists during the monsoon season. During the field observation, it has been observed that, in the upper catchment, most of the lateritic soil area was under the paddy cultivation. And the lower catchment area used for the sugarcane, wheat, jowar, etc. The entire watershed is underline by the Deccan trap basaltic lava flow, from the upper cretaceous to lower Eocene age. The physiographic features of the watershed can be divided into hills and ghats, plateaus, foothills and plains. From the field survey, it has been observed that, black soil and lateritic soils is present in the study area. It has been reported that, the Deccan trap is basically composed by hard rock and soft rock, i.e., alluvium. In this region, the mean temperature ranges from 14.4 to 36.8 °C The annual rainfall in Jaoli and Satara district varies between 1730.1 and 1048.4 mm, as estimated from 2001 to 2010 (CGWB 2013). The main source of rainfall in the study area is observed during the monsoon, i.e. from June to September (Praveen et al. 2020). The Urmodi River carries heavy sediment load during the monsoon. This river is not perennial after the rainy season due to the construction of a dam. Overall, the drainage pattern of the river is parallel to semi-dendritic. In the Urmodi river watershed, we find the agriculture, rural settlement, roadways, open forest and dense forest and water bodies as a main land cover.

3 Materials and methods

3.1 Datasets used

Toposheets of Survey of India (SoI) have been used for the demarcation of the stream network. We have used this toposheet maps numbered: E43O2(47 K/2), E43O3(47 K/3), and E43N14(47 G/14). The scale of toposheet is 1:50,000. The toposheets are scanned with 300 dots per inch in JPG

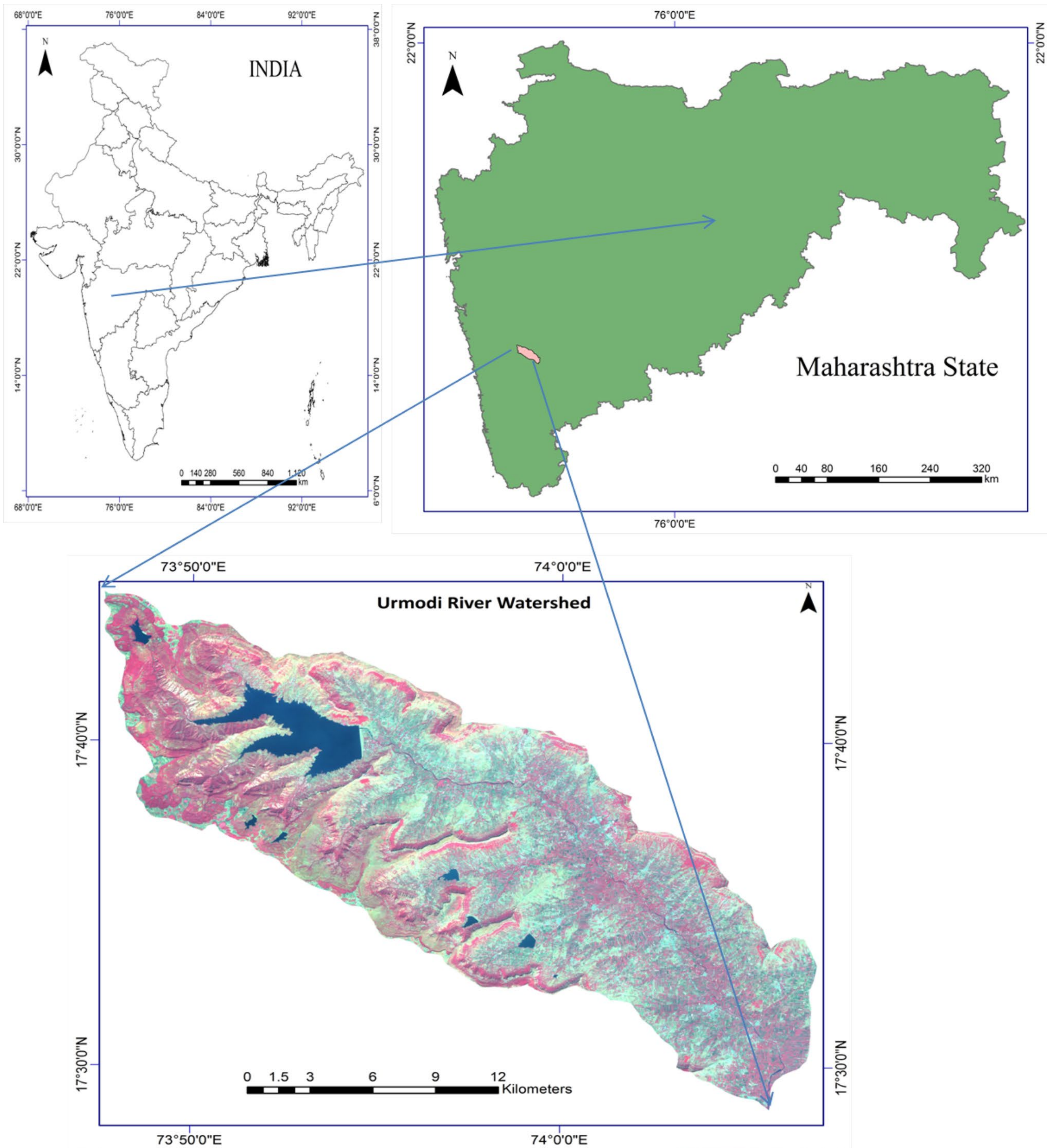

Fig. 1 Study area with Sentinel 2 False Colour Composition

format. The toposheet comes with WGS84 as a native datum. The three toposheets were georeferenced, and then cropped according to the area of interest. In the second step, they were processed with mosaic operation. Later, the sub-watershed boundary was demarcated and cropped. Finally, it was re-projected with WGS84 and UTM North zone 43.

3.2 Satellite data

The Sentinel 2 is the program which is a result of the joint initiative of the European Commission (EC) and European Space Agency (ESA). The Global Monitoring of Environment and Security (GMES) Sentinel 2 is able to provide the multispectral high-resolution imagery over world terrestrial surfaces (Drusch et al. 2012). The satellite imagery was downloaded from https://scihub.copernicus.eu; it was acquired on 11 November 2016 and used to derive the land use land cover thematic layer. The main advantage of the image is that the level of the product is Sentinel-2 level 1C, which is ortho-rectified in nature. The present imagery was cloud-free with JPEG2000 as file format. The location identifier of the acquired data is orbit 105 and tile number isT43QCV.

3.3 Digitization and sub-watershed generation

Ordering of streams including temporary and permanent flow is the basic of stream order. Strahler (1964) method was used for demarcation of streams which produces the drainage network. The study region was divided into seven sub-watersheds based on drainage flow and mean sea level values. Figure 2 portrays the flowchart of the executed methodology.

3.4 Morphometric analysis

Various morphometric aspect performed on watershed is helpful in its characterization. Study of drainage network plays a significant role in land and water resources management (Fenta et al. 2017). For the present study, three aspects were considered for the morphometric analysis of Urmodi river watershed. The linear, shape and relief aspects were calculated using GIS technique. The drainage pattern of Urmodi River watershed and its sub-basins are depicted in Fig. 3. Linear aspect consists of a section of the morphometric analysis, linked with the channel pattern of the drainage network (Pandey and Das 2016). Linear parameters are directly linked with erodibility, which includes bifurcation ratio (R_b), drainage density (D_d), texture ratio (R_t), stream frequency (F_s), length of overland flow (L_o) (Chandniha and Kansal 2017; Nooka Ratnam et al. 2005). Rho coefficient (ρ) indicates hydric storage and attenuates the erosion effect during discharge. The shape factors, included in this category, indicate the geomorphology and also provide an insight into infiltration

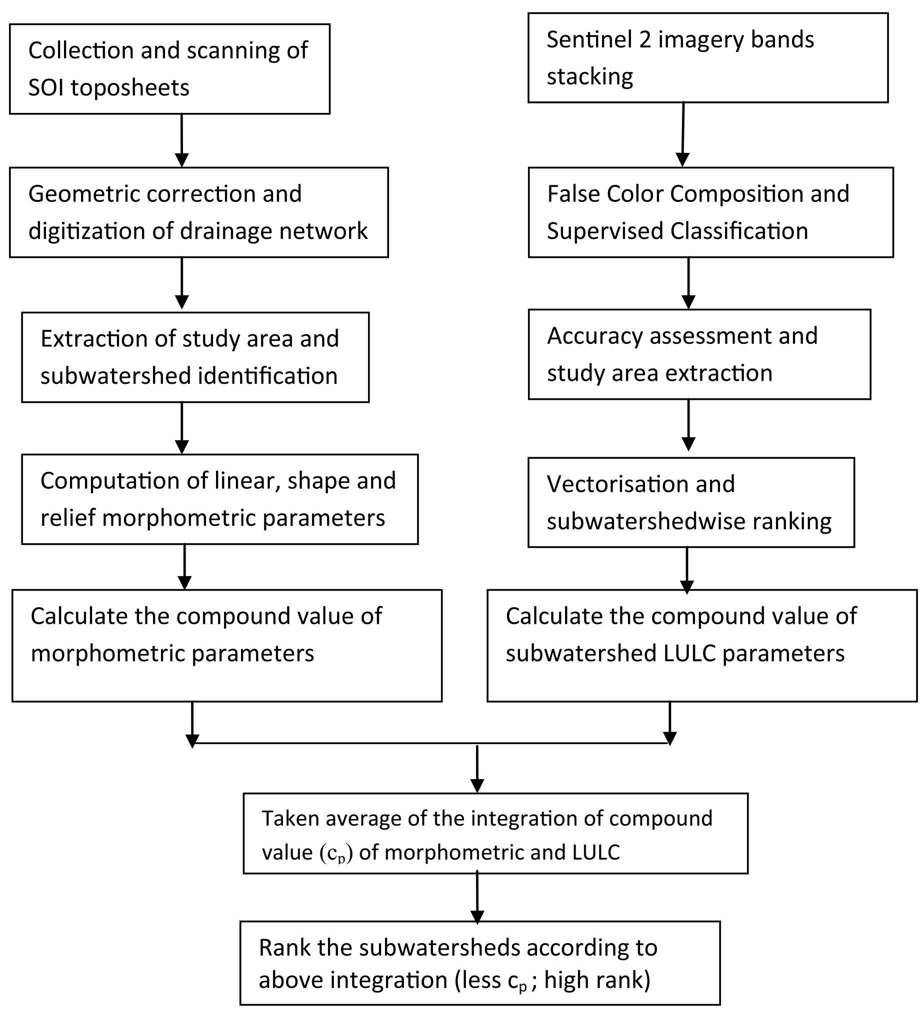

Fig. 2 Flowchart showing execution of research methodology

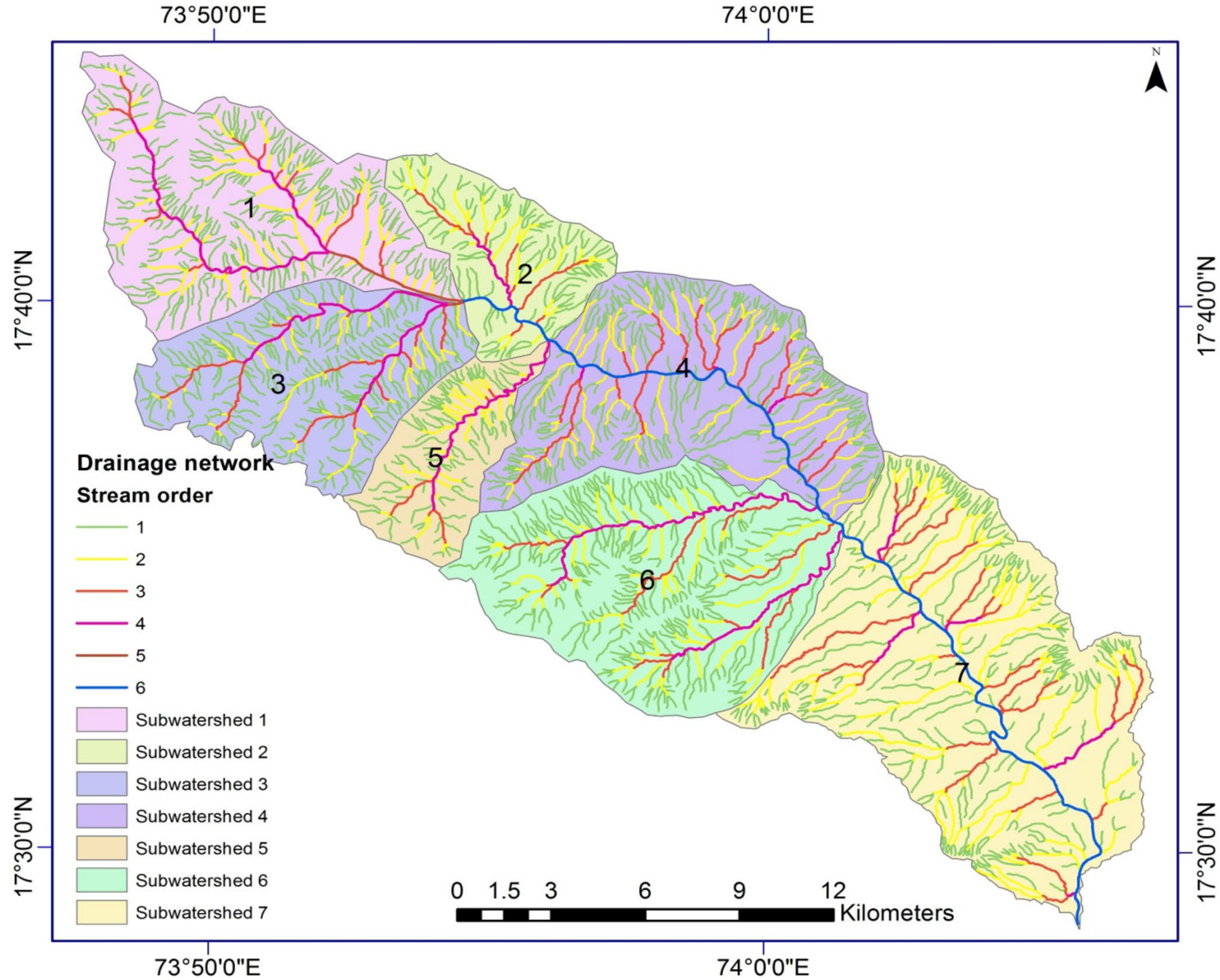

Fig. 3 Drainage network within subwatersheds of Urmodi River watershed

and runoff (Sujatha et al. 2015). Watersheds have different shapes and its shape reflects the runoff actions at the outlet. For the given study basin shape (B_s), circularity ratio (R_c), compactness coefficient (C_c), elongation ratio (R_e) and form factor (F_f) were used. Relief characteristics of watershed morphometry deal with three-dimensional features, which include area, volume, the elevation of landforms to analyze various geological and hydrological characteristics (Sahu et al. 2017). Basin relief (B_h), Relief ratio (R_h), Ruggedness number (R_n), Melton ruggedness number (MR_n), Dissection index (D_{is}) were computed for sub-basins and whole Urmodi river watershed. Table 1 shows the formulae used for the computation of linear, shape and relief aspects and their description.

3.5 Land Use Land Cover (LULC)

To achieve integrated analysis, RS data were employed to depict the land surface cover using multispectral bands. For the classification purpose, we need the spectral band combination to prepare the False Colour Composition (FCC) of imagery. Sentinel 2 remotely sensed Band 2—Blue (490 nm), Band 3—Green (560 nm), Band 4—Red (665 nm) and Band 8—NIR (842 nm) with a spatial resolution of 10 m has been used. Land Use Land Cover (LULC) was carried out with visual interpretation from FCC. Based on spectral characteristics of imagery, signature file is created, which is very helpful in investigating and demarcation of particular land cover. Various features on terrain show their own

Table 1 Description of formulae for linear, shape and relief parameters of morphometric analysis

Sr. no	Parameters	Formulae	Description	References
Linear aspect				
1	Area	km^2	Calculate geometry(vector file) tool in ArcGIS	
2	Perimeter	km	Calculate geometry(vector file) tool in ArcGIS	
3	Stream order	Assign value to polyline	Hierarchical rank	Strahler (1964)
4	Stream number	(N_u)	Total number of streams in basin of all order	
5	Stream length	(L_u)	Measurement of stream in kilometer	Horton (1932)
6	Mean stream length	$L_{sm} = L_u / N_u$	Total stream length of all orders divided by no. of streams in that segment order	Strahler (1964)
7	Stream length ratio	$R_L = L_u / L_u – 1$	Mean stream length of 'u' order with its preceding one that is 'u-1'	Sreedevi et al. (2005)
8	Stream frequency	$F_s = \Sigma N_u / A$	The ratio between all segments cumulated for all orders in a basin with its area	Horton (1945)
9	Bifurcation ratio	$R_f = N_u / N_{u+1}$	Ratio of given stream order with next higher order	Schumm (1956)
10	Mean bifurcation ratio	$R_{bm} =$ Average of R_b	Average bifurcation ratio of all stream orders	Strahler (1957)
11	Length of overland flow	$L_o = 1/(2D_d)$	It is half the reciprocal of drainage density(D_d)	Horton (1945)
12	Basin length	$L_b = 1.312 \times A^{0.568}$	Power factor of area with multiplication constant	NookaRatnam et al. (2005)
13	Rho coefficient	$P = R_l / R_f$	The ratio between mean stream length ratio with mean bifurcation ratio	Horton (1945)
14	Constant of channel maintenance	$C = 1/D_d$	It is inverse of drainage density	Schumm (1956)
15	Drainage density	$D_d = L_u / A$	It is ratio between length of all stream segments to drainage area of basin	Horton (1932)
16	Drainage texture	$T = D_d \times F_s$	The product of drainage density with stream frequency	Smith (1950)
17	Texture ratio	$T_r = \Sigma N_u / P$	The ratio between cumulative of all stream segments to perimeter of basin	Horton (1945)
Shape aspect				
1	Basin shape	$B_s = L_b{}^2 / A$	It is ratio of square of basin length (L_b)to the basin area(A)	Javed et al. 2011
2	Circularity ratio	$R_c = 4\pi A / P^2$	Ratio of basin area to area of circle having same perimeter as the basin	Miller (1953)
3	Compactness coefficient	$C_c = 0.2821 \times P / A^{0.5}$	It is perimeter of the basin divided by circumference of equivalent circular area	Horton (1945)
4	Elongation ratio	$R_e = 2\sqrt{(A/\pi)} / L_b$	It is ratio between circle's diameter of same area as the basin and maximum basin length	Schumm (1956)
5	Form factor	$F_f = A / L_b^2$	It is ratio of basin area with square of length of basin	Horton (1932)
Relief parameters				
1	Basin relief	$R_h = H – h$	Vertical distance between maximum (H) and minimum (h) elevation of the basin. Where H is highest elevation and h is lowest elevation of the basin	Hardely and Schumm (1961)
2	Relief ratio	$R_r = R_h / L_b$	The ratio between basin relief to maximum length of basin	Schumm (1956)
3	Ruggedness number	$R_n = D_d \times B_h$	It is product of drainage density and basin relief	Strahler (1958)
4	Melton ruggedness number	$MR_n = H – h / A^{0.5}$	Ratio between basin relief to half the power of basin area	Melton (1965)

Table 1 (continued)

Sr. no	Parameters	Formulae	Description	References
5	Dissection index	$D_{is} = B_h/H$	The ratio between basin relief and maximum elevation of the basin	Gravelius (1941)

unique spectral reflectance and can be identified by visual analysis. Supervised classification was done using ERDAS 2011 software package. We have applied maximum likelihood technique for the classification. For the present study area, six LULC classes were created, such as Agriculture, Waterbody, Barren land, Settlement, Dense forest, and Open forest. Out of these classes, water body and settlement were excluded as they do not have topsoil cover susceptible to water-induced and topography based on soil erosion. With the help classification technique, we can monitor the changes in LULC (Khanday and Javed 2016).

3.6 Priority assignment and integration

The major goal behind the prioritization is to conduct management action with best suited for its sub-watersheds (Malik and Bhat 2014). The linear morphometric aspects and relief are directly proportional to soil risk, whereas shape aspects are inversely related (Nooka Ratnam et al. 2005; Javed et al. 2011; Meshram and Sharma 2017). Morphometric parameters, like stream frequency, mean bifurcation ratio, drainage density, length of overland flow, circularity ratio, elongation ratio, basin shape, and compactness coefficient, have been used as erosion parameters for watershed prioritization (Biswas et al. 1999). As reported by Javed et al. (2011), the study shows that in case of linear parameters, high value is to be ranked as 1, the next low value has to be given as 2 and so on. Whereas, the shape aspect of sub-watersheds are inversely proportional with soil erosion, the lowest value has been given as 1, the next low value considered as 2 and so on. After all rating completion, compound value has been calculated by simply taking mean of rating. The lowest compound value has to be rated as 1 and next lowest value as 2 and so on. LULC has been considered as a parameter in which, each class has a role as priority criteria for watershed prioritization. High-priority ranking has been given to areas with less vegetation cover, low agriculture land, and high barren land (Malik and Bhat 2014).

4 Results and discussion

The digital morphometric analysis and land use land cover analysis were carried out in a GIS environment using ArcGIS 10. The morphometric parameters were pivotal in understanding the hydraulic role of the watershed. The development of drainage network is related with geology, while precipitation shapes the stream pattern. The investigation of various linear, shape and relief parameters is discussed as follows:

4.1 Linear Morphometric parameters

The linear parameters like stream frequency, drainage density, mean bifurcation ratio, length of overland flow, drainage texture has direct linkages to erodibility. Therefore, it can be used for erosion risk assessment (Chauhan et al. 2016). The linear parameter based on compound value was computed for each sub-watershed.

4.1.1 Area (A) and perimeter (P)

Based on SoI toposheet, the Urmodi River watershed occupies 414.27 km^2 (Fig. 3). Using the 'calculate geometry' tool in the polygon operation in ArcGIS platform, the area and perimeter were computed. The area range of sub-watershed is between 22.95 and 111.22 km^2. The boundary of the watershed is 106.20 km. The whole Urmodi River watershed is divided into seven sub-watersheds and their dimensions are given in Table 2. The 7th sub-watershed has highest area and perimeter, whereas, the 5th sub-watershed has the lowest size.

4.1.2 Stream order

Categorization of streams based on its number and types of the tributary junction is called stream ordering (Sujatha et al. 2015). Strahler (1964) method was followed for stream ordering, where the origination of first channel formation is ordered as 'first-order' stream and when two 'first-order' streams meet, it further runs as 'second order' and so on. Stream number is simply the computing of channel's number representing a particular order.

4.1.3 Stream number (N_u)

As we come downward across the watershed, the stream order decreases and also the stream number (N_u) is now directly related to the stream order. The N_u was calculated using the polyline demarcation of each individual stream by 'digitized' format in a shapefile. The number of streams of each order was described with respect to their sub-watershed in Table 2.

Table 2 Bifurcation ratios of Urmodi River watershed and its subwatersheds

Subwatershed name	Area (km^2)	Perimeter (km)	Stream order							Bifurcation ratio					Mean Bifurcation Ratio (R_{bm})
			I	II	III	IV	V	VI	Mean L_{sm}	1/2	2/3	3/4	4/5	5/6	
SW1	63.85	39.27	262 (161.57)	63 (46.87)	13 (10.55)	2 (14.8)	1 (4.65)		0.70	4.16	4.85	6.50	2	–	4.38
SW 2	27.75	23.11	100 (66.09)	28 (21.52)	8 (9.35)	1 (5.1)			0.74	3.57	3.50	8.00	–	–	5.02
SW 3	48.47	32.57	225 (135.07)	51 (27.68)	11 (15.71)	2 (13.35)	1(0.52)		0.66	4.41	4.64	5.50	2	–	4.14
SW 4	67.60	38.42	245 (160.17)	65 (62.24)	16 (29.9)	3 (6.15)	1 (6.85)		0.80	3.77	4.06	5.33	3	–	4.04
SW5	22.95	22.81	94 (54.09)	31 (18.28)	5 (4.01)	1 (8.54)			0.65	3.03	6.20	5.00	–	–	4.74
SW 6	72.43	35.21	244 (176.9)	65 (52.37)	13 (21.57)	2 (20.01)			0.84	3.75	5.00	6.50	–	–	5.08
SW 7	111.22	53.30	273 (182.85)	81 (90.38)	25 (46.65)	7 (9.79)	1 (14.95)		0.89	3.37	3.24	3.57	7	–	4.30
Urmodi watershed	414.27	106.20	1442 (935.57)	381 (316.18)	88 (135.43)	17 (70.32)	2 (5.18)	1 (36.26)	0.78	3.78	4.33	5.18	8.5	2	5.45

SW Subwatershed, L_{sm} Mean stream length, the values in the bracket shows (length in km) of particular stream order by the summation of all streams

4.1.4 Stream length (L_u) and mean stream length

It is derived by simply calculating the length of stream of all orders expressed in kilometres. The digitized polylines of shapefile were examined using 'calculate geometry' tool. The length of all stream orders according to sub-watershed is presented in Table 2; it also includes the mean stream length. For the whole watershed, its value is 0.78 km and the other sub-watersheds show values ranging from 0.65 to 0.89 km.

4.1.5 Stream length ratio (R_l)

Stream flow ratio has a direct relationship with surface runoff, erosion and discharge of the basin (Pandey and Das 2016). Table 3, illustrates the ratios of the sub-watershed wise and main watershed stream length. The Urmodi River watershed shows the R_l value 0.67 and its sub-watershed ranges between 0.39 and 2.91. This parameter revealed that the sub-watersheds 1 and 3 have higher surface runoff, based on erosion and in comparison to other sub-watersheds.

4.1.6 Stream frequency (F_s)

Stream frequency (F_s) and drainage density (D_d) have a close association with the sub-watersheds. F_s is also dependent on the basin geology, which reflects the drainage texture. Moreover, it is also related to permeability, infiltration capacity and relief of the sub-watersheds (Avinash et al. 2014). Table 4 shows F_s values of the sub-watersheds. The minimum value of F_s was 3.48 km/km^2 in subwatershed 7 and maximum value was 5.98 km/km^2 in subwatershed 3. Stream frequency of Urmodi river watershed was 4.66 km/km^2. There exists a positive correlation between drainage density and stream frequency ($R^2 = 0.64$).

4.1.7 Bifurcation ratio (R_b) and mean R_b

This is a dimensionless parameter that expresses the geometric similarity of catchment along with ramification of drainage network (Strahler 1964). Generally, R_b values have a range from 3.0 to 5.0, on homogenous rocky terrain (Thomas et al. 2010). For Urmodi River watershed, R_b value was found to be 5.45. As described in Table 2, the minimum R_b value was 4.04 and the maximum mean R_b value was 5.08 for the subwatersheds of Urmodi River. As reported by (Horton 1945), the R_b value ranged between 2 (on the flat regions) and 4 (hilly or mountainous zones). This parameter is clearly indicating that the whole watershed has a hilly topographic condition.

Table 3 Stream length ratio of subwatersheds and main watershed

Subwatershed name	Stream Length Ratio					Mean stream length ratio
Subwatershed 1	*2/1*	*3/2*	*4/3*	*5/4*		
	1.21	1.09	9.12	0.63		2.41
Subwatershed 2	*2/1*	*3/2*	*4/3*			
	0.86	0.66	0.23			0.44
Subwatershed 3	*2/1*	*3/2*	*4/3*	*5/4*		
	1.11	0.38	0.21	12.84		2.91
Subwatershed 4	*2/1*	*3/2*	*4/3*	*5/4*		
	0.68	0.51	0.91	0.30		0.48
Subwatershed 5	*2/1*	*3/2*	*4/3*			
	0.98	0.74	0.09			0.45
Subwatershed 6	2/1	3/2	4/3			
	0.90	0.49	0.17			0.39
Subwatershed 7	*2/1*	*3/2*	*4/3*	*5/4*		
	0.60	0.60	1.33	0.09		0.53
Urmodi watershed	*2/1*	*3/2*	*4/3*	*5/4*	*6/5*	
	0.78	0.54	0.37	1.60	0.07	0.67

4.1.8 Length of overland flow (L_o)

It is the length of water flow over the ground before accumulating into the stream channel. Greater the values of L_o, lesser the surface runoff (Horton 1932). This has a significant relationship with physiographic and hydrological development of drainage basin (Javed et al. 2011). The range of L_o varies from 0.126 to 0.161 for the subwatersheds of Urmodi catchment. For whole Urmodi river watershed, it showed 0.138. From Table 4, it is clear that the subwatershed 7 has the highest value and therefore, the lowest runoff.

4.1.9 Rho coefficient (ρ)

It is a dimensionless linear parameter of morphometric analysis. This factor relates to the drainage composition and physiographic development of the drainage basin (Horton 1945). Rho coefficient (ρ) varies according to natural conditions of climate, geological, biological, geomorphic and anthropogenic activities (Thomas et al. 2010). Rho coefficients of respective subwatersheds are shown in Table 4. Minimum and maximum values of the rho coefficient for the subwatersheds of Urmodi River were 0.47 and 0.92, respectively. For the whole watershed, it has been found that the ρ value 0.75.

4.1.9.1 Constant of channel flow (C) This factor is measured in km^2/km, as it is inverse of Dd. Geology, relative relief and climate of the watershed shape the constant of channel flow (C) (Schumm 1956). Value of C factor gives the number of km^2 of surface area, which needed to maintain one linear kilometre of the stream channel. As the value of C increases, the rock permeability also increases (Prabu and Baskaran 2013). Table 4 describes the C values of subbasins and Urmodi basin. Under less vegetation condition, low C values minimize the L_o and thus water discharge is more rapid (Samal et al. 2015). For the present study, C value ranged from 0.252 to 0.323 km^2/km. For the whole watershed, the C value was 0.276 km^2/km.

4.1.9.2 Drainage density (D_d) It is a linear morphometric parameter which is expressed in km/km^2. Drainage density (D_d) is a sensitive indicator for the calculation of erosion by streams and the effect of characteristics at the outlet (Chandniha and Kansal 2017). This parameter also indicates the closeness of the channel spacing; hence, it provides the quantitative measurement of the average stream length for the whole watershed (Dikpal et al. 2017). In the present study, D_d for subwatersheds ranged from 3.10 to 3.97 km/km^2. D_d for the Urmodi River watershed was 3.26 km/km^2. Higher D_d shows more effective operations of stream incision; moreover, high incision is associated with steep slopes (Langbein 1947).

4.1.9.3 Drainage texture (T) It is used to show the spacing of drainage lines (Smith 1950). This factor has a relationship with rock type and vegetation; massive and hard rock produces the coarse drainage texture whereas soft and weak rocks produce the fine texture. The value of T is for: coarse texture <4; intermediate 4–10; fine 10–15 and; ultrafine/badland topography >15 (Sreedevi et al. 2005). By considering the given categories, all the subwatersheds showed ultra-fine drainage texture, even though the Urmodi river watershed itself possesses the ultrafine texture.

4.1.9.4 Texture ratio (R_t) The Texture ratio (R_t) has been of a great importance in understanding the lithological infiltration capacity. The R_t values of subwatersheds of Urmodi River catchment range between 5.74 and 9.20. Hydrologically, the subwatershed 5 has longest basin lag time while, the subwatershed 6 has the shortest basin lag time. The R_t value of Urmodi River watershed is found to be 18.18.

4.2 Shape aspect

Five shape parameters, namely Basin shape (B_s), Circularity ratio (R_c), Compactness coefficient (C_c), Elongation ratio (R_e), Form factor (R_f) and Relief aspect, were analysed for the subwatersheds and entire Urmodi River watershed. Shape parameters have an inverse relationship with soil loss.

4.2.1 Basin shape (B_s)

Parameter B_s is related to the flood discharge (Javed et al. 2011). The Urmodi River watershed had a B_s value of 3.91. Sub-basins of Urmodi River watershed had B_s values between 2.70, for subwatershed 2, and 3.27, for the subwatershed 7. The subwatershed 2 is the one that produces more discharge, based on its shape, thus, having more proneness to erosion as compared to subwatershed 7, which has negative relationship to runoff, as the high B_s value is inversely proportional to low risk of erosion. So, the shape of subwatershed matters, as it relates both the runoff and the susceptibility to the erodibility.

4.2.2 Circularity ratio (R_c)

The R_c is a dimensionless parameter. The maximum value attained by R_c is 1.0, when the watershed boundary approaches to near circle (Miller 1953). This parameter is influenced by stream frequency, LULC and geological structures, climate, slope and relief factors of the basin (Singh et al. 2013). The Urmodi river watershed has a value of 0.46, whereas all subwatersheds have a value between 0.49 and 0.73 (Table 5). Low circularity ratio shows elongated shape whereas higher values shows approaches near to circularity. Values of $R_c > 0.60$ were found in subwatershed 2 and subwatershed 6, which indicates predisposition to flood risk during the peak period of concentrated flood flow. The values of R_c reflect the stages of evolution of watersheds, the lower values indicate young phases and the higher values

Table 4 Results of linear morphometric parameters of UrmodiRiver and its subwatersheds

Subwatersheds	Stream order	Stream number (N_u)	Stream length (L_u)	Drainage density (D_d)	Stream frequency (F_s)	Basin length (L_b)	Length of overland flow (L_o)	Constant of channel flow (C)	Drainage texture (T)	Texture ratio (R_t)	Rho coefficient(ρ)
Subwatershed 1	5	341	238.44	3.73	5.34	13.91	0.134	0.268	19.94	8.68	0.69
Subwatershed 2	4	137	102.06	3.68	4.94	8.66	0.136	0.272	18.16	5.93	0.47
Subwatershed 3	5	290	192.33	3.97	5.98	11.89	0.126	0.252	23.74	8.90	0.50
Subwatershed 4	5	330	265.31	3.92	4.88	14.37	0.127	0.255	19.16	8.59	0.49
Subwatershed 5	5	131	84.92	3.70	5.71	7.78	0.135	0.270	21.12	5.74	0.92
Subwatershed 6	5	324	270.85	3.74	4.47	14.94	0.134	0.267	16.73	9.20	0.60
Subwatershed 7	5	387	344.62	3.10	3.48	19.06	0.161	0.323	10.78	7.26	0.86
Urmodi watershed	6	1931	1498.94	3.62	4.66	40.23	0.138	0.276	16.87	18.18	0.75

Table 5 Result of shape morphometric aspects of Urmodi river watershed with its subwatersheds

Subwatershed name	Basin shape (B_s)	Circularity ratio (R_c)	Compactness coefficient (C_c)	Elongation ratio (R_e)	Form factor (F_f)
Subwatershed 1	3.03	0.52	1.386	0.65	0.33
Subwatershed 2	2.70	0.65	1.238	0.69	0.37
Subwatershed 3	2.92	0.57	1.320	0.66	0.34
Subwatershed 4	3.05	0.58	1.318	0.65	0.33
Subwatershed 5	2.64	0.55	1.343	0.70	0.38
Subwatershed 6	3.08	0.73	1.167	0.64	0.32
Subwatershed 7	3.27	0.49	1.426	0.62	0.31
Urmodi watershed	3.91	0.46	1.472	0.57	0.26

are related to the mature stages of watershed development (Thomas et al. 2010).

4.2.3 Compactness coefficient (C_c)

The compactness coefficient (C_c) is used to investigate the relationship between hydrologic basins with exact circular basin having the same area (Javed et al. 2011). From point of view for the circular shaped basin, when we consider the drainage standpoint, it will produce the shortest time of concentration before peak flow takes place in the catchment (Javed et al. 2009). The highest value of C_c was found for the subwatershed 7 (1.426), and the lowest C_c value was found for the subwatershed 6 (1.167). The C_c value for the whole watershed was found to be 1.472. Table 5 shows the values for the other subwatersheds.

4.2.4 Elongation ratio (R_e)

The elongation ratio (R_e) is used to indicate the shape of the watershed. The R_e varies from 0.6 to 1.0 over diverse geological and climatic conditions (Meshram and Sharma 2017). R_e values of all subwatersheds has been shown in Table 5, in which values of: $R_e > 0.9$ indicate the circular shape; $R_e > 0.9$–0.8 are related to oval shape and; $R_e < 0.7$ are less elongated shapes (Javed et al. 2009). The variations in values of R_e are caused by the guiding effect of thrusting and faulting in the watershed. Higher the values of R_e, higher the infiltration and thus lower the surface runoff. Low R_e reflects the high soil erosion susceptibility and sedimentation load (Sreedevi et al. 2013). This means that, subwatershed 7 with R_e value 0.62 carries more sediment load and the subwatershed 5 with R_e value 0.70 carries less sediment load. For the entire Urmodi River watershed, the average R_e values was found to be 0.57.

4.2.5 Form factor (R_f)

Form factor and elongation ratio has a close and inverse relationship. As the value of R_f decreases, the elongativity of the basin will be increased. The value of R_f for the perfect circle is 0.7854. For circular basins, R_f values are higher and high peak flow rates for a shorter period; for the elongated basin, R_f has lower value, thus low peak flow for longer period of time (Javed et al. 2011). For the present study area, the R_f range remained between 0.31 and 0.38. Smaller value of R_f, more elongated the shape of the basin. The subwatershed 5 is more elongated as compared to all other subwatersheds. For the whole watershed, the R_f value was 0.26.

4.3 Relief aspect

The relief parameters, including Basin relief (R_h), Relief ratio (R_r), Ruggedness number (R_n), Melton Ruggedness number (MR_n), Dissection index (D_{is}), are having a direct impact on soil erosion. For Urmodi River watershed, five relief components were computed for the whole basin and its sub-basins. The relief parameters have implications in summarizing the landforms, as well as the erosional and sedimentation properties of the watershed.

4.3.1 Basin relief (R_h)

Basin relief (R_h) is the controlling factor of stream gradient and thus shapes the sediment transport and flood patterns (Hadley and Schumm 1961). Denudation attributes of the basin can be well understood by analysing this relief parameter (Sujatha et al. 2015). This relief aspect has a crucial role in assessing drainage development, surface, and sub-surface water flow, landform development, permeability, terrain erosional characteristics (Vincy et al. 2012). Urmodi river watershed showed the R_h value of 685 m. Table 6 shows the R_h values of the subwatersheds ranging from 467 to 602 m.

4.3.2 Relief ratio (R_r)

The relief ratio (R_r) is a dimensionless parameter, which is a ratio of height to length. R_r factor describes the overall steepness of relief in the study region; this is an indicator to show erosion intensity taking place on a slope of the sub-basin

Table 6 Details of relief aspects of Urmodi River watershed with its subwatersheds

Subwatershed name	Max elevation (m)	Min elevation (m)	Relief (R_h)	Relief ratio (R_r)	Ruggedness number (R_n)	Melton Ruggedness no. (MR_n)	Dissection index (D_{is})
Subwatershed 1	1265	663	602	0.043	2.25	0.075	0.48
Subwatershed 2	1178	661	517	0.060	1.90	0.098	0.44
Subwatershed 3	1205	663	542	0.046	2.15	0.078	0.45
Subwatershed 4	1144	610	534	0.037	2.10	0.065	0.47
Subwatershed 5	1117	650	467	0.060	1.73	0.097	0.42
Subwatershed 6	1138	605	533	0.036	1.99	0.063	0.47
Subwatershed 7	1127	580	547	0.029	1.69	0.052	0.49
Urmodi watershed	1265	580	685	0.017	2.48	0.034	0.54

(Kaliraj et al. 2015). R_r represents the high energy basin with strong erosion and high sedimentation yield (Sujatha et al. 2015). For the whole Urmodi watershed, the R_r value was 0.017. Table 6 describes the R_r values of the subwatersheds and the whole Urmodi River watershed. The range of R_r was between 0.029 and 0.060. High R_r values also reflect hilly region and low represent pediplain and valley region (Kadam et al.2017). The subwatershed 7 shows mainly the pediplain region and the upper Urmodi catchment indicates hilly region; it includes subwatershed 1 and subwatershed 3. Subwatersheds 2 and 5 had the same value that is 0.060, thus, generating nearly the same sediment load.

4.3.3 Ruggedness number (R_n)

The structural complexity of the terrain can be indicated using the ruggedness number (R_n) parameter. Higher the R_n values, greater the erosion proneness and more susceptible to an increase peak discharge (Sreedevi et al. 2013). High values of R_n generated when drainage density and basin relief values are high. Ruggedness values are also slope dependent, which means slope steepness and length (Strahler 1958). High R_n indicates the more complex terrain conditions to erosion susceptibility (Samal et al. 2015). Subwatershed 7 presented the lowest R_n value (1.69) and the subwatershed 1 shows the highest R_n value (2.25). (Table 6) depicts the values of subwatersheds for the R_n parameter.

4.3.4 Melton Ruggedness number (MR_n)

The Melton ruggedness number (MR_n) is a specialized slope index used to evidence the relief ruggedness within the watershed (Melton 1965). MR_n values of Urmodi watershed and subwatersheds are shown in Table 6. Low values of MR_n signify the normal flow to Main River without heavy debris load (Soni 2017).

4.3.5 Dissection index (D_{is})

Normally, the values of D_{is} range between 0 and 1, where '0' represents the total absence of vertical erosion and reflects flat terrain surface. And, '1' represents a vertical cliff, escarpment of hill slope (Thomas et al. 2010). Dissection index of Urmodi River subwatersheds lies

Table 7 Ranking of linear (direct), shape (inverse) and relief (direct) morphometric parameters

Subwatershed name	N_u	L_u	Rbm	Mean R_l	L_{sm}	D_d	S_f	L_o	C	T	R_t	ρ	Bs	R_c	C_c	R_e	F_f	R_h	R_r	R_n	MR_n	D_{is}	Sum	Compound value (c_p)	Priority
SW 1	2	4	4	4	5	4	3	4	4	3	3	3	4	2	6	4	4	1	4	1	4	2	35	1.59	1
SW 2	6	6	2	5	4	6	4	2	2	5	6	7	2	6	2	6	6	6	2	5	1	6	48	2.18	6
SW 3	5	5	6	6	6	1	1	7	7	1	2	5	3	4	4	5	5	3	3	2	3	5	39	1.77	2
SW 4	3	3	7	7	3	2	5	6	6	4	4	6	5	5	3	3	3	4	5	3	5	4	44	2	4
SW 5	7	7	3	1	7	5	2	3	3	2	7	1	1	3	5	7	7	7	1	6	2	7	53	2.41	7
SW 6	4	2	1	3	2	3	6	5	5	6	1	4	6	7	1	2	2	5	6	4	6	3	43	1.95	3
SW 7	1	1	5	2	1	7	7	1	1	7	5	2	7	1	7	1	1	2	7	7	7	1	46	2.09	5

SW Subwatershed, N_u. Stream number, L_u Stream length, R_{bm} Bifurcation ratio, *Mean* R_l stream length ratio, L_{sm}. Mean stream length, D_d. Drainage density, S_f. Stream frequency, L_o. Length of overland flow, *C*. Constant of channel maintenance, *T*. Drainage texture, R_t. Texture ratio, ρ. Rho coefficient, B_s. Basin shape, R_c. Circularity ratio, C_c. Compactness coefficient, R_e. Elongation ratio, F_f. Form factor, R_h. Basin relief, R_r. Relief ratio, R_n. Ruggedness number, MR_n. Melton Ruggedness number, D_{is}. Dissection index between 0.42 and 0.49 (Table 6). High value of D_{is} indicates the long and steep slopes with high degree of dissection and related to more proneness of terrain to the erosion susceptibility. Here, subwatershed 7 shows more susceptibility and the subwatershed 5 shows less susceptibility. The whole watershed shows the value of 0.54 for this factor. Table 7 illustrates the ratings of linearity, shape and relief pertaining to morphometric parameters with their respective rankings.

4.4 Land Use Land Cover analysis

Figure 4 shows the final output of LULC map prepared from the Sentinel 2 band processing in the GIS environment. Moreover, accuracy assessment was carried out with Overall Classification Accuracy of 85.83% and Kappa Statistics 0.81. The description of LULC classes is described below. The areas acquired by different cover are shown in Table 8.

Area having land utilization with annual and perennial crops and scattered rural settlement nearby, it is included in this class (Hassen and Assen 2018). Urmodi watershed is mainly a paddy cultivation area, especially in its hilly laterite

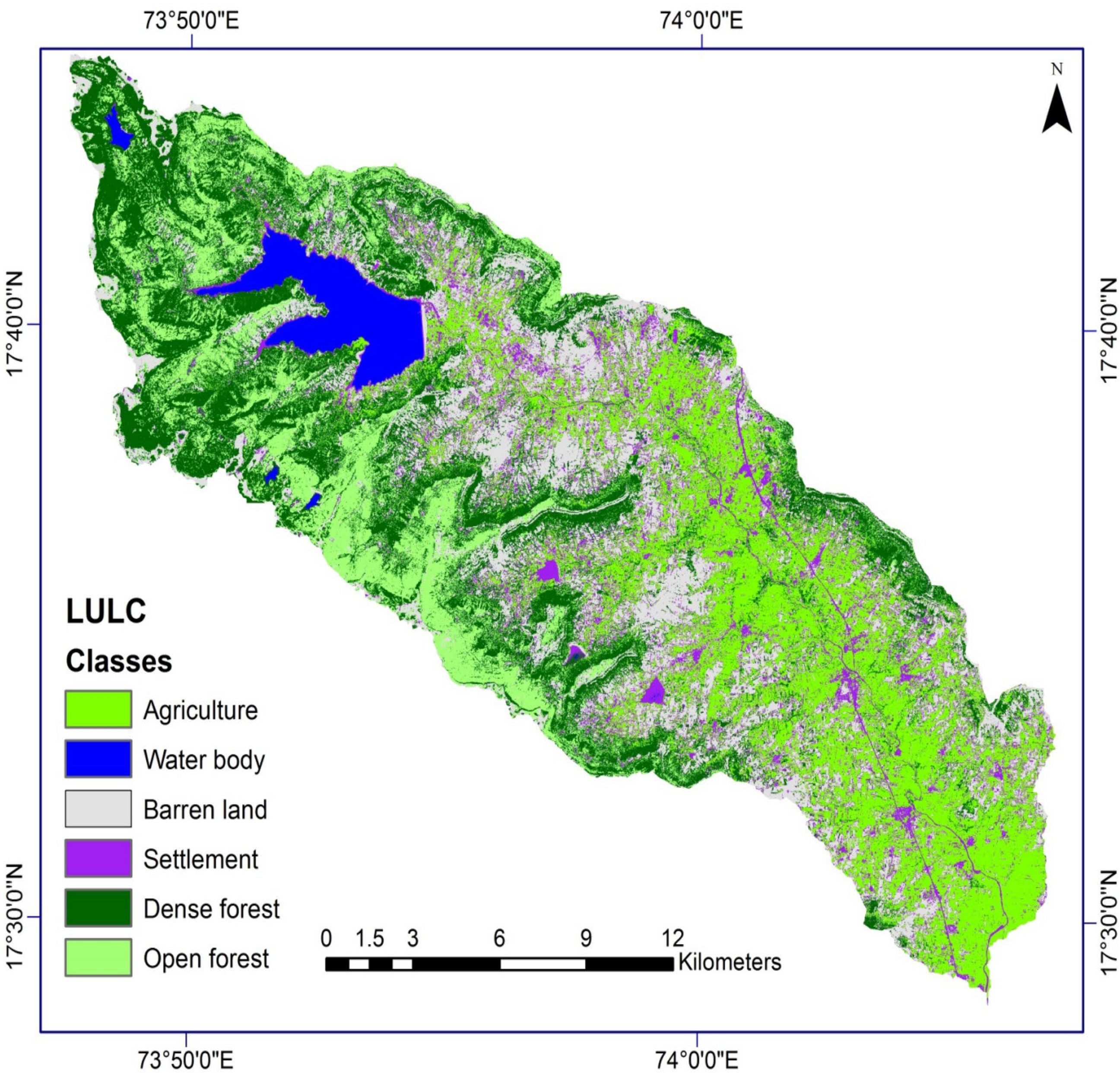

Fig.4 Supervised classification of land use land cover of Urmodi River watershed

Table 8 Sentinel 2 image based LULC of Urmodi River subwatersheds

Cover type (in km^2)	SW 1	SW 2	SW 3	SW 4	SW 5	SW 6	SW 7	Sum
Agriculture	1.30	4.69	1.58	21.77	1.15	15.51	58.92	104.92
Water body	8.16	0.25	6.58	0.03	0.00	0.04	0.04	15.1
Barren land	6.88	7.58	5.24	21.43	4.31	19.20	23.64	88.28
Settlement	1.55	3.44	1.35	9.62	0.93	7.28	14.41	38.58
Dense Forest	30.22	8.65	20.48	12.16	7.15	19.17	13.56	111.39
Open Forest	15.74	3.14	13.24	2.59	9.41	11.23	0.65	56.0

SW Subwatershed

terrain. We can generally observe paddy fields behind the reservoir. And towards the downward region of the dam, we can find other croplands like sugarcane, maize, wheat, etc. Agriculture fields were the second most dominant cover type which acquired 25.33% of the whole watershed (Table 8). The maximum agriculture activities were found in subwatershed 7 which has low relative relief and it is also the largest covered area out of seven subwatersheds. Lowest percentage of agricultural land was observed in the subwatershed 1, which is located in the upper highlands of the Urmodi River watershed.

In the present study area, a large reservoir and small catchment ponds were prominently present. The permanent river channel is also marked as a water body. As we can observe from Fig. 4, subwatersheds 1, 2 and 3 constitute 8.16 km^2, 0.90 km^2 and 6.58 km^2 of the whole basin. Other subwatersheds are also having water bodies including river channels and small catchment structures. But for soil conservation purpose, in ranking criteria (Table 9), this category is excluded because of the absence of topsoil layer.

The areas with no or less vegetation cover are directly exposed to soil erosion and rock outcrop (Miheretu and Yimer 2018). Barren land occupies 88.28 km^2, which is the third rank category of land cover. Barren land is most susceptible to water led soil erosion as there are no obstacles to runoff, such as vegetation. So, the sub-basins with the higher barren surface have to be given a higher ranking. Subwatershed 4 shows maximum soil loss risk due to its 21.43 km^2 area, which is exposed to erosion and form barren conditions. Whereas to subwatershed 1 was given the lowest priority, as it contains only 6.88 km^2 of barren land.

Basically, the permanent settlement of concrete rooftops, roads, and villages is accounted for the settlement land cover. Subwatersheds 4, 6 and 7 have a dense settlement zone; one of the reasons is the passing of National Highway 4. From soil conservation point of view, this cover has not been included in ranking due to absence of topsoil.

High densities of naturally grown trees are taken into this class. From visual interpretation and ground truthing, the area has been classified. The upper sub-catchments show the higher area of dense forest as this is a part of reserved forests. As the area of dense forest cover gets lowered into sub-basins, more land is exposed to drain. While ranking, the percentage of the land with the less dense forest was given as rank 1. Subwatersheds 7, show less area that is 13.56 km^2 (12.19% of its own area) under this land cover class; for this reason, it needs to be ranked 1. LULC in the catchment also acts as an indicator for the environmental conditions and vulnerability to soil erosion. Incompatible land cover causes aggravation in soil erosion behaviour, which is among the main causes of land degradation (Chauhan et al. 2016). LULC is also applied as one of the main indicators used for watershed prioritization (Malik and Bhat 2014). Areas with vegetation cover along with their intricate root system are less prone to the impact of rainfall, as they bind to the topsoil (Nooka Ratnam et al. 2005).

LULC is a good indicator of land degradation at the catchment scale and has great importance in understanding

Table 9 Subwatershed wise ranking of LULC parameters

Subwatershed name	Agriculture	Barren land	Dense Forest	Open Forest	Sum	Compound value (c_p)	Final ranking
Subwatershed 1	1	7	7	5	20	5.00	6
Subwatershed 2	4	2	5	3	14	3.50	3
Subwatershed 3	2	6	6	6	20	5.00	6
Subwatershed 4	6	1	2	2	11	2.75	1
Subwatershed 5	3	5	4	7	19	4.75	5
Subwatershed 6	5	3	3	4	15	3.75	4
Subwatershed 7	7	4	1	1	13	3.25	2

the erosional behaviour. When the land cover alters the impact of rainfall on each land cover class, it also changes the surface runoff characteristics at the subwatershed level (Bagwan and Gavali 2020b). Along with the dense forest, LULC class, low density of tree canopy also can be considered as a separate class. It includes the bare soil with sparsely distributed tree cover. This type of land patch also includes the shrubs (Mariwah et al. 2017). As we have done the ranking of dense forest, likewise different vegetation classes follow proportionate ratings. Low vegetated and open forest areas, within the subwatershed, are needed to be given as top ranking. Subwatershed 7 has shown poor vegetation cover and hence need to be ranked one. Subwatershed 5 shows 9.41 km^2 of open forest which is 41.01% of its own area, therefore it is ranked 7.

4.5 Integration of morphometric parameters and LULC ranking

As mentioned earlier, morphometric parameters and land cover have a close relationship and goes hand in hand. Drainage density, constant of channel maintenance, drainage texture, etc. are the some of the parameters which influence the erosion process. On the same side, if a land cover pattern gets altered, it will also affect the drainage pattern. The geomorphometric parameters along with LULC have great potential to optimally prioritize the soil and water conservation structure (Chauhan et al. 2016; Ahirwar et al. 2019). The dynamics between the drainage characteristics and surface land cover depict collective reflection of the impact of stream channels and anthropogenic activities across the watershed. Hence, there was need to integrate these two components. The linear and relief morphometric components of the morphometry are directly proportional to the erosional activity and hence were arranged in descending order. Whereas, the shape parameters are inversely proportional and were arranged in ascending order (Table 7). In the same way, Table 9 depicting the land use and land cover based on ranking show the two subwatersheds with the same compound value, i.e. 5.0 for the subwatershed 1 and subwatershed 3. So, based on the LULC-based prioritization both comes under the same ranking.

Table 10 Final priority based on integration of morphometric and LULC

Subwatershed name	Morphometric	LULC	Compound value (c_p)	Integrated ranking
Subwatershed 1	1.59	5	3.30	5
Subwatershed 2	2.18	3.5	2.84	3
Subwatershed 3	1.77	5	3.39	6
Subwatershed 4	2.00	2.75	2.38	1
Subwatershed 5	2.41	4.75	3.58	7
Subwatershed 6	1.95	3.75	2.85	4
Subwatershed 7	2.09	3.25	2.67	2

To avoid ambiguity, the compound value for ranking of subwatersheds with respective parameters of morphometry and LULC (Tables 7, 9) was integrated and averaged to come across a precise ranking arrangement as shown in Table 10. The area of barren land was highest in the subwatershed 4, which is also the most susceptible area to erosion. This because, its LULC priority highly influenced the ranking and thereby affected the integrated compound value. Lowest compound value is also an indication of alarming degradation.

We need focus on such area on priority basis to safeguard the soil from being washed out and implement the appropriate soil conservation measures. Moreover, if the morphometric parameters are showing the same compound value for subwatersheds, the confusion could be avoided by integrating other component like LULC to solve the priority issue between two subwatersheds. From the integration of compound values of morphometric and LULC, we got more accurate ranking as shown in Fig. 5 about the final ranking assignment of the subwatershed. The studies carried out in India to mitigate the soil erosion show that, there is need to opt for the geo-morphometric parameter-based prioritization and it is necessary to determine the appropriate soil conservation measures for the integrated watershed management and planning (Das 2014; Singh and Singh 2018).

5 Conclusion

The current study attempts to prioritize the subwatersheds of Urmodi River with the purpose of decision-taking and appropriation of soil conservation measures. The digital morphometric analysis of linearity, shape and relief aspects of Urmodi river watershed and its sub-basins helped to identify the geological, geomorphological and hydrological characteristics of the entire watershed. In case of soil erosion, not only one factor but the several prevailing conditions are responsible for contributing to the dynamics of the watershed. The high-resolution Sentinel 2 images have played a vital role in understanding LULC more accurately, along with its orthorectified nature. By analysing the geomorphological and land cover factors, we can control the degradation of soil resources. The compound values of each subwatershed for morphometric parameters and LULC can be used to solve the confusion in priority ranking when one of the parameters shows the same ranking. Therefore, for a better reflection of stream linked land surface cover conditions, we may use the compounded values, which are averages of the above mentioned two parameters to prioritize the subwatersheds. The compounded values also help to identify the

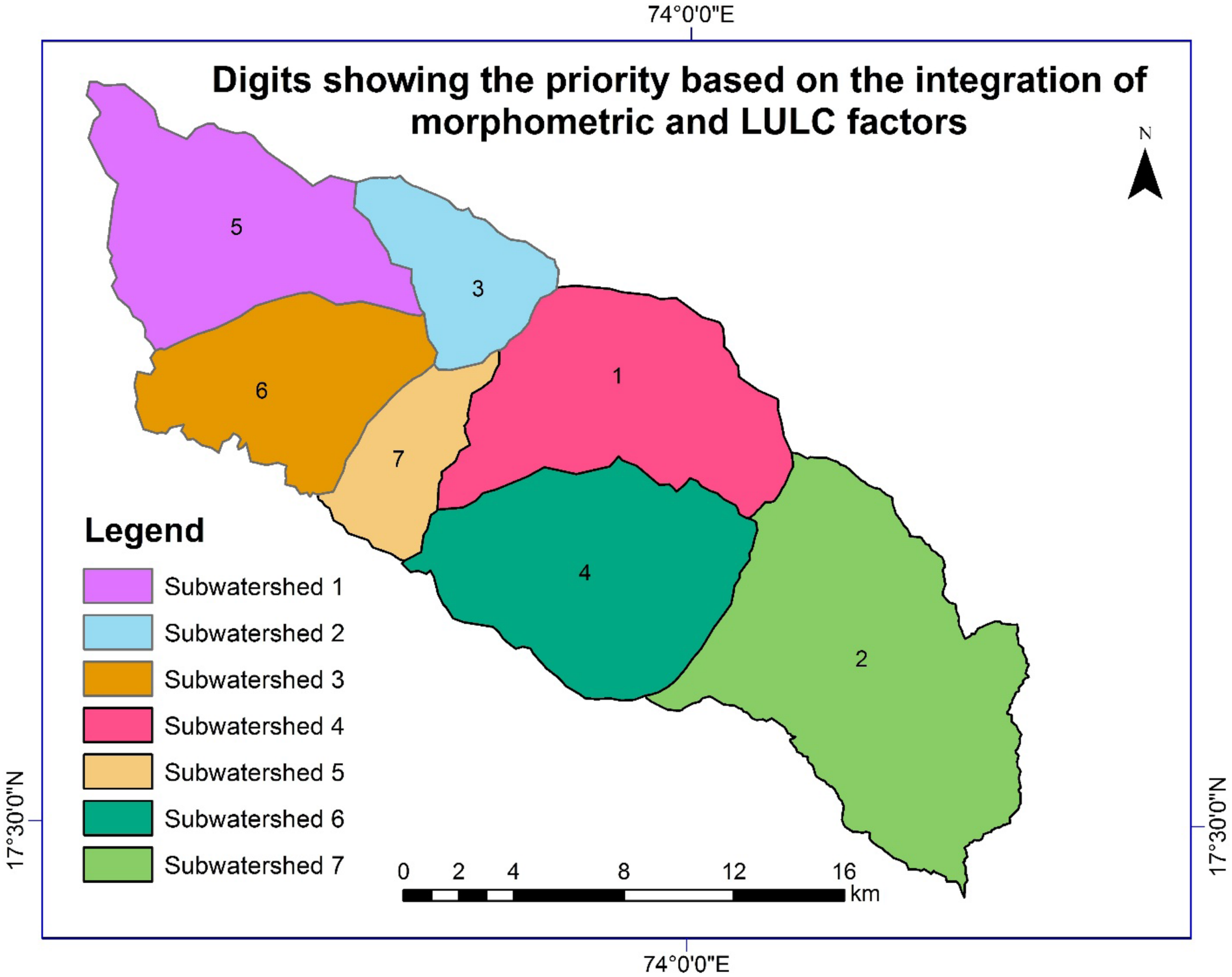

Fig. 5 Final ranking of Urmodi River subwatersheds by integrated approach of morphometric and LULC factors

vulnerability of each subwatershed. It has been revealed that the morphometric and LULC-based priorities are different but better and informed decisions can be arrived by integrating them. The subwatersheds in the upper catchment show the lowest ranking, while the lower catchment area indicated highest ranking priorities. Integrated rating also solved the confusion arising from equal ranking of subwatersheds, which may help us to prioritize soil conservation efforts. The present study will help the policymakers to develop a better and more scientific Catchment Area Treatment (CAT) plan. Land cover and morphometric analysis are also helpful in safeguarding the reservoir from siltation.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest or competing interest.

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