Prioritization of sub-watersheds vulnerable to soil erosion in Karjan river basin, India

ABSTRACT

The morphological characteristics of a river basin govern its hydrological response to a considerable extent and it alsorepresents its attributes, which may be employed in synthesizing its hydrological behaviour. Morphological study of the river basin explicit its vulnerability to get erosion.The study area is in the Southern part of Gujarat at 73.20' to 74.00' East Longitude and 21.20' to 22.00' North Latitude and 140 m Altitude covering regions of Narmada, Vadodara, Surat district, the area has semi-arid climate with erratic rainfall of around 1205 mm. The catchment area of the Karjan River basin is about 1538.38 km^2. To check the vulnerability regarding the soil erosion at sub watershed levelsfor the Karjan river basin, it was bifurcated in to 13 sub watersheds. The morphometric analysis was carried out for all the sub-watersheds, individually. Following standard procedure morphometric analysis was done using linear aspects, aerial aspects. Important 15 morphological parameters for Karjan river basin watershed were calculated using spatial resolution of30 m DEM in ArcMap software. There were 13 sub-watersheds were delineated in the Karjan river basin i.e. 5D1A6a, 5D1A6b, 5D1A6c, 5D1A6d, 5D1A6e, 5D1A6f, 5D1A6g, 5D1A6h, 5D1A6i, 5D1A6j, 5D1A6k, 5D1A6l and 5D1A6m. After analysing morphometric characteristics of 13 sub-watersheds, 5D1A6l, 5D1A6k and 5D1A6g sub watersheds fall under Very high priority, 5D1A6m, 5D1A6a, 5D1A6e sub watersheds falls under High priority, 5D1A6b, 5D1A6h, 5D1A6i sub watersheds falls under medium priority, 5D1A6c, 5D1A6d, 5D1A6i sub watersheds falls under Low priority and 5D1A6f falls under Very Low priority to soil erosion class.

Keyword: Morphometric analysis of watershed; Karjan river basin; soil erosion; prioritization of watershed

Introduction

"Morphometric parameters directly serve as indicators of soil erosion potential of the region; also, it has been termed as 'erosion risk' assessment parameters. Morphometric analysis includes the linear morphometric parameters such as drainage density, stream frequency, mean bifurcation ratio, drainage texture and length of overland flow. These parameters have a direct relationship to erodibility of the soil i.e. as the value of these parameters increases, the erosion possibilities will also increase and vice versa. Whereas, some of the parameters like, shape parameters in which elongation ratio, circularity ratio, form factor, shape factor and compactness coefficient have an inverse relationship with erodibility" (Biswas *et al.* 1999; Nooka Ratnam *et al.,* 2005 and Sadaf *et al.,* 2014). Based on this relationship between linear morphometric parameters and soil erosion, the highest value of a morphometric parameter was given rank 1; the immediate higher value rank was 2, and so on. Whereas for the shape parameters of watershed, the lowest value of a morphometric parameter was given rank 1; the value lower than this was ranked 2, and so on.

These linear parameters such as, Bifurcation ratio (R_b), Stream Frequency (F_s), Length of overland flow (L_g), Texture Ratio (T), Drainage Density (D_d) and relief parameters like relief, relative relief and relief ratio have a direct relationship with erodibility, higher the value of parameter indicates more erodibility.

Shape parameters such as Elongation Ratio (R_e), Form Factor (R_f), Circulatory Ratio (R_c) and Compactness Coefficient (C_c) have an inverse relationship with erodibility; lower the value of the shape parameter results more erodibility of the watershed. Thus, the lowest value of shape parameters was ranked as rank 1, next lower value was ranked as rank 2 and so on and the highest value was ranked last in rank. Hence, the ranking of the watersheds was ascertained by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters.

MATERIALS AND METHODS

2.1 Watershed delineation

Watersheds were delineated from a 30 m X 30 m SRTM DEM image as shown in Fig. 1 which was used with the Hydrology toolset from the Spatial Analyst toolbox of ArcMap 10.5 software. The steps to delineate a watershed are as follows:

i. Fill tool was used to remove imperfections from the DEM. It fills all the sinks regardless of depth.

Syntax: In Arc Toolbox, click Spatial Analyst Tools > Hydrology > Fill.

ii. Flow Direction tool was used to determine the direction of the flow from each cell to its steepest down slope neighbour.

Syntax: In Arc Toolbox, navigate to Spatial Analyst Tools > Hydrology > Flow Direction.

iii. Flow Accumulation tool was utilized to calculate the accumulated flow to each cell.

Syntax: In Arc Toolbox, click Spatial Analyst Tools > Hydrology > Flow Accumulation.

iv. A new shape file was created to mark the outlet point and named it as outlet.

v. Snap Pour Point tool was used to locate the pour points to cells of high accumulated flow. It is a point at which water flows out of an area (outlet point of watershed).

Syntax: In Arc Toolbox, click Spatial Analyst Tools > Hydrology > Snap Pour Points.

vi. The outlet point was marked at the desired coordinates of the area using Editor Tool in ArcGIS 10.5 software toolbar.

vii. Watershed tool was used to mark the boundaries of the catchment area.

Syntax: In Arc Toolbox, navigate to Spatial Analyst Tools > Hydrology > Watershed.

viii. ‘Raster to Polygon’ tool was used to create polygon features from the watershed raster, which created the shape file of the watershed.

2.2 Calculation of morphometric parameters

Various formula used for calculation of morphometric parameters are given in Table. 1.

Table 1: Mathematical formula to calculate morphometric parameters

SN	Morphometric Parameters	Formula	Reference
1	Stream order (N_u)	Hierarchical rank	Horton (1945)
2	Stream Length ratio (R_L)	$R_L=L_u/L_{u-1}$	Horton (1945)
3	Bifurcation ratio (R_b)	$R_b=Nu/Nu_{+1}$	Schumn (1956)
4	Drainage Density (Dd)	$D_d=Lu/A$	Horton (1932)
5	Length of over Land flow (L_g)	Lg=1/Dd*2	Horton (1945)
6	Fitness ratio (R_{fn})	Rfn=Lb/p	Melton (1957)
7	Circulatory Ratio (R_c)	$R_c=4*pi*A/P^2$	Miller (1953)
8	Elongation Ratio (R_e)	$Re=(2/Lb)X(A/pi)^{0.5}$	Schumn (1956)
9	Form factor (R_f)	$R_f=A/L_b^2$	Horton (1932)
10	Unity Shape factor (R_u)	$Ru=Lb/A^{0.5}$	Horton (1945)
11	Compactness Coefficient (C_c)	$C_c=0.2821*P/A^{0.5}$	Strahler (1964)
12	Drainage texture (R_t)	$R_t=Nu/P$	Horton (1945)
13	Total Relief (H)	$H=h_1-h_2$	Hardley *et.al.* (1961)
14	Relief Ratio (R_h)	$R_h=H/L_b$	Schumn (1956)
15	Relative relief (R_p)	$R_p=H/P$	Melton (1957)

Where, A = area of basin (km^2), N_u = total number of stream segment of order ‘u’, L_u = total stream length of all order (km), P = perimeter of basin (km), L_b = Basin length (km), D_c = Diameter of circle having same area as that of watershed, L_m = Length of main channel (km), N_u = total number of Stream of all orders, h_1 and h_2 = highest and lowest points on the valley floor of a watershed.

2.2 Prioritization of subwatershed

"Morphometric parameters directly serve as indicators of soil erosion potentialof the region; also, it has been termed as 'erosion risk' assessment parameters. Morphometric analysis includes the linear morphometric parameters such as drainage density, stream frequency, mean bifurcation ratio, drainage texture and length of overland flow" (Jayswal, *et al.* 2021 and Sondarva, *et al.,* 2023). These parameters have a direct relationship to erodibility of the soil i.e.as the value of these parameters increases, the erosion possibilities will also increase and vice versa. Whereas, some of the parameters like, shape parameters in which elongation ratio, circularity ratio, form factor, shape factor and compactness coefficient have an inverse relationship with erodibility. Based on this relationship between linear morphometric parameters and soil erosion, the highest value of a morphometric parameter was given rank 1; the immediate higher value rank was 2, and so on.

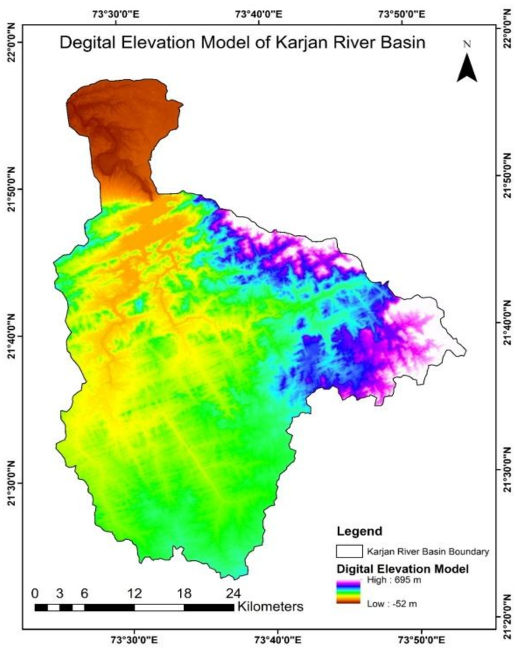
"Shape parameters such as Elongation Ratio (R_e), Form Factor (R_f), Circulatory Ratio (R_c) and Compactness Coefficient (C_c) have an inverse relationship with erodibility; lower the value of the shape parameter results more erodibility of the watershed. Thus, the lowest value of shape parameters was ranked as rank 1, next lower value was ranked as rank 2 and so on and the highest value was ranked last in rank. Hence, the ranking of the watersheds was ascertained by assigning the highest priority/rank based on highest value in case of linear parameters and lowest value in case of shape parameters" (Bhanderi, et al., 2020; Mishra et al., 2010).

"It was observed that no single one parameter can be used to explain the erosion susceptibility of any watershed. Therefore, after assigning ranks to every soil erosion risk morphometric parameter, compound value (Cp) was defined by calculating the average of ranks assigned to the individual parameters. The average value of rank is used as an index denoting sub-watershed erosion susceptibility. The sub-watershed with lowest Cp value is considered as the most susceptible to erosion and needs highest priority for construction of different site suitable soil conservation measures. Based on Cp value of these parameters, the sub-watershed having the least rank were assigned top priority, next higher value was assigned second priority and so on. The priority was assigned by classifying the highest and the lowest range of Cp value in to five categories as Very high (5.50-6.00), High (6.00-6.85), Medium (6.86-7.60), Low (7.61-7.83) and very low (>8.25).After ranking was done based on each morphometric parameter estimated, ranking values for all linear and shape parameters of each watershed were added up for each sub-watershed to calculate final compound value (C_p). Based on average value of these parameters, the watershed having the least rating values was assigned highest priority; next higher value was assigned second priority and so on" (Bhanderi, *et al.,* 2020; Mishra *et al.*, 2010). The watershed has the highest C_p value was assigned the last priority.

RESULTS AND DISCUSSION

In the Karjan River basin 13 sub-watersheds were delineated using GIS techniques. The watershed code was given as 5D1A6a, 5D1A6b, 5D1A6c, 5D1A6d, 5D1A6e, 5D1A6f, 5D1A6g, 5D1A6h, 5D1A6i, 5D1A6j, 5D1A6k, 5D1A6l and 5D1A6m. The sub-watershed 5D1A6e has the highest area, 167.52 (km^2) while the smallest sub-watershed is 5D1Ac, havingan area of 65.18 km^2. The highest perimeter is 87.32 km, which is of the sub-watershed 5D1A6h and the lowest perimeter of 48.40 km was of the sub-watershed is 5D1A6f. The highest basin length, 17.88 km was of 5D1A6e sub-watershed and smallest basin length was 11.73 km for 5D1A6m sub-watershed. The Digital Elevation Model of the

Karjan River Basin, Fig. 1 was used for delineation of 13 sub-watersheds as shown in Fig. 2.



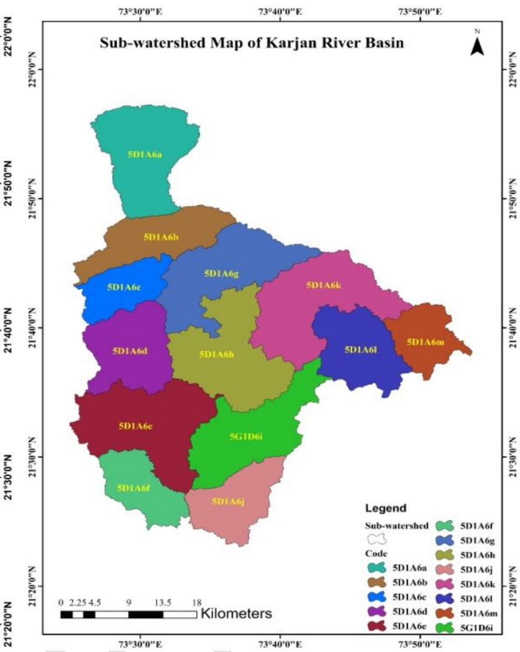


Fig. 1 DEM of Karjan river basin Fig. 2 Subwatershed in Karjan river basir

3.1 Linear parameters

In this study different important sevenlinear parameters of the Karjan watershed has been calculated and analysed using standard formulas. The Linear parameters like Stream order, Stream Frequency, Length of overland flow, Drainage Density, Fitness ratio, Shape factor, Drainage Texture were used to know the morphometric status of the sub-watershed under Karjan River Basin. The calculated value of these parameters isgiven in Table No. 2.

Table No. 2 Morphometric parameters of sub watersheds of Karjan River Basin: Linear aspect

Parameters	5D1A6a	5D1A6b	5D1A6c	5D1A6d	5D1A6e	5D1A6f	5D1A6g	5D1A6h	5D1A6i	5D1A6j	5D1A6k	5D1A6	5D1A6m
S_o	5	6	4	4	5	5	5	5	5	5	5	5	5
F_s	1.46	2.34	1.60	1.51	2.04	2.00	1.55	1.49	2.39	2.19	2.01	1.90	1.56
D_d	1.609	1.520	1.445	1.540	2.640	1.067	1.457	1.547	2.031	1.325	2.336	1.581	0.961
L_g	0.386	0.430	0.346	0.325	0.140	0.878	0.343	0.323	0.242	0.569	0.183	0.400	1.082
R_{fn}	0.025	0.150	0.273	0.212	0.210	0.224	0.215	0.736	0.105	0.003	0.158	0.064	0.068
R_u	1.389	1.587	1.528	1.153	1.426	1.62	1.483	5.112	1.736	1.082	0.908	1.481	1.453
W_s	1.947	2.550	2.335	1.329	3.428	1.896	2.200	1.464	4.178	1.016	1.360	2.246	1.361
T	3.271	2.910	2.309	2.908	3.947	2.933	2.708	2.690	3.421	3.669	3.754	3.382	2.433
H	281.0	368.0	233.0	238.0	142.0	109.0	596.0	297.0	294.0	139.0	542.0	356.0	391.0
R_h	0.017	0.023	0.018	0.019	0.007	0.007	0.033	0.019	0.014	0.014	0.047	0.023	0.033
R_p	0.450	0.58	0.517	0.419	0.168	0.225	0.717	0.340	0.271	0.271	0.624	0.620	0.897
R_g	0.45	0.56	0.34	0.37	0.37	0.12	0.87	0.46	0.60	0.18	1.27	0.56	0.38

S_o**=**Stream order, F_s=Stream Frequency, D_d=Drainage density, L_g = Length of overland flow, R_{fn} = Fitness ratio,R_u=Unity shape factor, W_s=Shape factor, T = Drainage texture, H= Total relief, R_h = Relief ratio, R_p = Relative reliefand R_g= Ruggedness Number

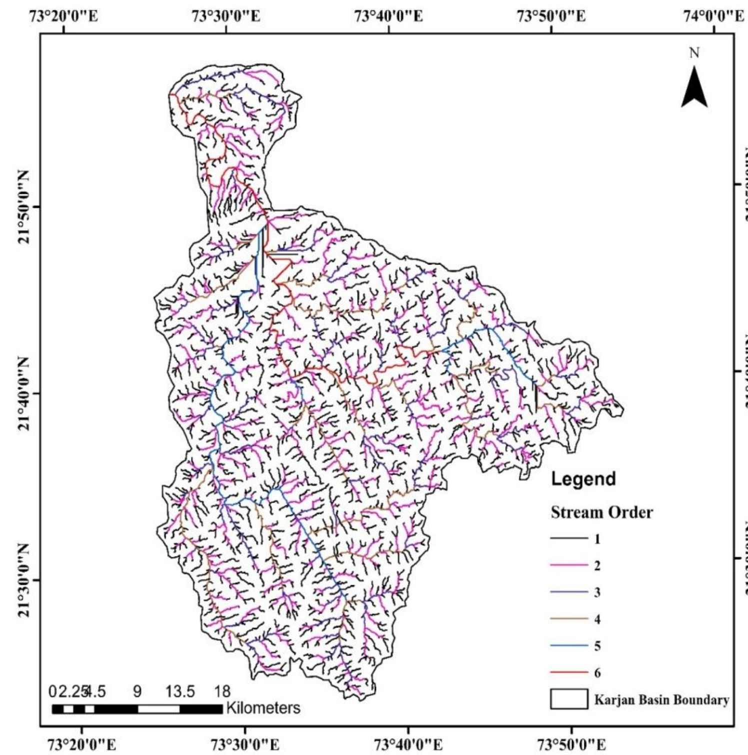


Fig. 3 Stream order map of Karjan River Basin

It was observed that no single one parameter can be used to explain the erosion susceptibility of any watershed. Therefore, after assigning ranks to every soil erosion risk morphometric parameter, compound value (C_p) was defined by calculating the average of ranks assigned to the individual parameters. The average value of rank is used as an index denoting sub-watershed erosion susceptibility. The sub-watershed with lowest C_p value is considered as the most susceptible to erosion and needs highest priority for construction of different site suitable soil conservation measures. Based on C_p value of these parameters, the sub-watershed having the least rank were assigned top priority, next higher value was assigned second priority and so on. The priority was assigned by classifying the highest and the lowest range of C_p value in to five categories as Very high (5.50-6.00), High (6.00-6.85), Medium (6.86-7.60), Low (7.61-7.83) and very low (>8.25) (Jayswal, 2021). "After ranking was done based on each morphometric parameter estimated, ranking values for all linear and shape parameters of each watershed were added up for each sub-watershed to calculate final compound value (C_p). Based on average value of these parameters, the watershed having the least rating values was assigned highest priority; next higher value was assigned second priority and so on" (Sondarva, *et al.*,2023).

3.2 Linear parameters

3.2.1 Stream Order

Stream network is highly influenced by various hydrological characteristics i.e. infiltration, runoff, soil erosion, groundwater recharge etc of any basin. Based on the review, four different stream ordering techniques were available as suggested by Gravelius(1914), Horton (1945), Strahler (1952) and Scheidegger (1970). Following Strahler scheme, it was found that in the Karjan watershed, the total number of streams are 2289, out of which 1772 are of 1st order, 400 are of 2nd order, 89 areof 3rd order, 24 are of 4th order, 3 are of 5th order and 1 are of 6th order. The sub-watershed wise number and order is given in Table No. 3. It reveals that the highest number of streams arein sub-watershed 5D1A6e 341, followed by 330 in sub-watershed 5D1A6i, 329 in 5D1A6k, 236 in 5D1A6b, 235 in sub-watershed 5D1A6h, 225 in sub-watershed 5D1A6g, 204 in sub-watershed 5D1A6a, 194 in 5D1A6l, 165 in sub-watershed 5D1A6d, 144 in sub-watershed 5D1A6f, 104 in sub-watershed 5D1A6c and 100 in sub-watershed 5D1A6m. It is obvious that the 1st order stream is the highest in number in all sub-watersheds which decreases as the order increases and the highest order has the lowest number of streams.

Table No. 3 Number of streams under each stream order in different Sub-watersheds of Karjan River Basin

Sub-watershed	Order of stream						Total Number of streams
	1st order	2nd order	3rd order	4th order	5th order	6th order	
5D1A6a	160	34	7	2	1	-	204
5D1A6b	199	28	5	4	0	-	236
5D1A6c	79	21	3	1	0	-	104
5D1A6d	126	30	8	1	0	-	165
5D1A6e	297	29	10	1	4	-	341
5D1A6f	130	8	3	3	0	-	144
5D1A6g	175	39	7	3	1	-	225
5D1A6h	177	45	9	3	1	-	235
5D1A6i	281	30	15	2	2	-	330
5D1A6j	152	20	3	10	4	-	189
5D1A6k	274	27	15	7	6	-	329
5D1A6l	171	11	9	1	2	-	194
5D1A6m	78	6	9	5	2	-	100
5D1A6	1772	400	89	24	3	1	2289

3.2.2 Stream length (Lu)

The sub-watershed wise lengths of streams in different orders mean length of the streams is given in Table 4. It is revealed from these table that the drainage network of the Karjan watershed is characterised by total length of 2329.08 km, the sub-watershed 5D1A6h is having highest length of streams as 244.91 km followed by 241.72 km, 230.60 km, 221.24 km, 211.65 km, 167.67 km, 156.49 km, 145.67 km, 130.85 km, 105.44 km, 95.51 km and 94.72 km respectively for sub-watersheds 5D1A6i, 5D1A6k, 5D1A6a, 5D1A6g, 5D1A6d, 5D1A6l, 5D1A6b, 5D1A6j, 5D1A6f, 5D1A6m and 5D1A6c. The stream of relatively smaller length suggests that the area is having larger slopes and finer textures. Longer lengths of streams denote the flatter gradient of the watershed. Generally, the maximum stream length of first order and it is decreasing with increase in the stream order.

Table No4 Stream length in Sub-watersheds of Karjan River Basin

Sub-watershed	Stream length (km)					Total streams Length
	1st order	2nd order	3rd order	4th order	5th order	
5D1A6a	112.71	62.11	19.03	25.77	1.63	221.24
5D1A6b	79.83	35.33	14.99	15.51	0	145.67
5D1A6c	50.40	22.85	11.06	10.42	10.42	94.72
5D1A6d	83.75	53.76	21.72	8.46	0	167.67
5D1A6e	136.44	65.84	18.86	29.87	8.51	259.52
5D1A6f	57.90	27.38	9.35	10.80	0	105.44
5D1A6g	107.54	49.08	20.92	31.72	2.41	211.65
5D1A6h	132.92	60.49	24.14	24.32	3.01	244.91
5D1A6i	127.90	61.92	24.44	24.34	3.08	241.72
5D1A6j	76.03	26.27	21.55	6.86	0.15	130.85
5D1A6k	108.37	59.24	29.11	30.97	2.90	230.60
5D1A6l	74.98	38.09	19.76	19.99	3.67	156.49
5D1A6m	53.28	22.39	8.29	8.61	2.92	95.51

3.2.3 Stream frequency (Fs)

"Stream frequency is inversely related to permeability of the surface, infiltration capacity of the media and directly related to the relief of any watersheds" (Montgomery and Dietrich, 1989, 1992). The higher value of stream frequency indicates that the watershed has rocky terrain and very less infiltration capacity which results in more erosion and vice versa. The stream frequency of the sub-watersheds of the Karjan watershed varies from 1.46 to 2.39.

3.2.4 Mean Bifurcation ratio (R_{bm})

"Mean bifurcation ratio of any watershed is an indicator of structural complexity and permeability of the terrain surface and is also negatively correlated with the permeability of a watershed" (Surve, *et al*., 2015). "High Mean bifurcation ratio suggests that the hydrograph is having peak rate or runoff with a potential for flash flooding during the rainfall events which will cause degradation of top fertile soil" (Howard 1990; Rakesh *et al.*, 2000). The mean bifurcation ratio of all the sub-watersheds is very high, which indicates that all the sub-watersheds are structurally complex and have low permeability.

3.2.5 Drainage Density (D_d)

"It is the ratio of total channel segment length of all stream orders within a basin to the basin area. It is expressed in terms of Km/Km^2.The drainage density, indicates how different streams are close to each other or in other words the stream network development in the watershed provides quantitative measure of the average length of stream channel for the whole drainage basin. Lower drainage density of any watershed indicates that it has permeable subsurface material with good vegetation cover and low relief and vice versa" (Luo 1900; Harlin and Wijeyawickrema 1985). In Karjan Rivera Basin the highest drainage density was observed as 2.64 / km in

5D1A6e sub-watershed which indicates that it has the lowest permeability and thus highest erosion susceptibility in terms of drainage density. The lowest value of drainage density was observed as 0.96 in 5D1A6m sub-watershed. The low value of drainage density shows that it has greatest permeability among other sub-watershed or conversely it has the greatest tendency to withstand erosion if only D_d is taken as a criterion for erosion susceptibility.

3.2.6 Drainage Texture (T)

Drainage texture is highly affected by the infiltration capacity of the watershed (Horton 1945). Regions having low infiltration capacity will enhance the drainage texture. The highest drainage texture was observed in 5D1A6e as 3.95 which indicate that it has the lowest infiltration capacity and thus highest erosion susceptibility in terms of drainage texture. The lowest value of drainage texture was observed in 5D1A6c as 2.31.

3.2.7 Length of overland flow (Lg)

Among the sub-watersheds of the Karjan River Basin, the highest length of the overland flow was observed in sub-watershed 5D1A6m as 1.08 km which shows that it has the highest potential to erode the land in a single stretch. The lowest length of overland flow was observed in 5D1A6e as 0.14 km which indicates sub-watershed is least susceptible to erosion as far as length of overland flow is concerned.

3.3.1Relief ratio (Rh)

The highest relief ratio was observed 0.05 in 5D1A6k which indicates quick depletion of water which results in large peak and steep limb of the hydrograph,consequently higher soil loss. It is noticed that high value of Relief ratio indicates high relief, while the lower value of Relief ratio indicates the presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope (**GSI, 1981**). The lowest value of relief ratio was observed 0.007 in 5D1A6e and 5D1A6f sub-watershed of Karjan River Basin.

3.3.2 Relative Relief (R_r)

The highest value of Relative Relief was observed in 5D1A6m as 0.89 which indicates "critical"fromthe erosion point of view and should be provided with suitable soil and water conservation measures.

3.3.3 Ruggedness Number (R_N)

The highest value of RN is 1.27 for 5D1A6k that indicates the structural complexity of the terrain in association with relief and drainage density and it also implies that the area is susceptible to more soil erosion. The lowest value of the Ruggedness number was observed in 5D1A6f (0.12) which indicates that the area is not under the effect of soil erosion, as compared to another sub-watershed of the Karjan River Basin.

3.4. Shape parameters

Shape parameters of the subwatershed of Karjan river basin are as shown in Table.5.

Table 5 Morphometric parameters: Shape parameter

Parameters	R_c	R_g	C_c	R_f	S_h
5D1A6a	0.448	0.808	1.504	0.513	1.947
5D1A6b	0.31	0.71	1.79	0.39	2.550
5D1A6c	0.403	0.738	0.431	0.428	2.335
5D1A6d	0.426	0.978	0.325	0.752	1.329
5D1A6e	0.176	0.609	2.402	0.291	3.428
5D1A6f	0.533	0.819	1.379	0.527	1.896
5D1A6g	0.164	0.76	0.418	0.54	2.201
5D1A6h	0.26	0.22	1.442	0.038	1.464
5D1A6i	0.188	0.552	2.323	0.239	4.178

5D1A6j	0.476	1.119	1.459	0.983	1.016
5D1A6k	0.165	0.967	2.473	0.735	1.360
5D1A6l	0.38	0.752	1.633	0.445	2.246
5D1A6m	0.659	0.967	1.24	0.735	1.361

Circularity ratio (R_c), Elongation ratio (R_g), Compactness coefficient (C_c), Form factor (R_f) and Shape factor (S_h)

3.4.1 Elongation ratio (Re)

In general, the range of the Elongation ratio varies from 0.6 to 1.0 and it is associated with a wide variety of climate and geology of the watershed.The values of elongation ratio close to 1.0 are typical of region with very low relief, whereas that of 0.6 to 0.8 are associated with high relief and steep ground slope (Ahmed*et al.*, 2010, Sadaf *et al.* 2014). These values can be grouped into four categories namely circle (greater than 0.9), oval (0.8 to 0.9), less elongated (0.7 to 0.8) and elongated (less than 0.7), (Strahler. 1964). Among the sub-watershed, the highest Elongation ratio was observed in 5D1A6j, 1.12, which shows that least susceptibility to erosion in terms of Elongation ratio.

3.4.2 Circularity ratio (R_c)

“As the value of the circularity ratio increase, it indicates that the late maturity stage of topography. Highest circularity ratio represents the shape of the watershed iscircular and it is having moderate to high relief and permeable surface. Low Circularity ratio shows watershed is of elongated shape, low relief and impermeable surface” (Sadaf *et al.* 2014). “A circular shaped basin generates more runoff than an elongated shape watershed” (Singh and Singh, 1997). Amongst the 13 sub-watersheds, the highest circularity ratio was observed in 5D1A6m as 0.66, which is resulting in more erosion susceptibility in terms of circularity ratio only. The lowest circularity ratio was observed in 5D1A6g as 0.16 which indicates that it is having low relief and higher infiltration capacity and resulting in lower erosion susceptibility.

3.4.3 Form factor (R_f)

For a perfectly circular basin, the value of the form factor is always less than 0.8. (Rudraiah*et al.,* 2008; Chopra *et al.*, 2005), smaller value of the form factor indicates that the shape of watershed is elongated. The higher value of the watershed suggests that the watershed is having peak flow for shorter durations, whereas, elongated watershed with low form factors has peak flow observed for the longer duration (Mishra*et al*., 2010). Among the sub-watershed of Karjan River Basin, highest form factor was observed in 5D1A6j as 0.98 indicating that the peak flows of shorter duration and are least susceptible to erosion in terms of form factor only. Form factor is observed lowest in 5D1A6h as 0.04 which indicates highest susceptibility to erosion.

3.4.4 Compactness coefficient (C_c)

"A circular shape watershed yields in the shortest time of concentration before peak flow occurs in the watershed" (Altaf *et al.*, 2013). "The compactness coefficient of watershed is directly proportional to the infiltration capacity of the watershed" (Sadaf *et al.*, 2014). "Compactness coefficient is inversely proportional to the erodibility of the soil in the watershed" (Nooka Ratnam *et al.*, 2005). Among the sub-watersheds of Karjan watershed, the highest Compactness coefficient was observed in 5D1A6k as 2.47 which indicate least susceptible to erosion in terms of Compactness coefficients only. The lowest compactness coefficient is observed in 5D1A6d as 0.33 which indicates highest susceptibility to erosion in terms of Compactness coefficient only.

3.4.5 Shape factor (Bs)

Among the sub-watersheds of Karjan River Basin, the highest shape factor was observed in 5D1A6i as 4.18 indicating it's least susceptible to erosion in terms of Shape factor only. Shape factor was observed lowest in sub-watershed 5D1A6j as 1.02 indicating highest susceptibility to erosion.

3.5 Prioritization of sub-watersheds based on Morphometric analysis

Prioritization of subwatershed in the Karjan river basin is as shown in Fig. 4 and Table 6. Out of 13 sub-watersheds, 5D1A6l, 5D1A6k and 5D1A6g fall under Very high priority, 5D1A6m, 5D1A6a, 5D1A6e falls under High priority, 5D1A6b, 5D1A6h, 5D1A6i falls under medium priority, 5D1A6c, 5D1A6d, 5D1A6i falls under Low priority and 5D1A6f falls under Very Low priority erosion class.

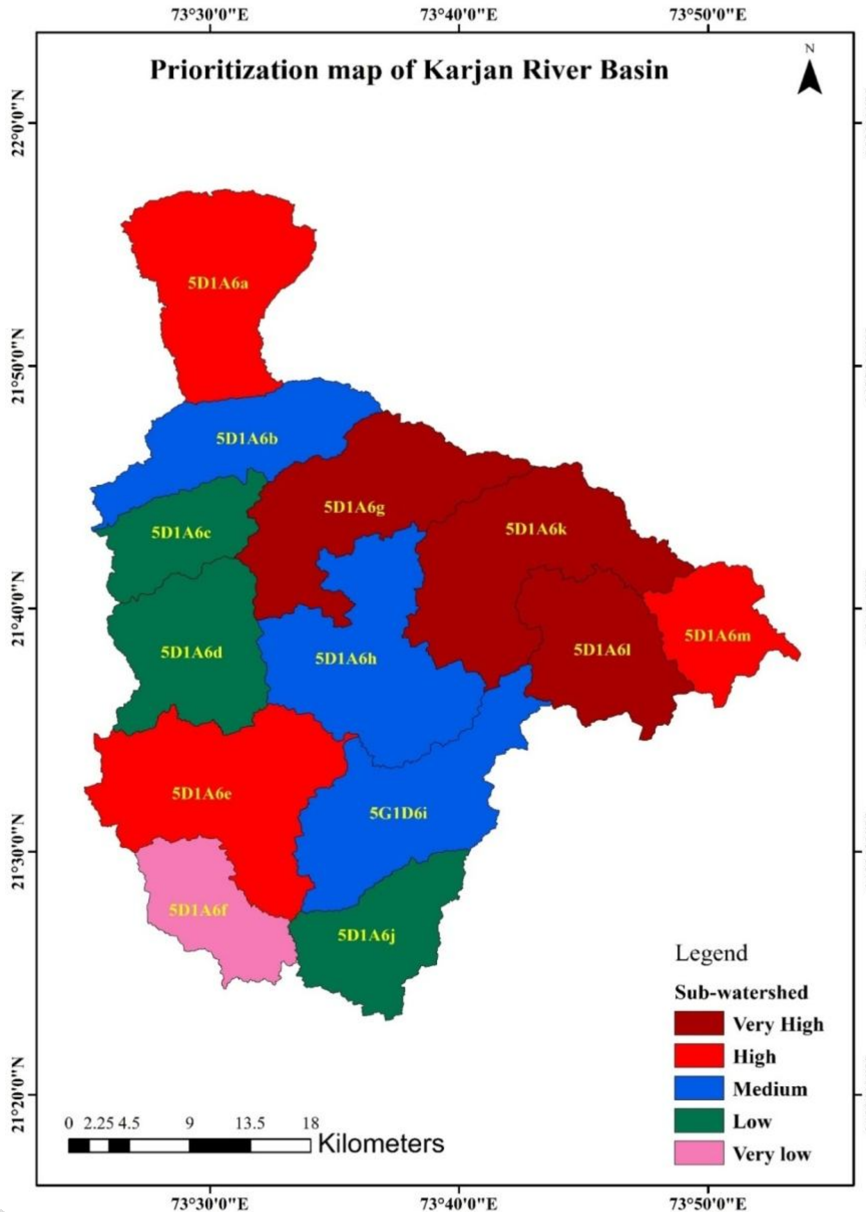


Fig. 4 Prioritization map of Karjan River Basin

Table No. 6 Sub-watershed prioritization of Karjan River Basin

Sub-Watershed	Linear Parameters								Shape parameters				Compound value	Interpretation
	R_b	F_s	L_g	T	D_d	H	R_p	R_r	R_g	R_f	R_c	C_c		
5D1A6a	4	6	4	6	4	8	7	9	8	8	10	8	6.83	High
5D1A6b	14	10	6	8	8	4	5	4	4	4	6	10	6.92	Medium
5D1A6c	6	9	8	13	13	10	6	8	5	5	8	3	7.83	Low
5D1A6d	4	2	12	9	9	9	8	6	12	12	9	1	7.75	Low
5D1A6e	3	11	2	1	1	11	13	12	3	3	3	12	6.25	High
5D1A6f	1	5	7	7	7	13	12	12	9	9	12	5	8.25	Very low
5D1A6g	9	7	9	10	10	1	2	2	7	7	1	2	5.58	Very High
5D1A6h	12	13	10	11	11	6	9	6	1	1	5	6	7.58	Medium
5D1A6i	8	12	10	4	4	7	10	10	2	2	4	11	7.00	Medium
5D1A6j	7	1	3	3	3	12	10	10	13	13	11	7	7.75	Low
5D1A6k	13	3	11	2	2	2	3	1	10	10	2	13	6.00	Very High
5D1A6l	2	8	5	5	5	5	4	4	6	6	7	9	5.50	Very High
5D1A6m	5	3	1	12	12	3	1	2	10	10	13	4	6.33	High

CONCLUSION

In the Karjan river basin,out of the total area of the basin, 27.18% area falls under very high priority class, 24.57 % area under high priority class, 26.24% area under medium priority class, 17.25% area under low priority class and 4.76% area under very low priority class susceptible to soil erosion. Soil erosion based prioritization of subwatershedwill behelpful to identify vulnerable area to soil erosion and further watershed development activity in the Karjan river basin.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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