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Morphometric analysis for sustainable development of natural resource management by using remote sensing and GIS techniques in Tikamgarh District, M.P., Central India

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ABSTRACT

Study of morphometric parameters decides the suitable location and adjustable natural resource management (NRM) practices along with durability and sustainability. Morphometric study of a region provides the various geological, topographical and others parameters which supports during the design and implantations of various water conservation approaches. Garhkundar –Dabar (GKD) watershed having two parts as first treated watershed and second control watershed, located in Tikamgarh District of Madhya Pradesh, Central India was selected for this analysis. ArcGIS ver. 10.3 was used for analysis and found IVth order stream in treated watershed area of 850 ha (8.50 km^2) and IInd order stream in control watershed area of 268 ha (2.68 km^2). In treated watershed, 19 streams were found in first order while 12, 5 and 1 streams were obtained in second, third and fourth order respectively. Similarly, 6 and 4 streams were found in first and second order respectively in control watershed. This study conclude all aspects of morphometric parameters *viz.* linear, areal and relief which elaborate the geometric as well as topographic features to support and identified the best location for various conservation interventions and their implementation with a long sustainability. RS and GIS based morphometric analysis provides the way of replication of conservation practices and suggested for sustainable conservation treatment and watershed development.

Introduction

Development of a basin and its drainage pattern over space and time is influenced by soil, area of vegetation, geology, geomorphology and structural components and their location. All the hydrologic and geomorphic process of a watershed is mainly depend on the basin of an area and their flowing pattern. Earth's surface, its shape and dimension of its landforms all such configurations elaborated by morphometric measurement and mathematical analysis (Agarwal, 1998; Obi Reddy *et al.*, 2002). Morphometric study of a region was carried out by thematic map generated in GIS environment to identify the appropriate places for artificial groundwater recharge structures. The field survey also required to find out the suitability and sustainability of proposed artificial groundwater recharge structures. Thereby, by RS and GIS recharge structures implemented and found 264.82 Mm^3 (30%) groundwater recharge (Kumar *et al.*, 2016). Due to high demand of water and depletion of groundwater recharge, RS and GIS provided a great opportunity during master plan for artificial

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recharge to groundwater in India (Pati, 2019). Due to the increase in demand of natural resources such as land and water, management of these resources at a watershed scale has become one of the important strategies for attaining a sustainable environment (Hema *et al.,* 2021). The information as a result of morphometric analysis of watersheds could be used as decisive tool in water resource management, conservation of soil erosion, landslide susceptibility mapping, evaluation of groundwater potential, and prioritization of watersheds (Salvi *et al.,* 2017; Jena and Dandabat, 2019). In view of the importance of morphometric analysis for Sustainable Development of Natural Resource Management, this study had been taken in Garhkundar–Dabar (GKD) located at Tikamgarh district of Madhya Pradesh, Central India.

Material and Methods

Selected watershed named Garhkundar –Dabar (GKD) was located at Tikamgarh district of Madhya Pradesh, Central India (figure 1). Watershed widely spread in longitudinal direction between 78° 52' 41" to 78° 54' 44" E and latitudinal direction between 25° 26' 24" to 25° 28' 31" N. Watershed categorized into two parts based on its geographical area first treated watershed area of 850 ha and second control watershed area of 268 ha. Watershed comprises four Panchayati villages namely Shivrampur, Dabar, Rautiana and Kundar in the Tikamgarh District of Madhya Pradesh, India. The range of watershed altitude above mean sea level (MSL) varies from 208 to 285 m.

Watershed is agro-climatic in nature among the Central Plateau Hill Region and suffers ecologically by hot moisture semi-arid and typical semi-arid sub-tropical features. The mean temperature of region varies from 3 ^{0}C to 49 ^{0}C. The geology and geomorphology of the watershed is characterized by hard rock terrains of archaen granite found below 8 m depth and disintegrated rock fragments locally called 'murram' are found between 25 to 800 cm depth. The soil of watershed is shallow (10-50 cm) variants of red soils, known as Parwa (Entisol) and Rakar (Alfisol) with having poor water holding capacity.

Base map of the basin is prepared in GIS environment by using ArcGIS ver. 10.3. Watershed geometry is systematic description which is understood by morphological characteristics of watershed. To understand the geometry of drainage basin and its stream channel system, basically three morphometric measurements were adopted i.e. (i) linear aspect (ii) areal aspect (iii) relief aspect. The proper way of analysis is presented by the flow chart (figure 2) and formulations for morphometric measurements are tabulated in Table 1. DEM of watershed was downloaded from USGS by digital elevation through SRTM with spatial resolution of 30 m (figure 3). For best land use, slope map and contour map of the study area is shown in figure 4 and 5 respectively.

Results and Discussion

Various thematic maps including slope map, contour map and drainage network has been carried out for the GKD watershed. Percent areal extent in different DEM classes at GKD watershed is shown in Table 2. Slope was divided into eight classes as per guidelines of IMSD (1995) and tabulated in table 3. Similarly, various contours are listed in table 4. Natural drainage system of watershed is shown in figure 6. Various parameters of drainage network *viz.* drainage area, stream order, no. of stream, stream length and maximum length were calculated in GIS software and from these parameters various drainage characteristics such as bifurcation ratio (Rb), drainage density (D_d), stream frequency (Fs) circulatory ratio (Rc), elongation ratios (Re) were estimated for sustainable development of natural resource management. The field survey of study area was also carried out to find out the suitability of proposed artificial groundwater recharge structures.

Stream order is the first step for morphometric characteristics of the watershed and thereby, the stream ordering was ranked based on hierarchic ranking method proposed by Strahler (1964). Streams of the watershed were counted along with their length from mouth to drainage divide and measured with the help of ArcGIS 10.3 based on the law by Horton, (1945). The order wise stream numbers and stream length of the area was designated as first to fourth order and first to second order for treated and control watershed respectively.There was a decrease in stream frequency as the stream order increases (figure 7 & 8). The main stream (outlet) of watershed was found in 4th order stream of 0.02 km. Total length of stream segment was maximum in the first order stream of 8.46 km for treated watershed while in case of control watershed, total length of stream segment was 2.92 km (Table 5). The length of drainage path in treated and control watershed was found 3.18 km and 2.14 km respectively. There was a decrease in stream length as the stream order increases (figure 9 & 10). Such type of result indicated flowing of streams from high altitude, lithological variations, and moderately steep slopes. The mean stream length (L_{sm}) and stream length ratio (R_L) was also calculated which provided a general idea about the permeability and its status in the region. The value of bifurcation ratio varied between 1.58 to 5 in treated watershed are characteristics of minimum structural disturbances while mean bifurcation ratio is observed as 2.99 and 1.5 in treated and control watershed respectively (Table 6). This indicated that the drainage pattern of the basin has not been affected by the structural disturbance (Nag, 1998).

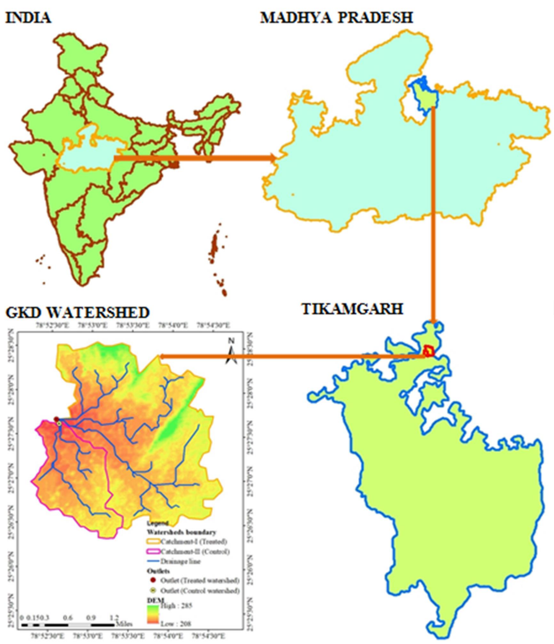

Figure 1: Location map of Garhkundar-Dabar (GKD) watershed

The area enclosed by watershed boundary line is called drainage area. Drainage area of treated and control watershed was measured with the help of ArcGIS and recorded 850 ha (8.50 km^2) and 268 ha (2.68 km^2) respectively. The ratio of total number of stream segments of all orders to the area of watershed is called stream frequency or channel frequency (Horton, 1932). The value of stream frequency (Fs) indicated positive correlation with the drainage density of the basin and suggesting that increase in stream population with respect to increase in drainage density. The estimated value of stream frequency for treated and control watershed was 4.35 and 3.73 exhibit positive correlation with the drainage density value of the area, indicating the increase in stream population with respect to increase in drainage density (Table 6). The value of drainage density of the area was recorded 2.09 and 2.10 km/km^2 for treated and control watershed respectively indicates low drainage density. This low drainage density shows the coarse drainage

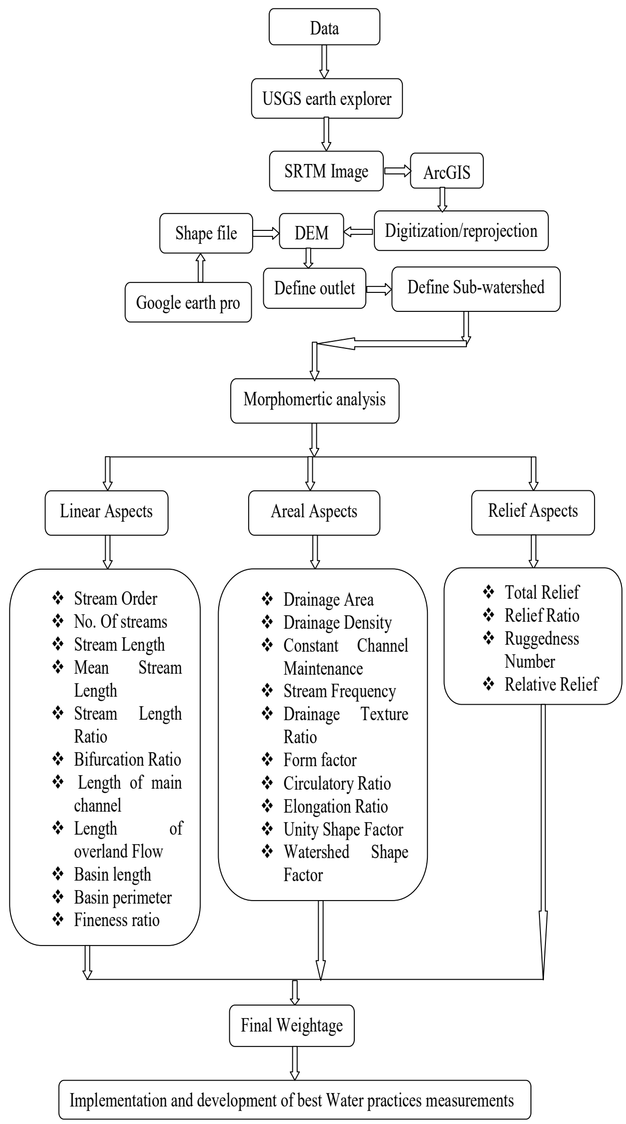

Figure 2: Way for morphometric measurements in GKD watershed.

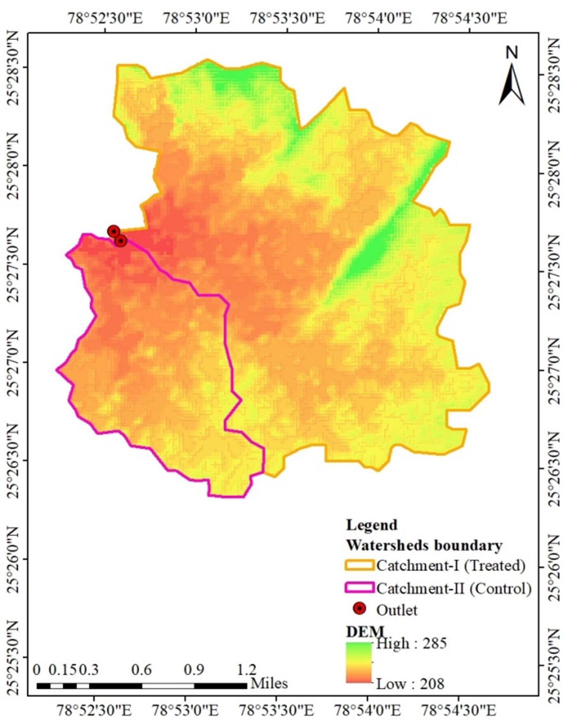

Figure 3: DEM of GKD Watershed

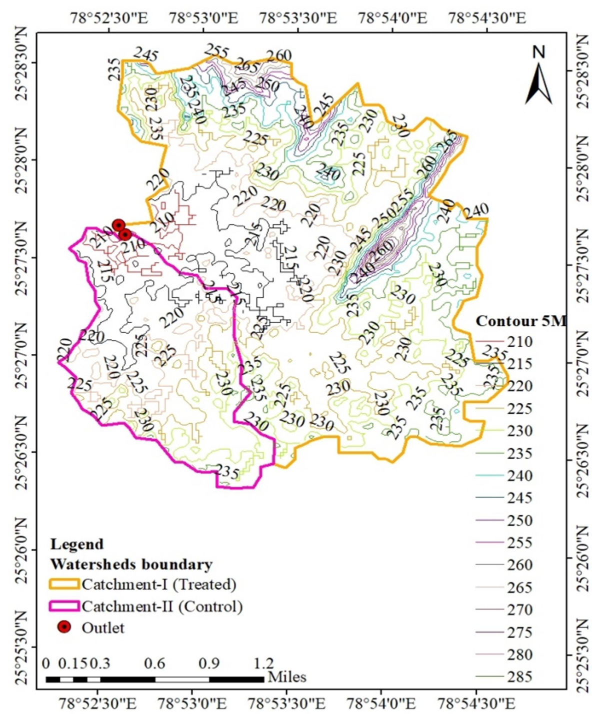

Figure 5: Contour map of GKD Watershed.

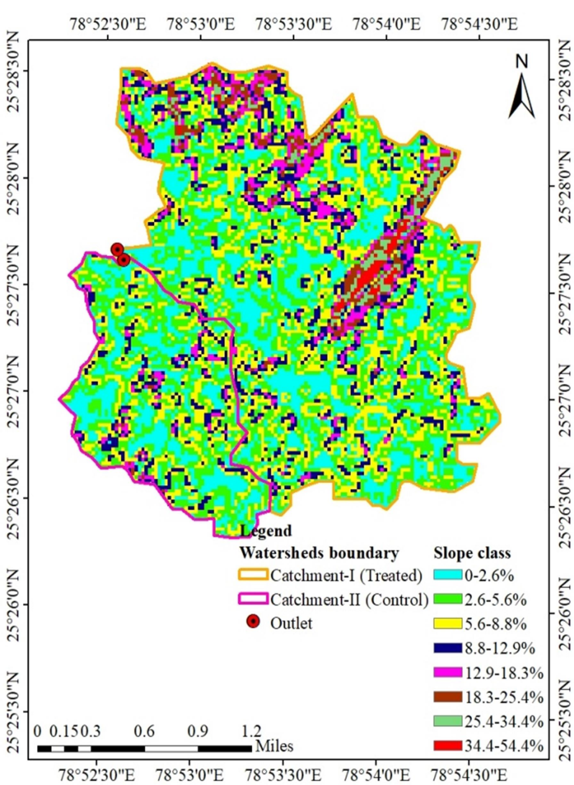

Figure 4: Slope map of GKD Watershed.

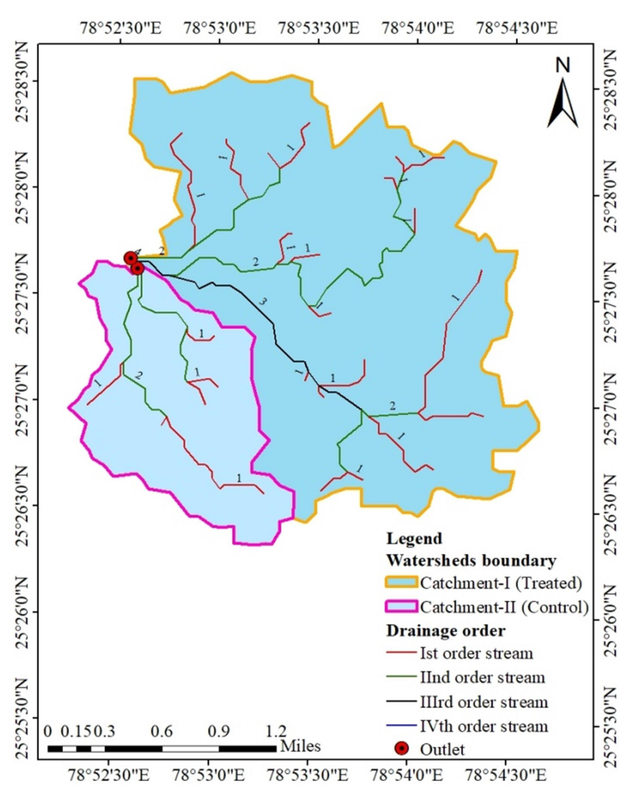

Figure 6: Drainage map of GKD Watershed.

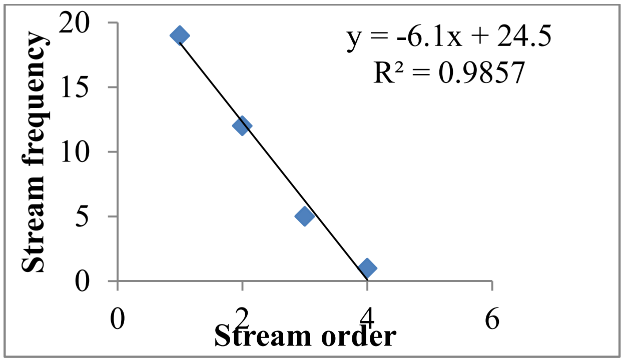

Figure 7: Relationship between stream number and stream order for treated watershed.

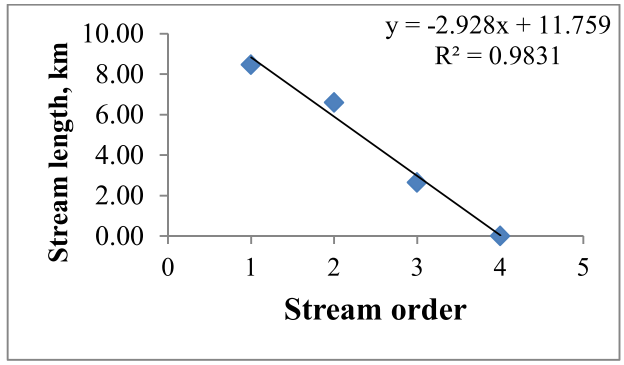

Figure 9: Relationship between stream length and stream order for treated watershed.

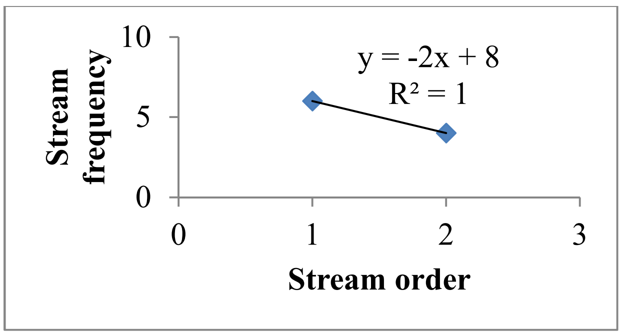

Figure 8: Relationship between stream number and stream order for control watershed

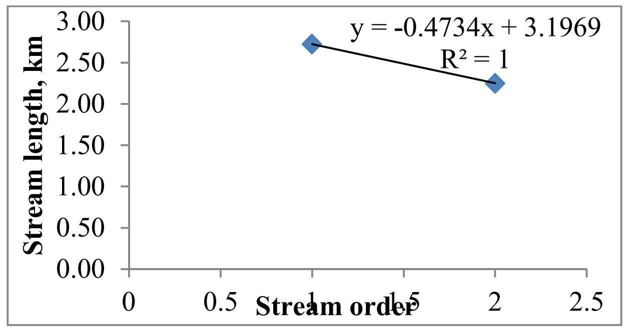

Figure 10: Relationship between stream length and stream order for control watershed.

pattern and semi-arid climate of the study area. The coarse texture gives more times for overland flow and hence leads to groundwater recharge. Smith (1950) has classified drainage density into five different classes. The drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. According to Horton (1932), form factor (R_f) may be defined as the ratio of basin area to square of the basin length. The value of form factor (R_f) was observed 0.49 and 0.25 for treated and control watershed respectively as per definition given by Horton (1932), suggested that the basin is elongated and would have lower peak flow foe longer duration. The value of elongation ratio (R_e) was found 0.79 and 0.57 for treated and control watershed respectively. The values of Re generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic conditions. Values close to 1.0 are typical of regions of very low relief, whereas values in the range 0.6–0.8 are usually associated with high relief and steep ground slope (Strahler 1964). These values can be grouped into three categories namely (a) circular ([0.9), (b) oval (0.9–0.8), (c) elongated (\0.7). The value of elongation ratio of the area was 0.79 indicated that the study area was elongated with high relief and steep ground slope.
The circulatory ratio (R_c) was recorded 0.39 and 0.53 for treated and control watershed respectively (Table 6). Circulatory ratio influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. Circularity ratios range 0.4–0.5 which indicates strongly elongated and highly permeable homogenous geology. The value of circulatory ratio was 0.39 indicated that the basin is elongated in shape, has low discharge of runoff and is highly permeability of the subsoil condition. Vertical distance from the highest elevation point of watershed to the point of mouth of that particular watershed is called basin relief or total relief.

Table 1: Analytical approaches for morphometric measurements.

Morphometric parameters		Methods	References
Linear aspect	Stream order (U)	Hierarchical order	Strahler, 1964
	Stream number (Nu)	Number of streams of each order	Strahler, 1964
	Stream length (Lu)	Length of the stream	Horton, 1945
	Mean stream length (Lsm)	Lsm = Lu/Nu where, Lu=Stream length of order 'U' Nu=Total number of stream segments of order 'U'	Horton, 1945
	Stream length ratio (R_L)	R_L =Lu/Lu-1; where Lu=Total stream length of order 'U', Lu-1=Stream length of next lower order.	Horton, 1945
	Bifurcation ratio (Rb)	Rb = Nu/ Nu+1; where, Nu=Total number of stream segment of order'u'; Nu+1=Number of segment of next higher order	Horton, 1932
	Length of overland flow (Lof)	Lof = 1/2Dd where, Dd=Drainage density	Horton, 1945
Areal aspect	Drainage density (D_d)	D_d = L/A where, L=Total length of streams;A=Area of watershed	Horton, 1945
	Constant channel maintenance (C)	Lof = 1/D_d where, D_d=Drainage density	Horton, 1945
	Stream frequency (Fs)	Fs = N/A where, N=Total number of streams; A=Area of watershed	Horton, 1945
	Drainage texture ratio (T)	T = N_1/P where,N_1=Total number of first order streams; P=Perimeter of watershed	Horton, 1945
	Form factor (R_f)	R_f=A/(L_b) 2 ;where, A=Area of watershed, L_b=Basin length	Horton, 1932
	Circulatory ratio (Rc)	Rc=4πA/P2 ;where, A=Area of watershed, π=3.14, P=Perimeter of watershed	Miller, 1953
	Elongation ratio (Re)	Re=2√(A/π)/L_b ;where, A=Area of watershed, π=3.14, L_b=Basin length	Schumn,1956
Relief aspect	Basin relief (B_h)	Vertical distance between the lowest and highest points ofwatershed.	Schumn, 1956
	Relief ratio (R_h)	R_h=B_h/L_b; where, B_h=Basin relief; L_b=Basin length	Schumn, 1956
	Ruggedness number (R_n)	R_n= B_h × D_d; where, B_h =Basin relief; D_d=Drainage density	Strahler, 1958
	Relative relief (R_r)	R_r = B_h/B_p; where,B_h=Basin relief; B_p=Basin perimeter	Melton (1957)

Table 2: Areal extent of various DEM classes in GKD watershed

Sr. No.	DEM classes (m)	Area (ha)	Area (%)	DEM classes (m)	Area (ha)	Area (%)
	Catchment-I (Treated)			**Catchment-II (Control)**		
1	208-217	129.96	15.29	208-211	17.73	6.61
2	218-224	175.69	20.67	212-214	31.41	11.72
3	225-230	196.46	23.11	215-217	36.9	13.76
4	231-236	192.80	22.68	218-220	50.94	19.00
5	237-242	73.27	8.62	221-224	37.44	13.96
6	243-250	39.96	4.70	225-228	44.64	16.65
7	251-259	19.98	2.35	229-231	25.65	9.57
8	260-269	14.85	1.75	232-233	13.05	4.87
9	270-285	7.03	0.83	234-239	10.35	3.86
Total		850.00	100.00		268.11	100.00

Table 3: Areal extent of various slope classes in GKD watershed

Sr. no.	Slope (%)	Area (ha)	Area (%)	Slope (%)	Area (ha)	Area (%)
	Catchment-I (Treated)			**Catchment-II (Control)**		
1	0-2.50	200.34	23.57	0-1.77	51.48	19.20
2	2.64-5.56	262.71	30.91	1.86-3.58	66.33	24.74
3	5.59-8.76	190.17	22.37	3.73-5.83	67.41	25.14
4	8.84-13.08	105.39	12.40	5.89-7.93	39.42	14.70
5	13.18-18.46	48.09	5.66	8.01-10.09	25.2	9.40
6	18.50-25.34	23.31	2.74	10.14-12.49	11.43	4.26
7	25.53-34.32	14.03	1.65	12.5-15.15	4.95	1.85
8	34.42-54.80	5.96	0.70	15.47-20.17	1.89	0.70
Total		850	100.00		268.11	100.00

Table 4: Linear extent of various contour classes in GKD watershed

Sr. No.	Contour (m)	Number of contours	Length of contour (km)	Contour (m)	Number of contours	Length of contour (km)
	Catchment-I (Treated)			**Catchment-II (Control)**		
1	210	5	3.45	210	6	3.98
2	215	9	12.00	215	10	6.71
3	220	19	11.94	220	19	11.11
4	225	18	25.60	225	11	5.56
5	230	26	27.86	230	12	5.23
6	235	37	22.95	235	11	1.69
7	240	19	10.87			
8	245	9	7.58			
9	250	5	5.55			
10	255	5	4.47			
11	260	5	3.97			
12	265	6	2.48			
13	270	3	1.48			
14	275	3	0.83			
15	280	1	0.46			
16	285	1	0.06			

Table 5: Characterization of drainage network

Parameters	Ist order	IInd order	IIIrd order	IVth order
Treated watershed				
No. of streams	19	12	5	1
Min. length (km)	0.08	0.08	0.08	0.02
Max. length (km)	1.43	1.49	1.65	0.02
Mean stream length (km)	0.45	0.55	0.53	0.02
Total length(km)	8.46	6.61	2.66	0.02
Control watershed				
No. of streams	6.00	4.00		
Min. length (km)	0.09	0.53		
Max. length (km)	1.25	0.89		
Mean stream length (km)	0.45	0.72		
Total length(km)	2.72	2.91		

Table 6: Morphometric characteristics of Garhkundar Dabar watershed

Linear aspect:

	Stream order	No of streams	Stream length (km)	Mean stream length (km)	Stream length ratio	Bifurcation ratio	Mean bifurcation ratio	Length of main channel (km)	Length of overland flow (km)	Basin length (km)	Basin perimeter (km)	Fineness ratio
Treated watershed	Ist	19	8.46	0.45	0.00	1.58	2.99	4.55	0.24	4.16	16.63	0.25
	IInd	12	6.61	0.55	0.78	2.40						
	IIIrd	5	2.66	0.53	0.40	5.00						
	IVth	1	0.02	0.02	0.01	0.00						
Control watershed	Ist	6	2.92	0.49	1.07	1.50	1.50	2.84	0.24	3.27	7.99	0.41
	IInd	4	2.71	0.68								

Areal Aspect:

	Drainage area (sq km)	Drainage density	Constant of channel maintenance	Stream frequency	Form factor	Circulatory ratio	Elongation ratio	Unity shape factor	Watershed shape factor	Drainage texture ratio
Treated watershed	8.5	2.09	0.48	4.35	0.49	0.39	0.79	1.43	1.38	2.23
Control watershed	2.68	2.10	0.48	3.73	0.25	0.53	0.57	2.00	1.54	1.25

Relief Aspect:

	Total relief (m)	Relief ratio	Ruggedness number	Relative relief
Treated watershed	77	0.02	0.16	0.005
Control watershed	31	0.01	0.07	0.004

In this study, total relief was recorded 77 and 31 m for treated and control watershed respectively. The relief ratio was found as 0.02 and 0.01 for treated and control watershed respectively showed the major portion of the basin having gentle slope (Table 6). The relief ratio normally increases with the decreasing drainage area and size of the sub-watersheds of a given drainage basin (Gottschalk, 1964). It measures the overall steepness of a drainage basin and is an indicator of the intensity of the erosion processes operation on the slope of the basin.

Conclusion

The morphometric analysis carried out for the GKD watershed confirms that stream length decreases as the stream order increases and such type of result indicates flowing of streams from high altitude, lithological variations, and moderately steep slopes. Mean bifurcation ratio indicated that the drainage pattern of the basin had not been affected by the structural disturbance. Low drainage density of the area showed the coarse drainage pattern and semi-arid climate of the study area. The value of form factor indicated that the basin was elongated and would have lower peak flow for longer duration. The value of elongation ratio of the area indicated that the study area was elongated with high relief and steep ground slope. The value of circulatory ratio indicated that the basin was elongated in shape, had low discharge of runoff and highly permeability of the subsoil condition. This analysis will be used as a guideline for site suitability and sustainable development of natural resource management. Study also shows that GIS techniques have efficient tools in delineation of the drainage pattern to understanding the status of land form and their processes, drainage management and evolution of groundwater potential for watershed planning and management. This work will be useful for sustainable development of natural resource management.

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Conflict of interest

The authors declare that they have no conflict of interest.

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