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Morphometric analysis and sub-watersheds prioritization of Nagmati River watershed, Kutch District, Gujarat using GIS based approach

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Abstract

Morphometric analysis of any watershed and its prioritization is one of the important aspects of planning for implementation of management programmes. Present study evaluates the quantitative morphometric characteristics of Nagmati River watershed in Kutch District of Gujarat by utilizing Cartosat-1 data (CartoDEM). In all 19 aerial and 6 linear morphometric parameters of the watershed have been evaluated. Drainage map of the study area reveals a dendritic drainage pattern with sixth order stream network comprising 492 numbers of streams and confining an area of 129.41 km^2. Mean bifurcation ratio (R_b) and stream length ratio (R_L) of the watershed evaluated are 3.44 and 0.54 respectively which corroborates the fact that drainage pattern is not influenced by the geological evolutions and disturbances in the recent past. The drainage density of 2.68 km·km^{-2} indicates impermeable subsoil material with sparse vegetation and moderate to low relief. Elongation ratio of 0.956 infers the basin to be closer to a circular shape. The geologic stage of development and erosion proneness of the watershed is quantified by hypsometric integral (*HI*) bearing value as 0.5, indicating the landscape to be uniform and in early mature stage. The study prioritizes eight sub-watersheds as high, medium and low for taking up soil and water conservation activities. Hence, remote sensing applications proved to be highly useful in extracting the precise data for the evaluation and analysis of watershed characteristics.

Key words: *hypsometric analysis, morphometric analysis, Nagmati watershed prioritization*

INTRODUCTION

Geomorphometry is the science of quantitative land surface analysis that consolidates various mathematical, statistical and image processing techniques for quantifying morphological, hydrological, ecological and other aspects of any geographical area. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms [CLARKE 1996]. This analysis can be achieved through measurement of linear, aerial and relief aspects of basins by using remote sensing and GIS. Morphometric characteristics such as stream order, drainage density, aerial extent, watershed length and width, channel length, channel slope and relief aspects of watershed are important in understanding the hydrological aspects of a region. The stream order, stream pattern, and drainage density have a profound influence on watershed as to influence runoff, infiltration, land management etc. They also influence the flow characteristics and thus erosional behaviour. The hypsometric integral (*HI*) is a geomorphological parameter classified under the geologic stages of watershed development. It assumes importance in estimation of erosion status of watershed and subsequent prioritization for taking up soil and water conservation activities. The hypsometric integral is also an indication of the "cycle of erosion" [STRAHLER 1952] which is defined as the total time required for reduction of a land topological unit to the base level i.e. the lowest level. The entire period or the cycle of erosion can be divided into three stages viz. monadnock (old) ($HI \leq 0.3$), in which the watershed is fully stabilized; equilibrium or mature stage ($0.3 \leq HI \leq 0.6$); and in-equilibrium or young stage ($HI \geq 0.6$), in which the watershed is highly susceptible to erosion [SARANGI *et al.* 2001; STRAHLER 1952]. The hypsometric integral helps in explaining the erosion that had taken place in the watershed during the geological time scale due to hydrologic processes and land degradation factors [BISHOP *et al.* 2002]. Besides this, it also provides a simple morphological index with respect to relative height of the elevation distribution within the area considered, which can be used in surface runoff and sediment yield prediction from watersheds [JAIN *et al.* 2001].

Many recent studies have focussed towards mapping of hydro-geomorophological characteristics using Geographic Information System (GIS) and Remote Sensing techniques [BOUHADEB *et al.* 2018; KUMAR *et al.* 2010]. Several studies in the recent past have carried out extensive research on prioritization of sub-watersheds useful for soil and water conservation based policies [ARUN *et al.* 2005; BISWAS *et al.* 1999; IQBAL, SAJJAD 2014; JAVEED *et al.* 2009; PAUL, INAYATHULLA 2012; RAHAMAN *et al.* 2015; THAKKAR, DHIMAN 2007]. In the present study, quantitative morphometric analysis as well as prioritisation of sub-watersheds has been carried out in Nagmati river watershed in the Kutch District of Gujarat by utilizing Cartosat-1 data (CartoDEM) having 2.5 meter spatial resolution downloaded from ISRO's (Indian Space Research Organisation) Geo-portal "Bhuvan", using remote sensing and GIS. Hypsometric analysis and watershed prioritization has also been carried out to investigate into the phase of evolution and geologic formation of the study area and to attribute priority to sub-watersheds for conservation and management of natural resources.

MATERIALS AND METHODS

STUDY AREA

Nagmati River watershed lies approximately 28 km on South-West from the Bhuj city of Kutch district in Gujarat covering an area of 129.41 km^2 and is confined between longitudes 69°31' E to 69°41' E and latitudes 23°4' N to 23°12' N (Fig. 1).

The maximum and minimum elevation of the watershed is 259 m and 58 m a.s.l. respectively. The average annual rainfall averages 358 mm and the average annual temperature is 26.3°C. Maximum temperature reaches beyond 50°C whereas minimum temperatures ranges between 12° and 16°C. Ninety-seven small rivers flow in the Kutch district and drains into the Arabian Sea. Twenty major dams, and numerous smaller dams constructed in Kutch district to capture the runoff data from precipitation.

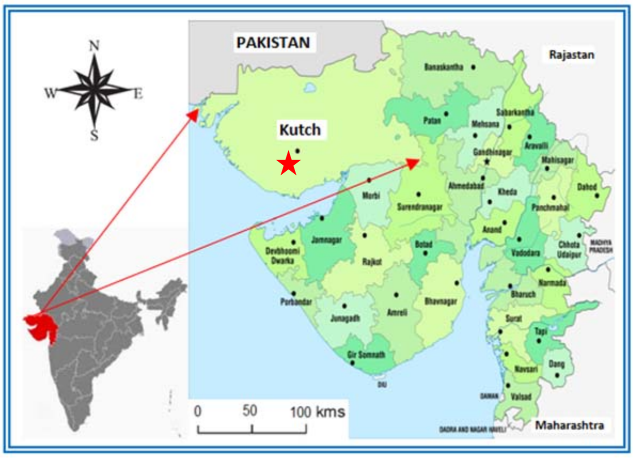

Fig. 1. Location map of the study area; source: own elaboration

DATA USED

Drainage map of the study area considered as the base map has been prepared in 1:50,000 scale using topographical map and CartoDEM having 2.5 m resolution. CartoDEM is an Indian National DEM generated from Cartosat-1 stereo data and meets the specifications of height and horizontal accuracies at 90% confidence as compared with ASTERDEM and SRTM. In terms of application potential, CartoDEM produces high quality drainage demarcation capability [MURALIKRISHNAN *et al.* 2012]. ArcGIS (version 10.2) software is used for integrating maps and other relevant data wherein attributes were allocated to generate the digital data base for drainage layer of the river basin.

METHODS

Remote Sensing (RS) data and Geographic Information System (GIS) applications are integrated for the morphometric analysis of watershed characteristics of the Nagmati River watershed. Watershed boundary was delineated and drainage network map was derived as a line coverage giving unique id for each order of stream from CartoDEM data (Fig. 2). Horton's law was followed to assign un-branched streams as first order streams, conjugation of two first order streams designated as second order and so on. The number of streams of each order were counted and recorded.

SUB-WATERSHED DELINEATION AND PRIORITIZATION

The Nagmati River watershed being a medium size watershed category extending an area of 129.41 km^2 was further sub-divided into eight sub-watersheds on the basis of ridge lines, water divide, contours, and topographical variables carried through the analysis of hydro- morphological features of terrain and digital elevation model (DEM). Also, sub-watershed boundaries were demarcated by taking into consideration the only lone villages (other than barren and agricultural land cover) existing within each sub-watershed classified for prioritization based on

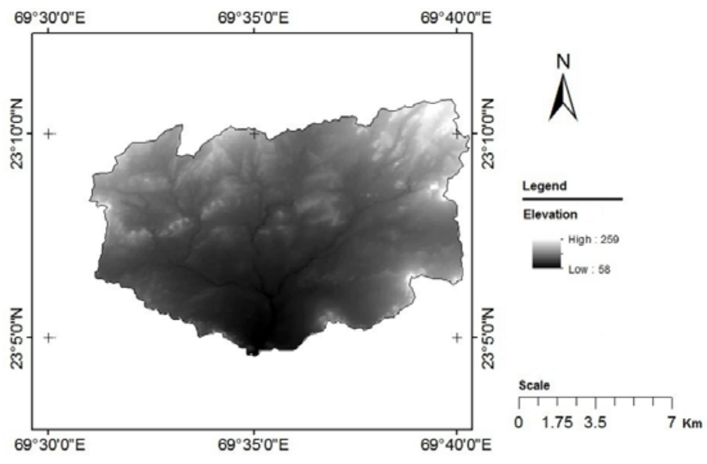

Fig. 2. CartoDEM of the study area; source: own study

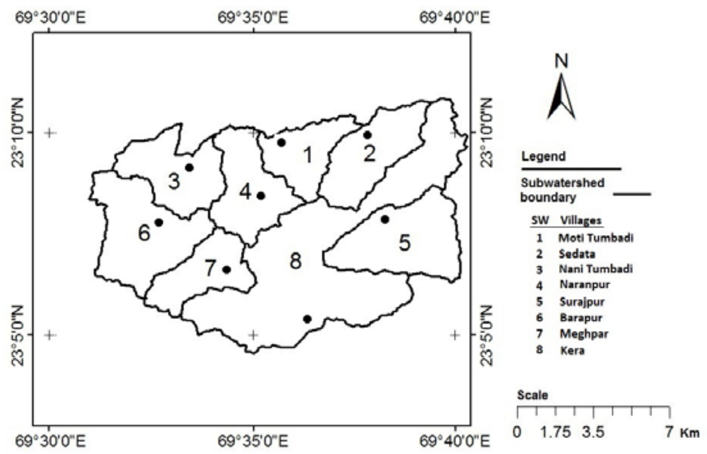

Fig. 3. Delineated sub-watersheds within Nagmati watershed; black dots representing only villages existing within each watershed boundary; source: own study

morphometric characteristics, also reckoned as erosion risk assessment parameters (Fig. 3). Since, effective management strategies yield productive results when initiated at grass root level thereby, conceptualising the eight sparse villages existing in the present scenario for delineating the sub-watershed boundaries apart from the topographic considerations. Each sub-watershed extends over a geographical area from 8.576 to 43.671 km^2. The sub-watersheds were allocated as SW1 to SW8.

Morphometric parameters such as bifurcation ratio (R_b), basin shape (*Bs*), compactness coefficient (*Cc*), drainage density (D_d), stream frequency (*Fs*), drainage texture (R_t), length of overland flow (L_o), form factor (R_f), circularity ratio (R_c), and elongation ratio (R_e), also termed as erosion risk assessment parameters and have been used for prioritizing sub-watersheds [BISWAS *et al.* 1999]. Linear parameters such as D_d, *Fs*, R_b, R_t, L_o have a direct relationship with erodibility in a way that higher the value, more is the erodibility. Hence for prioritization of sub-watersheds, the highest value of linear parameters is assigned as rank 1, second highest value as rank 2 and so on. Similarly, aerial parameters such as R_e, *Cc*, R_c, basin shape and R_f possesses an inverse relationship with erodibility [GLIZ *et al.* 2015; NOOKA RATNAM *et al.* 2005], i.e. lower the value, more is the erodibility. Thus the lowest value of aerial parameters is assigned as rank 1, next lower value as rank 2 and likewise. Prioritization of the sub-watersheds of Nagmati watershed was achieved by assigning the ranks based on the highest or lowest values for linear and aerial parameters as the case may be. After assigning the ranks to each linear and aerial parameters comprising within eight sub-watersheds, rank values were added and averaged out to arrive at a compound value (i.e. C_p). The sub-watersheds were then categorized into three classes as high (3.6–3.9), medium (4.0–4.3) and low (>4.3) priority on the basis of the range of C_p values. The sub-watershed which got the highest C_p value is assigned the least priority.

Morphometric analysis has been carried out to analyse the characteristics and geometry of the watershed as well as at sub-watersheds level. Linear and areal aspects of the drainage basin have been computed using standard methods and formulae [HORTON 1932; 1945; STRAHLER 1964] and have been briefly discussed in Table 1 and 2 along with the results to interpret the erosional and development processes operating in various parts of the watershed. Aerial morphometric parameters of eight sub-watersheds are provided in Table 3.

HYPSOMETRIC ANALYSIS

Hypsometric analysis is an important tool to assess and compare the geomorphic evolution of various landforms irrespective of the factor that may be responsible for it. The main components controlling the evolution of landscape are tectonics and/or climate and the variation in lithology. The hypsometric integral assists to specify the erosion that has taken place over geological time period. For different basins under the same climatic condition and approximately equal areas, the shape of the hypsometric curves provide relative insights into the past erosional environment of the basins [AWASTHI *et al.* 2002]. The hypsometric integral (*HI*) calculated from the area under the curve, represents the volume of the region that has remained unweathered. Hypsometric curves are generally interpreted as youthful (convexity upward curves), mature (S shaped curves) and peneplain or old age (concavity upward curves) stages of landscape evolution. Convex hypsometric curves are more likely typical of a plateau with little erosion, which can evolve into an S shape, while concave hypsometric curves indicate greater erosion [HURTREZ *et al.* 1999]. The hypsometric curve represents the relative proportions of a watershed area that lies below a given height. The shape of hypsometric curves represents different stages of land degradation. For Nagmati watershed, the elevation range of watershed was divided into equal intervals and for each interval the watershed area proportion was calculated to obtain the hypsometric integral.

Table 1. Aerial morphometric parameters of the Nagmati watershed

Sl. No.	Morphometric parameter	Formula/definition	Value	Reference
1	basin area (km^2)	total basin area (*A*)	129.41	HORTON [1945]
2	number of stream (*Nu*)	hierarchical order	492.00	STRAHLER [1964]
3	stream length (*Lu*)	total length of the stream (km)	347.64	HORTON [1945]
4	basin perimeter (km)	length of watershed divide which surround the basin (*P*)	58.71	HORTON [1945]
5	length of the basin (km)	distance between outlet and farthest point on basin boundary (*Lb*)	13.41	HORTON [1945]
6	drainage density (km·km^{-2})	$D_d = L/A$ where, L = total length of stream, A = area of basin	2.69	HORTON[(1945]
7	stream frequency (*Fs*)	$Fs = \Sigma Nu/A$, where, Nu = total number of stream segments of all order	3.80	HORTON [1945]
8	length of overland flow	Lo =1/2 D_d where, D_d = s drainage density	0.186	HORTON [1945]
9	basin shape	$Bs = (L_b)^2/A$ where, A = area of basin, L_b = basin length	1.384	HORTON [1945]
10	form factor	$R_f = A/(Lb)^2$ where, A = area of basin, L_b= basin length	0.722	HORTON [1932]
11	elongation ratio	$Re = (2/Lb) \times\sqrt{(A/\pi)}$ where, A = area of basin, π = 3.14, L_b = basin length	0.956	SCHUMM [1956]
12	circularity ratio	$Rc = 2\pi\ (A/P^2)$ where A = area of basin, π = 3.14, P = perimeter of basin	0.471	MILLER [1953]
13	fitness ratio	$Rfn = L_b/P$ where, L_b= basin length (km)	0.228	MELTON [1957]
14	texture ratio	$T = N_1/P$ where, N_1 = total number of first order stream, P = perimeter of basin	6.438	HORTON [1945]
15	compactness constant (*Cc*)	$Cc = 0.2821P/A0.5$, where, A = area of the basin, km^2, P = basin perimeter (km)	1.455	HORTON [1945]
16	drainage intensity (*Di*)	$Di = Fs/D_d$	1.415	FANIRAN [1968]
17	infiltration number (I_f)	$I_f = Fs \cdot D_d$	10.209	FANIRAN [1968]
18	drainage texture (D_t)	$D_t = Nu/P$	8.38	HORTON [1945]
19	constant of channel maintenance	$C = 1/D$, D = drainage density (km·km^{-2})	0.372	HORTON [1932]

Source: own study.

Table 2. Linear morphometric parameters of the Nagmati watershed

Sl. No.	Morphometric parameter	Formula/ definition	Stream order						Total	Reference
			1	2	3	4	5	6		
1	number of stream (*Nu*)	hierarchical order	378	85	21	5	2	1	492	STRAHLER [1964]
2	stream length (*Lu*)	total length of the stream (km)	188.0	85.52	44.97	23.35	3.06	2.74	347.6	HORTON [1945]
3	mean stream length (L_{sm})	$L_{sm} = Lu/Nu$; where, Lu = total stream length of a given order (km), Nu = number of stream segment	0.497	1.006	2.14	4.67	1.53	2.74	–	HORTON [1945]
4	stream length ratio (R_L)	$R_L = Lu/Lu$-1 where, Lu = total stream length of order (u), Lu-1 = the total stream length of its next lower order	–	0.454	0.525	0.519	0.131	0.89	–	HORTON [1945]
5	bifurcation ratio (R_b)	$R_b = Nu/Nu$+1 where, Nu = number of stream segments present in the given order Nu+1 = number of segments of the next higher order	4.447	4.047	4.2	2.5	2	–	–	HORTON [1945]
6	mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratios of all orders	3.438							SCHUMM [1956]

Source: own study.

Table 3. Aerial morphometric parameters of sub-watersheds

Sl. No.	Morphometric parameter	SW1	SW2	SW3	SW4	SW5	SW6	SW7	SW8
1	basin area (km^2)	8.576	11.782	11.467	11.844	15.652	16.642	9.269	43.671
2	number of stream (*Nu*)	36	40	39	40	65	65	47	159
3	stream length (*Lu*)	24.496	30.312	28.92	33.337	45.603	42.682	23.842	118.24
4	basin perimeter (km)	15.879	16.817	18.558	18.213	18.226	21.441	15.807	52.247
5	length of the basin (km)	3.390	3.868	4.016	5.331	5.817	5.525	3.796	13.409
6	drainage density (km·km^{-2})	2.856	2.573	2.522	2.815	2.913	2.564	2.572	2.707
7	stream frequency (*Fs*)	4.198	3.395	3.401	3.377	4.152	3.906	5.070	3.640
8	length of overland flow	0.175	0.194	0.198	0.178	0.171	0.195	0.194	0.184
9	basin shape	1.340	1.270	1.406	2.400	2.161	1.834	1.554	4.117
10	form factor	0.746	0.787	0.711	0.417	0.462	0.545	0.643	0.242
11	elongation ratio	0.974	0.784	0.951	0.728	0.767	0.833	0.904	0.555
12	circularity ratio	0.427	0.524	0.418	0.449	0.592	0.455	0.466	0.201
13	fitness ratio	0.213	0.230	0.216	0.292	0.319	0.258	0.240	0.255
14	texture ratio	1.763	1.784	1.616	1.867	2.743	2.285	2.087	2.373
15	compactness constant (*Cc*)	1.529	1.382	1.546	1.493	1.299	1.483	1.464	2.230
16	drainage intensity (*Di*)	1.470	1.319	1.349	1.200	1.425	1.523	1.971	1.344
17	infiltration number (I_f)	11.989	8.735	8.577	9.506	12.094	10.015	13.040	9.850
18	drainage texture (D_t)	2.267	2.378	2.102	2.196	3.566	3.032	2.973	3.043
19	constant of channel maintenance	0.350	0.388	0.396	0.355	0.343	0.390	0.388	0.369

Explanations: SW1–SW8 as in Fig. 3. Source: own study.

RESULTS AND DISCUSSION

MORPHOMETRIC ANALYSIS

Nagmati River watershed is a 6th order watershed that signifies higher contribution of surface runoff and sediment into the stream channels (Fig. 4). Further, when numbers of streams of a given order are plotted against the stream order on logarithm scale, the points lie on a straight line.

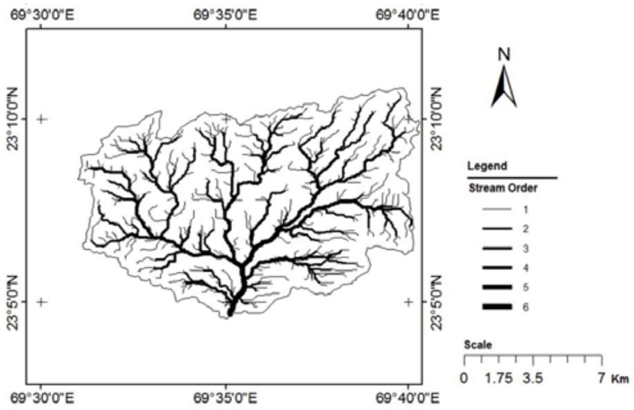

Fig. 4. Drainage network map of the study area; source: own study

Similar geometric relationship is found to exist between the stream order and stream numbers for the watershed under consideration which further indicates the area to be having uniform underlying lithology, and geologically, there has been no probable uplift (Fig. 5a, b). Above outcomes also exemplifies that the watershed hydrology depends mainly on the drainage characteristics. The drainage pattern of the stream network constitutes mainly of dendritic type which indicates the homogeneity in texture and lack of structural control. The pattern is characterized by a tree like or fernlike pattern with branches that intersect primarily at acute angles.

The mean R_b for the watershed under study is 3.438, the value usually common in areas where geologic structures causing fewer interference to the drainage pattern. Also, the drainage density of Nagmati watershed is obtained as 2.686 km·km^{-2} which suggest that the region is underlain by highly permeable material and represents low relief. Stream frequency obtained for the watershed under consideration has been obtained as 3.801 which is indicative of the fact that the watershed produces high runoff. The value of D_t evaluated for Nagmati watershed is 8.38, which according to the already discussed classification, falls under very fine drainage texture composed of soft or weak rocks unprotected by vegetation. Drainage texture values for sub-watersheds are also evaluated (refer Table 4) indicating moderate to coarse drainage texture. The value of R_f for the watershed is 0.722 which indicates the shape

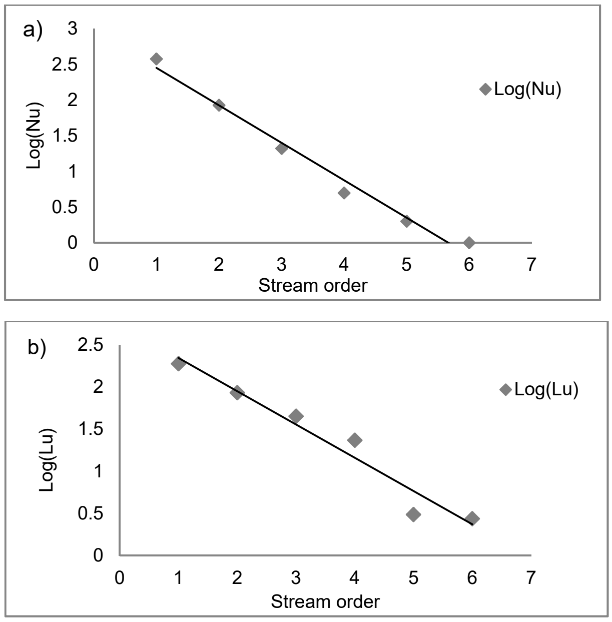

Fig. 5. Plot of stream order with: a) log of stream number, b) log of stream length; source: own study

Table 4. Priorities of sub-watersheds and their ranks

SWs	Area (km) Rank	Morphometric parameter										C_p value	Final priority
		linear parameters					aerial parameters						
		D_d	*Fs*	L_o	R_b	D_t	R_c	*Re*	R_f	*Bs*	*Cc*		
1	8.58	2.86	4.19	0.18	5.5	2.27	0.43	0.97	0.75	1.34	1.53	4.6	low
	rank	2	2	7	3	6	3	8	7	2	6		
2	11.78	2.57	3.39	0.19	3.26	2.38	0.52	0.78	0.79	1.27	1.38	4.9	low
	rank	5	7	3	7	5	7	4	8	1	2		
3	11.47	2.52	3.40	0.19	5.88	2.11	0.42	0.95	0.71	1.41	1.55	4.9	low
	rank	8	6	1	1	8	2	7	6	3	7		
4	11.84	2.82	3.38	0.18	5.5	2.19	0.45	0.73	0.42	2.4	1.49	4.6	low
	rank	3	8	6	2	7	4	2	2	7	5		
5	15.65	2.91	4.15	0.17	3.74	3.57	0.59	0.77	0.46	2.16	1.29	3.8	high
	rank	1	3	8	4	1	8	3	3	6	1		
6	16.64	2.56	3.91	0.19	3.69	3.03	0.46	0.83	0.55	1.83	1.48	4.3	medium
	rank	6	4	2	5	3	5	5	4	5	4		
7	9.27	2.57	5.07	0.19	3.21	2.97	0.47	0.90	0.64	1.55	1.46	4.8	low
	rank	7	1	4	8	4	6	6	5	4	3		
8	43.67	2.71	3.64	0.18	3.51	3.04	0.20	0.56	0.24	4.12	2.23	4.1	medium
	rank	4	5	5	6	2	1	1	1	8	8		

Explanations: SW1–SW8 as in Fig. 3, D_d = drainage density, *Fs* = stream frequency, L_o = overland flow, *Rb* = bifurcation ratio, *Dt* = drainage texture, R_c = circularity ratio, R_e = elongation ration, R_t = drainage texture, *Bs* = basin shape, *Cc* = compactness coefficient.
Source: own study.

to be almost circular. Channel maintenance constant of the watershed is 0.372, which means that on an average 0.028 m^2 surface is required in the watershed for creation of one linear foot of the stream channel length. The circularity ratio of 0.471 of the watershed corroborates the Miller's range, which suggest that the watershed is elongated in shape having low discharge of runoff and highly permeability of the subsoil condition. The above discussed morphometric parameters evaluated for Nagmati watershed are summarized in Tables 1 and 2.

The drainage network map with eight delineated sub-watersheds is illustrated in Figure 6. The highest value of drainage density (i.e. 2.913) is recorded in SW5, whereas lowest drainage density which is 2.522 is found in SW3. High drainage density along with agricultural lands is found in SW5, whereas, SW3 has sparse agriculture practice, low relief, low drainage density with permeable sub soil material. The rest of all the sub-watersheds lie in moderate drainage density category. Stream frequency values of the sub-watersheds vary from 3.401 (SW3) to 5.07 (SW7), indicating sub-watersheds having lower *Fs* values bearing low relief and permeable sub surface material whereas, sub-watersheds with higher *Fs* values show resistant or low conducting subsurface material, sparse vegetation and high relief.

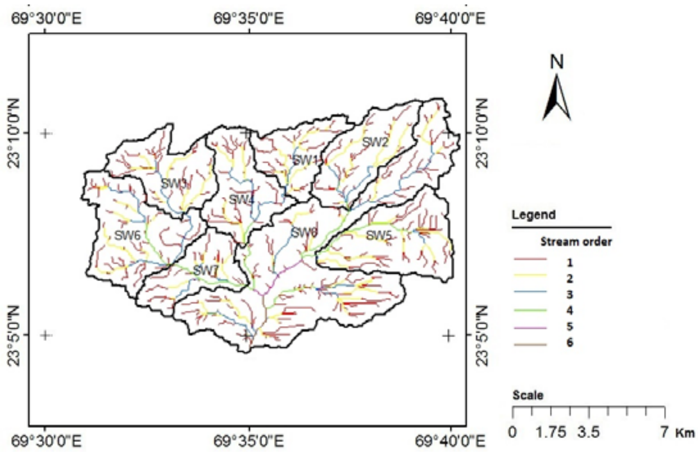

Fig. 6. Drainage network map of Nagmati sub-watersheds; source: own study

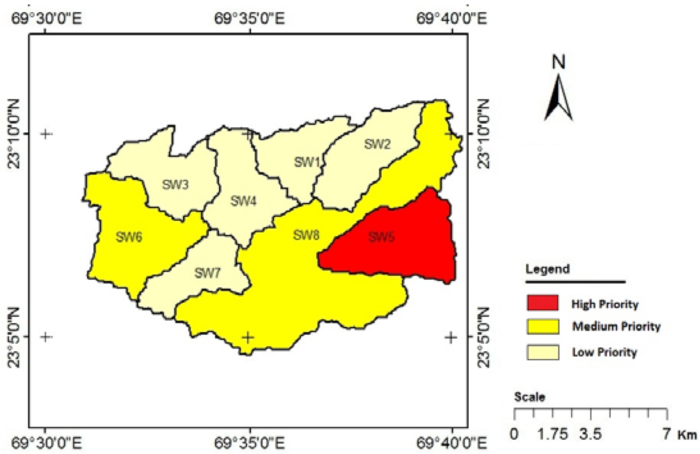

Fig. 7. Prioritization map of Nagmati sub-watersheds; source: own study

The R_f values for sub-watersheds have been found varying from 0.242 (SW8) to 0.787 (SW2), evidencing the sub-watersheds representing elongated to circular shaped. Nagmati watershed measures R_t value as 6.438 that categorizes it under moderate texture area. R_e for the watershed is evaluated as 0.956 which represents the watershed to be circular in shape. R_e values for sub-watersheds SW1, SW3 and SW7 exemplify the watersheds to be circular in shape whereas sub-watersheds SW2, SW4 and SW6 represents oval to less elongated in shape. Sub-watershed SW8 having lower value of R_e indicates the region to be elongated shaped.

Rc values for sub-watersheds lies within the Miller's range, certifying the sub-watersheds to be elongated in shape. The L_o value of the study area is 0.186 km indicating low relief and consequently low surface runoff. Aerial morphometric parameters evaluated for sub-watersheds are listed in Table 3.

PRIORITIZATION OF SUB-WATERSHEDS

The compound values (C_p) of all eight sub-watersheds of Nagmati watershed are calculated and final priorities allotted as shown in Table 4. The sub-watershed SW5 with a C_p value of 3.8 receives the highest priority followed by SW6 and SW8 with medium priority. SW4 is characterized with high water holding capacity because of poor zone of D_d, high zone of R_b, very low zone of *Fs*, low zone of R_t, high zone of L_o and high zone of the constant channel maintenance. All these factors together make these sub-watersheds of high water holding nature. Sub-watersheds with high and medium priorities (i.e. SW5, SW6 and SW8) falls under moderate to intense agricultural practices involving high irrigation demands mainly inundation type that tends to augment top soil erosion. Sub-watersheds SW1, SW2, SW3, SW4 and SW7 comprising majorly barren land, falls under the low priority zones characterized by high zone of D_d, poor zone of R_b, high zone of *Fs*, high zone of R_t, low zone of L_o and low zone of constant channel maintenance. Highest priority indicates the greater degree of erosion in the particular sub-watershed and it becomes potential area for enforcing soil conservation measures. Therefore, soil conservation measures can first be implemented to the sub-watershed SW5 and then to other sub-watersheds dependingupon their priority. The final prioritized map for Nagmati sub-watersheds is shown in Figure 7.

In order to quantify the water distribution and erosion patterns within any watershed, morphometric based studies coupled with remote sensing and Geographical Information System (GIS) forms to be the most appropriate techniques furnishing valuable information about physical terrain parameters of the region. Present study utilizes remote sensing and GIS techniques for generating drainage pattern, drainage order, watershed delineations and other inventories for the study area which are an essential prerequisites for sustainable planning of land and water resources and its management.

Table 5. Data for hypsometric analysis

Sl. No.	Elevation (m) min (1)	max (2)	mean (3)	(3) – (1) = (4)	(2) – (1) = (5)	*HI* = (4)/(5)	Area (km²)	Area accumulated (km²)	% area
1	58	74	66	8	16	0.5	2.97	130.14	100
2	75	91	83	8	16	0.5	17.04	127.17	98
3	92	108	100	8	16	0.5	27.48	110.14	85
4	109	125	117	8	16	0.5	32.16	82.66	64
5	126	141	133.5	7.5	15	0.5	21.58	50.503	39
6	142	158	150	8	16	0.5	13.61	28.92	22
7	159	175	167	8	16	0.5	8.35	15.31	12
8	176	192	184	8	16	0.5	3.55	6.96	5
9	193	208	200.5	7.5	15	0.5	2.83	3.40	3
10	209	225	217	8	17	0.5	0.52	0.579	0
11	226	242	234	8	16	0.5	0.038	0.051	0
12	244	259	251.5	7.5	15	0.5	0.013	0.013	0

Source: own study.

HYPSOMETRIC ANALYSIS

Table 5 illustrates the results of hypsometric analysis for the Nagmati watershed. The hypsometric integral (*HI*) for the present study area is evaluated as 0.5, which indicates the watershed to be in early mature stage. Plot between percent area and mean elevation values is also illustrated in Figure 8.

It is also observed that there was a combination of moderate convex-concave and slightly S shape of the hypsometric curves for the Nagmati watershed. This could be due to the soil erosion from the basin and down slope movement of topsoil and bedrock material, washout of the soil mass and cutting of stream banks. The hydrologic response of the watershed exhibits youthful stage, having high to moderate rate of erosion during peak runoff and need appropriate soil and water conservation measures as similar results has also been evaluated from prioritization analysis for SW5, SW6 and SW8 needing immediate management strategies.

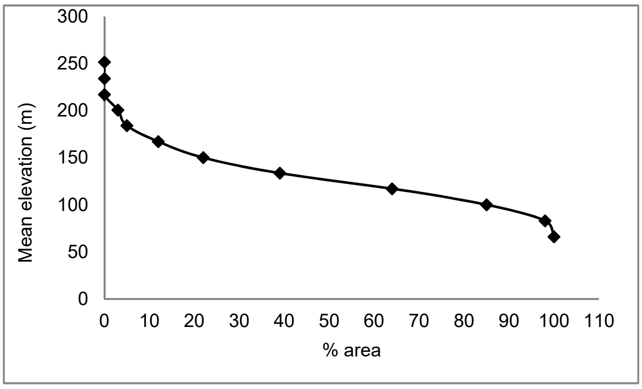

Fig. 8. Hypsometric curve of the study area; source: own study

CONCLUSIONS

Prioritization of the watershed is one of the important aspects of planning for implementation of its development and management programs. The present study demonstrates the usefulness of remote sensing and GIS for morphometric analysis, prioritization of the sub-watersheds and hypsometric analysis of Nagmati watershed in Kutch district, Gujarat (India). The morphometric characteristics of different sub-watersheds show their relative characteristics with respect to hydrologic response of the watershed. The drainage pattern of the stream network reveals a dendritic type with sixth order stream network which is indicative of homogeneity in texture and lack of structural control. The mean bifurcation ratio (R_b) and stream length ratio (R_L) of the watershed evaluated are 3.44 and 0.54 respectively confirming the fact that drainage pattern is not influenced by the geological evolutions and disturbances in the recent past. Prioritization of eight sub-watersheds reveals that sub-watershed SW5 falls in the high priority category hence may be taken for conservation measures by planners and decision makers in the watershed management. The hypsometric integral (HI) value of entire watershed is 0.5 which indicates that 50% of original rock masses still exist in the river basin and that the study area is passing through early mature stage under the cycle of erosion. The hypsometric curve revealed a combination of moderate convex-concave and slightly S shaped attributed to the soil erosion from the watershed and down slope movement of topsoil and bedrock material, washout of the soil mass and cutting of stream banks. The morphometric parameters evaluated using remote sensing and GIS techniques furnished better understanding of the watershed evolution and its response towards hydrologic conditions of the enabling efficient management strategies for natural resources even at sub- and micro-watershed level.

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Analiza morfometryczna i ustalanie priorytetów dla zlewni rzeki Nagmati, dystryktu Kutch w prowincji Gujarat na podstawie GIS

STRESZCZENIE

Analiza morfometryczna dowolnej zlewni i ustalanie dla niej priorytetów jest jednym z aspektów planowania podczas wdrażania programów zarządzania zlewnią. W prezentowanych badaniach dokonano oceny ilościowych cech morfometrycznych zlewni rzeki Nagmati w dystrykcie Kutch, prowincja Gujarat, wykorzystując dane Cartosat-1 (CartoDem). Oceniono łącznie 19 powierzchniowych i 6 liniowych parametrów morfometrycznych tej zlewni. Na podstawie mapy obszaru badań można mówić o dendrytowym charakterze drenażu z siecią strumieni szóstego rzędu obejmującą 492 strumienie i pokrywającą obszar 129,41 km^2. Średni stosunek bifurkacji (R_b) i stosunek długości strumieni (R_L) w zlewni wynoszą odpowiednio 3,44 i 0,54, co potwierdza fakt, że na układ zlewni nie mają wpływu zmiany geologiczne czy zaburzenia w nieodległej przeszłości. Zagęszczenie drenażu równe 2,68 km·km^{-2} wskazuje na nieprzepuszczalny materiał podglebia z rzadką roślinnością i urzeźbieniem terenu od umiarkowanego do niewielkiego. Współczynnik wydłużenia 0,956 pozwala wnioskować, że basen ma kształt zbliżony do koła. Geologiczny stan rozwoju i podatność zlewni na erozję wyrażone ilościowo całką hipsometryczną o wartości 0,5 wskazują, że krajobraz jest jednorodny i znajduje się we wczesnym stadium dojrzałości. W badaniach ustalono priorytety dla ośmiu pod-zlewni, nadając priorytet wysoki, średni i niski ze względu na ochronę gleb i wody. Zastosowanie teledetekcji okazało się przydatne w pozyskiwaniu dokładnych danych do oceny i analizy cech zlewni.

Słowa kluczowe: *analiza hipsometryczna, analiza morfometryczna, priorytety dla zlewni Nagmati*