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Watershed prioritization based on morphometric analysis in Kandi region of Punjab using geospatial technology

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ABSTRACT

In this study morphometric analysis of eight watersheds of the Kandi region of Punjab, India was done using remote sensing (RS) and geographical information system (GIS). On the basis of the morphometric analysis, prioritizations of the watersheds for the application of soil and water conservation (SWC) measures and preparation of watershed plan was carried out. The study included computation of linear parameters (stream order, stream length, bifurcation ratio etc.), areal parameters (drainage density, stream frequency, texture ratio, length of overland flow etc.), shape parameters (form factor, circulatory ratio, elongation ratio etc.) and relief parameters (relief, relief ratio, ruggedness number etc.). The other watershed parameters like relative perimeter (P_{rel}), Mean basin width (W_{mb}), Fitness ratio (R_f), Lemniscate ratio (K), Hypsometric integral (HI), RHO coefficient (ρ), Drainage intensity (D_i), Drainage texture (D_t), Infiltration number (I_n) and Melton ruggedness number (M_{Rn}) were estimated for the assessment of the soil erosion in the watersheds. The Simbal Mazara, Lalpur, Ballowal Saunkhari, Dohali and Fatepur watersheds are having fifth order stream network. The priority rank for each watershed was assigned using compound factor value. The results of this analysis illustrated that Lalpur watershed has lowest compound parameter value so it is subjected to more erosion hence first priority is given to this watershed for the application of appropriate SWC measures for its development and management. Then Sahungra, Rakran Dahan and Dobhali watersheds needs immediate attention for the application of the SWC measures because Sahungra watershed was given second and Rakran Dahan and Dobhali watersheds were given third priority for its development and management.

1. INTRODUCTION

Water resource assessment and development at watershed scale is an important step towards sustainable agriculture in Shivalik foot-hills, locally known as Kandi area. The Shivalik foot-hills are a part of the Himalayan mountain chain which continuously runs from Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana and finally end up at Bhabbar tracts of Garhwal and Kumaon in Uttarakhand. Erratic distribution of rainfall, small land holdings, lack of irrigation facilities, heavy biotic pressure on the natural resources, inadequate vegetative cover, heavy soil erosion, landslides, declining soil fertility and frequent crop failures resulting in scarcity of food, fodder and fuel are the characteristics of this region (Kushwaha *et al.,* 2016). A large portion of monsoon rainfall (35-40%) goes as runoff in the torrents originating from the Shivalik foot-hills (Bhardwaj and Rana, 2008). The average annual soil loss in the Shivalik foothills is 16 t ha^{-1} yr^{-1} and in some watersheds it is more than 80 t ha^{-1} yr^{-1} owing to steep slopes, lack of vegetation and high intensity rainfall storms (Singh *et al.,* 1992, Bhardwaj and Kaushal, 2009).

Morphometric analysis is an important technique to evaluate and understand the behaviour of hydrological system. It provides quantitative specification of basin geometry to understand initial slope or inconsistencies in rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler, 1964; Esper, 2008). Detailed morphometric analysis provide an insight on basin evolution and further its role on development of drainage morphometry on land-forms and their characteristics. It is a vital tool in any hydrological investigation like assessment of groundwater potential and management, pedology and environmental assessment and is a subject of interest to both geomorphologists and hydrologists. Physiographic characteristics of drainage basins like the size, shape, slope, drainage density, size and length of streams can be correlated with various important hydrologic phenomena (Chorley, 1969a; Chorley, 1969b; Gregory and Walling, 1973; Rastogi and Sharma, 1976). The morphometric parameters describe and compare the basin characteristics and its processes explaining the geologic and geomorphic history of the drainage basin (Strahler, 1964). Morphometric analysis is a crucial step in understanding the watershed dynamics. Drainage basin morphometry attempts to explain and predict the long-term aspects of basin dynamics resulting in morphological changes within the basin (Thomas *et al.*, 2011) and also delineate physical changes in drainage system with time in response to natural or anthropogenic disturbances (Thompson *et al.,* 2001).

Prioritization is very important to prepare a comprehensive basin management and conservation plan. Several studies have been carried out on prioritization of watersheds based on morphometric analysis such as Krishnamurthy, 1996; Khan, 2001; Srinivasa, 2004; Nookaratnam, 2005; Thakkar and Dhiman, 2007; Javed, 2009; Avinash, 2011; Kumar, 2011; Vincy, 2012; Gajbhiye *et al.*, 2013; Meshram and Sharma, 2015; Balasubramanian *et al.*, 2017; Gaikwad and Bhagat, 2018; Meshram and Sharma, 2018. Sidhu *et al.,* 1998 used RS and GIS techniques for prioritization of sub-watersheds in upper Machkund watershed in Andhra Pradesh, India. Shrimali *et al.,* 2001 introduced a contextual investigation of the Sukhana lake catchment in the Shiwalik hills for prioritizing the soil erosion areas. A study by Mesa (2006) reveals that geology, relief and climate are the primary causes of running water ecosystems at the basin scale. Rao (2009) has attempted to define how the numerical scheme is helpful in watershed development planning programmes. Gajbhiye *et al.* (2013) used RS and GIS techniques for morphometric analysis and prioritization of 14 sub-watersheds of Manot river catchment, India. Aher *et al.* (2014) proposed weighted sum analysis method for prioritization of sub-watersheds of Pimpalgaon Ujjaini watershed located in Maharashtra, India. The quantitative analysis of morphometric parameters was done using RS and GIS techniques. Meshram and Sharma (2015) utilized RS and GIS for morphometric analysis and prioritization of the sub-watersheds of Shakkar river Catchment, India. Balasubramanian *et al.* (2017) analyzed morphometric characteristics of lower Bhavani basin, Tamil Nadu, using RS and GIS techniques, and prioritized the sub-watershed based on compound parameter. Gaikwad and Bhagat (2018) assessed morphometric parameters and prioritized sub-watersheds of Kas river basin, India, using RS and GIS techniques. Malik *et al.* (2019) prioritized sub-watersheds in a hilly watershed using weighted sum approach and results shows that the 20.34% area under highly susceptible sub watersheds (SW-5 and SW-10) needs appropriate SWC measures for its development and management.

The study area receives high intensity of rainfall and also has undulating topography, inadequate vegetative cover and high erodibility of soils, so major portion of rainfall goes to runoff and cause severe erosion. So for the watershed development and management in Kandi region of Punjab the study was carried out using RS and GIS.

2. MATERIALS AND METHODS

Study Area

The study area is located longitudes 76°6'30"E to 76°33'30"E and latitudes 30°45'30" to 31°19'30"N in Kandi region of Punjab (Fig. 1). The average maximum temperature is 41°C and minimum temperature 5.2°C. The region receives average annual rainfall of 1100 mm. A major portion of rain goes as runoff. The soils of the study area are

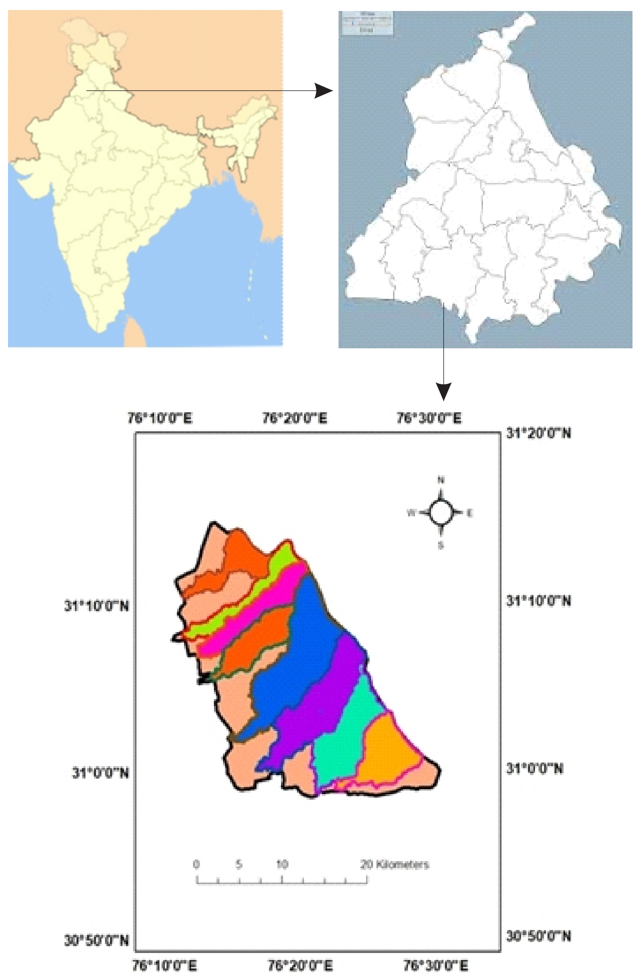

Fig. 1. Location map of study area

loamy sand, sandy loam, sand clay loam and sandy in texture, slightly alkaline in reaction and low in organic carbon content. The major physiographic units in the area are Siwalik hills, piedmont plain and seasonal rivulets locally known as Choes. Erosion and deposition due to fluvial action of the Choes are two geomorphological processes active in the study area. The forests are confined to hill slopes and piedmont plain. Agriculture is the main stay of the people. Wheat, gram, maize and turmeric are the main crops of the area. The area has semi-arid sub-tropical climate with hot summers and cold winters (Bazgeer *et al*., 2008).

Data Collection

The digital elevation model (DEM) of advanced space born thermal emission and reflection radiometer (ASTER) 30 × 30 m resolution (https://earthexplorer.usgs.gov/) was used to delineate the boundary and stream network of the watersheds using Arc-GIS 10.8 software.

Morphometric Analysis

Geomorphological analysis is the systematic description of watershed's geometry and its stream channel system to measure the linear parameters of drainage network, aerial parameters of watershed, shape parameters and relief parameters of channel network (Strahler, 1964). The morphological parameters directly or indirectly reflect the entire watershed based causative factors affecting runoff and sediment loss. The geomorphological parameters were estimated using different formulas as shown in Table 1.

Other Watershed Parameters

The other watershed parameters like relative perimeter (P_{rel}), Mean basin width (W_{mb}), Fitness ratio (R_f), Lemniscate ratio (K), Hypsometric integral (HI), RHO coefficient (ρ), Drainage intensity (D_i), Drainage texture (D_t), Infiltration number (I_n) and Melton ruggedness number (M_{Rn}) were

Table: 1
Formulas used for the computation of different morphometric parameters

Morphometric parameters	Formula	Reference
	Linear parameters	
Length (L)	$L= 1.312A^{0.568}$ where L=Basin length (km) A = Area of the basin (km^2)	Nooka *et al.* (2005)
Stream order (u)	Hierarchical rank	Strahler (1964)
Stream length (L_u)	Length of the stream	Horton (1945)
Mean stream length (L_{sm})	$L_{sm} = L_u / N_u$ where L_{sm} = Mean stream length L_u = Total stream length of order 'u' N_u = Total no. of stream segments of order 'u'	Strahler (1964)
Stream length ratio (R_L)	$R = L_u/L_{u-1}$ where R_L = Stream length ratio L_u = Total stream length of order 'u' L_{u-1} = The total stream length of its next lower order	Horton (1945)
Bifurcation ratio (R_b)	$R_b = N_u / N_{u+1}$ where R_b = Bifurcation ratio N_u = Total no. of stream segments of order 'u' N_{u+1} = Number of segments of the next higher order	Schumm (1956)
Mean bifurcation ratio (R_{bm})	R_{bm} = Average of bifurcation ratios of all orders	Strahler (1957)
	Aerial and shape parameters	
Form factor (F_f)	$F_f = A/L^2$ where F_f = Form factor A = Area of the basin (km^2) L = Basin length (km)	Horton (1932, 1945)
Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)} / L$ where R_e = Elongation ratio A = Area of the basin (km^2) L= Basin length (km)	Schumm (1956)
Circularity ratio (R_c)	$R = 4\pi A/P^2$ where R_c=Circularity ratio π = 3.14 A = Area of the basin (km^2), P = Perimeter (km)	Miller (1953), Strahler (1964)
Compactness co-efficient (C_c)	$C_c = 0.2821 * P/A^{0.5}$ where C_c = Compactness coefficient P = Perimeter (km)	Gravelius (1914)
Drainage density (D_d)	$D_d = L_u/A$ where D_d = Drainage density L_u = Total stream length of all orders A = Area of the basin (km^2)	Horton (1932, 1945)
Stream frequency (F_s)	$F_s = \Sigma N_u / A$ where F_s = Stream frequency ΣN_u = Total no. of streams of all orders A = Area of the Basin (km^2)	Horton (1932, 1945)
Texture ratio (T_r)	$T_r = N_1 / P$ N_1 = Total number of first order streams P = Perimeter of watershed	Horton (1945)
Constant of channel maintenance (c)	$C = 1 / D_d$ where C = Constant of channel maintenance D_d = Drainage density	Schumm (1956)
Length of overland flow (L_g)	$L_g = 1/2D_d$ where L_g = Length of overland flow D_d = Drainage density	Horton (1945)
	Relief parameters	
Basin relief (R)	R = H-h where R = Basin relief H = Maximum elevation in meter H = Minimum elevation in meter	Hadley and Schumm (1961)
Relief ratio (R_r)	$R_r = R/L$ where R_r = Relief ratio R = Basin relief L = Longest axis in kilometre	Schumm (1956)
Ruggedness number (R_n)	$R_n = H*D_d$ where R_n = Ruggedness number H = Basin relief D_d = Drainage density	Schumm (1956)

estimated for the assessment of the soil erosion in the watersheds.

P_{rel} is the area of watershed to the perimeter of watershed. W_{mb} is the area of watershed to watershed length. R_f is the ratio of length of the basin to its perimeter (Melton, 1957), which is used to measure the topographic fitness of the basin (Rai *et al.,* 2017 and 2018). K is defined as the ratio of square of basin length to the basin area (Chorley *et al.,* 1957). The higher the K value, the higher the soil erosion will be, requiring high priority for sub-basin prioritization. According to Chorley *et al.*, 1957, a basin is circular in shape for K is 0.9. Channel sinuosity (C_s) or sinuosity index (I_s) is the ratio of channel length to the longest flow path (Le Roux 1992). It deals with the pattern of channels of a drainage basin. Usually, C_s value varies from 1.0 to 4.0 or more. For computation of sinuosity parameter, the channel is divided into a number of segments as suggested by Mueller (1968). A channel with C_s or I_s < 1.5 is called sinus or straight whereas C_s or I_s > 1.5 called meandering (Leopold *et al.,* 1964). HI can be estimated using the elevation-relief ratio method as proposed by Pike and Wilson (1971). D_t is the ratio of the sum of stream segments to the perimeter of a catchment (Horton, 1945). It is dependent upon rainfall, infiltration capacity, underlying lithology, vegetative cover and the relief conditions of the catchment (Sreedevi *et al*., 2013). Smith (1950) classified the D_t into five categories, *viz.,* very coarse (< 2), coarse (2-4), moderately coarse (4-6), fine (6-8) and very fine (>8). I_n is the product of F_s and D_d (Faniran, 1968). It provides information about the infiltration characteristics in relation to the high relief conditions and impermeable subsoil materials of the catchment (Umrikar, 2017). The lower I_n value indicates very low runoff and very high infiltration capacity. Gupta *et al.* (2019) categorized RHO coefficient (ρ) into five groups, *viz.,* low (<0.2), medium (0.2-0.3), medium high (0.3-0.4), high (0.4-0.5), very high (>0.5). Higher the ρ value, higher will be the water storage capacity of the catchment. Gradient ratio (R_g) is a good measure of the slope of the channel, which allows to evaluate the runoff volume generated (Rai *et al*., 2017). MR_n is the ratio of B_r to the square root of the basin area (Melton, 1965). It can provide specific representation of relief ruggedness in a catchment, as it is a slope index (Melton, 1965; Rai *et al*., 2018). Channel gradient (C_g) is the total drop in elevation from the source to the mouth of the basin. The average channel slope gets decreased with increased stream order number.

Prioritization of Watersheds

Watershed prioritization is the ranking of different watersheds according to the order in which they have to be taken for treatment for soil conservation. Morphometric analysis is a significant tool for prioritization of watersheds. The morphometric parameters bifurcation ratio (R_b), basin shape factor (S), compactness coefficient (C_c), drainage density (D_d), stream frequency (F_s), drainage texture (T_r), form factor (R_f), circularity ratio (R_c) and elongation ratio (R_e) are also termed as erosion risk assessment parameters and have been used for prioritizing watersheds for treatment and conservation measures (Biswas, 1999). The linear and areal parameters such as drainage density, stream frequency, bifurcation ratio, texture ratio has a direct relationship with erodibility as higher the value, more is the erodibility (Biswas *et al.,* 1999; Nookartnam *et al.,* 2005; Thakkar and Dhiman, 2007; Gajbhiye *et al*., 2013). Hence, for prioritization of watersheds, the highest value of these linear and areal parameters was rated as rank 1, second highest value was rated as rank 2 and so on, and the least value was rated last in rank. Shape parameters such as elongation ratio, compactness coefficient, circularity ratio and form factor has an inverse relationship with erodibility (Nookartnam, 2005), lower the value, more is the erodibility. Thus the lowest value of these shape parameters was rated as rank 1, second lowest value was rated as rank 2 and so on and the highest value was rated last in rank. The ranking of the watersheds have been determined by assigning the highest priority/rank based on highest value in case of linear and areal parameters and lowest value in case of shape parameters. After completion of rating based on every single parameter, the rating values for every watershed were averaged to arrive at a compound value. Based on these compound rating values, the watershed having the least rating value was assigned highest priority number of 1, next higher value was assigned priority number 2 and so on. The watershed which received the highest compound value was assigned the last priority number (Nookartnam *et al.,* 2005; Thakkar and Dhiman, 2007; Gajbhiye *et al*., 2013). If two watersheds have same values of linear, areal and shape parameters, equal rank was assigned to such watersheds (Himanshu Kandpal *et al*., 2017).

3. RESULTS AND DISCUSSION

The morphometric analysis was conducted in Kandi region for eight watersheds namely Sahungra, Bakapur, Rakran Dahan, Simbal Mazara, Lalpur, Ballowal Saunkhari, Dohali and Fatepur of Kandi region in Punjab to assess the drainage properties and its characteristics for the application of SWC measures. These parameters are categorised into linear parameters (basin area, perimeter, stream order, stream length, mean stream length, bifurcation ratio etc.), areal parameters (drainage density, stream frequency, texture ratio, length of overland flow etc.), shape parameters (form factor, circulatory ratio, compactness coefficient, elongation ratio etc.) and relief parameters (relief, relief ratio, slope etc.) and results are presented in Table's 2, 3 and 4.

Linear Parameters

The linear aspects of the basin such as stream order (N),

Table: 2
Linear parameters of watersheds

Watershed	Area (km^2)	Perimeter (km)	Stream numbers of different orders					Total	Order wise total stream length (km)					Total
			1	2	3	4	5		1	2	3	4	5	
Sahungra	26.94	38.4	80	32	25	19		156	40.35	21.65	10.24	10.5		82.74
Bakapur	25.04	44.94	76	36	13	25		150	30.91	19.11	5.29	15.21		70.52
Rakran Dahan	34.17	43.61	95	38	30	26		189	44.72	22.42	17.38	14.44		98.96
Simbal Mazara	33.87	36.34	97	41	31	21	2	192	42.06	25.73	19.17	12.94	0.31	100.21
Lalpur	86.16	63.4	284	121	87	56	16	564	115.34	61.06	33.22	28.37	5.59	243.58
Ballowal Saunkhri	66.43	56.53	209	100	57	29	19	414	90.45	44.05	26.09	13.63	6.23	180.45
Dohali	53.26	45.78	162	68	52	33	5	320	70.13	40.21	19.82	14.61	2.87	147.64
Fatepur	40.99	37.062	129	70	24	22	11	256	54.79	31.62	13.85	8.35	4.02	112.63
Total	366.86	366.02	1132	506	319	231	53		488.75	265.85	145.06	118.05	19.02	

Table: 3
Linear parameters of watersheds

Watershed	Average stream length (km)					Total	Stream length ratio (R_L)				Total
	1	2	3	4	5		2/1	3/2	4/3	5/4	
Sahungra	0.50	0.67	0.40	0.55		2.12	1.34	0.60	1.38	0.00	3.31
Bakapur	0.40	0.53	0.40	0.60		1.93	1.33	0.75	1.50	0.00	3.58
Rakran Dahan	0.46	0.59	0.57	0.55		2.17	1.28	0.97	0.96	0.00	3.21
Simbal Mazara	0.43	0.62	0.61	0.61	0.15	2.42	1.44	0.98	1.00	0.25	3.67
Lalpur	0.40	0.50	0.69	0.50	0.34	2.43	1.25	1.38	0.72	0.68	4.03
Ballowal Saunkhri	0.43	0.44	0.45	0.47	0.32	2.11	1.02	1.02	1.04	0.68	3.77
Dohali	0.43	0.59	0.38	0.44	0.57	2.41	1.37	0.64	1.16	1.30	4.47
Fatepur	0.42	0.45	0.57	0.37	0.36	2.17	1.07	1.27	0.65	0.97	3.96
Total	3.47	4.39	4.07	4.09	1.74						

Watershed	Bifurcation Ratio (R_b)					Average
Sahungra	2.50	1.28	1.32			1.70
Bakapur	2.11	2.77	0.52			1.80
Rakran Dahan	2.50	1.27	1.15			1.64
Simbal Mazara	2.37	1.32	1.48	10.50		3.92
Lalpur	2.35	1.39	1.55	3.50		2.20
Ballowal Saunkhri	2.09	1.75	1.97	1.53		1.83
Dohali	2.38	1.31	1.58	6.60		2.97
Fatepur	1.84	2.92	1.09	2.00		1.96

stream length (L) and bifurcation ratio (R_b) were determined and results have been given in Table's 2 and 3. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964). Out of these eight watersheds, five watersheds are fifth order watersheds it includes Simbal Mazara, Lalpur, Ballowal Saunkhari, Dohali and Fatepur watersheds. The order wise total number of stream segment is known as the stream number. Horton's (1945) law of stream numbers states that number of stream segments of each order form an inverse geometric sequence with order number. Most drainage networks show linear relationship, with small deviation. The logarithmic plotting position of number of streams against stream order shows the number of streams usually decreases in geometric progression as the stream order increases (Fig. 2).

The stream length ratio (R_L) has an important relationship with the surface flow discharge and erosional stage of the watershed. In the present study, it was observed that the plot of logarithm of the cumulative stream length as ordinate and stream order as abscissa is not a straight line fit. This pattern indicates that the ratio between cumulative length and order is not constant throughout the successive orders of a watershed (Fig. 3).

The drainage map of all the watersheds along with stream order was prepared using DEM and Arc-GIS software as shown in the Fig. 4. The stream lengths for all watersheds of various orders were measured. The total length of stream segments is maximum in first order streams and decreases as the stream order increases. The total stream length in the Sahungra, Bakapur, Rakran Dahan, Simbal Mazara, Lalpur, Ballowal Saunkhari, Dohali and Fatepur watersheds are 82.74, 70.52, 98.96, 100.21, 243.58, 180.45, 147.64 and 112.63 km, respectively are presented in Table 2. The value of the R_L varies from 0.60 to 1.50 for the eight watersheds. It

Table: 4
Relief parameters of watersheds

Watershed	Elevation (m)		Relief	Relief ratio	Ruggedness number	Watershed	Slope (degree)	Area (km^2)
	Maximum	Minimum					1-2	16.180
Sahungra	455	265	190	0.017	0.584	Sahungra	2-5	14.54
Bakapur	519	258	261	0.017	0.735		5-10	4.28
Rakran Dahan	469	260	209	0.013	0.605		10-23	1.65
Simbal Mazara	359	262	97.00	0.008	0.287	Bakapur	0-2	14.66
Lalpur	471	252	219	0.011	0.619		2-8	12.8
Ballowal Saunkhri	493	204	289	0.016	0.785		8-16	4.07
Dohali	491	206	285	0.019	0.790		16-26	0.86
Fatepur	429	209	220	0.021	0.605	Rakran Dahan	1-2	21.42
							2-5	18.022
Watershed	Slope (degree)	Area (km^2)					5-10	4.74
Ballowal Saunkhri	1-2	46.11					10-28	2.2
	2-7	32.71						
	7-18	8.95						
	18-40	1.99				Simbal Mazara	0-1	9.83
Dohali	1-2	36.02					1-3	24.26
	2-10	28.97					3-5	12.06
	10-19	4.31					5-12	4.64
	19-42	1.94						
Fatepur	1-3	24.39				Lalpur	1-2	55.49
	3-8	20.43					2-6	50.77
	8-21	8.56					6-13	14.73
	21-42	1.87					13-29	4.05

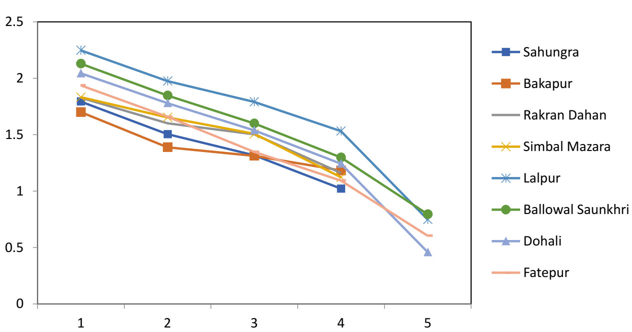

Fig. 2. Relation between Stream order and Log (No. of streams)

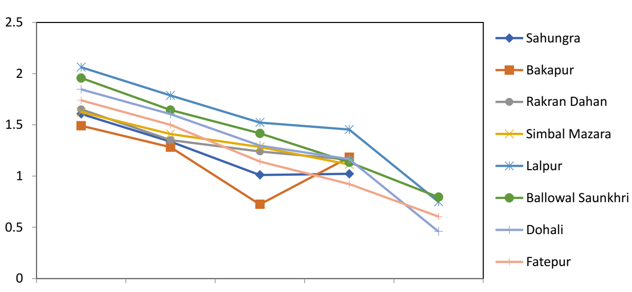

Fig. 3. Relation between Stream order and Log (Cumulative stream length)

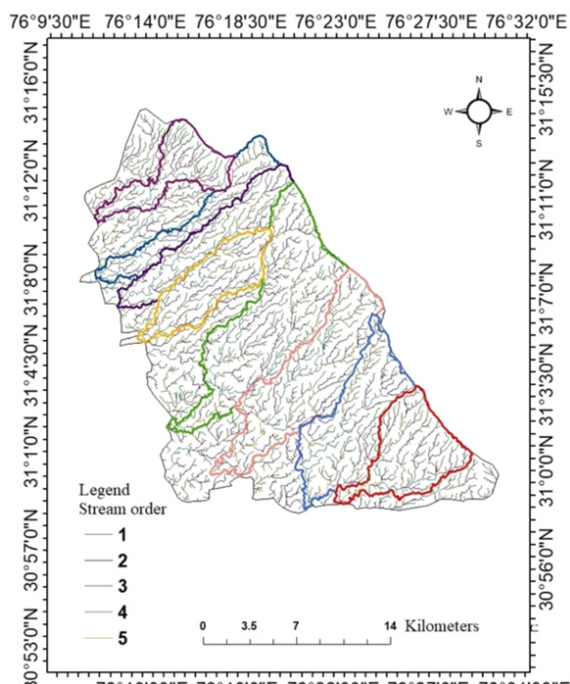

Fig. 4. Drainage map of watersheds

is noticed that the R_L between successive stream orders of the basin vary due to differences in slope and topographic conditions (Sreedevi, 2005). The mean bifurcation ratio value ranges from 1.64 to 3.92 (Table 3) of the study area indicating that all the basins are falling under normal basin category (Strahler, 1957). The higher value of R_b indicates a strong structural control in the drainage pattern whereas the lower value indicates that the watersheds are less affected by structural disturbances (Strahler, 1964; Vittala, 2004; Chopra, 2005).

Areal Parameters

The aerial aspects of the basin like drainage density (D_d), stream frequency (F_s), Texture ratio (T_r), length of overland flow (L_g) etc. were calculated and results are presented in Fig. 5. Drainage density is one of the often-used morphometric parameters in the analysis of various environmental variables. It is a measure of the degree of fluvial dissection and depends on a number of factors like topography, lithology, climate, pedology and vegetation (Nag, 2003; Mesa, 2006; Thomas *et al.*, 2011). The smaller value of drainage density indicates that the overland flow is predominant and larger value indicates that the channel flow is predominant. The drainage density in the study area shows variation from 2.71 to 3.07 km km^{-2} (Fig. 5). Sahungra, Simbal Mazara and Rakran Dahan watersheds has highest drainage density than the other watersheds. So these watersheds require proper drainage line treatment measures for controlling runoff. The higher drainage density indicates that the region is composed of weak or impermeable subsurface materials; sparse vegetation, mountainous relief (Reddy, 2004).

The stream frequency (F_s) mainly depends on the lithology of the basin and reflects the texture of the drainage network. The stream frequency (F_s) values of the study area vary from 5.53 to 6.54 as shown in Fig. 5. The lower value of stream frequency indicates low runoff and higher value indicates higher runoff in the watershed. It is also seen that the drainage density values of the watersheds exhibit positive correlation with the stream frequency, suggesting that there is an increase in stream population with respect to increasing drainage density. Generally, High value of stream frequency (F_s) is related to impermeable sub-surface material, sparse vegetation, high relief conditions and low infiltration capacity (Reddy, 2004).

Texture ratio (R_t) is the ratio of sum of first-order streams to the catchment perimeter (Horton, 1945; Schumm, 1956). It ranges from 1.69 to 4.47 as shown in Fig. 5. It is dependent upon lithological properties of the basin (soil type), soil infiltration rate and relief aspects (Vijith and Satheesh, 2006). The smaller R_t values indicate a plain basin with fewer variation in the slopes, whereas the higher values indicate low infiltration rate and higher runoff. Gupta *et al.* (2019) have categorized R_t as low (<3), moderately (3-4), moderately high (4-5), high (5-6) and very high (>6).

The length of overland flow (L_g) is the length of water over the ground before it gets concentrated into definite stream channels. It is approximately equals to half of the reciprocal of drainage density (Horton, 1945). This factor relates inversely to the average slope of the channel and is synonymous with the length of the sheet flow to the large degree. The length of overland flow (L_g) is one of the most important independent variables, affecting both the hydrological and physiographical development of the drainage basins (Horton, 1945). The computed value of L_g for all the watersheds varies from 0.16 to 0.18 km as shown in Fig. 5. The low L_g value of watershed indicates that short flow paths with steep ground slopes and reflecting the areas associated with more runoff and less infiltration.

Shape Parameters

Form factor (R_f) proposed by Horton (1945) is to predict the flow intensity of basin of a defined area. The index of R_f shows the inverse relationship with the square of the axial length and a direct relationship with peak discharge. The value of form factor would always be greater than 0.7854 for a perfectly circular basin (Rai *et al*., 2014). Smaller the value of form factor, more elongated will be the basin. Form factor (R_f) values of watersheds of the study area vary from 0.090 to 0.145, which indicate that they are elongated in shape. The elongated basin with low form factor indicates that the watershed have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin (Nautiyal, 1994).

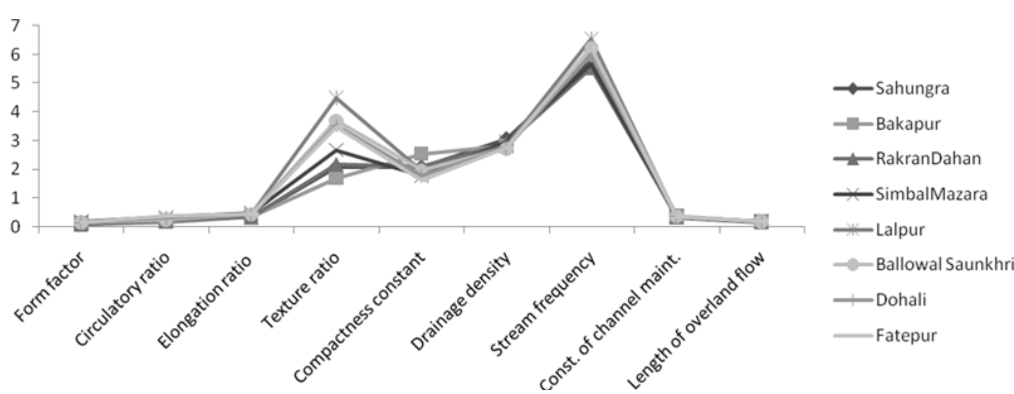

Fig. 5. Areal and shape parameters of watersheds

The circularity ratio (R_c) is affected by the lithological character of the basin. Its values ranges from 0.2 to 0.8 or ≤ 1. The higher value >0.5 indicates the shape of watershed is like circular and as a result, it gets scope for uniform infiltration and takes long time to reach excess water at basin outlet, which further depends on the prevalent geology, slope and land cover. The ratio is more influenced by length, frequency (F) and gradient of various orders rather than slope conditions and drainage pattern of the basin. The R_c of the watersheds varies from 0.156 to 0.375 (Fig. 5) which indicates that watersheds are having elongated shape.

The elongation ratio (R_e) is a very significant index in the analysis of watershed shape which helps to give an idea about the hydrological character of a drainage basin. Elongation ratio (R_e) for the study area varies from 0.33 to 0.45 as shown in Fig. 5. The value near 1 is typical of regions of very low relief, whereas values in the range of 0.4 to 0.8 are generally associated with strong relief and steep ground slopes (Strahler, 1968).

Schumm (1956) used the inverse of drainage density as a property known as the constant of channel maintenance (C). It is the area of basin surface needed to sustain a unit length of stream channel and depends on the rock type, permeability, climatic regime, vegetation cover as well as duration of erosion. In areas of close dissection, its value is very low. The values of constant of channel maintenance (C) varies from 0.33 to 0.36 are presented in Fig. 5. which indicates that watersheds are under the influence of high structural disturbance, low permeability, steeps to very steep slopes and high surface runoff.

Compactness coefficient (C_c) is defined as the ratio of perimeter of the watershed to the perimeter of the equivalent circular area of the watershed (Strahler 1964). In the study area C_c values varies from 1.63 to 2.53 as shown in Fig. 5. The value C_c greater than one indicates that the more compact watersheds.

Relief Parameters

Relief aspect of the watershed plays an important role in drainage development, surface and sub-surface water flow, permeability, landform development and associated features of the terrain. Relief is the maximum vertical distance between the lowest and the highest points of a basin. It is reveal from the Table 4 and Fig. 6 the relief of watershed varies from 97 to 289 m. The Simbal Mazara watershed has low relief and the Ballowal Saukhari watershed has high relief. The high relief value indicates the gravity of water flow, low infiltration and high runoff conditions of the study area.

Relief ratio has direct relationship between the relief and C_g. The relief ratio normally increases with decreasing drainage area and size of the watersheds of a given drainage basin. The relief ratio of the watersheds varies from 0.008 to 0.021 and values are presented in Table 4. The relief ratio of the watersheds is low which are characteristic features of less resistant rocks of the area (Sreedevi, 1999).

Ruggedness number is the product of relief and drainage density in order to define the slope steepness and length. It is a dimensionless term and indicates the structural complexity of the terrain. The ruggedness number of watersheds varies from 0.287 to 0.790 as given in Table 4. It is reveal from the Table 4 and Fig. 7 slope of the watersheds varies from 1 to 42 degree. Ballowal Saunkhri watershed shows the 32.71% area falls under the slope 2-7 degree whereas Dohali watershed has maximum area which represent slope 2-10 degree. All the watersheds have maximum area under the slope ranges from 1 to 3 degree.

Other Watershed Parameters

The P_{rel} was computed on the basis of basic parameters and it ranges from 0.557 to 1.163 km. Lowest value of P_{rel} was observed in Bakapur watershed and highest value observed in Dobhali watershed. W_{mb} varies from 1.534 to 4.57 which is lowest for Bakapur watershed and highest for Lalpur watershed as shown in Fig.8. R_f ranges from 0.363 to 0.447 which is lowest in Bakapur watershed whereas highest value observed in Rakran Dahan watershed. K was computed to be in the range of 1.522 to 2.686. The lowest K value observed in Simbal Mazara watershed and highest value observed in Sahungra Watershed. The higher the K

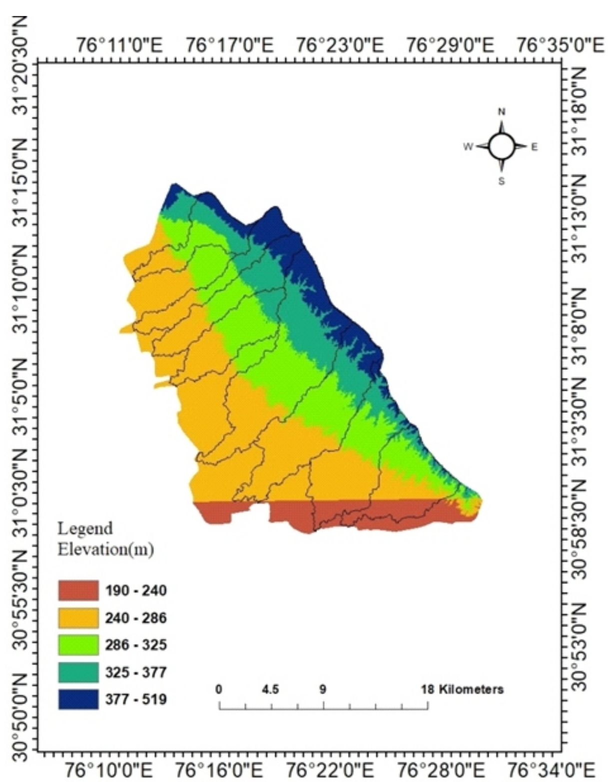

Fig. 6. Elevation map of watersheds

value, the higher the soil erosion. Channel sinuosity (C_s) value ranges from 5.52 to 8.82. The lowest value observed in Bakapur and highest value observed in Fatepur watershed. It shows the meandering path of channel. HI was computed to be in the range of 0.382 to 0.480. The lowest value observed in Dobhali watershed and highest value observed in Ballowal Saunkhri watershed which is presented in Fig. 8. RHO coefficient (ρ) was computed to be in the range of 0.62 to 1.32. The lowest value observed in Simbal Mazara watershed and highest value observed in Rakran Dahan watershed as shown in Fig. 8. The lower value indicates that the watershed has low storage capacity.

D_i varied in the range of 1.89 to 2.32 which is lowest in Sahungra and highest in Lalpur watershed. D_t was computed to be in the range of 3.34 to 8.90. Smith (1950) classified D_t into five classes such as i) very coarse (< 2), ii) coarse (2-4), iii) moderate (4-6), iv) fine (6-8) and v) very fine (>8). The Bakapur watershed shows very coarse D_t and remaining all the watersheds shows the coarse drainage texture. D_t was recorded to be lowest and highest for Bakapur and Lalpur watershed respectively. I_n varies from 16.02 to 18.51 which is lowest in Rakran Dahan watershed and highest in Lalpur watershed. The average slope ranges from 0.68% to 1.60%. M_{Rn} was computed to be in the range of 0.53 to 1.65. The highest value observed in Bakapur watershed and lowest value observed in Simbal Mazara watershed. The C_g value extends from 0.004 to 0.010 as shown in Fig. 8.

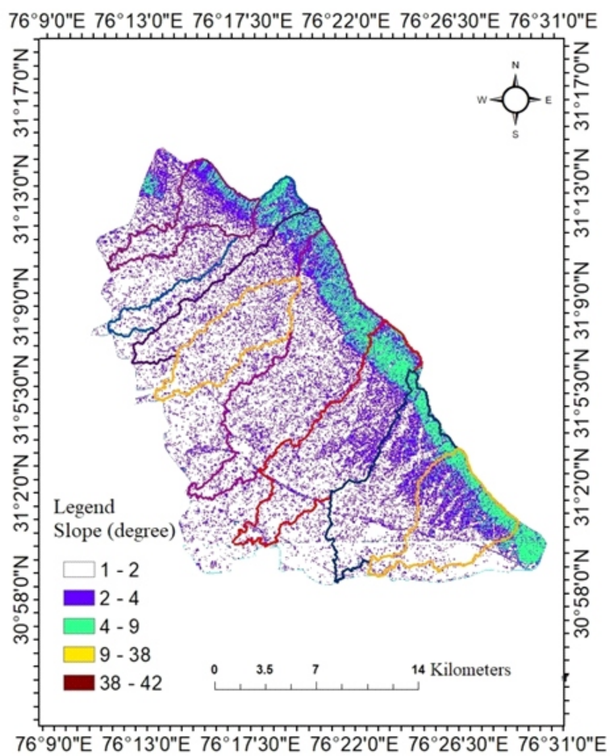

Fig. 7. Slope map of watersheds

Prioritization of Watersheds

All of the morphometric parameters were compounded and a final rating scale was generated for the study area as shown in Table 5. Watersheds were prioritized according to the ratings. On the basis of average value of compound parameters, the watershed which having the lowest rating value are assigned the highest priority number of 1, next higher value was assigned second priority number of 2 and so on. The watershed which got the highest compound parameters value was assigned last priority. It was found that the lowest compound parameter value is 3.25 occurred in the Lalpur watershed so given the highest priority for its development and management. This watershed requires proper drainage line treatment measures for controlling runoff. The next priority is given to Sahungra watershed. Rakran Dahan and Dohali watershed got same compound parameter value so given same priority for its development and management. The Simbal Mazara and Fatepur watershed receives highest compound parameter value so these watersheds have given last priority for development and management.

4. CONCLUSIONS

The morphometric analysis of eight watershed of Kandi region of Punjab was done for understanding hydrological behavior for efficient watershed planning. The morphometric parameters (linear, areal, shape and relief) of

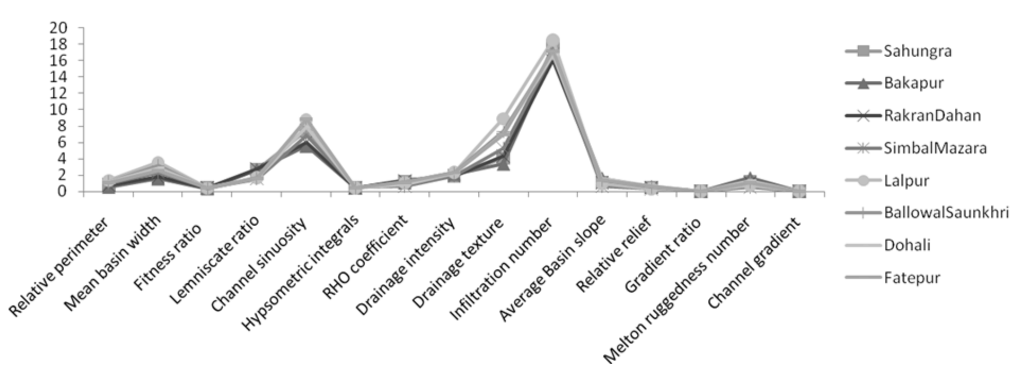

Fig. 8. Other watershed parameters

Table: 5
Prioritization of watersheds

Watershed	Bifurcation ratio	Drainage density	Stream frequency	Texture ratio	Circulatory ratio	Form factor	Elongation ratio	Compactness constant	Compound parameter	Final priority
Sahungra	7	1	6	7	3	2	2	6	4.25	2
Bakapur	6	5	5	8	1	3	3	8	4.87	5
Rakran Dahan	8	3	8	6	2	1	1	7	4.50	3
Simbal Mazara	1	2	7	5	7	8	8	2	5.00	6
Lalpur	3	4	1	1	5	4	4	4	3.25	1
Ballowal Saunkhri	5	8	3	2	4	5	5	5	4.62	4
Dohali	2	6	4	3	6	6	6	3	4.50	3
Fatepur	4	7	2	4	8	7	7	1	5.00	6

eight watersheds were estimated using RS and GIS. The mean bifurcation ratio value ranges from 1.64 to 3.92 of the study area indicating that all the basins are falling under normal basin category. The drainage density in the study area shows variation from 2.71 to 3.07 km km^{-2}. Sahungra, Simbal Mazara and Rakran Dahan watersheds has highest drainage density than the other watersheds. The values of constant of channel maintenance (C) varies from 0.33 to 0.36 which indicates that watersheds are under the influence of high structural disturbance, low permeability, steeps to very steep slopes and high surface runoff. The prioritization of watersheds demonstrated that Lalpur watershed has very high vulnerability to soil erosion followed by Sahungra, Rakran Dahan and Dohali watershed. So appropriate SWC measures are required in these watersheds to safeguards against land and water degradation.

REFERENCES

Aher, P.D., Adinarayana, J. and Gorantiwar S.D. 2014. Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: a RS and GIS approach. *J. Hydrol.,* 511: 850-860.

Avinash, K., Jayappa, K.S. and Deepika, B. 2011. Prioritization of subbasins based on geomorphology and morphometric analysis using remote sensing and geographic information system (GIS) techniques. *Int. J. Geocarto.,* 26(7): 569-592.

Balasubramanian, A., Duraisamy, K., Thirumalaisamy, S., Krishnaraj, S. and Yatheendradasan, R.K. 2017. Prioritization of subwatersheds based on quantitative morphometric analysis in lower Bhavani basin, Tamil Nadu, India using DEM and GIS techniques. *Arab. J. Geosci.,* 10.

Bazgeer, S., Sharma, P.K., Mahey, R.K., Hundal, S.S. and Sood, A. 2008. Assessment of land use changes using remote sensing and GIS and their implications on climatic variability for Balachaur watershed in Punjab, India. *Desert,* 12: 139-147.

Bhardwaj, A. and Kaushal, M.P. 2009. Two dimensional physically based finite element runoff model for small agricultural watersheds: I. Model development, *Hydrol. Process*, 23: 397-407.

Bhardwaj, A. and Rana, D.S. 2008. Torrent control measures in Kandi area of Punjab - A case study. *J. Water Manage.,* 16: 55-63.

Biswas, S., Sudhakar, S. and Desai, V.R. 1999. Prioritization of sub watersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach. *J. Indian Soc. Remote Sens.,* 27(3): 155-166.

Chopra, R., Dhiman, R.D. and Sharma, P.K. 2005. Morphometric analysis of sub-watersheds in Gurudaspur district, Punjab using remote sensing and GIS techniques. *J. Indian Soc. Remote Sens.,* 33(4): 531-539.

Chorley, R.J. 1969a. Introduction to physical hydrology. Methuen and Co. Ltd., Suffolk, 211p.

Chorley, R.J. 1969b. Introduction to fluvial processes. London: Methuen, pp 30-52.

Chorley, R.J., Malm, D.E. and Pogorzelski, H.A. 1957. A new standard for estimating drainage basin shape. *Am J. Sci.,* 255:138-141.

Esper, M.Y. 2008. Morphometric analysis of Colanguil river basin and flash flood hazard, San Juan, Argentina. *J. Env. Geo.,* 55(1):107-111.

Faniran, A. 1968. The index of drainage intensity-a provisional new drainage factor. *Aust. J. Sci.,* 31: 328-330.

Gaikwad, R. and Bhagat, V. 2018. Multi-criteria watershed prioritization of Kas basin in Maharashtra (India): AHP and influence approaches. *Hydrospa. Anal.,* 1(1): 41-61.

Gajbhiye, S., Mishra, S.K. and Pandey, A. 2013. Prioritizing erosion-prone area through morphometric analysis: an RS and GIS perspective. *Appl. Water Sci.,* 4(1): 51-61.

Gravelius, H. 1914. Flusskunde, Goschen'sche Verlagshandlung, Berlin, 176p.

Gregory, K.J. and Walling, D.E. 1973. Drainage basin form and process: a geomorphological approach. New York: Wiley, 456p.

Hadley, R.F. and Schumn, S.A.1961. Sediment sources and drainage basin characteristics in the upper Cheyenne River Basin. US Geological Survey, Water supply paper, 1531(B): 137-197.

Horton, R.E. 1932. Drainage basin characteristics*. Trans. Ame. Geophy. Union,* 13(1): 350-361.

Horton, R.E. 1945. Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. *Bull. Am. Geol. Soc.,* 56(2): 275-370.

Javed, A., Khanday, Y.M. and Ahmed, R. 2009. Prioritization of subwatersheds based on integrated approach using remote sensing, GIS and socio-economic data. *Indian Soc. Remote Sen.,* 37(2): 261-274.

Kandpal, H., Kumar, A., Reddy, C.P. and Malik, A. 2017. Watershed prioritization based on morphometric parameters using remote sensing and geographical information system. *Indian J. Ecol.,* 44(3): 433-43.

Khan, M.A., Gupta, V.P. and Moharana, P.C. 2001. Watershed prioritization using remote sensing and geographical information system: a case study from Guhiya, India. *J. Arid Env*., 49(3): 465-475.

Krishnamurthy, J., Venkataesa Kumar, N., Jayraman, V. and Manivel, M. 1996. An approach to demarcate groundwater potential zones through Remote Sensing and GIS. *Int. J. Remote Sen.,* 17(10): 1867-1884.

Kumar, A., Sharma, H.C. and Kumar, S. 2011. Planning for replenishing the depleted groundwater in upper Gangetic plains using RS and GIS. *Indian J. Soil Cons.,* 39(3): 195-201.

Kushwaha, N.L., Bhardwaj, A. and Verma, V.K. 2016. Hydrologic response of Takarla-Ballowal watershed in shivalik foot-hills based on morphometric analysis using remote sensing and GIS. *J. Indian Water Resour. Soc.,* 36(1): 17-25.

Le Roux, J.P. 1992. Determining the channel sinuosity of ancient fluvial systems from paleocurrent data. *J. Sediment Res*., 62: 283-229.

Leopold, L.B., Wolman, M.G. and Miller, J.P. 1964. Fluvial processes in geomorphology, 1st edition. Dover Publications, W.H. Freeman, San Francisco.

Malik, A., Kumar, A. and Kandpal, H. 2019. Morphometric analysis and prioritization of sub-watersheds in a hilly watershed using weighted sum approach. *Arab. J. Geosci.,* 12:118.

Melton, M.A. 1957. An analysis of the relations among elements of climate, surface properties and geomorphology (Project NR 389042, Tech. Rep. 11). Columbia University, New York.

Melton, M.A. 1965. The geomorphic and paleo-climatic significance of alluvial deposits in Southern Arizona. *J. Geol.,* 73: 1-3.

Mesa, L.M. 2006. Morphometric analysis of a subtropical Andean basin (*Tucuman, Argentina*). *J. Env. Geo.,* 50(8): 1235-1242.

Meshram, S.G. and Sharma, S.K. 2015. Prioritization of watershed through morphometric parameters: a PCA-based approach. *Appl. Water Sci.,* 7: 1505-1519.

Meshram, S.G. and Sharma, S.K. 2018. Hydrologic modeling. In: V.P. Singh *et al.* (eds.), Hydrologic modeling, water science and technology library 81, Springer Nature Singapore Pvt. Ltd, doi.org/10.1007/978-981-10-5801-1_31.

Miller, V.C. 1953. A quantitative geomorphic study of drainage basin characteristics in the clinch mountain area, NR Technical Report 3: Va. and Tenn. Office Naval Research Project.

Morisawa, M. 1985. Morphometric and land use analysis using remote sensing and GIS techniques. Rivers: form and process. Longman, New York, 222p.

Mueller, J.E. 1968. An introduction to the hydraulic and topographic sinuosity indexes. *Ann. Am. Assoc. Geogr.,* 58: 371-385.

Nag, S.K. and Chakraborty, S. 2003. Influence of rock types and structures in the development of drainage network in hard rock area*. J. Indian Soc. Remote Sen.,* 31(1): 25-35.

Nautiyal, M.D. 1994. Morphometric analysis of drainage basin using aerial photographs: A case study of Kharikuli basin, district Dehradun, U.P. *J. Indian Soc. Remote Sen.,* 22(4): 251-261.

Nookaratnam, R.K., Srivastava, Y.K., Rao, V.V., Amminedu, E. and Murthy, K.S.R. 2005. Check dam positioning by prioritization of micro watersheds using SYI model and morphometric analysis - remote sensing and GIS perspective. *J. Indian Soc. Remote Sen.,* 33(1): 25-38.

Pike, R.J. and Wilson, S.E. 1971. Elevation-relief ratio, hypsometric integral, and geomorphic area-altitude analysis. *Geol. Soc. Am. Bull.,* 82: 1079-1084.

Rai, P.K., Chandel, R.S., Mishra, V.N. and Singh, P. 2018. Hydrological inferences through morphometric analysis of lower Kosi river basin of India for water resource management based on remote sensing data. *Appl. Water Sci.,* 8(15): 2-16.

Rai, P.K., Chaubey, P.K., Mohan, K. and Singh P. 2017. Geoinformatics for assessing the inferences of quantitative drainage morphometry of the Narmada basin in India. *Appl. Geom.* 9(3): 1-23.

Rai, P.K., Mishra, V.N. and Mohan, K. 2017. A study of morphometric evaluation of the Son basin, India using geospatial approach. *Rem. Sens. App. Soc. Environ*., 7: 9-20.

Rai, P.K., Mohan, K., Mishra, S., Ahmad, A. and Mishra, V.N. 2014. A GIS based approach in drainage morphometric analysis of Kanhar river basin, India. *Appl. Water Sci.,* 7(1): 217-232.

Rai, P.K., Mohan, K., Mishra, S., Ahmad, A. and Mishra, V.N. 2017. A GIS-based approach in drainage morphometric analysis of Kanhar river basin, India. *Appl. Water Sci.,* 7: 217-232.

Rastogi, R.A. and Sharma, T.C. 1976. Quantitative analysis of drainage basin characteristics. *J. Soil Water Cons. India,* 26(1-4): 18-25.

Reddy, G.P., Maji, A.K. and Gajbhiye, K.S. 2004. Drainage morphometry and its influence on landform characteristics in a basaltic terrain, Central India: A remote sensing and GIS approach*. Int. J. Appli. Earth Observ. Geoinfor.,* 6(6):1-16.

Schumn, S.A. 1956. Evolution of drainage systems and slopes in badland, at Perth Amboy, New Jersey. 67(5): 597-646.

Shrimali, S.S., Aggarwal, S.P. and Samra, J.S. 2001. Prioritizing erosion-prone areas in hills using remote sensing and GIS - A case study of the Sukhna lake catchment Northern India. *Int. J. Appl. Earth Obs. Geoinf.* 3(1): 54-60.

Sidhu, G.S., Das, T.H., Singh, R.S., Sharma, R.K. and Ravishankar, T. 1998. Remote sensing and GIS techniques for prioritization of watershed-a case study in the upper Machkund watershed, Andhra Pradesh. *Indian J. Soil Cons.,* 26(2): 71-75.

Singh, G., Babu, R., Narian, P., Bhushan, L.S. and Abrol, I.P. 1992. Soil erosion rates in India. *J. Soil Water Cons.,* 47: 97-99.

Smith, K.G. 1950. Standards for grading textures of erosional topography. *Am. J. Sci.,* 248(9): 655-668.

Sreedevi, P.D. 1999. *Assessment and management of groundwater resources of Pageru river basin, Cuddapah district, Andhra Pradesh, India*. Unpublished Ph.D. Thesis, Sri Venkateswara Univ., Tirupati.

Sreedevi, P.D., Sreekanth, P.D., Khan, H.H. and Ahmed, S. 2013. Drainage morphometry and its influence on hydrology in a semi-arid region: using SRTM data and GIS. *Environ. Earth Sci.,* 70: 83-848.

Sreedevi, P.D., Subrahmanyam, K. and Ahmed, S. 2005. The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *J. Env. Geo.,* 47(3): 412-420.

Srinivasa, V.S., Govindaonah, S. and Gowda, H. 2004. Morphometric analysis of sub-watersheds in the Pawagada area of Tumkur district South India using remote sensing and GIS technique. *J. Indian Soc. Remote Sens.,* 32(4): 351-362.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. *Trans. Am. Geophys. Union,* 38(6): 913-920.

Strahler, A.N. 1964. Quantitative gcomorphology of drainage and channel networks. Handbook of Applied Hydrology (ed. Ven Te Chow) Mc Graw Hill Book Company, New York, pp 439-76.

Strahler, A.N. 1968. Physical Geography, 3 edition, Chapter 29, Quantative analysis of erosional land form.

Subba, Rao, N. 2009. A numerical scheme for groundwater development in a watershed basin of basement terrain: a case study from India. *Hydrogeo. J.,* 17(3): 379 396.

Thakkar, A.K. and Dhiman, S.D. 2007. Morphometric analysis and prioritization of mini watersheds in Mohr watershed, Gujarat, using remote sensing and GIS techniques. *J. Indian Soc. Remote Sen.,* 35(4): 313-321.

Thomas, J., Joseph, S., Thrivikramji, K.P. and Abe, G. 2011. Morphometric analysis of the drainage system and its hydrological implications in the rain shadow regions, Kerala, India. *J. Geograp. Sci.,* 21(6): 1077-1088.

Thompson, J.R., Taylor, M.P., Fryirs, K.A. and Brierley, G.J. 2001. A geomorphological framework for river characterization and habitat assessment. *Aquatic Conser. Marine Freshwater Ecosyst.*, 11: 373-389.

Umrikar, B.N. 2017. Morphometric analysis of Andhale catchment, Taluka Mulshi district Pune, India. *Appl. Water Sci.,* 7: 2231-2243.

Vijith, H. and Satheesh, R. 2006. GIS based morphometric analysis of two major upland sub-catchments of Meenachil river in Kerala. *J. Indian Soc. Rem. Sens*., 34: 181-185.

Vincy, M.V., Rajan, B. and Pradeepkumar, A.P. 2012. Geographic information system based morphometric characterization of sub-watersheds of Meenachil river basin, Kottayam district, Kerala, India. *Int. J. Geocarto*., 27(8): 661-684.

Vittala, S.S., Govindaiah, S. and Gowda, H.H. 2004. Morphometric analysis of sub-watersheds in the Pavagada area of Tumkur district, South India, Using remote sensing and GIS techniques. *J. Indian Soc. Remote Sen.,* 32(4): 351-362.