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ARTICLE OF PROFESSIONAL INTERESTS

Identification of Erosion Prone Areas by Morphometric Analysis Using GIS

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Abstract This study was undertaken to determine the priority watersheds for conservation of natural resources of the Haharo sub catchment in the Damodar catchment of upper Damodar valley area having an area of 565 km^2 involving four watersheds in Jharkhand State in eastern India by morphometric analysis using topographical maps on a scale of 1:50,000. To define the morphometric features of the watershed, the topographic information of the study area at 1:50,000 scaled are taken for analysis with the help of GIS tools. The topographical information derived from this map is utilized for calculating parameters and fixing of priority of watershed for suggesting conservation measures. The parameters computed include the morphometric parameters like bifurcation ratio, drainage density, stream frequency, texture ratio, and three basin shape parameters i.e., form factor, circularity ratio, and elongation ratio. A rating was done for each of these parameters according to their value. Average of all these parameter for each watershed is calculated to determine the priority. Among the four watersheds 4/4 was the highest priority area where conservation measure has to be taken first then watershed 4/3. Watershed 4/1 was the medium priority area and watershed 4/2 was the low priority area.

Keywords Watershed prioritization · Morphometric analysis · GIS

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Introduction

Soil erosion is a serious problem though out the world. Globally, 1,964.4 Mha of land is affected by human-induced degradation (UNEP 1997). Of this, 1,903 Mha are subject to soil erosion by water and 548.3 Mha by wind erosion. In India out of the total geographical area of 329 Mha, about 167 Mha is affected seriously by water and wind erosion. This includes 127 Mha affected by soil erosion and 40 Mha degraded through gully and ravines, shifting cultivation, water logging, salinity and alkalinity, shifting of river courses and desertification. Land affected due to water erosion is estimated to be about 113.3 Mha [1]. In quantitative terms, an estimated amount of about 5334 Mt (million tones) of soil is being detached annually [2]. In terms of erosion rates this corresponds to about 16.75 t/ha/yr (or about 1 mm depth of top soil each year) against permissible range of 7.5–12.5 t/ha/yr (DAC 1988b). About 29 % of the soil detached is carried away by the rivers into the sea and about 10 % is deposited in reservoirs resulting in the considerable loss (by 1–2 % annually) of the storage capacity [2]. Estimates also indicate that the loss of nutrients due to soil erosion ranges from 5.37 to 8.4 million tons thus involving a production loss of 30–40 million tons of food grain per year (DAC 1988a).

Soil erosion begins with detachment, which is caused by break down of aggregates by raindrop impact, shearing or drag forces of water and wind. Detached particles are transported by flowing water and wind, and may get deposited when the transport capacity of water or wind decreases [3]. However, water is probably the most important single agent causing soil erosion. Accelerated erosion due to human activities is a serious environmental problem as it increases level of sedimentation in the rivers and reservoirs reduce their storage capacity and life, causes flood due to reduction in carrying capacity of rivers and streams.

Proper assessment of soil erosion in space and time involve identification of source areas of sediments and the nature of the areas, their variability, and other basin variables indicative of source areas.

Soil and water conservation are key issues in watershed management in India behind demarcating the priority watersheds. Therefore, any sediment control management or policy should be directed to those areas that are the major contributors of sediment. Therefore, it becomes essential to locate those critical sediment yielding source areas within a (representative) watershed, that need priority attention to improve soil productivity and to prevent further damage from soil erosion.

Many soil erosion and sediment yield estimating methods have been designed so far for watershed prioritization ranging from simple empirical models to process oriented physically based models. Despite the development of a range of physically based soil erosion and sediment transport equations, sediment yield predictions at a watershed or regional scale are at present achieved mainly through simple empirical models. Simple methods include models based on the geomorphological parameters were widely used for the estimation of surface erosion and sediment yield from the catchment area [4–11] methods based on sediment yield index (SYI) [12, 13].

Major factors responsible for soil erosion include rainfall, soil type, and vegetation, topographic and morphological characteristics of the basin. Where there is a lack of data on rainfall and sediment yield, the relative vulnerability of watersheds can be assessed with respect to time-independent factors like soil type, topography and morphology [9].

This study is, therefore, undertaken to use conventional Morphometric analysis of the watershed for its ability to assess vulnerability of watersheds with respect to time-independent topographic, morphometric and soil factors in GIS environment.

Study Area

In the present study, Haharo subcatchment located in the Damodar catchment of Damodar–Barakar river system in the Upper Damodar Valley (UDV) area, Jharkhand, India is taken up for analysis. The study area is a head water catchment in Damodar–Barakar river system. Downstream of the study watershed the Damodar–Barakar river system has a network of five reservoirs, namely Maithan and Tilaiya on the Barakar River, Panchet, Tenughat and Konar on river damodar. Among these, Panchet is the largest dam constructed across the Damodar River.

Geographically the Haharo sub catchment is located between 85°00′E to 85°24′E longitude and 23°45′N to 23°49′N latitude. As per the priority delineation report (AISLUS 1980) it has been codified as, Tg subcatchment. However, as per the national world atlas it has been codified as watershed No. 2A2H3. The total area of the sub-catchment up to the gauging point on the main stream is 565 km^2. The study sub-catchment is covered in Survey of India topographic sheets of 73E/1, 73E/2, 73E/5, and 73E/6 at 1:50,000 scale. Figure 1 depicts the location of Haharo subcatchment in Jharkhand state of India. Physiographically the catchment falls into three main landscapes, viz the hilly and undulating area in the north-west gently undulating and rolling uplands and valley lands. Most of the area of the catchment comprises of gently sloping uplands except for hilly and undulating areas. Elevation of the watershed is ranging from 300 to 830 m above mean sea level. Most of the uplands are subjected severe sheet erosion. Digital elevation model of the area is shown in Fig. 2.

The climate of the study watershed is sub-humid tropica. The annual rainfall ranges between 1,160 and 1,400 mm. About 63 % of annual rainfall is concentrated in the 3 months of July, August and September. Average numbers of rainy days per year are 56. Average seasonal percentage of annual rain fall for January to February is 3.9 %, March to May is 6.5 %, June to September is 82 %, October to December is 7.6 % [14]. The average storm intensity, by considering storms of more than 30 min duration is about 10 cm/h [13].

The predominant land use in the sub-catchment is agricultural land and forest lands. The sub-catchment like, the main catchment is characterized by overgrazing, degraded forest cover and undulating topography coupled with erratic and intense rainfall.

The surface soil texture of the area is mainly loamy type and particle size classes are fine loamy type. Depth of soil varies from shallow to very deep and having parent material as granite-Gneiss and sand stone.

Hydro Meteorological Observation

In Haharo sub-catchment rainfall, run-off and sediment data are being collected at

(1) Sirma
(2) Barkagaon
(3) Bisrampur and
(4) Simratari

by DVC since 1979. At all four locations, rainfall is being observed with ordinary rain gauge, runoff is being

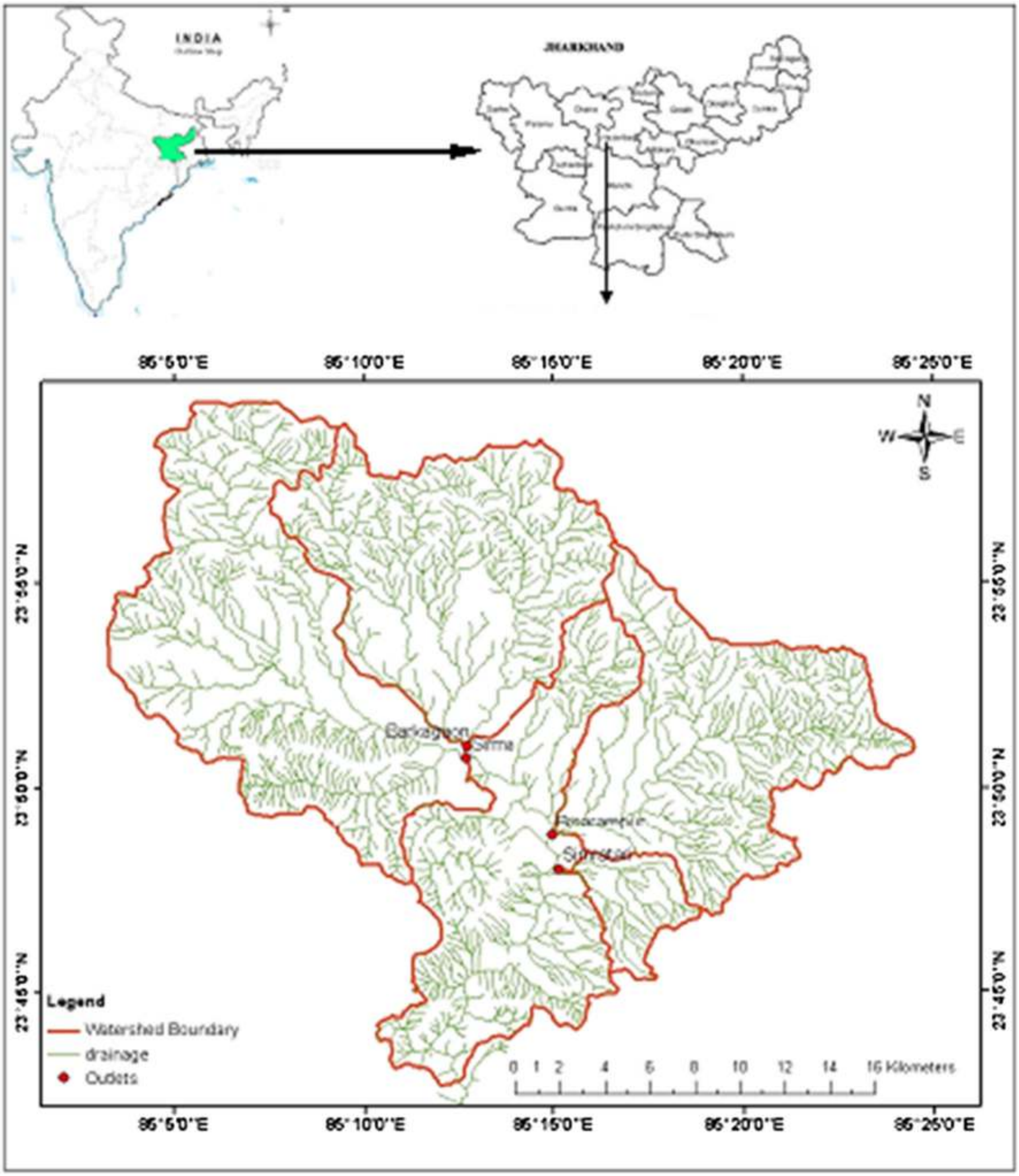

Fig. 1 Location of Haharo sub catchment

measured with a stage level recorder and sediment samples are being collected with the help of USDH-48 depth integrating sampler. Salient features of these sub watersheds are given in Table 1. The sediment samples are filtered at the gauging site itself after allowing it to settle for sometime. The total volume of runoff is multiplied by the sediment concentration to compute the total sediment volume. The density of sediment is taken as1.4gms/cc. in order to accommodate the bed load, 20 % of suspended silt load was added to the measured suspended load as suggested by various researchers [15].

Review of Literature

The researchers have divided the Murli sub-watershed in the Subarnarekha Basin of the Nayagram block in the Midnapore district of West Bengal State in eastern India

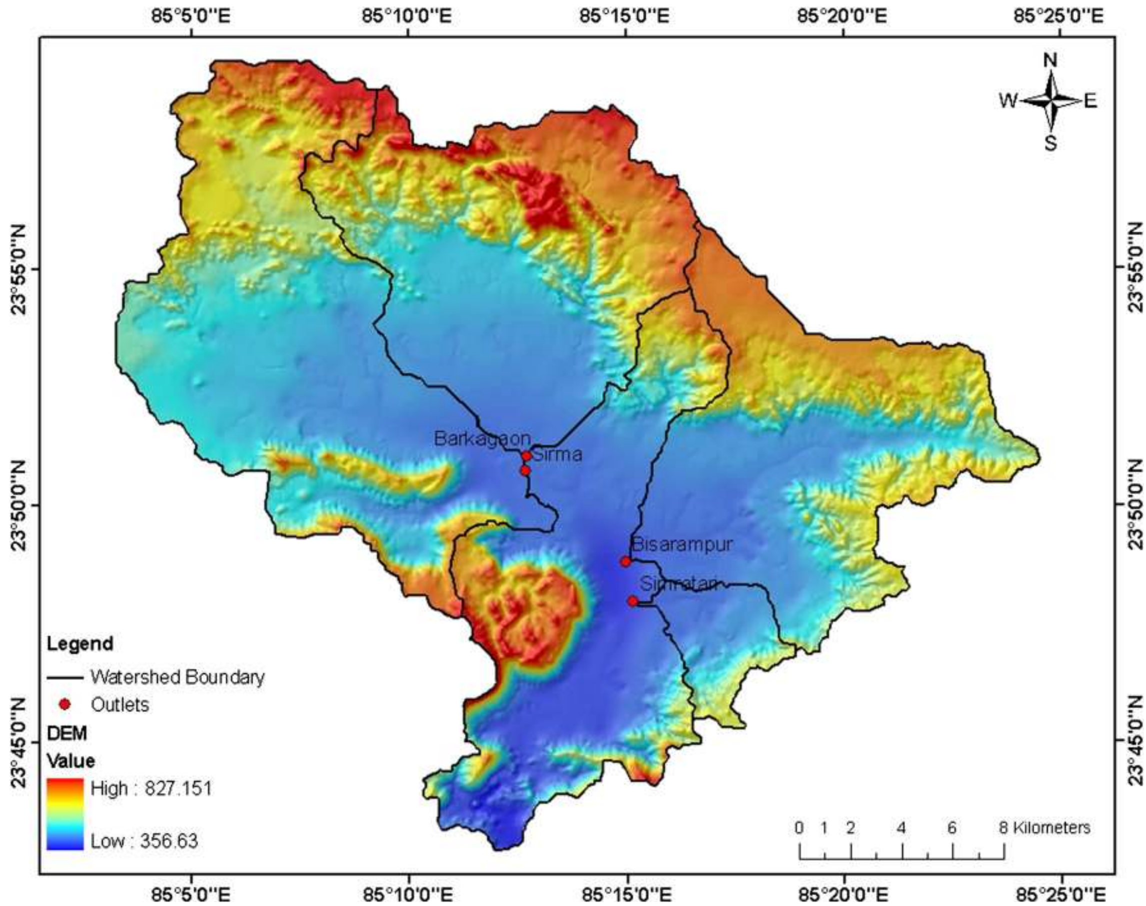

Fig. 2 Digital elevation model of Haharo sub-catchment

into 44 micro watersheds with areas less than 10 km^2, which were prioritized based on morphometric parameters [11]. Morphometric indices are determined after the rating has been done based on every single morphometric parameter, the rating values for every sub-watershed are arranged to arrive at a compound value. Based on average value of these parameters, the sub-watershed priority of the sub-watershed was done. Accordingly, suitable soil conservation measures were suggested. It also proposed the location of check dam sites depending on morphometric analysis and satellite image of the study area. Same procedure was adopted for prioritization of critical erosion producing watershed by several literatures [5, 9, 16].

The researchers have carried out the study of morphometric characteristics of Kotmale reservoir catchment of Sri Lanka using a GIS [10]. A method has been utilized to rank the stream segments using GIS techniques [25, 27]. The relevant numbers of the streams and all other morphometric analyses has been done based on the mathematical formulas. It shows the effectiveness to analyze the morphometric features of the catchment using GIS.

The scientist have used morphometric analysis to understand the topography, erosion status, drainage pattern and the drainage characteristics of Pageru river basin a chronically drought prone area of the Rayalaseema region, Cuddapah district, Andhra Pradesh, India [8]. The importance of such analyses is emphasized in the utilisation of its results, for locating sites for artificial recharge.

The researchers have also developed a model for predicting sediment production rate of watershed by combining rainfall, length width ratio, bifurcation ratio, weighted slope and percents of area covered [17]. It was evident from the analysis that the sediment production rate is inversely proportional to variables like length of main stream, length width ratio, compactness coefficient and rotundity factor. Bifurcation ratio, drainage area and weighted average slope of watershed have positive direct influence on sediment production rate.

It has been studied earlier on the effect of different topographical characteristics such as area, drainage density, form factor, etc. for the sediment production rate of the sub-watersheds in the upper Damodar Valley in eastern India and concluded that the increase of the form factor reduces the sediment production rate [4].

The researchers have observed that the shape parameters show a negative correlation with the runoff-rainfall ratio

Table 1 Salient features of watersheds in Haharo sub-catchment

Sl. no.	Particulars	Watershed no.							
		4/4 (Simratari)		4/3 (Bisrampur)		4/2 (Barkagoan)		4/1 (Sirma)	
1	Size, km^2	18.15		124.58		131.87		169.91	
2	Longitude	85°15′E to 85°19′E		85°15′E to 85°24′E		85°07′E to 85°16′E		85°04′E to 85°12′E	
3	Latitude	23°45′ N to 23°48′ N		23°47 N to 23°56′N		23°51′N to 23°58′N		23°47′N to 23°59′N	
4	Shape	Oval		Rectangular		Oval		Elongated	
5	Soil type	Fine loam		Coarse loam		Coarse and fine loam		Fine loam	
6	Average slope, %	5.35		6.57		8.85		6.86	
7	Relief, m	192		269.9		428.69		346.7	
8	Land use, %								
	(i) Agriculture	48.57		33.33		24.88		27.05	
	(ii) Water body	2.89		1.13		0.88		1.36	
	(iii) Waste land	4.10		3.65		14.08		25.07	
	(iv) Settlement	9.17		4.68		2.26		1.88	
	(v) Forest	35.27		57.21		57.89		44.65	
9	Vegetation	Sheesham, Sal, Palash		Sheesham, Sal, Palash		Sheesham, Sal, Palash		Sheesham, Sal, Palash	
10	Method of measurement								
	(i) Rainfall	Std.R.G.		Std.R.G.		Std.R.G.		Std.R.G.	
	(ii) Runoff	Velocity-area		Velocity-area		Velocity-area		Velocity-area	
	(iii) Sediment	USDH-48		USDH-48		USDH-48		USDH-48	
11	Nature of stream	Ephemeral		Ephemeral		Ephemeral		Ephemeral	
12	Period of record	1979–1989		1979–1990		1980–1985		1981–1985	
13	Missing period	1981				1981			
14	Summary of data (Annual)	Max	Min	Max	Min	Max	Min	Max	Min
	(i) Rainfall, mm	1,392	548	1,392	521	1,186	567	1,321	649
	(ii) Runoff, mm	298	140	379	240	491	176	422	226
	(iii) Sediment production rate, t/ha	2.98	2.06	3.13	1.08	2.81	1.17	2.33	1.01
	(iv) Sediment yields, t	5,403	3,739	39,009	13,416	37,111	15,474	39,633	17,129
	(v) Mean SY, t	2.54		1.97		1.69		1.5	

The missing data, particularly for the year 1981 was incorporated by considering the values for the preceding 2 years and succeeding 2 years [15]

while analyzing the effect of different shape parameters on runoff-rainfall ratios in the United States [18].

Several studies reported by the researchers [3, 19] have found a relationship between cumulative stream length and stream order, and bifurcation ratio, drainage density, texture ratio, and relief ratio for assessing the level of soil erosion.

An urban land-use suitability analysis with the help of GIS in “Prioritization of land for urban development” was carried out by the Space Applications Center of the Indian Space Research Organization (ISRO), Ahmedabad, located in the western Indian state of Gujarat [20]. The researchers have used GIS for district planning based on soil and water conservation plan based on the SYI and socioeconomic criteria for the Panchmahal district within the same state of Gujarat [21].

Some researchers have also evaluated several morphological parameters for priority fixation of Kohali river basin in Tripura [22]. The scientists have developed a GIS customize package for characterization of drainage and shape parameters of watershed using ARC/INFO GIS, involves computation of morphometric parameters, which were further used for prioritization of watersheds [23]. For assessing soil erosion from the watersheds, several empirical models based on the geomorphological parameters were developed in the past to quantify the sediment yield [6].

It has been found from the above literature and theory of catchment morphometry that the morphometric parameters generally show positive co-relation with soil erosion while the basin shape parameters generally show negative co-relation with soil erosion of the watersheds. These concepts were used in the determination of ranking of the watershed based on morphometric parameters.

Methodology

In the present study, prioritization of different areas according to soil erosion severity in a watershed is

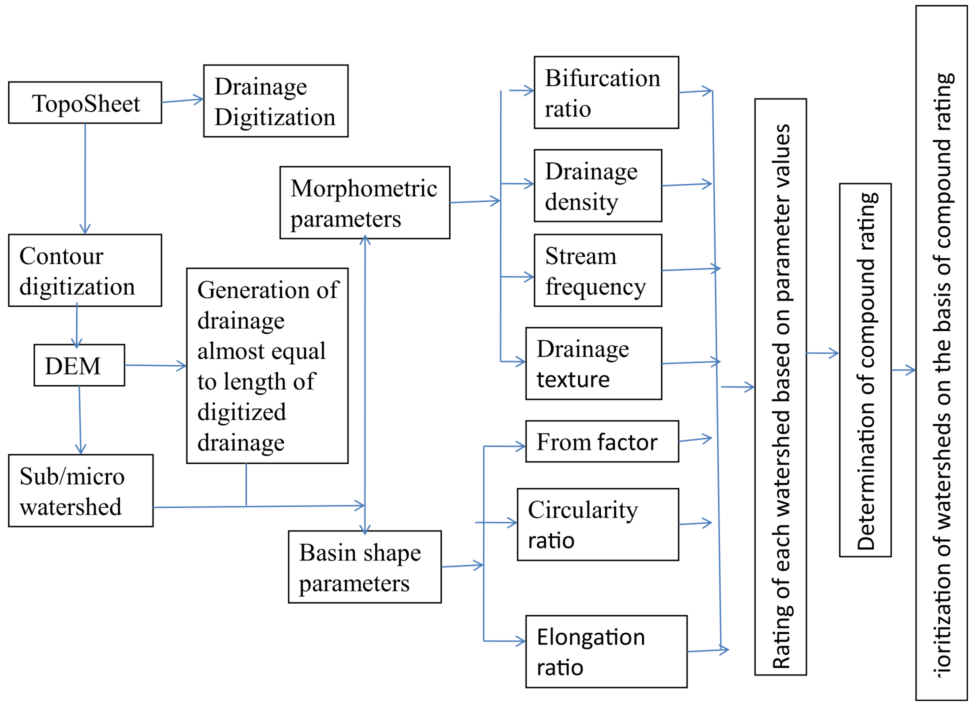

Fig. 3 Flow Chart for watershed prioritization based on morphometric analysis

attempted using methods based on morphometric analysis and USLE based spatially distributed approach. The details of methods used are presented in following text.

Watershed Prioritization Based on Morphometric Analysis of the Catchment

To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosion status and drainage patterns of the region. Development of morphometric technique was a major advance in the quantitative description of the geometry of the drainage basins. These techniques helps in characterizing the drainage network and their inter comparison. Using a GIS, topographical and morphological characteristics of the watersheds can be estimated quite easily and all such information can be integrated for assessing the vulnerability of different watersheds to soil erosion.

To define the morphometric features of a watershed, the topographic information of the study area at 1:50,000 scaled can be taken for analysis with the help of GIS tools. The topographical information derived from this map can be utilized for fixing of priority of watershed for suggesting conservation measures. Steps needed for priority determination include,

(1) Generation of digital input maps
(2) Computation of morphometric parameters
(3) Ranking of each watershed of the catchment according to calculated values of morphometric parameters
(4) Determination of average ranking and assignment of priority for watershed.

Figure 3 shows a flow chart depicting methodology adopted for watershed prioritization using morphometric analysis. Detailed steps needed to carry out morphometric analysis are described in following text.

Generation of Digital Input Maps

(1) The river network and contour lines of the study area are digitized in ArcGIS from topographic map at 1:50,000 scale.
(2) Digital elevation model (DEM) of the area is created from digitized contour map by interpolating it at 30 m grid cells in Arc GIS.
(3) The DEM is further analyzed to remove pits and flat areas to maintain continuity of flow to the catchment outlet. The DEM was further conditioned by burning digitized drain lines on it to enforce observed drainage pattern on flatter areas.
(4) The corrected DEM is then used to generate channel network using the concept of channel initiation threshold. The value of channel initiation threshold can be chosen such that the length of generated channel network is equivalent to the digitized channel network by following the prior literature.
(5) The generated drainage and DEM can be used for further division of the sub catchment into sub watersheds.

Table 2 Formula used for computation of morphometric parameters

Sl. No.	Parameters	Formula	Type of parameters
1	Area	A	Geometric
2	Perimeter	P	Geometric
3	Basin length	L_b	Geometric
4	Stream length	L	Stream
5	No of streams of order U	Nu	Stream
6	Bifurcation ratio (R_b)	$R_b = Nu/N_{(u+1)}$	Morphometric
7	Drainage density (D_d)	$D_d = L/A$	Morphometric
8	Stream frequency (Fs)	$Fs = \sum Nu/A$	Morphometric
9	Drainage texture (T)	$T = D_d$ X Fs	Morphometric
10	From factor (R_f)	$R_f = A/(L_b)^2$	Morphometric(basin shape)
11	Circularity Ratio (Rc)	$R_c = 4\pi A/P^2$	Morphometric(basin shape)
12	Elongation ratio (Re)	$R_e = (2/L_b)\sqrt{(A/\pi)}$	Morphometric (basin shape)

Computation of Morphometric Parameters

The method of Strahler was used to rank the stream segments using GIS. The relevant numbers of the streams and other measured parameters were entered into the attribute table. The morphometric analysis of the watersheds was carried out with the help of drainage patterns and other measured parameters in ArcGIS. The parameters computed include the morphometric parameters (i.e. the bifurcation ratio, drainage density, stream frequency, and texture ratio), three basin shape parameters (i.e., form factor, circularity ratio, and elongation ratio), three geometric parameters (i.e. area, perimeter, basin length) and two stream parameter (i.e. stream length and no of stream of order u). Computation of morphometric parameters was done on the basis of formula given in Table 2.

Ranking of Each Watershed Based on Morphometric Parameters

The highest value of each of the first four morphometric parameters (i.e., bifurcation ratio, drainage density, stream frequency and texture ratio) among 4 watersheds was given a rating of 1, the next highest value was given a rating of 2, and so on as the morphometric parameters generally shows positive co-relation with soil erosion. The lowest value was rated last in the series of numbers.

For the basin shape parameters (i.e. form factor, circularity ratio and elongation ratio) the lowest value was given a rating of 1, the next lowest value was given a rating of 2, and so on as the basin shape parameters generally shows negative co-relation with soil erosion.

Determination of Average Ranking and Watershed Priority

After assigning ranking based on every single parameter, rated values for each watershed were averaged to arrive at a composite value. Based on the average value of these parameters, the watershed having the least value of composite rating is assigned the highest priority denoted by 1, the watershed with next highest value of composite rating is assigned a priority denoted by number 2, and so on. The watershed that got the highest value of composite number is assigned the last priority number. The same procedure was adopted by various researchers [5, 9, 11, 16, 19] for prioritization of watersheds with in a catchment.

Analysis and Discussion of Results

Observed information on rainfall and sediment outflow was available at 4 gauging stations depicted in Fig. 1. Therefore, the entire area is divided into four sub-watersheds defined at gauging station at Sirma (4/1), Barkagaon (4/2), Bisarampur (4/3) and Simratari (4/4).

Morphometric Analysis

Basic Parameters

Geometric (area, perimeter, basin length) and stream parameters (stream length, stream order) were measured from topographic map using ArcGIS.

Geometric Parameters

Area (A)

The total drainage area of Haharo sub catchment was of 565 km^2. The areas of each watershed are shown in Table 5. Watershed 4/4 is the smaller sub-basin ($A = 18.15$ km^2) and watershed 4/1 is bigger than the others ($A = 169.91$ km^2).

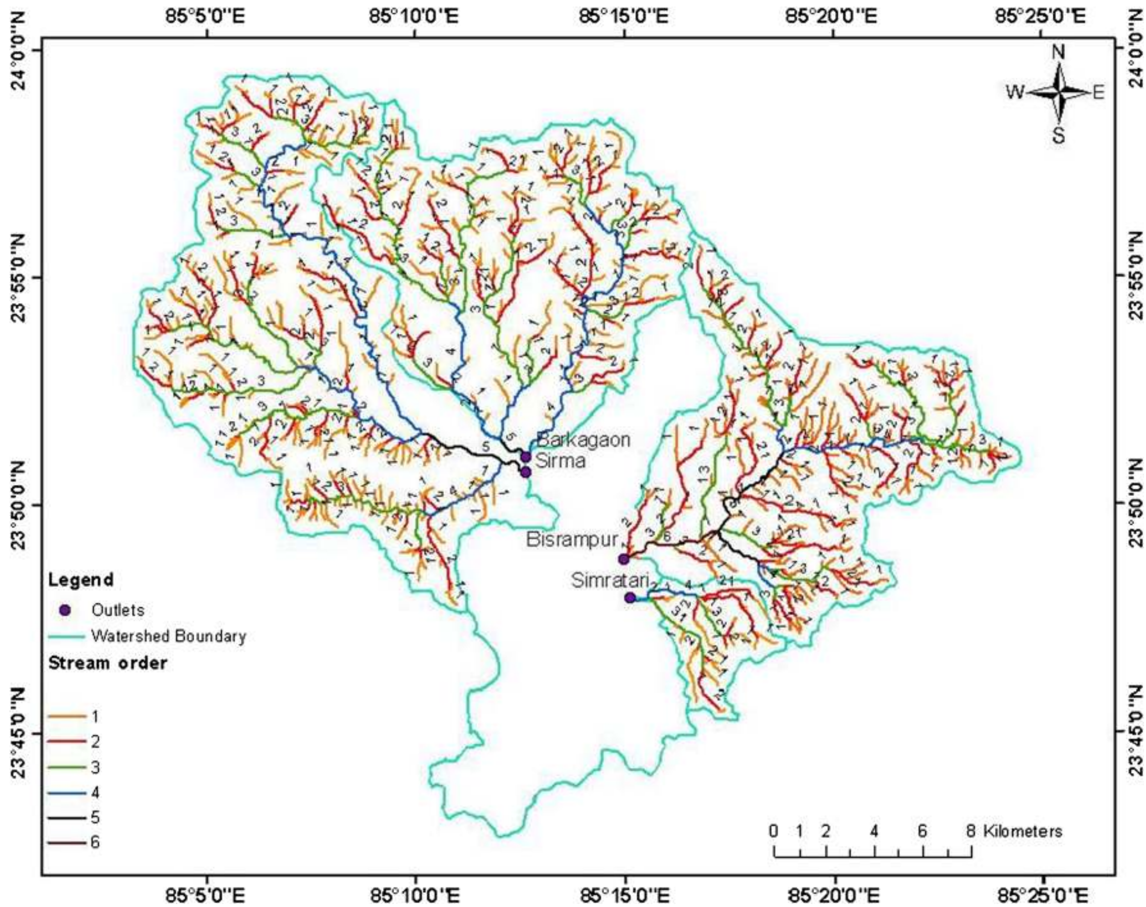

Fig. 4 Haharo sub watershed drainage pattern with stream order

Perimeter (P)

The perimeter is the total length of the drainage basin boundary. The perimeter of Haharo is 302 km, and the P of the four sub watershed is shown in Table 5. Sirma has the higher value ($P > 79$ km) and coincides with the higher value of area (A), while the perimeter of Simratari is less ($P < 23$ km) coincides with the lower value of area (A).

Basin Length (L_b)

The basin length corresponds to the maximum length of the basin and sub-basins. The basin length (L_b) of Haharo is 32.77 km and the values of L_b for the four watersheds are shown in Table 5. Sirma is the longest sub-basins ($L_b > 20$ km) while Simratari has the minimum value of L_b ($L_b < 6$ km).

Stream Parameters

Stream Length (L)

The values of L for the four watersheds are shown in Table 5. Sirma has the longest Stream length (L = 278.01 km) while Barkagaon has the minimum value of L (L = 37.19 km).

Total Number of Stream of all Order (N)

The values of total number of stream of all order for each watershed are shown in Table 5. Sirma has the highest number of stream of all order ($N = 647$) while Simratari has the minimum N (=71).

Stream Order (Nu)

Haharo is designated as a seventh order basin; Sirma (4/1), Barkagaon (4/2) 5th order and Simratari (4/4) is of 4th order watersheds respectively and Bisarampur (4/3) is of 6th order [24]. The R_b of the four watersheds varies from 1.81 to 2.45 (Table 5).

Determination of bifurcation ratio (R_b) of watersheds

Figure 4 shows stream ordering of various watersheds. Calculation on an average value of bifurcation ratio (R_b) for a given channel network can be made by determining

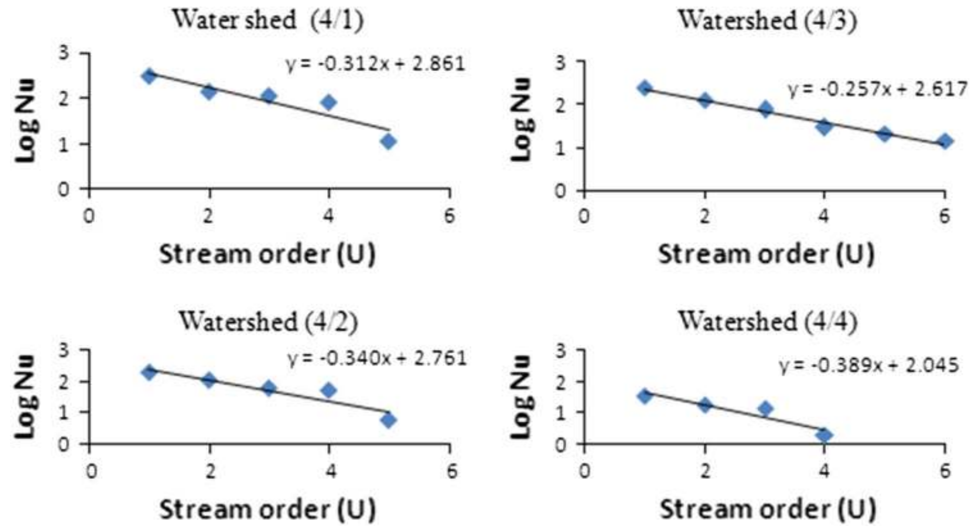

Fig. 5 Regression of number of stream segments on order of four watersheds

Table 3 Determinations of average value of R_b of watersheds

Watershed no.	Total number of stream (N_u) of order (U)						log (Nu)						Slope of trend line	Bifurcation ratio
	1st	2nd	3rd	4th	5th	6th	1st	2nd	3rd	4th	5th	6th		
Sirma (4/1)	307	138	111	80	11		2.49	2.14	2.05	1.90	1.04		0.321	2.094
Barkagaon (4/2)	207	116	64	54	6		2.32	2.06	1.81	1.73	0.78		0.34	2.188
Bisarampur (4/3)	248	127	75	29	21	14	2.39	2.10	1.88	1.46	1.32	1.15	0.257	1.807
Simratari (4/3)	36	19	14	2	–		1.56	1.28	1.15	0.30			0.389	2.449

the slope of the fitted regression of logarithm of numbers (ordinate) on order (abscissa).Regression of number of stream segments on stream order of watersheds Sirma (4/1), Barkagaon (4/2), Bisarampur (4/3), Simratari (4/4) are shown in Fig. 5. Average value of R_b of watersheds Sirma (4/1), Barkagaon (4/2), Bisarampur (4/3), and Simratari (4/4) are shown in Table 3.

Derived Parameters

Estimation of all the morphometric and basin shape parameters was done as per formula given in Table 2. Values of morphometric parameters are tabulated in Table 4

Bifurcation Ratio (R_b)

The R_b of the four watersheds vary from 1.81 to 2.45 (Table 4). Usually these values are common in the areas where geologic structure does not exercise a dominant influence on the drainage pattern. Watershed 4/1 and 4/3 are elongated and rectangular shape respectively and that of 4/2 and 4/4 is oval. The effect of the elongate basin with high bifurcation ratio value would yield low but extended peak flow, where as the rotund basin with low bifurcation ratio value would produce a sharp peak.

Drainage Density (D_d)

The D_d of the four watersheds vary from 1.64 to 2.05 (Table 4). A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response. In general, low drainage density is favored in regions of highly resistant or highly permeable subsoil materials under dense vegetative cover and where relief is low. High drainage density is favoured in regions of weak or impermeable subsurface materials, sparse vegetation and mountainous relief (Chow 1964). The D_d of the watersheds reveals that the nature of subsurface strata is permeable, which is a characteristic feature of coarse drainage as the density values are less than 5.

Stream Frequency (Fs)

The Fs values for the four watersheds vary from 3.39 to 4.13 (Table 4). According to Kale and Gupta (2001) greater the drainage density and stream frequency in a basin, the runoff is faster, and therefore, flooding is more likely in basins with a high drainage and stream frequency.

Table 4 Geometric and morphometric parameters of watershed

Name of watershed	Geometric parameter			Stream parameter		Morphometric parameters				Basin shape parameters		
	Area (A), Km^2	Perimeter (P), km	Basin length (L_b), km	Stream length (L), km	Total No. of stream(N)	Bifurcation ratio [$R_b = (N_u/N_{(u+1)})$]	Drainage density ($D_d = L/A$)	Stream frequency ($F_s = \sum N/A$)	Drainage texture ($T) = D_d * Fs$	Form factor [$R_f = A/(L_b)^2$]	Circularity ratio ($R_c = 4\pi A/P^2$)	Elongation ratio [$Re = (2/L_b) * \sqrt{(A/\pi)}$]
Sirma (4/1)	169.91	79.94	20.04	278.01	647	2.05	1.64	3.81	6.23	0.42	0.33	0.73
Barka Gaon (4/2)	131.87	58.28	15.45	218.52	447	2.19	1.66	3.39	5.62	0.55	0.49	0.84
Bisarampur (4/3)	124.58	64.33	16.67	234.7	514	1.81	1.88	4.13	7.77	0.45	0.38	0.76
Simratari (4/4)	18.15	23.39	6.69	37.19	71	2.45	2.05	3.91	8.02	0.41	0.42	0.72

Table 5 Prioritizing watersheds based on morphometric parameters and observed sediment yield are shown in table below

Name of watershed	Ranking based on parameters							Priority based on average rating and observed sediment yield value			
	R_b	D_d	F_s	T	R_f	R_c	R_e	Average rating	Priority	Observed average sediment production rate, t/ha	Priority
Sirma (4/1)	3	4	3	3	2	1	2	2.57	Medium	1.50	Low
Barkagaon (4/2)	2	3	4	4	4	4	4	3.57	Low	1.85	Medium
Bisarampur (4/3)	4	2	1	2	3	2	3	2.43	High	1.97	High
Simratari (4/4)	1	1	2	1	1	3	1	1.43	Very high	2.38	Very high

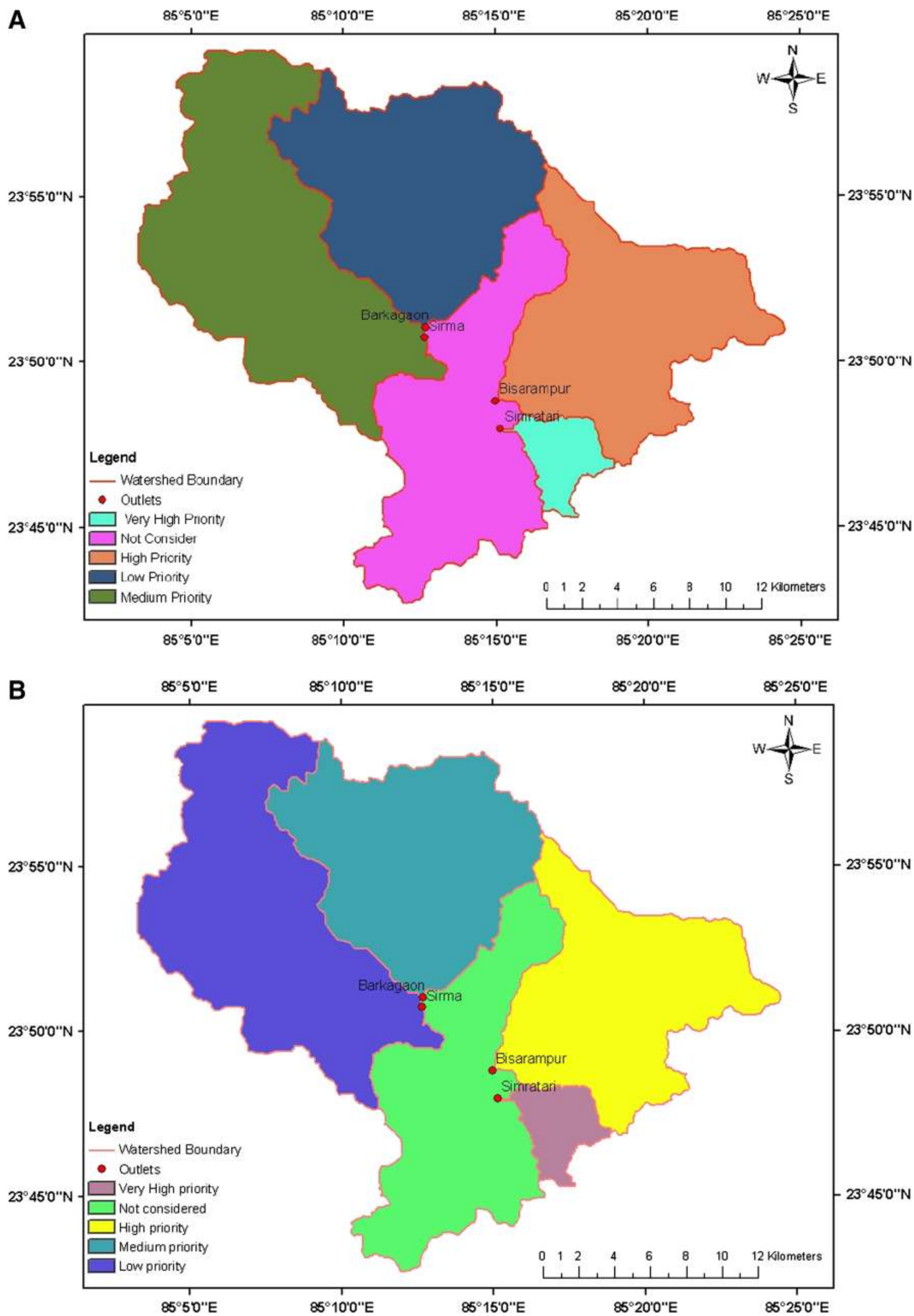

Fig. 6 **a** Priority of watershed based on morphometric parameters. **b** Priority of watershed based on observed sediment yield value

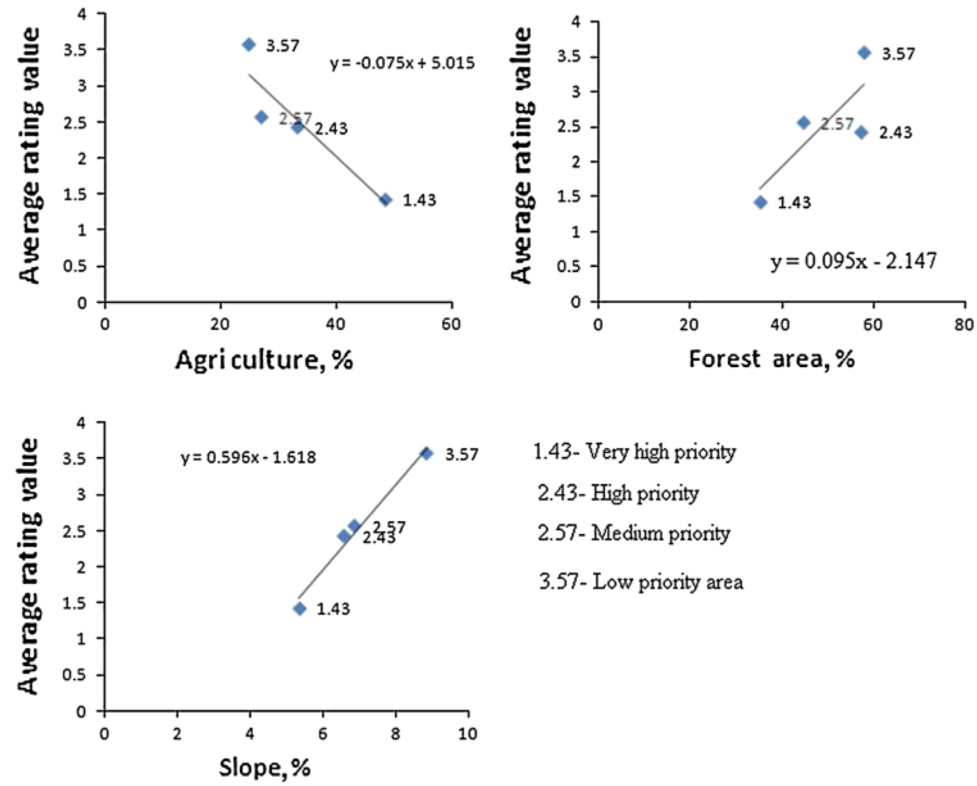

Fig. 7 Relationship with various land use pattern and average slope and priority watersheds

Drainage Texture (T)

The value of T for four watersheds are shown in Table 4. The values are very well between 4 and 10 and therefore the watersheds are intermediate in texture [26].

Form Factor (R_f)

The R_f for the four watersheds are ranging between 0.41 to 0.55 (Table 4). There is a low form factor in a basin that indicates less intense rainfall simultaneously over its entire area than an area of equal size with a large form factor (Gupta 1999).

Circularity Ratio (R_c)

The R_c for the watersheds 1 and 3 are below 0.39 and that of watersheds 2 and 4 are more than 0.41 (Table 4). Those values are indicative of the lack of circularity. Its low, medium and high values are indicative of the youth, mature and old stages of the life cycle of the tributary basins.

Elongation Ratio (R_e)

The R_e for the four watersheds vary from 0.72 to 0.84 (Table 4). All of those values are indicative of elongated shapes rather deviation from a circular shape.

Ranking of Each Watershed Based on Morphometric Parameters and Watershed Prioritization

Ranking of each watershed is done depending on values of the morphometric and basin shape parameters. The highest value of each of the first four morphometric parameters (i.e., bifurcation ratio, drainage density, stream frequency, and texture ratio) among 4 watersheds was given a rating of 1, the next highest value was given a rating of 2, and so on as the morphometric parameters generally shows positive co-relation with soil erosion. The lowest value was rated last in the series of numbers.

For the shape parameters, the lowest value was given a rating of 1, the next lowest value was given a rating of 2, and so on as the basin shape parameters generally shows negative co-relation with soil erosion.

After the rating had been done based on every single parameter, these were averaged to arrive at a compound value for each watershed. Based on the average value of these parameters, the watershed having the least rating value was assigned the highest priority number of 1, the next highest value was assigned a priority number of 2, and so on. The watershed that got the highest value was assigned the last priority number. The same procedure was adopted by the researchers [5, 9, 11, 16, 19] for prioritization of watersheds of a catchment. The results of prioritization of watersheds based on morphometric parameters and comparison of the same with the observed sediment yield data are shown in Table 5. Figure 6a and b compare the result of prioritization based on morphometric analysis and observed sediment yield.

Discussion

It is observed from the result (Table 5) that among the four watersheds 4/4 is the highest priority area where conservation measure has to be taken first. Watershed 4/3 falls under next higher priority watershed. Watershed 4/1 is the medium priority area and watershed 4/2 is the low priority area. The major factors that contribute to soil erosion potential in these watersheds were analyzed. The catchment has overall loamy soil so soil has equal influence for the entire four sub watershed. For the very high priority watersheds 4/4 has high morphometric and low basin shape parameters. As it has the lowest slope of 5.35 % among the watersheds of the catchment and is nearest to the main outlet of the catchment so it has the largest flow convergence therefore subjected to high sediment yield. Moreover the land use pattern (agriculture 48.5 %, forest 35 %) is also responsible for higher soil erosion compare to others. The high priority watershed 4/3 is the 2nd nearest to the main outlet of the catchment and 2nd highest 33.33 % of the agricultural area.

Land may be the main reason for high erosion rate. Mainly high percentage of wasteland and low forested area are the main reason for medium priority of watershed 4/1. Watershed 4/2 as having low morphometric and high basin shape parameters value is prioritize as low priority. It is also justified from the land use of the watershed as it has more than 57 % forested area. It has also been observed that watershed more nearer to the main outlet of the catchment more prone to soil erosion. Attempt was made to establish relationship between average index value with land use pattern, average slope of the watersheds and the same are shown in Fig. 7. It can be seen from Fig. 7 that with the increase in forested area soil erosion decreases and with the agriculture area it shows the reverse co-relation as conventional. But with percentage of average slope (rolling topography of 5 % to 9 %) it shows totally reverse result with general convention.

The results obtained above were compared with the observed sediment yield from these sub-watersheds. It was found that the order of priority arrived at using morphometric analysis does not correspond fully with observations. Watershed 4/4 and 4/3 are identified as very high priority and high priority watershed respectively from morphometric analysis as observed from the sediment yield data and others are showing reverse result. This is due to non-utilization of hydrologic parameters like rainfall, runoff etc., this methodology has its own limitations of quantifying absolute sediment production rate from the catchment. It is therefore found that morphometry based analysis have inherent limitations and may result in assignment of erroneous priority to watersheds. Also this method lacks details about within watershed variability of sediment source areas.

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