Watershed prioritization for soil and water conservation aspect using GIS and remote sensing: PCA-based approach at northern elevated tract Bangladesh

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Abstract

The current study has been derived to understand morphometric parameters to pledge the reduction in the proclaimed drought influence for climate change. Watershed prioritization has been studied using the geographical information system and remote sensing techniques for soil erosion and water preservation measure at Plio–Pleistocene elevated tract in Bangladesh. Secondary data, i.e., SRTM DEM and the topographical sheets, have been used for the drainage network identification. Seventeen watersheds of fifth order and three watersheds of sixth order are selected for the whole study. Sixteen basic morphometric parameters that are categorized as areal, linear and relief aspects have been used for the study area. The study area comprises sixth stream order that has been obtained using a stream threshold value of 100-m length. Morphometric analysis is suitable for water and soil conservation practice where groundwater and relevant data sets are not available. For the categorization and correlation of the morphometric parameters, principal component analysis (PCA) has been used in the present study. PCA analysis is more suitable, well-known and widely used method for its simplicity to choose more influencing parameters (correlated parameters) that are responsible for watershed prioritization. Strongly correlated components (D_d , R_c , R_e and R_b) are used for the compound parameter (C_p) and final priority (R_p) calculation. Low C_p value is suitable for water and soil conservation measure. Therefore, the corresponding low C_p has been taken as one for final priority ranking (R_p) purpose, then second lowest value as two, and so on.

Keywords GIS · RS · Watershed · Morphometric analysis · Prioritization · PCA · Plio–Pleistocene · Bangladesh

Introduction

High inhabitant's dilation, mercurial urbanization, climate change along with the jerky frequency, less vigor of rainfall make water management and storage plans difficult, but there is a compelling need for the appraisal of water resources for livelihood and economics all over the world (Singh et al. 2014). Water is the primary safeguard against drought and plays remarking aid in food storage for an

ever-growing population and urbanization at local, national and global levels that staying at the brink of collapse (Singh et al. 2013; Jha et al. 2007).

Morphometric analyses are mathematical measurement of the earth's surface, its shape and dimension of land form that provides knowledge about the hydrological nature of the surface rock (Agarwal 1998; Reddy et al. 2002). The morphometric study describes basin characters and gives the concept of geological and geomorphic history for the drainage area (Strahler 1964). Literature review shows that morphometric analyses involve evaluation of linear, aerial and relief parameters (Choudhari et al. 2018; Farhan et al. 2017; Rahaman et al. 2015; Singh et al. 2014; Meshram and Sharma 2015; Gajbhiye et al. 2014; Rai et al. 2014, 2017a, b, 2018, 2019; Magesh et al. 2012; Sharma et al. 2018).

Drainage network provides information about local elevation gradient, the difference in rock resistance against erosion, structural control, the geological and geomorphological activity of the watershed (Rai et al. 2014). In the absence

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of hydrological data, geomorphological parameters help for characterizing watershed in the context of geomorphological and climatic characteristics of a basin (Meshram and Sharma 2018).

According to Chopra et al. (2005), Gajbhiye et al. (2014), Rahaman et al. (2015), watershed is an ideal part for land and water resource management where rainwater (surface runoff), melting snow or ice move toward a particular location of lower elevation, called an outlet of the basin to join another water unit such as a river, lake, reservoir, estuary, wetland, sea or ocean. Soil erosion and water conservation measure for a large area is difficult. Therefore, large area is divided into sub-watershed using drainage network (Meshram and Sharma 2015).

Morphometric analyses are essential for detection of water recharge site, watershed delineation, modeling, groundwater prospect mapping, geotechnical investigation, flow intensity and runoff (Ozdemir and Bird 2009; Magesh et al. 2011; Thomas et al. 2012).

Different techniques are available for morphometric analysis, viz. Arc Hydro Tool, Ilwis, Basin 4, Arc GIS, HEC-GeoRAS, etc. These softwares are used nowadays for automatic watershed extraction from digital elevation model (DEM). Markose et al. (2014) use 'bearing, azimuth and drainage (bAd) calculator' which is a modern and easy technique for the extraction of watershed morphometric parameters. Akram et al. (2012) briefly described the watershed delineation from DEM using Arc GIS.

For the detection of the prioritized watershed, other methods are quantitative analysis, statistic methods, fuzzy logic, analytical hierarchical process (AHP) (Rahaman et al. 2015). Scientists, viz. Gurmesssa and Bárdossy (2009), Brown (1992), Pandžić and Trninić (1992), Bouvier et al. (2003), Samani et al. (2007), Al-Alawi et al. (2008), have used PCA analysis for their works in different fields of scientific research. Mishra and Satyanarayana (1988) applied principal component analysis with varimax rotation on ten geomorphic parameters that are classified into drainage, slope and shape components at Damodar Valley watershed. Jaiswal et al. (2014), Rahaman et al. (2015) used morphometric indices and the fuzzy analytical hierarchy, including the Saaty analytical hierarchy process (AHP) to prioritize watersheds for determination of the controlling factor. Javed et al. (2011) and Puno and Puno (2019) have carried out watershed prioritization using morphometric analysis and land use/land cover (LULC) parameters. Javed et al. (2011) showed that the result of prioritization on the basis of morphometric analysis revealed that SW 7 and SW 10 have fall under very high priority, whereas SW 6, SW 11 and SW 13 also fall under very high priority on the basis of land use/land cover (LULC) analysis. However, on the superimposition of the thematic layers of morphometric and land use/land cover in GIS environment, only SW 14 has indicated a common

priority, whereas the rest of sub-watersheds show little or no correlation. The sub-watersheds which are falling under very high priority may be taken up for implementation of soil and water conservation measures. Puno and Puno (2019) showed that from 14 sub-watersheds, SW 13, SW 14 and SW 4 were observed as the most susceptible to land degradation and soil erosion; therefore, immediate attention for soil and water conservation is important for these watersheds.

Previously, drainage network and watersheds were determined using topographical sheet and field survey data. But now the digital elevation model (DEM) with the combination of topographical sheet and field survey data is used in rapid, more precise, updated and cost-effective manner for the watershed analysis (Maathuis and Wang 2006; Moore et al. 1991). According to Choudhari et al. (2018) and Sreedevi et al. (2013), morphometric parameters were derived from Shuttle Radar Topographic Mission (SRTM) DEM and works on C-band interferometry radar setup. Yadav et al. (2014) used CARTOSAT DEM for the morphometric analysis purpose. The study has been carried out aiming to implication:

- Watershed prioritization for soil erosion and water preservation purpose using the morphometric study.
- Application of principal component analysis (PCA) for watershed prioritization.
- Completing spatial maps that describe the final priority for the 20 sub-watersheds.
- Propose suitable soil erosion and water preservation measures for the watershed.

GIS and remote sensing techniques are helpful for rapid and precise analysis on a large scale with the lower cost.

Study area

The study area is located at northern part of Bangladesh and comprises terrace like geomorphic features that was formed due to the sea level rise and fall. Oldest alluvium of Plio–Pleistocene age has exposed at the surface and comprises 1931 km² area. Tectonically, the proposed area occupies the regional plate (Precambrian Indian Platform) that covers the saddle and the shelf area at the northwestern part of Bangladesh. The proposed area is relatively higher than the adjoining floodplain. The contour line map suggests that two terrace levels exist in this area; one remains between 19.8 and 22.9 m elevation, and the other is 40 m elevation from average mean sea level (AMSL). Therefore, during the rainy season, the area remains free from flooded water and rain water drained through narrow intermittent streams. About 47% area of the region is classified as highland, 41%

as medium highland, and the rest are lowlands. Figure 1 shows the study area map.

Slope

According to the Magesh et al. (2011) and Gayen et al. (2013), slope is followed by the climato-morphogenic influence where rocks of varying resistance are existing. Slope map was generated from SRTM DEM. Figure 2 shows the slope map of the study area. Berhanu et al. (2013) classified slope as flat, gentle, moderate, and steep. Slope ranges from 0 to 29 degree for the proposed area. Analysis shows that 82% area comprises 0° – 3° , 16% area comprises $> 3^{\circ}$ – 8° ,

1.5% areas comprises $> 8^{\circ}$ – 15° , and 0.5% area comprises 15° – 29° .

Land use/land cover (LULC)

Four land use-type classes were detected for the proposed area, viz. cultivated land, water body, sand bar and settlement (Fig. 3), where cultivated land comprises 91% area, water body comprises 1% area, sand bar comprises 0.5% area, and settlement comprises 8% area. Land use type describes the knowledge on infiltration, soil moisture, groundwater, surface water, etc. (Ibrahim-Bathis and Ahmed 2016).

Fig. 1 Map of study area

Fig. 2 Slope map of the proposed area

Aspect map

Aspect map produces from SRTM DEM that is shown in Fig. 4. Aspect value represents the compass direction of the slope (Magesh et al. 2011). Aspect controls the influence of climate because the sun shines incident on the soil to west during the warmer time in the afternoon, so slope will become hotter than east-facing slope, and eastern-facing slopes have a high moisture content and low evaporation rate. Aspect also controls the distribution of vegetation.

Surface lithology

According to Akinlalu et al. (2017), lithology controls groundwater recharge because fine grain size materials decrease permeability. McGarry (2006) describes the role of lithology as an important factor for the physical conditions of soil like structure, porosity, adhesion and consistency. Lithological information was obtained from the Geological Survey of Bangladesh (GSB 2001). Three types of soil layer, namely clay (covering 93% area), marsh clay and peat (3%

Fig. 3 Land use map of the proposed area

area) and alluvial silt (4% area), were found for the proposed area. Alluvial silt has a relatively high porosity. Figure 5 shows the exposed soil map of the target area.

Materials and methodology

Watershed character and their management require knowledge of topography, drainage network, water divide, channel length, geomorphological and geological setup of an area (Sreedevi et al. 2013). Quantitative analyses of the morphometric parameters provide detailed information on hydrological condition and rock formation stability, their permeability, storage capacity that shows the yield of the basin. In the research paper, integrated secondary data sets have been used that were obtained from different sectors, as provided in Table 1. Topographical sheets were geometrically rectified and geo-referenced by taking ground control points (GCPs) using UTM projection and WGS 1984 datum. Drainage network and all parameters were calculated using SRTM DEM using ARC GIS. The workflow adopted for the computation of morphometric parameters is shown in Fig. 6.

Fig. 4 Aspect map of the proposed area

The methodology includes drainage network identification and watershed extraction using DEM in combination of Arc GIS and Arc Hydro tool used for this study. Fifteen parameters are calculated for morphometric analysis. PCA analysis is used for reduction in the parameters and determines the more sensitive parameter for watershed prioritization. Morphometric study will help for water resource management for this region.

Results and discussion

Stream network determination

Fill DEM The original DEM contains some depressions that create termination for the continuity of the stream length. To get proper drainage map, the DEM must be filled. The task has been completed using fill of hydrology tool of Arc GIS tool.

Flow direction The filled DEM was used to generate the flow direction for each cell. Values range from 1 to

Fig. 5 Lithology map of the proposed area

255. The eight-direction D8 method was introduced by O'Callaghan and Mark (1984) and widely used in recent time for flow direction detection (Band 1986; Marks et al. 1984; Mark 1984).

Flow accumulation Using the flow accumulation tool of Arc GIS, a flow accumulation raster has been created. The flow direction raster has been used to prepare the flow accumulation raster.

Stream threshold Drainage network generation is critical to extract from DEM (Bertolo 2000). For the proposed area, stream threshold value was taken 100 m. A reference stream has been used for stream network. The whole step was executed using con tool of Arc GIS. Con tool is existing in the arc toolbox>spatial analyst tools>conditional>con of ARC GIS.

Stream order Stream order was generated from the stream network raster and flow direction raster. Sixth-order stream of 3 nos. and fifth-order stream of 17 nos. stream networks were generated for the proposed location.

Stream link From stream order raster attribute table, fifth- and sixth-order stream selected individually and

Table 1 Data sources and characteristics

Data	Sources
Slope map	DEM (USGS 1 arc second), UTM-45, WGS 1984
Aspect map	DEM (USGS 1 arc second), UTM-45, WGS 1984
Topographical sheet	Topographical sheet in 1955 and 1:250,000 scales (https://legacy.lib.utexas.edu/maps/ams/india/)
Soil map	GSB (Geological Survey of Bangladesh)
Land use map	Landsat image OLI—2016, row/path-43/138
Drainage network	DEM (USGS 1 arc second), UTM-45, WGS 1984
Reference stream	Barind Multipurpose Development Authority (BMDA).

Fig. 6 Workflow for the whole study

stream link are also created individually. The step is performed using the stream link tool of Arc GIS.

Watershed determination

Catchment grid generation: This step is conducted using Arc Hydro tool. It is an extension of Arc GIS. Flow direction raster and stream link raster are used for catchment grid generation. For fifth- and sixth-order streams, catchment grid delineation is conducted separately (two times

for fifth- and 6th-order stream links). The output catchment grid is a raster.

Catchment polygon processing: From catchment raster file, the fifth- and sixth-order catchment shape files are generated. This step is also conducted using the Arc Hydro tool. Fifth-order watersheds of 17 nos. and sixth-order watersheds of 3 nos. are identified.

Drainage network extraction

Stream order extraction For extraction of drainage network, fifth-order watersheds of 17 nos. and sixth-order watersheds of 3 nos. are used individually for extraction of the stream order raster. The steps are applied using the extraction tool of Arc GIS.

Stream to feature For morphometric calculation, stream feature shape file is generated from the extracted stream order raster using stream to raster tool of Arc GIS.

Basic parameter

The basin area (A), perimeter (P) and basin length (L) of the individual watershed were determined using Arc GIS. Table 2 describes the procedure, and Table 3 describes the value of basin area, perimeters and length. Maximum 215 km² basin area, 108 km perimeter and 27.74 km basin length were detected (watershed 19), and minimum 19 km² basin area, 12 km perimeter and 6.99 km basin length were detected (watershed 8).

Stream order (U)

Gravelius (1914), Horton (1945) and Strahler (1957, 1964) describe stream order in different ways. Strahler (1964) method was used to determine stream order for its simplicity. Calculation is given in Table 2. Fifth-order stream of seventeen watersheds and sixth-order stream of three watersheds were found using stream threshold value 100 m (length). Dendrite to the sub-dendrite stream has been obtained for the proposed site. According to Choudhari et al. (2018), dendritic drainage pattern shows homogeneous and uniform

Table 2 Calculation of morphometric parameter for all watersheds

Parameters	Equation	Eq. no.	References
Watershed area (A) (km^2)	Arc GIS		Nooka et al. (2005)
Perimeter (P) (km)	Arc GIS		Nooka et al. (2005)
Stream order (U)	Hierarchical rank		Strahler (1964)
Number of stream (N_u)	Individual order stream number		Horton (1945)
Stream length (L) (km)	Individual order length		Horton (1945)
Bifurcation ration (R_b)	$R_b = N_u / N_{u+1}$ where N_u = total number of stream segments of order u and N_{u+1} = number of stream segment of next higher order	1	Schumm (1956)
Mean bifurcation ration (R_{bm})	$R_{bm} = \text{Avg. } R_b$ of all orders	2	Strahler (1957)
Drainage density (D_d)	$D_d = L_u / A$ where L_u = total stream length of all orders and A = area of the basin	3	Horton (1945)
Stream frequency (F_s)	$F_s = N_u / A$ where N_u = total number of streams of all orders and A = area of the basin (km^2)	4	Horton (1945)
Texture ratio (T)	$T = N_u / P$ where N_u = total number of streams of all orders and P = perimeter (km)	5	Horton (1945)
Elongation ratio (R_e)	$R_e = (2/L_b) \times (A/P)^{0.5}$ where L_b = length of basin (km) and A = area of the basin (km^2)	6	Schumm (1956)
Circularity ratio (R_c)	$R_c = 4\pi A / P^2$ where R_c = circularity ratio, A = area of the basin (km^2), and P = perimeter (km)	7	Miller (1953) Strahler (1964)
Form factor (R_f)	$R_f = A / L^2$ where A = area of the basin (km^2) and L = basin length (km)	8	Horton (1932; 1945)
Shape factor (B_s)	$B_s = L_b^2 / A$ where A = area of the basin (km^2) and L_b (basin length) = $1.312 \times A^{0.568}$	9	Nooka et al. (2005), Horton (1932)
Compactness factor (C_c)	$C_c = 0.2821P / A^{0.5}$ where A = area of the basin (km^2) and P = perimeter of the basin (km)	10	Horton (1945)
Length of over land flow (L_o)	$L_o = 1 / (2D)$ where D = drainage density of the basin	11	Horton (1945)
Relief ratio (R_h)	$R_h = R / L$ where R = basin relief and L = longest axis of major river (basin length) in km	12	Schumm (1956)
Ruggedness number (R_N)	$R_N = R \times D_d$ where R = basin relief and D_d = drainage density	13	Schumm (1956)
Hypsometric integral (HI)	$f(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + \dots + a_nx^n$ where $f(x)$ = relative-altitudes (h/H) and x = relative-areas (a/A)	14	Harlin (1978)

lithological resistance and tectonically stable area. The change in stream order suggests that streams flow from high altitude with less lithological variations. Rai et al. (2014) and Choudhari et al. (2018) notice that maximum stream order is found in first-order streams. Stream order is shown in Fig. 7, and values are given in Table 4.

Stream number (N_u)

N_u is reciprocal to the stream order. Stream number identification process is illustrated in Table 2. During stream number identification, it was obtained that the number of

stream decreases as the stream order increases. Stream order and its size largely depend on the physiographical, geomorphological and geological conditions of the interested region (Rai et al. 2014). Different stream order and the total stream number of a particular order have been quantified using Arc GIS. N_u for individual watershed is described in Table 4.

Stream length (L_u)

Table 2 provides the calculation procedure of the stream length for a particular order of a watershed. Stream length was determined according to Horton (1945) law. Horton's

Table 3 Basin parameters of the proposed watershed

WS no.	WS name	Basin area (km ²)	Perimeter (km)	Basin length (km)
1	S1	27	18	8.54
2	S2	26	21	8.35
3	S3	30	21	9
4	S4	51	47	12.25
5	S5	22	20	7.6
6	S6	24	18	7.98
7	S7	25	18	8.17
8	S8	19	12	6.99
9	S9	26	19	8.35
10	S10	38	39	10.36
11	S11	39	47	10.52
12	S12	25	19	8.17
13	S13	34	32	9.73
14	S14	49	59	11.97
15	S15	30	20	9.06
16	S16	25	18	8.17
17	S17	40	61	10.67
18	S18	124	77	20.29
19	S19	215	108	27.74
20	S20	141	72	21.83

second law suggested that as stream order increases, stream length decreases. It means the first-order stream has the maximum length. The stream length expresses the hydrological characteristics of the bedrock and the drainage extent of a basin. It explains the rock formation permeability. A small number but longer streams are formed in the well-drained watershed, where the soil layer is permeable (Sethupathi et al. 2011). The stream length is given in Table 4.

Bifurcation ratio (R_b)

According to Schumm (1956), R_b is the ratio of stream number of a particular order to the stream number of the next higher order (Eqs. 1 and 2 in Table 2). It is a dimensionless property and detects integration between streams of various orders. According to Horton (1945), R_b is an indicator of relief and erosion, while Strahler (1957) stated that R_b shows a small change with different environments, but the value is higher where strong geological control dominates. Lower R_b values express structurally low disturbance in the watershed (Nag 1998; Strahler 1964; Vittala et al. 2004; Chopra et al. 2005). According to Strahler (1964), R_b value ranging from 3.0 to 5.0 indicates the area geologically stable or

Fig. 7 Stream network of the proposed area

drainage pattern is negligible. R_b values for all watersheds are described in Table 4.

Drainage density (D_d)

According to Strahler (1964), D_d is the ratio of stream length to the area of the basin (Eq. 3). D_d depends on valley density, channel origin, relief, slope, climate and vegetation, soil and rock properties such as infiltration and soil resistance (Farhan et al. 2017) and landscape evolution processes. D_d for the proposed area is 1.36 km/km². High D_d indicates that basin soil is less resistive and high relief in association with weak and impermeable subsurface material, sparse vegetation, fine drainage texture, high runoff and erosion potential (Strahler 1964; Prasad et al. 2008). Maximum D_d was obtained as 3.71 km/km² (watershed 17) and minimum 1.22 km/km² (watershed 7) as shown in Table 5. Figure 8 shows the D_d map of the study area.

Table 4 Linear aspects of watersheds

Sub-watershed	Parameters	Stream order						Mean bifurcation ratio (R_b)
		I	II	III	IV	V	VI	
Sub-watershed 1	Stream no	59	30	3	2	1	–	3.87
	Stream length	22	13	4	5	0.5	–	
Sub-watershed 2	Stream no	118	39	3	2	1	–	4.88
	Stream length	26	11	8	6	0.5	–	
Sub-watershed 3	Stream no	92	27	3	1	2	–	3.98
	Stream length	22	16	4	7	1	–	
Sub-watershed 4	Stream no	187	36	8	2	1	–	3.92
	Stream length	55	35	22	8	1	–	
Sub-watershed 5	Stream no	103	20	18	2	1	–	4.32
	Stream length	24	6	12	4	0.5	–	
Sub-watershed 6	Stream no	65	13	2	1	–	–	3.38
	Stream length	20	13	2.5	6	–	–	
Sub-watershed 7	Stream no	101	14	4	2	1	–	3.68
	Stream length	19	7.5	2	1.5	0.5	–	
Sub-watershed 8	Stream no	48	6	4	3	1	–	3.46
	Stream length	11	7	6	1	0.5	–	
Sub-watershed 9	Stream no	92	18	6	3	1	–	3.28
	Stream length	24	12	7	2	0.5	–	
Sub-watershed 10	Stream no	252	26	6	2	1	–	4.76
	Stream length	50	20	14	8	0.5	–	
Sub-watershed 11	Stream no	167	35	5	2	1	–	4.07
	Stream length	56	29	15	10	0.5	–	
Sub-watershed 12	Stream no	86	30	3	1	–	–	3.97
	Stream length	19	14	5	4	–	–	
Sub-watershed 13	Stream no	132	37	13	2	1	–	3.73
	Stream length	40	15	14	4	1	–	
Sub-watershed 14	Stream no	262	44	7	4	1		4.5
	Stream length	74	36	13	17	1		
Sub-watershed 15	Stream no	72	11	4	2	1		3.32
	Stream length	29	10	4	4.5	1		
Sub-watershed 16	Stream no	150	10	4	2	1		5.38
	Stream length	26	13	7	2	1.5		
Sub-watershed 17	Stream no	262	77	7	3	1		4.93
	Stream length	75	40	18	15	0.5		
Sub-watershed 18	Stream no	392	94	26	15	2	1	2.03
	Stream length	167	83	34	23	11	10	
Sub-watershed 19	Stream no	736	164	42	9	2	1	3.19
	Stream length	262	137	66	32	29	4	
Sub-watershed 20	Stream no	631	131	40	7	5	1	4.04
	Stream length	174	81	45	26	13	6	

Stream frequency (F_s)

F_s is the ratio (Eq. 4) of the total number of stream to the area of watershed (Horton 1945). The value of F_s varies from 3.91 to 9.99 and depends on the underlying bedrock of the drainage basin. F_s values are positively correlated with the D_d values of a catchment. This means that any increase in stream population is connected to that of drainage density.

For small and large drainage basins, F_s and D_d are not comparable. High F_s shows more percolation through slope materials and bedrock; thus, more groundwater potential exists. Reddy et al. (2004) stated that lower value of F_s indicates permeable subsurface material and low relief. The F_s value ranges from 3 (watershed 15) to 8.75 (watershed 17). F_s value is given in Table 5.

Table 5 Aerial aspect parameters value of watersheds

Sub-watershed	Drainage density (D_d)	Stream frequency (F_s)	Texture ratio (T)	Elongation ratio (R_e)	Circularity ratio (R_c)	Form factor (R_f)	Shape factor (B_s)	Compactness constant (C_c)	Length of overland flow (L_o)
1	1.65	3.52	5.28	0.69	1.05	0.37	2.7	0.04	0.30
2	1.98	6.27	7.76	0.67	0.74	0.37	2.68	0.05	0.25
3	1.67	4.17	5.95	0.68	0.85	0.36	2.73	0.04	0.30
4	2.37	4.59	4.98	0.66	0.29	0.34	2.94	0.04	0.21
5	2.11	6.55	7.2	0.67	0.69	0.38	2.62	0.06	0.24
6	1.73	3.38	4.5	0.69	0.93	0.38	2.65	0.05	0.29
7	1.22	4.88	6.78	0.69	0.97	0.37	2.67	0.05	0.41
8	1.34	3.26	5.17	0.70	1.65	0.39	2.57	0.05	0.37
9	1.75	4.62	6.32	0.69	0.90	0.37	2.68	0.05	0.29
10	2.43	7.55	7.36	0.67	0.31	0.35	2.82	0.05	0.20
11	2.83	5.38	4.47	0.67	0.22	0.35	2.83	0.05	0.18
12	1.68	4.80	6.32	0.69	0.87	0.37	2.67	0.05	0.30
13	2.18	5.44	5.78	0.68	0.42	0.36	2.78	0.05	0.23
14	2.88	6.49	5.39	0.66	0.18	0.34	2.92	0.04	0.17
15	1.62	3.00	4.5	0.68	0.94	0.36	2.73	0.04	0.31
16	1.98	6.68	9.28	0.69	0.97	0.37	2.67	0.05	0.25
17	3.71	8.75	5.74	0.67	0.13	0.35	2.84	0.05	0.13
18	2.58	4.27	6.88	0.12	0.26	0.30	3.32	0.02	0.19
19	2.47	4.44	8.83	0.10	0.23	0.28	3.57	0.01	0.20
20	2.45	5.78	11.32	0.13	0.34	0.30	3.38	0.02	0.20

Texture ratio (T)

T is the ratio of the total number of the stream of a particular order to the watershed perimeter (Eq. 5). The parameter is considered as significant factor in the drainage basin morphometric study and depends on lithology, surface materials, infiltration capacity and the relief of an area (Altat et al. 2013). The value T for the proposed area is given in Table 5.

Elongation ratio (R_e)

According to Schumm (1956), R_e is the ratio of diameter of a circle having an equal area of the basin to the maximum basin length (Eq. 6) and helps to understand the hydrological nature of a drainage basin. The value of R_e varies from 0.6 to 1.0 depending on climate and geology. For very low relief, R_e value is close to 1.0, and for high relief and steep slope R_e value ranges from 0.6 to 0.8 (Strahler 1964). Runoff is high in a circular basin compared to the elongated basin (Singh and Singh 1997). Higher R_e indicates a high percolation rate, low runoff and limited soil erosion (Reddy et al. 2004). The value of R_e is given in Table 5.

Compactness constant (C_c)

C_c was elaborated by Gravelius (1914) and also known as Gravelius index (GI). It is the ratio of watershed perimeter to the circumference of the circular area equal to the watershed area (Eq. 10). The catchment is a perfect circle when C_c is one and takes a short time for the concentration of peak flow, for C_c value of 1.28 watersheds are square-shaped, and for C_c value greater than 3.0 watersheds are varying in their shape (Zavoianu 1985; Altat et al. 2013). C_c parameter of a watershed is independent of size, but dependent on the slope (Horton 1945). C_c values of the watersheds are illustrated in Table 5.

Length of overland flow (L_o)

According to Miller (1953), L_o is calculated as half of the D_d (Eq. 11). Overland flow and runoff are two different terms. Overland flow is the water after rainfall that moves over the land to reach into the channels, and runoff is the water that moves through the channel to reach a particular outlet. The overland flow is dominant in the smaller watershed. Table 5 describes the L_o value for all watersheds.

Fig. 8 Drainage density of the proposed area

Relief ratio (R_h)

According to Schumm (1956), R_h is the ratio of the maximum relief of a basin to the distance along the longest dimension of the basin (Eq. 12). Difference between the highest and lowest elevation points is termed as the total relief. Low relief ratio occurred for the resistant basement and flat sloping area. R_h normally rises for decreasing drainage area and size. R_h value for each watershed is given in Table 6.

Average slope (S_a)

S_a is related to the erosion of the watershed. The researcher proved that the more the percentage of slopes are, the more the erosion if other factors remain unchanged. The average slope varies from 1.62 (watershed 16) to 2.13 (watershed 5). S_a value for all watersheds is given in Table 6.

Relative relief (R_r)

R_r is the ratio of the maximum watershed relief to the perimeter of the watershed. Table 6 shows the relative relief values for all watersheds. Relative relief values range from 0.001 to 0.003 for the proposed area. Figure 9 describes the relative relief map of the study area.

Ruggedness number (R_N)

Table 6 shows the ruggedness number of the watersheds, and Eq. 13 has been used to calculate the R_N . The ruggedness number varies from 0.04 (watershed 7, watershed 8 and watershed 15) to 0.13 (watershed 19). The watershed has the overall low roughness which shows the structural complexity of the terrain in association with relief and drainage density. It also implies that the area is less susceptible to erosion.

Hypsometric integral (HI)

HI refers to the relation of the cross-sectional area along the horizontal direction to the elevation (Langbein 1947). HI shows the erosional stages of the watershed, and the volume of mass remains above the base. Harlin (1978) derives cumulative probability distribution for detection hypsometric curve and various statistical parameters to quantify HI. HI, an analysis, was carried out using the polynomial function, viz. second or third grade (Harlin 1978), and has been derived using Eq. 14. HI values for all watersheds are given in Table 6.

HI value ≥ 0.60 shows youth stage/convex upward curves, and basin is highly susceptible to erosion and land sliding, when $0.30 \leq HI \leq 0.60$, basin is the mature stage or equilibrium/S-shaped, and when HI value ≤ 0.30 , basin is old (monadnock) or peneplain stage (concave upward curve).

Inter-correlation among geomorphic parameters

Inter-correlation among geomorphic parameters was carried out using SPSS 25 software. Meshram and Sharma (2015) have described that when correlation coefficient value > 0.9 , the parameter is strongly correlated, when correlation coefficient value > 0.75 , the parameter has good correlation, when correlation coefficient value > 0.6 , the parameter is moderately correlated, and when correlation coefficient value is 0.6 to < 0.6 , the parameter has poor correlation. Table 7 reveals that elements among D_d to L_o and B_s to R_f , R_e and C_c are strongly correlated. Besides R_h to R_r , B_s , R_c , R_f ; R_r to R_c , L_o ; R_N to D_d , B_s , R_c , R_f , L_o ; and D_d to R_c have good correlation,

Table 6 Relief aspect of watersheds

WS no.	Maximum elevation	Minimum elevation	Total relief or basin relief	Relief ratio R_h	Average slope S_a	Relative relief R_r	Ruggedness number (R_N)	HI
1	54	19	35	0.004	2.12	0.002	0.06	0.501
2	51	25	26	0.003	1.98	0.001	0.05	0.527
3	53	19	34	0.004	2.07	0.002	0.06	0.506
4	54	16	38	0.003	1.94	0.001	0.09	0.492
5	53	18	35	0.005	2.13	0.002	0.07	0.482
6	54	20	34	0.004	2.11	0.002	0.06	0.533
7	55	22	33	0.004	2.04	0.002	0.04	0.507
8	55	23	32	0.005	1.93	0.003	0.04	0.501
9	53	26	27	0.003	1.86	0.001	0.05	0.487
10	55	26	29	0.003	1.84	0.001	0.07	0.492
11	54	18	36	0.003	1.68	0.001	0.10	0.459
12	52	22	30	0.004	1.63	0.002	0.05	0.507
13	50	22	28	0.003	1.73	0.001	0.06	0.512
14	54	21	33	0.003	1.68	0.001	0.09	0.502
15	49	24	25	0.003	1.85	0.001	0.04	0.578
16	46	12	34	0.004	1.62	0.002	0.07	0.505
17	48	21	27	0.002	2.09	0.001	0.10	0.523
18	47	5	42	0.002	2.03	0.001	0.11	0.532
19	54	0	54	0.002	1.96	0.001	0.13	0.556
20	54	15	39	0.002	1.90	0.001	0.09	0.449

and R_h to R_N , D_d , R_e , L_o , C_c ; R_r to D_d , R_f ; R_N to R_e , C_c ; R_b to F_s ; D_d to F_s ; F_s to L_o ; B_s to R_c ; R_c to R_f , L_o ; R_e to T have a moderate correlation. Several elements have no correlation among the other elements. Therefore, it is very difficult to carry a correlation among elements (Meshram and Sharma 2015). Therefore, principal component analysis has been carried out to the inter-correlation matrix for grouping the components.

Principal component analysis

The principal component analysis method was applied to the inter-correlation matrix to get the first-factor loading matrix and afterward rotated the loading matrix using the orthogonal transformation. Discussion of principal component analysis has been given in the following section.

First-factor loading matrix

Table 8 shows that the eigenvalue of the first 3 components is greater than 1 and the total cumulative value is 81.02%. Table 9 shows that the first component is strongly correlated with B_s and R_f (> 0.9), good correlation is existing for R_h , R_r , R_N , D_d , R_c , R_e and L_o (> 0.75), and moderate correlation exists for C_c (> 0.6). The second component is good for correlation with R_b and F_s and moderate correlation with C_c .

The third component is good for correlation with T . From the above result, it is found that S_a and HI have no correlation with any component. Therefore, some components have strong correlation, some have moderate correlation, some components contain good correlation, and some components have no correlation. In this stage, it is not possible to identify significant component for correlation. Therefore, it is important to rotate the first-factor loading matrix to get a reliable correlation.

Rotation of first-factor loading matrix

Rotated factor loading matrix from the first-factor loading matrix was obtained by post-multiplying the transformation matrix with the selected component. Table 10 gives the result of the rotation matrix. Table 10 shows first PCA component values D_d and R_c have a strong correlation, R_h , R_r , R_b and L_o have good correlation, and R_f has a moderate correlation. The second component shows that R_e has a strong correlation, B_s , R_f , T and C_c have good correlation, and R_f has moderate correlation. The third component has a good correlation with R_b and F_s and moderate correlation with HI and S_a . Therefore, D_d , R_c , R_e and R_b are the most important factors that can be taken for further priority measurement for erosion and water conservation measurement.

Fig. 9 Relative relief map of the proposed area

Comparison of two approaches to prioritization of sub-watersheds for soil and water conservation

According to Nooka et al. (2005), liner features are directly related to erosion of the soil and the high value of linear feature reflects that the area is more erosive. Similarly, the relief feature has an influence on erosion. Compound parameters (C_p) are produced by summing all the ranks of linear, shape and relief parameters and then dividing by the number of total parameters, as provided in Table 11. PCA-based analyses results (Table 10) reveal that parameters (viz. R_c , R_e and R_b) that have a strong correlation later are used for watershed prioritization after calculating the compound parameter (C_p) and priority rank (R_p) values (Table 12). The highest prioritized rank (R_p) was assigned to the watershed having the lowest compound parameters (C_p) values. The C_p values ranges from 8.47 (Watershed 2) to 12.87 (watershed 11). Final priority R_p that has been taken for watershed 2 is one as higher rank, and for watershed 11, R_p value has been taken twenty as a lower rank. Figure 10 shows the completed map for the water and soil conservation practice.

Conclusion

GIS- and RS-based morphometric studies were conducted to select watershed for water and soil conservation measures at the Plio–Pleistocene elevated tract in Bangladesh. Sixteen areal, linear and relief parameters were chosen for twenty watersheds, where seventeen are fifth order and three are sixth order. Principal component analysis, compound parameters detection and priority ranking were carried on the morphometric parameters for reduction in the elements from

Table 7 Inter-correlation matrix among geomorphic parameters of the study area

	R_h	R_r	R_N	R_b	D_d	F_s	B_s	R_c	R_f	R_e	T	L_o	C_c	S_a	HI
R_h	1.00	0.88	−0.67	0.15	−0.68	−0.28	−0.77	0.77	0.81	0.63	−0.28	0.69	0.64	0.09	−0.16
R_r	0.88	1.00	−0.52	0.01	−0.65	−0.36	−0.54	0.82	0.61	0.36	−0.14	0.71	0.37	0.20	−0.08
R_N	−0.67	−0.52	1.00	−0.09	0.79	0.31	0.82	−0.81	−0.83	−0.68	0.27	−0.81	−0.63	0.01	−0.05
R_b	0.15	0.01	−0.09	1.00	0.26	0.74	−0.36	−0.09	0.32	0.47	0.23	−0.25	0.49	−0.26	−0.31
D_d	−0.68	−0.65	0.79	0.26	1.00	0.68	0.49	−0.87	−0.53	−0.30	0.09	−0.95	−0.22	−0.10	−0.13
F_s	−0.28	−0.36	0.31	0.74	0.68	1.00	0.03	−0.55	−0.08	0.08	0.37	−0.62	0.26	−0.17	−0.30
B_s	−0.77	−0.54	0.82	−0.36	0.49	0.03	1.00	−0.65	−0.99	−0.94	0.51	−0.55	−0.92	0.03	0.07
R_c	0.77	0.82	−0.81	−0.09	−0.87	−0.55	−0.65	1.00	0.71	0.44	−0.18	0.89	0.39	0.13	0.11
R_f	0.81	0.61	−0.83	0.32	−0.53	−0.08	−0.99	0.71	1.00	0.91	−0.48	0.59	0.91	0.02	−0.08
R_e	0.63	0.36	−0.68	0.47	−0.30	0.08	−0.94	0.44	0.91	1.00	−0.60	0.37	0.91	−0.14	−0.08
T	−0.28	−0.14	0.27	0.23	0.09	0.37	0.51	−0.18	−0.48	−0.61	1.00	−0.19	−0.42	−0.07	−0.23
L_o	0.69	0.71	−0.81	−0.25	−0.95	−0.62	−0.55	0.89	0.59	0.37	−0.19	1.00	0.29	0.17	0.14
C_c	0.64	0.37	−0.63	0.49	−0.22	0.26	−0.92	0.39	0.91	0.91	−0.42	0.29	1.00	−0.11	−0.22
S_a	0.09	0.20	0.01	−0.26	−0.10	−0.17	0.03	0.13	0.02	−0.14	−0.07	0.17	−0.11	1.00	0.19
HI	−0.16	−0.08	−0.05	−0.31	−0.13	−0.30	0.07	0.11	−0.08	−0.08	−0.23	0.14	−0.22	0.19	1.00

Table 8 Total variance of the watersheds

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)	Total	% of variance	Cumulative (%)
1	7.39	49.30	49.30	7.39	49.30	49.30	5.29	35.24	35.24
2	3.25	21.65	70.95	3.25	21.65	70.95	4.32	28.79	64.03
3	1.51	10.07	81.02	1.51	10.07	81.02	2.55	16.99	81.02
4	0.99	6.60	87.62						
5	0.81	5.42	93.04						
6	0.51	3.40	96.44						
7	0.20	1.36	97.80						
8	0.14	0.92	98.71						
9	0.10	0.68	99.40						
10	0.05	0.31	99.70						
11	0.02	0.13	99.83						
12	0.01	0.09	99.92						
13	0.01	0.04	99.96						
14	0.00	0.03	99.99						
15	0.00	0.01	100.00						

Table 9 Unrotated matrix

Parameters	Component		
	1	2	3
R_h	0.890	0.015	0.211
R_r	0.759	− 0.217	0.346
R_N	− 0.896	0.035	− 0.031
R_b	0.111	0.844	0.293
D_d	− 0.773	0.511	− 0.222
F_s	− 0.351	0.840	0.191
B_s	− 0.912	− 0.365	0.150
R_c	0.872	− 0.343	0.206
R_f	0.936	0.306	− 0.098
R_e	0.784	0.515	− 0.297
T	− 0.436	− 0.020	0.825
L_o	0.818	− 0.471	0.156
C_c	0.737	0.615	− 0.132
S_a	0.065	− 0.356	− 0.087
HI	− 0.003	− 0.429	− 0.529

Table 10 Rotated matrix

Parameters	Component		
	1	2	3
R_h	0.790	0.448	0.115
R_r	0.845	0.168	0.026
R_N	− 0.722	− 0.531	0.039
R_b	− 0.088	0.330	0.833
D_d	− 0.906	− 0.099	0.280
F_s	− 0.496	0.095	0.781
B_s	− 0.490	− 0.851	− 0.153
R_c	0.910	0.257	− 0.163
R_f	0.558	0.806	0.141
R_e	0.259	0.932	0.180
T	0.087	− 0.766	0.525
L_o	0.892	0.187	− 0.292
C_c	0.268	0.857	0.363
S_a	0.142	− 0.090	− 0.732
HI	− 0.106	0.088	− 0.667

more parameters through inter-correlation matrix and then unrotated matrix and rotated matrices. The watershed that is suitable for water and soil conservation has been taken one as priority ranking (R_p), and the corresponding compound parameter (C_p) value is 7.75. A strongly correlated component from PCA was later used for the compound parameter and for final priority detection. The first three components have an eigenvalue greater than one, and the cumulative value is 81.02%.

The findings that can be concluded are as follows:

- The whole work has been carried out using SRTM DEM used to extract morphometric parameters using GIS and RS.
- PCA analysis component showing that D_d , R_c , R_e and R_b parameters are strongly correlated that were later used for the final prioritization ranking.

Table 11 Priorities of sub-watersheds and theirs ranks

Watershed no.	R_b	D_d	F_s	R_c	R_f	B_s	R_e	T	L_o	C_c	R_N	R_r	R_h	S_a	HI	Compound parameter (C_p)	Final priority (R_p)
1	12	4	17	2	17	7	18	15	6	6	14	15	5	2	13	10.20	8
2	3	9	6	10	12	9	9	4	10	13	17	2	10	8	5	8.47	1
3	9	5	16	9	10	10	12	11	5	7	13	16	6	5	10	9.60	3
4	11	13	13	15	5	17	5	17	13	5	5	8	15	10	15	11.13	16
5	6	11	4	11	18	2	10	6	11	20	8	19	1	1	18	9.73	4
6	16	7	18	6	19	3	19	18	8	15	11	17	7	3	3	11.33	17
7	14	1	10	4	15	4	16	8	1	19	18	13	3	6	8	9.33	2
8	15	2	19	1	20	1	20	16	2	18	19	20	2	11	14	12.00	19
9	18	8	12	7	14	8	15	9	7	16	16	3	11	13	17	11.60	18
10	4	14	2	14	8	13	8	5	16	11	10	5	13	15	16	10.27	10
11	7	18	9	18	7	14	7	20	18	10	3	10	16	17	19	12.87	20
12	10	6	11	8	13	5	14	10	4	17	15	14	4	19	9	10.60	12
13	13	12	8	12	9	12	11	12	12	12	12	4	12	16	7	10.93	14
14	5	19	5	19	4	16	4	14	19	4	6	7	14	18	12	11.07	15
15	17	3	20	5	11	11	13	19	3	8	20	1	9	14	1	10.33	11
16	1	10	3	3	16	6	17	2	9	14	9	18	8	20	11	9.80	5
17	2	20	1	20	6	15	6	13	20	9	4	9	18	4	6	10.20	9
18	20	17	15	16	2	18	2	7	17	2	2	11	19	7	4	10.60	13
19	19	16	14	17	1	20	1	3	15	1	1	12	20	9	2	10.07	7
20	8	15	7	13	3	19	3	1	14	3	7	6	17	12	20	9.87	6

Table 12 Priorities of sub-watersheds and their rank using PCA-correlated elements

Watershed no.	R_b	D_d	R_c	R_e	Compound parameter (C_p)	Final priority (R_p)
1	12	4	2	18	9	5
2	3	9	10	9	7.75	1
3	9	5	9	12	8.75	3
4	11	13	15	5	11	12
5	6	11	11	10	9.5	6
6	16	7	6	19	12	14
7	14	1	4	16	8.75	4
8	15	2	1	20	9.5	7
9	18	8	7	15	12	15
10	4	14	14	8	10	11
11	7	18	18	7	12.5	18
12	10	6	8	14	9.5	8
13	13	12	12	11	12	16
14	5	19	19	4	11.75	13
15	17	3	5	13	9.5	9
16	1	10	3	17	7.75	2
17	2	20	20	6	12	17
18	20	17	16	2	13.75	20
19	19	16	17	1	13.25	19
20	8	15	13	3	9.75	10

Fig. 10 Final priority map shows ranking for soil and water conservation practice

- GIS and RS methods are cost-effective, less time-consuming and reliable with recurrence analysis.
- Watershed 2 has high priority and watershed 11 has less priority for water and soil conservation.

The study area is drought-prone area, and impunity lies at the root of water conservation; therefore, the study will help to provide better understanding for the decision-maker and use as a guideline for the hydro-geologist so that water resources are managed properly.

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Compliance with ethical standards

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