WATERSHED PRIORITIZATION ACROSS ERBIL PROVINCE FOR SOIL EROSION MANAGEMENT VIA MORPHOMETRIC ANALYSIS

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ABSTRACT

Soil erosion is one of the foremost factors giving rise to watershed deterioration due to improper and unwise utilization of natural resources without proper vision, particularly in developing countries like Iraq. Since it is not possible to implement rehabilitation programs over all areas at a time, prioritization plays a major role in identification of the areas which are in need of immediate actions. Accordingly, the current study was conducted to perform morphometric analysis as the basis for prioritization. To achieve the above objective, 30 watersheds of different scales were delineated within Erbil governorate and standard procedures were followed to carry out morphometric analysis. Prioritization ranks were determined for the study watersheds based on computation of compound factors and on the technique for order preference by similarity to ideal solution (TOPSIS). The results indicated that nearly two approaches offered similar results. The regression analysis indicated that the priority rank from (TOPSIS) can be predicted from the priority rank from compound factor computation with a reasonable accuracy. Based on TOPSIS approach, watersheds: Kawlan-smelan, Nawandee, Warte, Prdi-qasre, Nawprdan, Darbandy-rayat, Dargalla and Mergasor fall within the very high priority class and as a consequence immediate actions should be taken to protect these watersheds. By contrast, the watersheds: Kasnazan, Smaquly, Bestana, Kawanyan, Rulka and Degala 1 are categorized under the low prioritization level. Further improvements in specifying the priority ranks can be expected upon coupling land use/land cover with morphometric analysis.

Keywords: watershed ranking, compound factor, prioritization techniques, watershed attributes

تحديد أولويات احواض الانهر من خلال التحليل المورفوميترى للسيطرة على التعرية المائية ضمن محافظة أربيل

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المستخلص

تعد التعرية المائية أحدى العوامل المؤدية إلى تدهور احواض الانهر بسبب الاستخدام غير السليم للموارد الطبيعية ودون رؤية مناسبة خاصة في البلدان النامية مثل العراق. نظرًا لعدم امكانية تنفيذ برامج التنمية في جميع احواض الانهر في وقت واحد، فإن تحديد الأولويات يلعب دورًا رئيسيًا في تحديد المناطق التي تحتاج إلى إجراءات فورية. وفقا لذلك أجريت الدراسة الحالية لإجراء التحليل المورفوميترى كأساس لتحديد الأولويات. ولتحقيق الهدف المنشود أعلاه، تم تحديد 30 حوض نهر من مستويات مختلفة ضمن محافظة أربيل، وتم اتباع الإجراءات القياسية لإجراء التحليل المورفوميترى او الصرفي. تم تحديد صفوف الأولويات لاحواض الانهر في الدراسة بناءً على حساب العوامل المركبة وعلى تقنية رتبة التفضيل عن طريق التشابه مع الحل المثالي (TOPSIS). أشارت النتائج إلى أن النهجين تقريبًا قد قدما نتائج مماثلة. كما أشار تحليل الانحدار إلى أنه يمكن التنبؤ بترتيب الأولوية حسب TOPSIS من رتبة الأولوية وفقا للطريقة التقليدية بدقة معقولة. كما اوضحت النتائج الى وقوع احواض الانهر: كاولان–سميلان،ناوندى، ورتى، بردى –قسرى، ناوبردان، دربندى–رايات، دركلة و ميركسور ضمن فئة الأولوية العالية جدًا وفقًا لنهج TOPSIS ونتيجة لذلك يجب اتخاذ إجراءات فورية لحماية هذه الاحواض الانهر. على النقيض من ذلك، تم تصنيف احواض الانهر: كسنزان، سماقولى، بيستانة، كاوانيان، رولكة و ديكلة1 تحت مستوى تحديد الأولويات المنخفض.كما يمكن توقع مزيد من التحسينات في تحديد صفوف الأولوية عند اقتران استخدام الأرض / الغطاء الأرضي بالتحليل المورفوميتري.

كلمات مفتاحية: ترتب احواض الانهر، العامل المركب، طرق تحديد الأولويات، خصائص احواض الانهر .

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INTRODUCTION

Soil erosion is one of the foremost factors giving rise to land degradation (43). The notion of land degradation originates from soil degradation, as a synonym for land degradation (17). It can be defined as deterioration of land quality and productivity in a given area of interest (15). It causes soil resources exploitation; lowers land productivity and changes the composition of vegetation's (43). Furthermore, Vittala et al. (39) reported that watershed deterioration is a common phenomenon worldwide due to improper and unwise utilization of natural resources without proper vision, particularly in developing countries. This problem is a subject of urgency and should be given higher priority on the environmental agenda (1). Accelerated erosion in watersheds can be minimized through identification and prioritizations of sensitive regions to soil erosion (5). In some studies by Baumgardner (4) the characteristics of basin morphometry have been used for predicting flood peak, assessing sediment yield and erosion rates. By morphometry is meant, measurement and mathematical analysis of earth surface configuration, shape and landforms dimensions (8). Tavassol and GS (37) reported that the assessment of basin hydrologic characteristics is a mandate basin management schemes. It includes basin size, shape, slope, drainage density besides length and size of the existing streams. As linear and shape parameters of watershed morphometric characteristics have direct and indirect relationship with soil erodibility, they can be used as basis for prioritization (14). This implies that the quantitative analysis of drainage basins can be considered as a basic technique for watershed prioritization (12). Watershed prioritization is a technique of ranking subwatersheds based on degree of denudation caused by accelerated erosion and criticality state of the drainage basins (24). Sujatha et al. (34) reported that geomorphometric analysis has wide applications and can be considered as an indirect assessment tool for estimating soil erosion, land slide susceptibility besides groundwater and topography analyses. Puno and Puno (26) stated that the criteria for ranking do not include only geomorphometric factors, but it also encompasses the average soil loss, land use or land cover, and other pertinent factors. Vittala et al. (39) demonstrated that it is not possible to implement rehabilitation programs over all areas at a time. For this reason, prioritization plays a major role in identification of the areas which are in need of immediate actions. It is commendable to mention that the study watersheds are under the threat of degradation due to uncontrolled agricultural activities and most of didn't have the required database for decision making. Under this situation, the morphometric analysis is of enormous usefulness (35), in the prioritization of soil conservation at a watershed level because the agricultural activity plays a major role in socio-economic development (2). Accordingly, the current study was conducted and the main objectives were: to conduct quantitative morphometric analysis as a basic technique for characterizing the existing watersheds within Erbil province and to prioritize these watersheds based on morphometric analysis by computing compound factor and using TOPSIS MCDM approach.

MATERIALS AND METHODS

Brief description of the study area

The study area is located in the realm at the mountainous area of Erbil province, Iraq, which lies within the geographical coordinates of 35° 30′ 00″ to 37° 15′ 00″ north latitudes and from 43° 30′ 00″ to 45° 15′ 00″ East longitudes. The whole study region is covering an area of 47285 km^2 and feeding the Greater Zab and the Lesser Zab are the major upland tributaries of the Tigris River (Figure 1). Several basins at the lower part of the study area fall in the semiarid class (0.2 < AI < 0.5), while the remaining basins fall in the dry subhumid class (0.5 < AI < 0.65) according to the aridity index (AI) proposed by (38). Furthermore, based on the annual and monthly averages of temperature and precipitation for the study area, with no exception, the study basins fall in C_{sa} climatic class according to the scheme proposed by Koppen. The study region is characterized by having a broad range of annual precipitation from about 400 mm at its lower part to more than 1000 mm at the borders. The rainfall has a unimodal distribution and there is water surplus during the months of December to March.

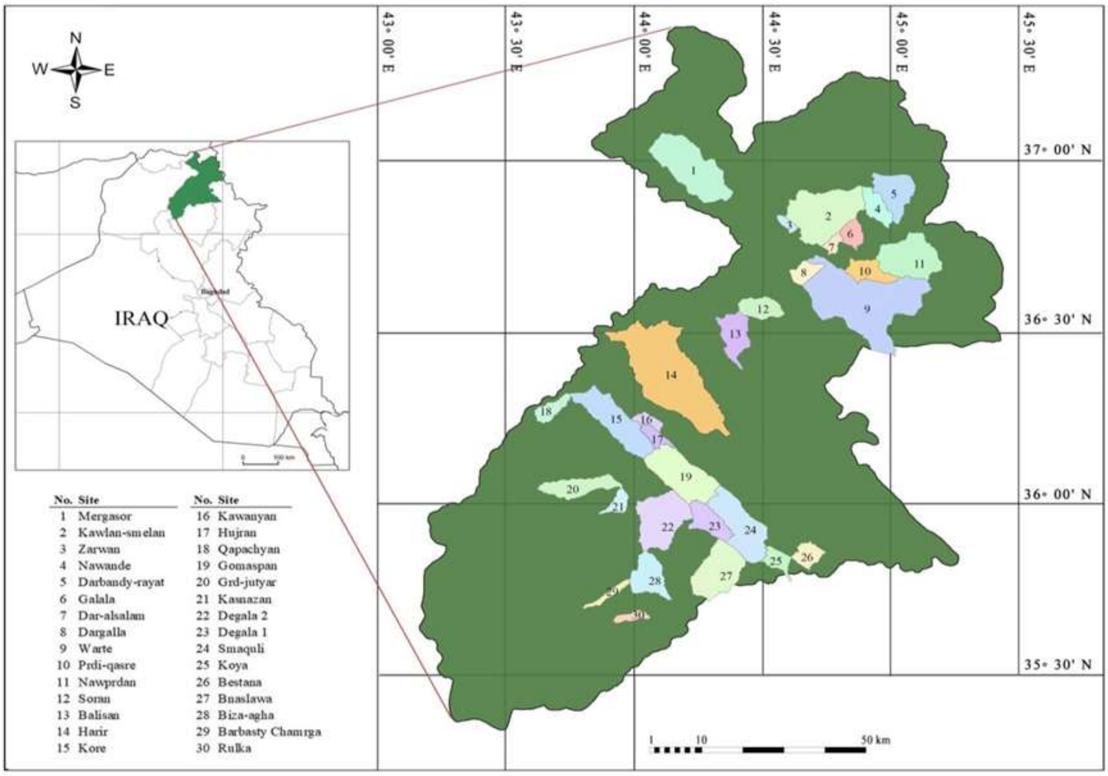

Figure1. Location map showing the delineated watersheds under study

Most of the study area, particularly its middle and upper parts can be generally described as rough broken and stony lands. These soils are either truncated or completely removed so that the diagnostic horizons of all orders other than Entisols are absent in most cases. The existing soils are variables due to variation in exposure, runoff, relief, parent materials, soil depth and maturity (6). The most common great groups on the sloppy lands are Rendolls and Xerorthents. On the other hand, Calcixerolls and Chromoxererts are the most abundant great groups over the plains intermountain valley. Considerable area were occupied by forest lands in the past, but at the present, the forest density ranges from treeless lands near the urban areas to very dense forestlands at remote places. The dominant forest tree species is oak trees. The majority of the agricultural lands are rain fed, wheat, barley, lentil, chick pea and faba bean are the principal winter crops.

Measurement of morphometric parameters

This approach required a digital elevation model as a base input for specifying topographic and other features in the study area (42). The DEM of district was downloaded from http://earthexplorer usgs.gov/ after registering and logging in. The study area was partitioned into 30 main catchment delineations and each of these catchments was further divided into a group of subcatchments depending on the nature of each main catchments using ArcMap v. 10.Furthermore, the same software was employed for deriving basic parameters to illustrate the morphometric characteristics of the 30 watersheds. The parameters encompassed area, perimeter, basin length, total length of stream segments and slope. These databases were used for characterizing the basins in term of morphometric parameters, which fell in three categories, namely, linear, areal and relief. The different morphometric parameters were determined using standard methodologies (11, 16, 22, 30 and 34).The procedure followed by Strahler (33) was followed to determine the stream orders of the study basin.

Prioritization procedure

1. Five linear, four shapes and three relief features parameters were regarded as erosion risk parameters and considered in the prioritization of the study watershedsTable1.

Table 1. The decision matrix used for ranking the existing watersheds in the study area

Watersheds	Watershed Code	Bifurcatio ratio (Rb)	Drainage density (Dd)	Drainage frequency (Fs)	Texture ratio(Tr)	Slope length (Lg)	Compactness coefficient (Cc)	Elongation ratio (Re)	Form factor (Ff)	Circularity ratio (Rc)	Basin relief (Bh)	Relief ratio (Rr)	Ruggedness Number (Rn)
Balisan	WS 1	4.094	1.476	1.374	1.546	0.368	1.562	0.851	0.569	0.416	1289	0.122	1.903
Barbasty Chamrga	WS 2	3.500	1.876	1.010	0.356	0.274	2.222	0.371	0.108	0.206	391	0.036	0.734
Bestana	WS 3	3.574	1.578	1.619	1.453	0.329	1.337	0.932	0.682	0.568	500	0.074	0.789
Biza-agah	WS 4	4.391	1.248	1.429	1.158	0.371	2.316	0.795	0.497	0.189	420	0.036	0.524
Bnaslawa	WS 5	8.545	1.578	1.332	1.408	0.337	1.756	0.668	0.350	0.329	540	0.042	0.852
Darbandy-rayat	WS 6	3.113	1.322	1.373	1.849	0.405	1.369	0.783	0.482	0.542	2386	0.194	3.154
Dargalla	WS 7	3.278	1.307	1.588	1.266	0.412	1.309	0.706	0.392	0.592	1861	0.226	2.432
Dar-alsalam	WS 8	3.500	1.319	1.315	0.663	0.399	1.430	0.648	0.330	0.496	1407	0.225	1.856
Degala 1	WS 9	4.311	1.252	1.443	1.951	0.363	1.342	1.196	1.124	0.563	639	0.084	0.800
Degala 2	WS 10	5.315	2.006	1.543	2.648	0.360	1.330	0.914	0.656	0.574	764	0.055	1.533
Galala	WS 11	3.367	1.160	1.598	1.364	0.337	1.230	0.781	0.479	0.670	1809	0.239	2.098
Gomaspan	WS 12	2.365	1.490	1.656	2.804	0.352	1.372	1.325	1.380	0.539	1156	0.119	1.722
Grd-jutyar	WS 13	4.045	2.311	1.176	1.080	0.294	1.804	0.610	0.293	0.312	672	0.049	1.553
Harir	WS 14	4.486	1.624	1.487	3.642	0.382	1.666	0.830	0.541	0.366	1453	0.057	2.360
Hujran	WS 15	5.000	1.375	0.923	0.649	0.364	1.543	0.767	0.462	0.426	1108	0.166	1.524
Kasnazan	WS 16	2.833	1.436	1.371	0.857	0.334	1.467	0.728	0.417	0.471	429	0.061	0.616
Kawanyan	WS 17	4.400	1.333	1.606	0.921	0.334	1.485	1.211	1.152	0.460	570	0.155	0.760
Kawlan-smelan	WS 18	3.920	1.289	1.416	2.980	0.378	1.336	0.949	0.708	0.568	4647	0.298	5.990
Kore	WS 19	5.390	1.456	1.502	2.214	0.359	1.670	0.586	0.269	0.364	934	0.043	1.368
Koya	WS 20	3.078	1.545	1.595	0.985	0.305	1.610	0.578	0.262	0.391	717	0.071	1.108
Mergasor	WS 21	6.096	1.524	1.481	3.141	0.380	1.350	0.673	0.356	0.557	1476	0.067	2.249
Nawandee	WS 22	3.778	1.776	2.219	1.645	0.377	1.608	0.541	0.230	0.393	2427	0.217	3.201
Nawprdan	WS 23	3.426	1.434	1.520	2.798	0.393	1.268	0.811	0.517	0.631	2513	0.165	3.604
Prdi-qasre	WS 24	3.894	1.330	1.797	1.661	0.355	1.522	0.868	0.592	0.438	2548	0.296	3.389
Qapachyan	WS 25	3.583	1.435	1.731	1.346	0.303	1.508	0.594	0.277	0.446	319	0.032	0.458
Rulka	WS 26	3.833	0.763	0.665	0.649	0.339	1.178	0.848	0.566	0.732	333	0.048	0.254
Smaquly	WS 27	3.974	1.554	1.547	2.466	0.323	1.550	1.088	0.929	0.423	756	0.065	1.175
Soran	WS 28	6.500	1.426	1.312	1.405	0.355	1.302	0.745	0.436	0.599	274	0.032	0.390
Warte	WS 29	3.444	1.226	1.490	3.388	0.437	1.745	0.688	0.372	0.333	2854	0.095	3.499
Zarwan	WS 30	3.625	1.080	1.696	0.874	0.349	1.297	0.434	0.148	0.603	1133	0.134	1.224

2. The highest value of each parameter having a direct relationship with erodibility was rated as rank one. By contrast, the lowest value of each parameter which has an inverse relationship with erodibility was rated as rank one.

3. The compound value was calculated for each watershed after adding the corresponding ranks of all the morphometric parameters that were considered for prioritization and the results were divided by number of the parameters.

4. The watershed with the lowest compound factor was assigned the highest priority.

5. The TOPSIS model was also implemented for classifying the watersheds into priority classes according to the procedure described by (23). The details of the procedure are as follows:

The normalized decision matrix, R, was computed from the decision matrix X_{ij} by using the following relationship:

$$R_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^{2}}} \qquad [1]$$

To obtain the weighted normalized matrix V, each column of matrix R was multiplied by the corresponding weight (W_j):

$$V_{ij} = R_{ij}\, W_j \qquad [2]$$

Upon attaining the positive ideal and negative ideal solutions from weighted normalized matrix, the separation measures from the positive ideal (S_i^+) and the negative ideal (S_i^-) solutions were calculated for all the watersheds according to:

$$S_i^{+} = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^{+}\right)^2} \qquad [3]$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_j^{-}\right)^2} \qquad [4]$$

Thereafter, the following formula was applied to determine the relative closeness to the ideal solution.

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-} \quad [5]$$

RESULTS AND DISCUSSION

General aspects about the delineated watersheds

As a whole the study watersheds having 4th order streams covering areas varying from as low as 1061.2 ha to as high as 34901.9 ha. Based on the classification scheme reported by Suresh (36), 70% of them fall in the Milliwatershed class (1000 – 10000 ha). Based on the classification scheme proposed by Walsh and Lawler (40), most of the stations at the lower part of the study area like Ankawa, Qushtapa and Khabat showed markedly seasonal with a long drier season (SI= 0.80 - 0.99). By contrast, the stations within the mountainous area showed rather seasonal (SI= 0.40 - 0.59) to seasonal (SI= 0.6 - 0.79) rainfall distribution. The majority of the watersheds are 4th order basins with dendritic drainage pattern, signifying moderate contribution of runoff and sediments into the existing channels. The prioritization was based on morphometric analysis. The watershed attributes encompasses some selected linear, areal and relief features parameters. The obtained data were cross tabulated in (Table 1).

Linear aspects

The drainage density varies from as low as 0.763 for WS26 to as high as 2.311 for WS13 (Table 1). It can also be observed that the majority of watersheds (more than 93%) have drainage density of less than 2 km^{-1}. Except for watershed WS10 and WS13, all the study watersheds fell in the low class (0 – 2 km^{-1}). Relatively low relief, dense vegetation cover and permeable subsoil are responsible for low drainage density (41). The drainage density values presented in Table 1 suggest that the watersheds are underlain by permeable materials and characterized by having dense vegetation and relatively low relief. Furthermore, they have relatively slow hydrologic response to rainfall events. Srivastave et al., (32) reported that a basin with a low drainage density has a slow hydrologic response.It is obvious from Table 1 that the bifurcation ratio ranges from a minimum of 2.365 for WS12 to a maximum of 8.545 for WS5 and the remaining watersheds fell between these two extremes. The results also indicated that the majority of bifurcation ratio fell in the range of 3-4.5 with average values of 4.16. These moderate values indicated moderate overland flow and moderate recharge for the study watersheds. Nag (22) reported that low value for the bifurcation ratio reflects partially disturbed without any distortion in drainage pattern. On the other hand, high bifurcation is an indicative of remarkable distortion by geological structure. It is also obvious from Table 1 that the drainage frequency varies from as low as 0.665 in WS26 to as high as 2.219 for WS22. Close examination of Table 1 discloses that with one exception, all the watersheds fell in poor class ($Fs < 2.0\ km^{-2}$) based on the scheme shown by (19). This parameter is basin lithology dependents and is an indication of the basin drainage network texture (31). The low drainage frequency for the study watersheds indicates that the watersheds are bearing low relief and having conducting subsurface materials (28). It is also evident from Table 1 that the texture ratio ranges from as low as 0.356 for WS2 to as high as 3.642 for WS14 and the rest of the watersheds fell between these two extremes. This implies that the value of this parameter is below 4. Such values are indications of the fact that the watersheds are of moderate runoff (12). The semiarid climate along with non-intensive vegetative cover may be responsible for the coarse texture of the study watersheds.

Areal aspects

The results of Table 1 also show that the circularity ratio values (Rc) vary from a minimum of 0.189 for WS4 to a maximum of 0.732 for WS26.This implies that there is a wide variation in watershed shape across the study area. No Rc value falls above 0.75 evidencing that no watershed has a circular or close to a circular shape. More than 66% of the Rc values are in the range of 0.40 - 0.70. This implies that the shape of the majority of the watersheds is intermediate between elongated and circular shape. According to Miller (2), most of the watersheds are characterized by having permeable and homogeneous geologic materials.=====Furthermore, the intermediate shape for most of the watersheds is an indication that most of the watersheds are at medium stage of topographical maturity (18). Regarding the influence of shape on hydrologic response, there are conflicting reports. For instance, it was reported that a circular shaped basin takes long time to reach excess water to the basin outlet (31). This statement was supported by Arabameri et al. (3) who demonstrated that lower values of shape parameters indicating higher susceptibility to erosion. By contrast, many researchers, for instance, Farhan and Anaba (12) have shown that a circular basin is more efficient in runoff inducement than an elongated one. Similarly, Singh and Singh (30) reported that a circular basin is more efficient in the discharge of runoff than an elongated watershed. The results presented in Table 1 also reveal that the values of the elongation ratio are characterized by a wide variation, falling in between 0.371 for WS2 to 1.325 for WS12. About 67% of the presented values fell in between 0.6 and 1.0. This finding is in concordant with Schumm (3) findings, who reported that the values of elongation ratio generally vary between 0.6 and 1.0 over a wide range of geological and climatic environments. Close inspection of the results also revealed that the majority of the study watersheds (60%) fall in less elongated (0.7-0.8), elongated (0.5-0.7) and more elongated (Re < 0.5) and the rest of the watersheds falls in the oval and circular categories (Re >0.8). Watershed with Re values in the range of 0.6 - 0.8 are representing watersheds with high rugged relief and steep slopes (13). As mentioned earlier, conflicting results are found in literature about the effect of the shape parameters about the hydrologic response of the watershed. However, Da Cunha and Bacani (9) reported that a more elongated shape facilitates the runoff of water, which has a higher tendency to support erosion process. Similarly, Said et al. (29) revealed that the lower the value of the basin shape, the more will be the erodibility. Based on the obtained values of Re, it can be inferred that the obtained values are usually associated with high relief. It is worthy to mention that the analysis of form factor leads to similar conclusions. For instance, the present values of form factor are concomitant with those of elongation ratio. This implies the higher the elongation ratio the higher will be the form factor and vice versa. The Pearson's correlation coefficient is more than 0.98. On the contrary, it was observed that the compactness coefficient (Cc) was negatively correlated with the elongation ratio. However the majority of the C_c values are in the range of 1.0 – 2.0. The compactness coefficient close to 1 is for circular shaped basins, while the high values of this parameter indicate high degree of zigzagging and low flood (10).The length of overland flow is quietly synonymous with the length of sheet flow and approximately equals half the reciprocal of the drainage density (7). It can also be noticed from Table 1 that the slope length varies from as low as 0.274 km for WS2 to as high as 0.437 km for WS29. Additionally it can be observed that most of the study watersheds have slope lengths exceeding 0.30 km. A high value of slope length means gentle slopes and long flow paths more infiltration, and reduced runoff (27). Previous research revealed that the shorter the slope length, the faster will be the surface runoff from the streams.

Relief aspects

The relief aspects of the water under study encompass basin relief; relief ratio and ruggedness value (Table 1). The presented data in Table 1 discloses that with the one exception all the watersheds have basin relief of more than 300 m (0.3 km). This implies that judging from the basin relief the study area is characterized by having high relief (Bh > 0.30 m) (42). On the other hand, more than 56% of the watersheds fall in the weak relief ratio class (Rr < 0.1) (29). The higher values of relief ratio reflects steeper slope and high relief and vice versa. Meshram and Sharma (20) reported that low values of Rr suggest lesser soil erodibility mainly due to resistant basement rocks and low degree of slope. The results depicted in Table 1 also indicated that the ruggedness values of the study watershed are less than 8%. According to this parameter, all the watersheds fall in the low class (10). Furthermore, the low values of this parameter suggest that these watersheds are resistant to erosional process (27).

Watershed prioritization

Prioritization based on computation of compound factor

This study emphasizes on the prioritization of the study watersheds based on morphometric analysis of the watersheds that has been carried out using mathematical equations. Out of a huge number of watershed attributes, 12 parameters were selected as criteria for prioritization. The criteria are related to linear, shape and relief morphometric attributes. The linear attributes encompassed bifurcation ratio (Rb), drainage density (Dd), drainage frequency (Fs), texture ratio (Tr) and slope length or length of overland flow (Lg). The shape factor included each of elongation ratio (Re), form factor (R_f) and circularity ratio (R_c). On the other hand the relief feature covered each of basin relief (Bh), relief ratio (Rn) and ruggedness number (Rn) (Table 1). As each of the linear and relief feature parameters has a direct relationship with erodibility, the highest value of each parameter was rated as rank 1 and the second highest value as rank 2 and so forth. On the contrary, it was observed that each of the shape parameters has an inverse relationship with soil erodibility (25**).** Therefore, the lowest value of each of the shape parameters was rated as rank 1 and the second lowest value was rated as rank 2 and so forth (Table 2).The compound factor (C_f) for each watershed was calculated by summing up the ranks of the abovementioned parameters and dividing the result by (12). Thereafter, the lowest compound factor was rated as rank 1 and the lowest one was rated as rank 30. Finally, priority group was given to each watershed based on the value of its compound factor (Table 2). It appears from the data presented in Table 2 that the watersheds like WS18, WS22, WS29, WS24, WS23, WS6, WS7 and WS21 fell in the very high priority class. By contrast, the watersheds: WS16, WS27; WS3, WS17, WS26 and WS9 fell in the low priority class.

Prioritization based of TOPSIS

The same parameters utilized for prioritization according to the compound factor approach, were employed to determine the order of preference according to technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). As mentioned earlier, they are comprised of 5 linear parameters (Rb, D_d, F_s, Tr and L_g); 4 areal or shape parameters (R_e, F_f, C_c and R_c) and 3 relief features (B_h, R_r and R_n) (Table 1). The normalized decision matrix, R, was computed from the decision matrix X by using the Eq. [1] (Table 3). To obtain the weighted normalized matrix V, each column of matrix R was multiplied by the corresponding weight (Table 4). As a first approximation, an equal weight of 0.083 was given to each criterion instead of determining the relative weights by following the Saaty's Analytical Hierarchy Process (AHP).

Table 2. Prioritized ranks assigned to the erosion risk parameters of the study watersheds

Watershed ID	Bifurcation ratio (Rb)	Drainage density (Dd)	Drainage frequency (Fs)	Texture ratio(Tr)	Slope length (Lg)	Compactness coefficient (Cc)	Elongation ratio (Re)	Form factor (Ff)	Circularity ratio (Rc)	Basin relief (Bh)	Relief ratio (Rr)	Ruggedness Number	Compound Factor(Cf)	Prioirty rank
WS 1	11	12	21	14	11	21	22	22	10	12	12	11	14.917	14
WS 2	21	3	28	30	30	29	1	1	2	27	28	25	18.750	25
WS 3	20	6	6	15	25	9	25	25	22	24	16	23	18.000	23
WS 4	9	26	19	21	10	30	18	18	1	26	27	27	19.333	28
WS 5	1	7	24	16	21	27	9	9	4	23	26	21	15.667	16
WS 6	27	21	22	11	3	12	17	17	19	6	7	6	14.000	10
WS 7	26	23	10	20	2	6	12	12	25	7	4	7	12.833	7
WS 8	21	22	25	27	4	14	8	8	17	11	5	12	14.500	13
WS 9	10	25	18	10	13	10	28	28	21	21	15	22	18.417	24
WS 10	5	2	12	7	14	7	24	24	24	17	22	15	14.417	11
WS 11	25	28	8	18	21	2	16	16	29	8	3	10	15.333	15
WS 12	30	11	5	5	18	13	30	30	18	13	13	13	16.583	20
WS 13	12	1	27	22	29	28	7	7	3	20	23	14	16.083	18
WS 14	7	5	16	1	6	24	20	20	7	10	21	8	12.083	4
WS 15	6	18	29	28	12	19	15	15	12	15	8	16	16.083	18
WS 16	29	14	23	26	23	15	13	13	16	25	20	26	20.250	29
WS 17	8	19	7	24	23	16	29	29	15	22	10	24	18.833	27
WS 18	14	24	20	4	8	8	26	26	23	1	1	1	13.000	9
WS 19	4	13	14	9	15	25	5	5	6	16	25	17	12.833	7
WS 20	28	9	9	23	27	23	4	4	8	19	17	20	15.917	17
WS 21	3	10	17	3	7	11	10	10	20	9	18	9	10.583	2
WS 22	17	4	1	13	9	22	3	3	9	5	6	5	8.083	1
WS 23	24	16	13	6	5	3	19	19	28	4	9	2	12.333	5
WS 24	15	20	2	12	16	18	23	23	13	3	2	4	12.583	6
WS 25	19	15	3	19	28	17	6	6	14	29	30	28	17.833	22
WS 26	16	30	30	29	20	1	21	21	30	28	24	30	23.333	30
WS 27	13	8	11	8	26	20	27	27	11	18	19	19	17.250	21
WS 28	2	17	26	17	16	5	14	14	26	30	29	29	18.750	25
WS 29	23	27	15	2	1	26	11	11	5	2	14	3	11.667	3
WS 30	18	29	4	25	19	4	2	2	27	14	11	18	14.417	11

Upon attaining the positive ideal and negative ideal solutions from weighted normalized matrix, the separation measures from the ideal (S_i^+) and the negative ideal (S_i^-) solutions were calculated for all the watersheds according to Eqs. [3] and [4]. It is interesting to note that the minimum values of the shape factors are in favour of high erodibility, they were considered as negative criteria and the reverse was true for the linear and relief feature parameters. Thereafter, Eq. [5] was applied to determine the relative closeness to the ideal solution and the results were presented in the 4th column of Table 5. Finally, upon ranking the relative closeness of the watersheds in ascending order, the orders of preference of the watersheds were determined and presented in the last column of Table 5.

Table 3. The normalized decision matrix for ranking the existing watersheds in the study area

Watershed	Bifurcation ratio (Rb)	Drainage density (Dd)	Drainage frequency (Fs)	Texture ratio(Tr)	Slope length (Lg)	Compactness coefficient (Cc)	Elongation ratio (Re)	Form factor (Ff)	Circularity ratio (Rc)	Basin relief (Bh)	Relief ratio (Rr)	Ruggedness Number(Rn)
WS 1	0.173	0.182	0.169	0.147	0.188	0.185	0.191	0.175	0.155	0.146	0.156	0.160
WS 2	0.148	0.232	0.124	0.034	0.140	0.264	0.083	0.033	0.077	0.044	0.046	0.062
WS 3	0.151	0.195	0.199	0.138	0.168	0.159	0.209	0.209	0.211	0.057	0.096	0.066
WS 4	0.185	0.154	0.176	0.110	0.190	0.275	0.179	0.152	0.070	0.048	0.047	0.044
WS 5	0.360	0.195	0.164	0.134	0.172	0.208	0.150	0.107	0.123	0.061	0.053	0.072
WS 6	0.131	0.163	0.169	0.176	0.207	0.162	0.176	0.148	0.202	0.271	0.250	0.266
WS 7	0.138	0.161	0.195	0.120	0.210	0.155	0.159	0.120	0.221	0.211	0.292	0.205
WS 8	0.148	0.163	0.162	0.063	0.204	0.170	0.146	0.101	0.185	0.160	0.289	0.156
WS 9	0.182	0.155	0.177	0.185	0.185	0.159	0.269	0.345	0.210	0.072	0.109	0.067
WS 10	0.224	0.248	0.190	0.251	0.184	0.158	0.205	0.201	0.214	0.087	0.070	0.129
WS 11	0.142	0.143	0.196	0.130	0.172	0.146	0.175	0.147	0.250	0.205	0.307	0.177
WS 12	0.100	0.184	0.203	0.266	0.180	0.163	0.298	0.423	0.201	0.131	0.153	0.145
WS 13	0.171	0.285	0.145	0.103	0.150	0.214	0.137	0.090	0.116	0.076	0.063	0.131
WS 14	0.189	0.201	0.183	0.346	0.195	0.198	0.186	0.166	0.136	0.165	0.074	0.199
WS 15	0.211	0.170	0.113	0.062	0.186	0.183	0.172	0.142	0.159	0.126	0.214	0.128
WS 16	0.119	0.177	0.168	0.081	0.171	0.174	0.164	0.128	0.175	0.049	0.079	0.052
WS 17	0.186	0.165	0.197	0.088	0.171	0.176	0.272	0.353	0.171	0.065	0.200	0.064
WS 18	0.165	0.159	0.174	0.283	0.193	0.159	0.213	0.217	0.212	0.527	0.383	0.504
WS 19	0.227	0.180	0.184	0.210	0.183	0.198	0.132	0.083	0.135	0.106	0.056	0.115
WS 20	0.130	0.191	0.196	0.094	0.156	0.191	0.130	0.080	0.146	0.081	0.091	0.093
WS 21	0.257	0.188	0.182	0.298	0.194	0.160	0.151	0.109	0.207	0.167	0.086	0.189
WS 22	0.159	0.219	0.273	0.156	0.193	0.191	0.122	0.071	0.146	0.275	0.279	0.270
WS 23	0.144	0.177	0.187	0.266	0.201	0.151	0.182	0.158	0.235	0.285	0.212	0.303
WS 24	0.164	0.164	0.221	0.158	0.181	0.181	0.195	0.182	0.163	0.289	0.381	0.285
WS 25	0.151	0.177	0.213	0.128	0.155	0.179	0.133	0.085	0.166	0.036	0.041	0.039
WS 26	0.162	0.094	0.082	0.062	0.173	0.140	0.191	0.173	0.272	0.038	0.062	0.021
WS 27	0.168	0.192	0.190	0.234	0.165	0.184	0.244	0.285	0.157	0.086	0.084	0.099
WS 28	0.274	0.176	0.161	0.134	0.181	0.155	0.167	0.134	0.223	0.031	0.042	0.033
WS 29	0.145	0.151	0.183	0.322	0.223	0.207	0.155	0.114	0.124	0.324	0.123	0.295
WS 30	0.153	0.133	0.208	0.083	0.178	0.154	0.098	0.045	0.225	0.129	0.172	0.103

Furthermore, the study watersheds are categorized into 4 groups based on the relative closeness to the ideal solution (Table 6). It is evident from the above results (Tables 5 and 6) that watershed: WS18, WS22, WS29, WS24, WS23, WS6, WS7 and WS21 in descending order are very highly vulnerable to soil erosion. Accordingly, these watersheds should be put on to the top agenda to take immediate actions to conserve the natural resources via reducing excess soil and water losses. This will assist addressing the problematic areas to arrive at proper solutions. Soil, agronomic and mechanical measures can be taken to reduce the risk of soil erosion first in the watersheds categorized in very high level of priority level. Examples of mechanical measures are bench terracing, establishment of bunds, percolation tanks contour trenches, recharge shaft, check dams, etc. (7). This ensures the sustainability of agricultural production in the study area. By contrast, the watersheds: WS16, WS27, WS3, WS17, WS26 and WS9 are categorized under the low prioritization level.

Table 4. The weighted normalized decision matrix for ranking the existing watersheds in the study area

Watersheds	Bifurcatio ratio (Rb)	Drainage density (Dd)	Drainage frequency (Fs)	Texture Ratio (Tr)	Slope length (Lg)	Compactness coefficient (Cc)	Elongation ratio (Re)	Form factor (Ff)	Circularity ratio (Rc)	Basin relief (Bh)	Relief ratio (Rr)	Ruggedness Number (Rn)
WS 1	0.0144	0.0152	0.0141	0.0122	0.0157	0.0154	0.0159	0.0145	0.0129	0.0122	0.0130	0.0134
WS 2	0.0123	0.0193	0.0103	0.0028	0.0117	0.0220	0.0069	0.0028	0.0064	0.0037	0.0038	0.0051
WS 3	0.0126	0.0162	0.0166	0.0115	0.0140	0.0132	0.0174	0.0174	0.0176	0.0047	0.0080	0.0055
WS 4	0.0154	0.0129	0.0146	0.0092	0.0158	0.0229	0.0149	0.0127	0.0059	0.0040	0.0039	0.0037
WS 5	0.0300	0.0162	0.0136	0.0111	0.0143	0.0174	0.0125	0.0090	0.0102	0.0051	0.0045	0.0060
WS 6	0.0109	0.0136	0.0141	0.0146	0.0172	0.0135	0.0147	0.0123	0.0168	0.0226	0.0208	0.0221
WS 7	0.0115	0.0135	0.0163	0.0100	0.0175	0.0129	0.0132	0.0100	0.0184	0.0176	0.0243	0.0171
WS 8	0.0123	0.0136	0.0135	0.0053	0.0170	0.0141	0.0121	0.0084	0.0154	0.0133	0.0241	0.0130
WS 9	0.0152	0.0129	0.0148	0.0154	0.0155	0.0133	0.0224	0.0287	0.0175	0.0060	0.0091	0.0056
WS 10	0.0187	0.0207	0.0158	0.0210	0.0153	0.0132	0.0171	0.0168	0.0178	0.0072	0.0059	0.0108
WS 11	0.0118	0.0119	0.0164	0.0108	0.0143	0.0122	0.0146	0.0122	0.0208	0.0171	0.0256	0.0147
WS 12	0.0083	0.0153	0.0170	0.0222	0.0150	0.0136	0.0248	0.0353	0.0167	0.0109	0.0127	0.0121
WS 13	0.0142	0.0238	0.0120	0.0086	0.0125	0.0178	0.0114	0.0075	0.0097	0.0064	0.0052	0.0109
WS 14	0.0158	0.0167	0.0152	0.0288	0.0163	0.0165	0.0155	0.0138	0.0113	0.0137	0.0061	0.0166
WS 15	0.0176	0.0142	0.0095	0.0051	0.0155	0.0153	0.0143	0.0118	0.0132	0.0105	0.0178	0.0107
WS 16	0.0100	0.0148	0.0140	0.0068	0.0142	0.0145	0.0136	0.0107	0.0146	0.0041	0.0066	0.0043
WS 17	0.0155	0.0137	0.0164	0.0073	0.0142	0.0147	0.0227	0.0294	0.0143	0.0054	0.0166	0.0053
WS 18	0.0138	0.0133	0.0145	0.0236	0.0161	0.0132	0.0178	0.0181	0.0176	0.0439	0.0319	0.0420
WS 19	0.0189	0.0150	0.0154	0.0175	0.0153	0.0165	0.0110	0.0069	0.0113	0.0088	0.0046	0.0096
WS 20	0.0108	0.0159	0.0163	0.0078	0.0130	0.0159	0.0108	0.0067	0.0121	0.0068	0.0076	0.0078
WS 21	0.0214	0.0157	0.0152	0.0249	0.0162	0.0134	0.0126	0.0091	0.0173	0.0140	0.0072	0.0158
WS 22	0.0133	0.0183	0.0227	0.0130	0.0161	0.0159	0.0101	0.0059	0.0122	0.0229	0.0233	0.0225
WS 23	0.0120	0.0148	0.0156	0.0221	0.0167	0.0125	0.0152	0.0132	0.0196	0.0238	0.0177	0.0253
WS 24	0.0137	0.0137	0.0184	0.0131	0.0151	0.0151	0.0163	0.0151	0.0136	0.0241	0.0317	0.0238
WS 25	0.0126	0.0148	0.0177	0.0107	0.0129	0.0149	0.0111	0.0071	0.0138	0.0030	0.0034	0.0032
WS 26	0.0135	0.0079	0.0068	0.0051	0.0144	0.0116	0.0159	0.0145	0.0227	0.0031	0.0052	0.0018
WS 27	0.0140	0.0160	0.0158	0.0195	0.0138	0.0153	0.0204	0.0238	0.0131	0.0071	0.0070	0.0082
WS 28	0.0228	0.0147	0.0134	0.0111	0.0151	0.0129	0.0139	0.0112	0.0186	0.0026	0.0035	0.0027
WS 29	0.0121	0.0126	0.0153	0.0268	0.0186	0.0173	0.0129	0.0095	0.0103	0.0270	0.0102	0.0246
WS 30	0.0127	0.0111	0.0174	0.0069	0.0149	0.0128	0.0081	0.0038	0.0187	0.0107	0.0144	0.0086

Table 5. The closest coefficients, ranking and priority indices for ranking the existing watersheds in the study area

Watersheds	S+	S-	Sum	S-/Sum	Priority
WS1	0.0561	0.0350	0.0911	0.3843	16
WS2	0.0713	0.0426	0.1139	0.3739	19
WS3	0.0681	0.0282	0.0963	0.2931	27
WS4	0.0703	0.0330	0.1033	0.3198	23
WS5	0.0645	0.0415	0.1059	0.3915	14
WS6	0.0447	0.0462	0.0909	0.5082	6
WS7	0.0497	0.0448	0.0945	0.4737	7
WS8	0.0553	0.0425	0.0978	0.4346	11
WS9	0.0702	0.0232	0.0934	0.2481	30
WS10	0.0609	0.0364	0.0973	0.3739	18
WS11	0.0523	0.0426	0.0949	0.4490	10
WS12	0.0670	0.0305	0.0975	0.3130	24
WS13	0.0633	0.0400	0.1032	0.3871	15
WS14	0.0528	0.0444	0.0972	0.4565	9
WS15	0.0592	0.0362	0.0954	0.3796	17
WS16	0.0701	0.0318	0.1019	0.3119	25
WS17	0.0703	0.0240	0.0943	0.2548	28
WS18	0.0311	0.0720	0.1031	0.6980	1
WS19	0.0592	0.0417	0.1009	0.4129	12
WS20	0.0647	0.0378	0.1025	0.3691	20
WS21	0.0512	0.0459	0.0971	0.4723	8
WS22	0.0393	0.0546	0.0939	0.5817	2
WS23	0.0420	0.0494	0.0914	0.5405	5
WS24	0.0410	0.0518	0.0929	0.5582	4
WS25	0.0699	0.0371	0.1069	0.3467	21
WS26	0.0766	0.0261	0.1027	0.2544	29
WS27	0.0654	0.0290	0.0944	0.3069	26
WS28	0.0700	0.0346	0.1046	0.3312	22
WS29	0.0413	0.0537	0.0950	0.5654	3
WS30	0.0607	0.0423	0.1030	0.4106	13

Table 6. Classification of the watersheds into priority levels based on TOPSIS approach

Range of relative closeness to ideal solution		Priority level	Watersheds
Upper	Lower		
0.698	0.472	Very high	WS18, WS22, WS29, WS24, WS23,WS6,WS7,WS21
0.472	0.384	High	WS14, WS11, WS8,WS19, WS30, WS5, WS13, WS1
0.384	0.313	Moderate	WS15, WS10, WS2, WS20, WS25, WS28, WS4, WS12
0.313	0.248	Low	WS16, WS27, WS3, WS17, WS26, WS9

Comparison of the approaches for prioritization

Comparison of the results of the two approaches: compound factor computation and TOPSIS approaches revealed that they gave similar results. The high correlation between the priority ranks obtained by these two approaches (r = 0.80) is a good indication of close agreements between them (Figure 2). It can also be noticed from Figure 2 that the slope of the regression line is close to unity (0.80) and the intercept value close is to zero (1.70). Additionally, the non-parametric Wilcoxon signed rank test revealed no significant difference between the observed and the predictive values from the proposed model. The model: $Rank_{Topsis} = 0.897\ RanK_{compound\ factor} + 1.704$ can be used to convert the priority obtained from computation of compound factor to assess the rank level from TOPSIS approach with a reasonable accuracy

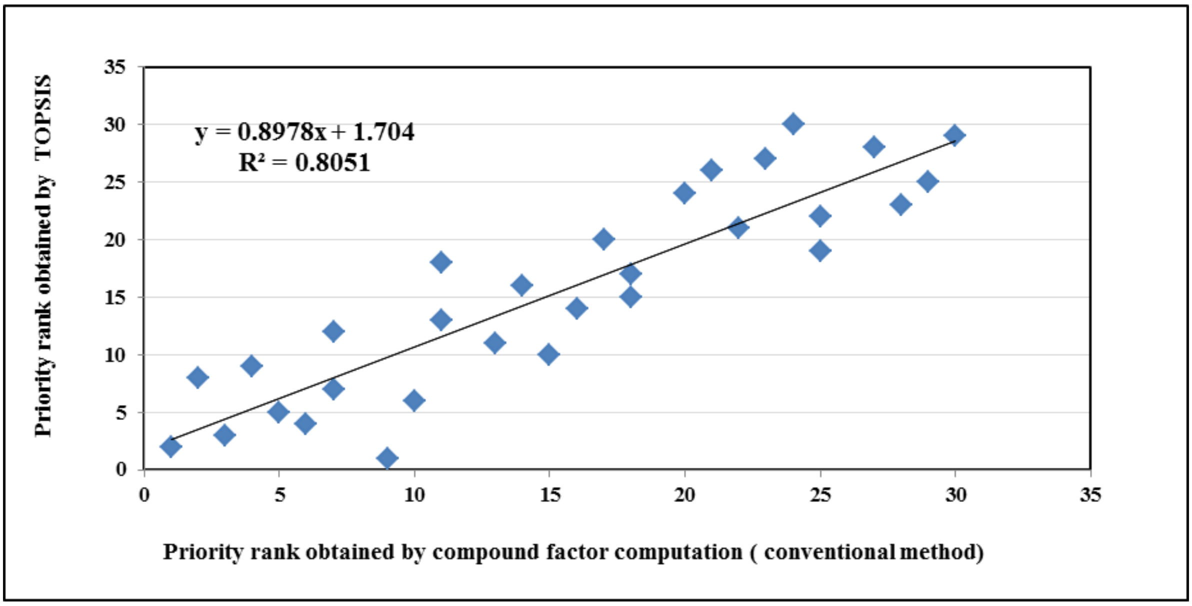

Figure 2. Plot of priority rank obtained by compound factor computation versus priority rank obtained by TOPSIS

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