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Watershed Prioritization Based on Morphometric Analysis and Soil Loss Modeling in Wadi Kerak (Southern Jordan) Using GIS Techniques

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Authors' contributions

This research was carried out in collaboration between both authors. It was designed, analyzed, interpreted, prepared and approved the final manuscript by both authors.

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ABSTRACT

Wadi Kerak catchment, located in southern Jordan, covers an area of 191 km². It is characterized by high soil erosion rates due to recurrent intense rainfall events and possibly climatic change, land use/land cover changes since the 1950s, and the dependence of people across the watershed upon rainfed and irrigated farming. The aim of this research is to determine soil conservation prioritization for thirty one third-order mini-watersheds (MW1-MW31) based on morphometric analysis and soil loss modeling methods. Linear and shape morphometric parameters have been computed for each mini-watershed on the basis of their value/relationship with erodibility, and rank is assigned in order to obtain compound values for final ranking of the mini-watersheds . Soil loss rates also have been estimated using the RULSE model. RULSE factors (R, K, L, S, C, and P) were calculated in a GIS environment, then multiplied together so as to compile soil loss maps/tables, and to estimate soil loss(ton ha^{-1} $year^{-1}$)for the thirty one mini-watersheds. Based on morphometic parameters and soil loss values, and their rankings, the mini-watersheds have been grouped into five classes: extremely high, very high, high, moderate, and low with reference to their priority for conservation practices and watershed management. Two maps were generated separately and illustrate the prioritization of the mini-watersheds based on morphometric analysis

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and soil loss modeling. Then an integration of the two maps was conducted to recognize the common mini-watersheds falling under each category of priority. It can be demonstrated that 50% of the mini-watersheds can be grouped under moderate, high, very high and extremely high priority based on both soil loss modeling method and morphometric analysis. Consequently, a considerable number of the mini-watersheds should be prioritized for implementing soil and water conservation measures to ensure future sustainable agriculture.

Keywords: Morphometry; soil loss modeling; watersheds prioritization; compound factor; Wadi Kerak; Jordan.

1. INTRODUCTION

Wadi Kerak watershed is part of the Kerak Governorate (Southern Jordan), and covers an area of 191 km^2. The terrain units exposed across the catchment are vulnerable to soil erosion due to geologic, geomorphic, climate, and land use conditions compared to other catchments draining to the Jordan rift. Hence, severe soil erosion is experienced including landslide activity. The predicted annual average of soil loss rates is highly exceeds other highland drainage basins [1]. The term "watershed" refers to a physical hydromorphic unit which proved to be fundamental for watershed management and sustainable development of natural resources. It is delineated by natural boundaries (water divide) which makes it distinct from other watersheds. Variation in physical composition such as morphology, slope, climate, hydrological conditions, soils and vegetation is visible across the watershed (i.e., the upper, middle and lower reaches of the catchment). Watersheds for prioritization purposes should be generally less than 500 km^2 in area. Therefore, watersheds are suggested to be classified based on area (km^2) as: sub-watersheds, covering an area of about 30-50 km^2; mini-watersheds (10-30 km^2) and micro-watersheds (5-10 km^2) [2].

Quantitative morphometric analysis of drainage basins was adopted recently as a fruitful technique to prioritize watersheds for soil and water conservation measures [3-7,2,7,8-11]. Morphometric analysis in this regard displays intrinsic information related to drainage basins such as morphology, slope, soils, runoff characteristics, and potential of water resources. The development of landforms and the associated terrain units, drainage network properties, drainage pattern and texture depends heavily on solid and drift geology including structure. Thus, geomorphometric analysis of watersheds and the drainage networks provide important and relevant information on the hydro-geomorphic characteristics of watersheds [12].

Morphometric analysis was conducted to prioritize watersheds for soil conservation purposes, using linear and shape morphometric parameters, which are selected based on their relation to erodibility. The linear parameters employed are: the bifurcation ratio, drainage density (km/ km^2), texture ratio, length of overland flow and stream frequency (no/km^2). Similarly, the shape parameters adopted are: compactness coefficient, circularity ratio, elongation ratio, shape factor, and form factor. Often, watersheds are prioritized based on different approaches of analysis. However, the common methods utilized are: the morphometric, land use/land cover, soil loss modeling (i.e., using USLE or RUSLE models), Sediment Yield Index (SYI) model, or alternatively two of these methods used to be carried out. Recent studies on prioritization of watersheds can be grouped based on the method of analysis adopted, into the following:

(i) Morphometric analysis, Sediment Yield Index(SYI)model, and sediment product rate(SPR) [3-5],
(ii) Morphometric analysis, and land use/land cover parameters [7, 2],
(iii) Morphometric indices, and annual soil loss prediction using RUSLE approach [6],
(iv) Morphometric analysis only [13, 9], and
(v) Morphometric indices and the Fuzzy Analytical Hierarchy Process [11].

Adoption of soil and water conservation measures is based heavily on intrinsic physical and cultural attributes which led to identify erosion prone areas. Sediment yield models in this context, does not provide absolute value of sediment yield at outlet of a watershed, but provide a relative erodibility based on limited factors(i.e. slope, soil type, and land use/land cover), occasionally combined with few morphometric indices (i.e. form factor, circularity ratio, and compactness coefficient) [3,6,4]. Further, morphometric analysis is considered an indicative of hydrological behaviour of a watershed. Similarly, the parameters of RUSLE model utilized in this study, were evaluated based on relatively precise grid cells of 30 m x 30 m, thus, the physical and cultural factors which affect soil loss rates were calculated for different cells. Consequently, prioritization of watersheds based on the integration of morphometric analysis, and soil loss modeling methods, provide more consistent results.

Soil loss modeling, integrated with morphometric analysis were employed in the prioritization of watersheds for soil conservation measures (Hlaing et al. 2008). Similarly, [14] the morphometric analysis method and soil erosion susceptibility approach [15-16] were adopted for prioritization of Wadi Shueib (Central Jordan) for conservation measures. In the present research, the intention is to prioritize W. Kerak watershed for soil conservation based on the morphometric analysis method, and soil loss modeling (RUSLE model) to produce two priority layers/maps. A third priority map was then generated by superimposition of the two maps obtained from both methods so as to assess the relationship, if any, between the resultant maps, and to explore the common priority that may exists between the mini-watersheds.

GIS techniques are considered an effective tool for watershed prioritization, sustainable development and management of environmental resources. Morphometric analysis is a key to understand the hydro-morphological processes, and characteristics of drainage networks. Basic, linear and shape morphometric parameters can be calculated using DEM's, Arc GIS tool, and mathematical formulas elaborated for this purpose [17-21]. The objective of the present study is to prioritize mini-watersheds of W. Kerak using morphometric analysis and soil loss modeling methods. A priority map was achieved based on each method. A third priority map was then compiled through superimposition of the two maps obtained earlier from the two methods. The resultant materials provide significant information which can be employed to establish an effective soil and water conservation plans, to secure sustainable agricultural development.

2. STUDY AREA

Wadi Kerak watershed, southern Jordan (Fig. 1) is bounded between latitudes 31° 14´–31° 17´ North, and longitudes 35° 30´–35° 44´ East, and covers an area of 191 km^2. Elevations vary from 1250 m(a. s. l) in the Mazar area, decreasing to 1000 m, and 410 m(b. s. l) at Kerak city, and the east shore of the Dead Sea respectively. The catchment represents a typical highland rift (Ghor) morphology, thus, climatic variation is pronounced along the watershed. The climate is "dry Mediterranean" in the Mazar–Kerak area (the upper reaches), and arid in Ghor Mazra'a/ Dead Sea area. The rainfall is concentrated in winter(October-March) months. Mean annual rainfall decreases rapidly from 325mm at Kerak city, to 77.5 mm at Ghor Mazra'a to the west, and 290 mm at Mazar town to the east. Heavy rain storms with maximum daily intensity of 2.1-6.66 mm hr^{-1} are recorded in the Jordan highlands including the Kerak area [22-23]. It is expected that rainfall intensity may increase in the future, possibly due to climate change [24]. Thus, serious soil erosion in W. Kerak watershed is predictable.

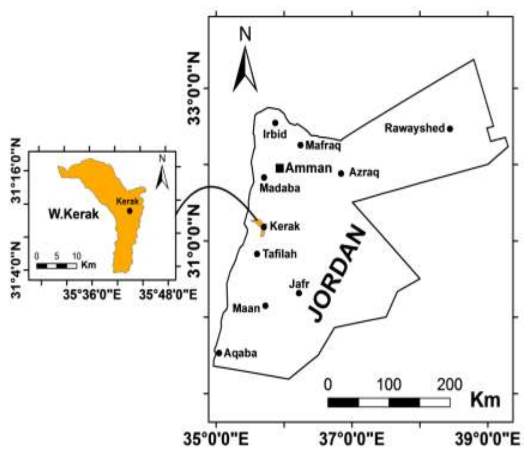

Fig. 1. Study area

The average maximum temperature for Kerak city is 17ºC, whereas, the minimum temperature for Mazar town is 2℃. Further, the average maximum temperature in Ghor Mazra'a is 32° C with summer months reaching 40℃. Several days of freezing temperature (below 0.0℃) are common in Mazar town between November and February. Successive rejuvenation of Wadi Kerak, associated with repeated lowering of the base level (the Dead Sea), resulted in progressive river incision of the wadi. Uplifting of the eastern plateau during late Tertiary and Quaternary tectonics produced irregular slope units (15-35º) separated by rocky benches. When major breaks of slopes combined with major long profile irregularities, four or five rejuvenation phases can be recognized [25]. The dominance of incised channels and over-steepened slopes across the watershed encourage soil erosion and landslide activity.

Most of the W. Kerak watershed is dominated by clay loam, silty clay, silty clay loam and silty loam soils [26] and are characterized by very low permeability. Therefore, the estimated soil loss due to water erosion is found to be extremely high in a considerable part of the basin [1].

The vegetation cover in the southern highlands is poor and degraded due to noticeable arid conditions characterized by low annual rainfall, and recurrent drought. Factors accelerating soil erosion could be summarized in the following: continuous deforestation, historical exploitation of land resources, past and present overgrazing, land use/land cover changes since the 1950s, farming system, and poor conservation measures. Several rock units are exposed across the wadi, and range from late Cambrian sandstone to Quaternary deposits (i.e., fluvial terraces, lacustrine Lisan Marl, and the alluvial fan of Wadi Kerak). The Kurnub sandstone of Lower Cretaceous age, is exposed along the incised middle course of the wadi. The Kurnub sandstone is overlain by two lithological units of Turonian–Cenomanian age (Upper Cretaceous), and dominate the middle catchment. These are the nodular limestone unit (or the marly-clay unit), and the echinoidal limestone unit (or the limestone-marl unit). A third lithological unit (Eocene–Senonian rocks) dominates the catchment east of Kerak. The spatial distribution of weak rocks with low shearing resistance represents a major factor controlling slope stability and soil erosion loss. In this regard, W. Kerak is also a part of the Kerak–Al–fiha fault system and the secondary dense branching faults to the north and south of the wadi. The major faults are of early Miocene, and are occasionally concealed under the regolith materials of the old landslide complexes [27-28].

3. MATERIALS AND METHODOLOGY

In the present investigation, soil loss modeling and morphometric analysis were employed in the prioritization for soil conservation (Fig. 2). Topographic maps of scale 1:50000 (20 m contour interval) were acquired for the Wadi Kerak catchment, then scanned, georeferenced, and converted toWGS–1984, zone 36° N projection system using Arc GIS 10.1 software and the associated packages. The catchment was demarcated using topographic sheets and ASTER DEM (30 m resolution).

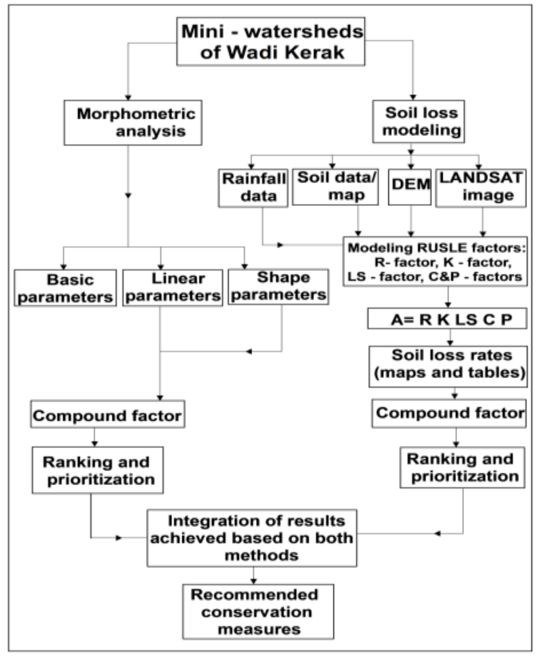

Fig. 2. Methodology of the present study

Slope categories and elevation zones were also derived from the ASTER DEM. The drainage network of W. Kerak and the thirty one third order mini-watersheds were generated. Stream ordering of the main catchment and the mini-watersheds has been ranked according to Strahler's method of the hierarchical ranking system [29]. Based on drainage order, the wadi Kerak catchment is classified as a fifth order basin (Fig. 3). The morphometric properties (basic, linear, and shape parameters) for the entire W. Kerak and the drainage networks related to the mini-watersheds were derived and calculated using GIS software and the mathematical equations developed and elaborated by [17,29,18-19,21,20,5] (Tables 1 and 2). Available quantitative and semi-qualitative models for estimating soil loss at a catchment scale were reviewed and assessed in detail [30-31]. Empirical (i.e., USLE and RUSLE), conceptual (i.e. AGNPS and SWAT), and physical–based models (i.e., AGNPS) for soil erosion and sediment transport were recently reviewed and discussed [32] in terms of their intrinsic characteristics. In the present study, average annual soil loss was estimated using the revised soil loss equation (RUSLE) [33], and the soil erosion risk map can be generated.

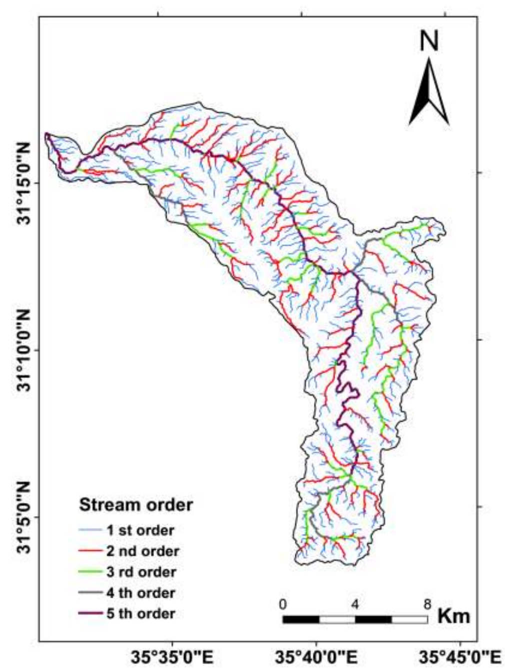

Fig. 3. Stream order of W. Kerak

The RUSLE model represents how climate (rainfall erosivity), topography (slope length and slope steepness), soil (soil erodibility), vegetation and land use/cover (cover management practice), and conservation measures (erosion control practice) affect rill and sheet erosion caused by raindrop impact and surface runoff [33]. It has been recognized that the RUSLE model is the most widely used empirical model to predict soil erosion loss spatially, and to guide a soil conservation plan in order to control soil erosion [34-35]. With the RUSLE model, it was possible to estimate the average annual soil loss for any number of scenarios in relation to cropping systems, land management techniques, and erosion control practices.

Coupled with the GIS environment, soil erosion loss is predicted on a cell-by-cell basis [34]. Thus, grid cells of 30 m × 30 m size were determined before the calculation of the physical characteristics of these cells such as: slope, land use, and soil type, all of which affect soil erosion processes in different cells of the catchment. Such a procedure is essential for creating a uniform spatial analysis environment for GIS modeling [36-37]. The average annual soil loss of (A) in tons per hectare per year was quantified using RUSLE, expressed by the following equation (Renard et al. 1997):

$$A = R \times K \times LS \times C \times P \quad (1)$$

Where:

A indicates the average annual soil loss due to water erosion (ton ha^{-1} $year^{-1}$);

R is the rainfall–runoff erosivity factor [MJ mm, (ha^{-1} h^{-1} $year^{-1}$)];

K is the soil erodibility factor (soil loss per erosion index unit for a specified soil measured on a standard plot, 22.1 m long, with uniform slope 5.13º, in continuous tilled fallow) [ton h MJ^{-1} ha^{-1} mm^{-1}];

LS is the slope/length and slope steepness factor;

C is the cover management practice factor (values are ranging between 0 and 1.5); and

P is the conservation support, or erosion control practices factor (values ranging between 0 and 1).

To generate a soil loss map, rainfall data for calculation of rainfall erosivity (R) was provided by the Ministry of Water and Irrigation. The soil data and the maps of soil units and the associated information, were obtained from the National Soil Map and Land Use Project [26]. Associated with soil map/data, is detailed information on slope (%), soil depth, texture, structure, permeability and organic matter. Clay loam, silty clay, silty clay loam, and silty loam soils dominate most of the catchment, and are characterized by very low permeability. Therefore, runoff erosion is expected to be high. The slope categories map (Fig. 4) suggests that the catchment is highly dissected, with high elevation, over steepened slopes and incised channels. The range of slopes varies from flat gentle slopes (5°-6°) to very steep slopes (25°-35, and > 35°), increasing towards the west along the valley–side slopes of the incised channels, and the hogbacks of Ed-Dhira flexure close to the Ghor. Here, extremely steep slopes exist, approaching 70° of gradient. The steepness of slope affects the erodibility of soils, where steep terrain units are more vulnerable to runoff erosion than flat terrain [38]. Moreover, [39] stressed the role of human impact on soil erosion, reporting that forest cover, agricultural and grazing practices, urbanization, road construction, deformation of slopes, and land use/cover changes have extensive spatial effects on runoff, which in turn control the rates of soil erosion and sedimentation. The data layers (maps) extracted for R, K, LS, C, and P factors of the RUSLE model were integrated within the raster calculator option of the Arc GIS spatial analyst in order to quantify and generate a soil erosion loss map for the entire W. Kerak catchment, and to estimate soil erosion loss for the thirty one third order mini-watersheds.

A great number of published studies have discussed the RUSLE model in detail, with application in a large variety of case studies worldwide, i.e., [33-34,40,35,41-42,36-37,43,1]. Morphometric analysis of linear and shape parameters, coupled with the estimated soil loss method, were employed for prioritization of the thirty one mini-watersheds. Two priority maps were produced based on each method, then a third priority map was generated by integrating the results obtained from both methods (the two maps) in order to evaluate the correlation if any between the two generated maps, and to illustrate the common priority that may found between the mini–watersheds.

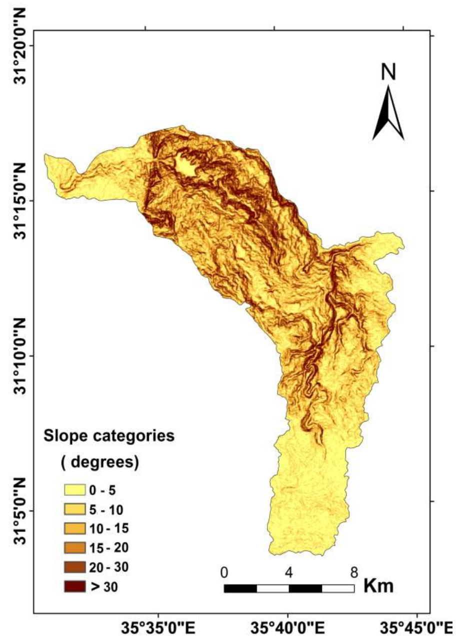

Fig. 4. Slope categories (degrees)

Table 1. Morphometric characteristics of W. Kerak

Par. no.	Parameters	Stream order				
1	Stream order(u) (5)	I	II	III	IV	V
2	No.of Streams order (Total) (N_u) (762)	616	110	30	5	1
3	Stream length (L_u) (km) (488.556)	256.771	116.984	51.145	20.813	42.823
4	Mean Stream length (L_{sm}) (km) (0.641)	0.416	1.063	1.704	4.162	42.823
5	Stream length ratio (R_L)		0.445 II/I	0.437 III/II	0.406 IV/III	1.057 V/Iv
6	Bifurcation ratio (R_b)		5.60 I/II	3.66 II/III	6 III/IV	5 IV/V
7	Mean bifurcation ratio (R_{bm})	5.302				
8	Perimeter (P) (km)	99.490				
9	Basin length (L_b)	33.950				
10	Basin area (A) (km^2)	190.900				
11	Basin relief (B_h) (m)	1661				
12	Relief ratio (R_r)	0.048				
13	Elongation ratio (R_e)	0.459				
14	Circularity ratio (R_c)	0.241				
15	Lemniscate ratio (k)	1.509				
16	Drainage density (D_d) (km/km^2)	2.559				
17	Stream frequency (F_s)	3.981				
18	Form factor (R_f)	0.165				
19	Shape factor (S_f)	6.050				
20	Drainage Texture (D_t)	7.659				
21	Dissection Index (D_Is)	1.300				
22	Ruggedness number (R_n)	4.250				
23	Drainage intensity (D_i)	1.555				
24	Length of overland flow (L_o)	1.279				
25	Hypsometric integral (H_i)	0.651				

Table 2. Morphometric characteristics of the thirty one mini-watersheds of Wadi Kerak

Mini-basin	A	P	L_b	L_u	N_u	N1	R_b	D_d	F_s	T	L_o	R_f	B_s	R_e	C_c	R_c	R_n	R_r
1	1.28	4.80	1.96	2.94	7	4	2.00	2.29	5.46	0.83	1.14	0.33	3.00	0.65	1.20	0.69	0.16	0.03
2	2.38	6.68	2.22	6.95	17	12	3.23	2.92	7.14	1.79	1.46	0.48	2.07	0.78	1.22	0.66	0.17	0.02
3	3.03	8.23	3.30	8.51	19	15	4.36	2.80	6.27	1.82	1.40	0.27	3.59	0.56	1.33	0.56	0.25	0.02
4	2.67	7.69	2.60	6.68	11	8	5.07	2.50	4.12	1.04	1.25	0.39	2.53	0.70	1.33	0.57	0.27	0.04
5	4.62	9.92	3.38	12.02	19	15	4.36	2.60	4.11	1.51	1.30	0.40	2.47	0.71	1.30	0.58	0.35	0.04
6	2.37	7.52	2.73	6.04	10	7	3.12	2.55	4.22	0.93	1.28	0.31	3.14	0.63	1.38	0.52	0.27	0.03
7	2.17	7.27	3.08	5.61	11	8	3.53	2.58	5.06	1.10	1.29	0.22	4.37	0.53	1.40	0.51	0.30	0.03
8	0.800	3.73	1.35	2.15	7	4	2.00	2.68	8.75	1.07	1.34	0.44	2.28	0.74	1.18	0.72	0.91	0.05
9	12.17	16.96	6.73	27.54	42	35	5.00	2.26	3.45	2.06	1.13	0.26	3.72	0.58	1.37	0.53	0.57	0.03
10	1.07	4.56	1.57	2.91	9	6	2.35	2.71	7.47	1.53	1.36	0.43	2.30	0.74	1.24	0.64	0.40	0.09
11	3.88	8.73	3.34	8.17	13	10	4.40	2.10	3.35	1.14	1.05	0.34	2.87	0.66	1.25	0.63	0.73	0.10
12	4.22	10.37	4.71	8.98	16	13	5.75	2.12	3.79	1.25	1.06	0.19	5.25	0.49	1.42	0.49	0.65	0.06
13	4.17	12.63	5.40	9.83	17	14	6.21	2.35	4.07	1.10	1.17	0.14	6.99	0.42	1.74	0.32	1.48	0.11
14	3.53	8.75	3.87	9.05	13	10	4.33	2.56	3.68	1.14	1.28	0.23	4.24	0.54	1.31	0.57	1.54	0.15
15	3.38	8.35	3.45	7.35	17	14	6.21	2.17	5.02	1.67	1.08	0.28	3.52	0.60	1.28	0.61	0.33	0.04
16	3.88	9	3.45	8.99	18	14	4.34	2.32	4.38	1.55	1.16	0.32	3.06	0.64	1.29	0.60	0.29	0.03
17	2.80	8.86	2.55	8.07	13	9	3.00	2.88	4.64	1.01	1.44	0.43	2.32	0.74	1.49	0.44	1.61	0.21
18	5.94	12.67	5.67	13.18	18	14	4.34	2.21	3.03	1.10	1.11	0.18	5.41	0.48	1.52	0.46	1.30	0.10
19	2.79	7.60	2.81	7.69	15	11	4.84	2.75	5.37	1.44	1.37	0.35	2.83	0.67	1.28	0.61	2.13	0.27
20	1.57	5.73	2.32	4.28	8	5	4.10	2.72	5.09	0.87	1.36	0.29	3.42	0.60	1.19	0.60	2.09	0.33
21	1.91	5.87	2.52	6.06	10	7	3.12	3.17	5.23	1.19	1.58	0.30	3.32	0.62	1.22	0.69	1.99	0.25
22	0.96	4.31	1.90	2.24	7	4	2.00	2.33	7.29	0.92	1.16	0.26	3.76	0.58	1.24	0.64	1.38	0.31
23	5.53	10.39	4.39	13.51	23	18	4.40	2.44	4.16	1.73	1.22	0.28	3.48	0.60	1.24	0.64	2.13	0.19
24	1.37	5.66	2.21	3.71	9	6	2.18	2.71	6.56	1.06	1.35	0.28	3.56	0.59	1.04	0.53	0.87	0.14
25	2.28	6.21	2.07	5.71	11	8	3.53	2.50	4.82	1.28	1.25	0.53	1.87	0.82	1.16	0.74	2.01	0.38
26	2.20	6.74	2.77	5.26	12	9	3.96	2.39	5.45	1.33	1.19	0.28	3.48	0.60	1.28	0.61	1.96	0.29
27	3.37	8.07	2.71	10.43	13	10	4.40	3.09	3.85	1.23	1.55	0.46	2.17	0.76	1.24	0.65	2.72	0.32
28	1.60	6.13	2.59	4.72	8	5	2.35	2.95	5.00	0.81	1.47	0.24	4.19	0.55	1.36	0.53	2.04	0.26
29	3.96	10.29	4.61	11.22	14	11	4.84	2.83	3.53	1.06	1.42	0.19	5.36	0.48	1.46	0.46	2.23	0.17
30	1.64	5.40	2.35	4.75	9	6	2.72	2.89	5.48	1.11	1.45	0.29	3.36	0.61	1.18	0.70	1.69	0.24
31	2.15	7.41	3.42	8.23	10	7	3.12	3.82	4.65	0.94	1.91	0.18	5.44	0.48	1.43	0.49	0.69	0.05

4. RESULTS AND DISCUSSION

4.1 Morphometric Analysis

Quantitative analysis of W. Kerak and the thirty one mini-watersheds was conducted to assess the properties and characteristics of the drainage networks. Twenty–five morphometric parameters which represent drainage network, basin geometry, drainage texture analysis, and relief characteristics were computed, namely: stream order, stream length, bifurcation ratio, perimeter, basin length, basin area, relief ratio, elongation ratio, circularity ratio, lemniscates ratio, drainage density, stream frequency, form factor, shape factor, drainage texture, dissection index, ruggedness number, drainage intensity, length of overland flow, and hypsometric integral (Table 1). Furthermore, five shape and five linear parameters were also calculated for the thirty one third-order mini-watersheds to prioritize them for soil conservation. All the mini-watersheds showed trellis drainage pattern, which indicates the influence of geological structure (mainly the Kerak-Al-fiha fault system)on drainage networks. Stream ordering has been ranked according to the method elaborated by Strahler [29]. Based on drainage order, W. Kerak watershed is classified as a fifth–order basin with an area of 191 km^2, 33.95 km in length, and a perimeter of 99.49 km. The total number of streams (Nu) is 762, and the first–order streams account for 81% of the total number of streams in the watershed [44]. The first–order streams constitute 52.1% of the total stream length, and the total stream length is 488.54 km. The mean stream length (L_{sm}) values for the W. Kerak watershed vary from 0.42 to 4.162, and the mean bifurcation ratio (R_{bm}) for the entire catchment is 5.3 (Table 1).

4.1.1 Basic parameters

The calculated basic parameters for the thirty one mini-watersheds are: the area (A), perimeter (P), stream order (u), basin length (L_b), and stream length (L) (Table 2).

4.1.1.1 Area (A) and perimeter (P)

The drainage area is considered the most hydrological variable characterized a watershed. It reflects the volume of water that can be generated from precipitation. The mini-watershed no. 4 has a minimum area of 0.8 km^2, while the mini-watershed no. 9 covers the maximum area (12.17 km^2). The basin perimeter refers to the length of the water divide line of the mini-watershed. The maximum and minimum values of perimeter are 16.96 km for mini-watershed no. 9, and 3.73 km for mini-watershed no. 8 respectively.

4.1.1.2 Stream order (u)

The stream order parameter was developed by [17,29,18-19] to describe the drainage network quantitatively. The flow of first order stream which has no tributary depends totally on the surface overland flow to it. Similarly the second–order stream has a higher surface flow, and the third–order streams receive flow from two second–order streams [8]. In the present research, all the thirty one mini-watersheds are of third-order, and the numbers of first–order streams (N_1) vary from one mini-watershed to another. It ranges from 35 first–order streams (MW no. 9) to 4 first–order streams (MW nos. 1, 8, and 22). By contrast, the number of first–order streams (N_1) and the number of streams (N_u) for each mini-watershed is higher in the middle part of W. Kerak than in the upper and lower reaches of the basin (Table 2). This is attributed mainly to: the influence of dense faults, joints, and fissures associated with the Kerak-Al-fiha fault system, the presence of weak rocks (the clay-Marl, and the marly-limestone units), and landslides, where most of the springs also issuing at the middle part of the catchment. It is expected that surface overland flow, landslide activity, and soil erosion rates are higher on this part of the watershed.

4.1.1.3 Total length of streams (L_u)

The number of different stream orders related to each mini-watershed was computed, and their lengths measured (Table 2). The flow of first-order stream depends totally on the surface overland flow connected with it. Thus, the second-order stream has a higher surface flow, and the third-order streams receive overland flow from two second-order streams [9]. All mini-watersheds are of third- order streams, but the total stream length of all orders varies considerably. Among the thirty one mini-watersheds MW no. 9 has the lowest total length of streams (2.15 km). Whereas,, the greatest total length of streams is related to mini-watersheds located at the middle part of the W. Kerak watershed.

4.1.1.4 Basin length (L_b)

Basin length refers to the ratio of the longest dimension of a watershed, to its main channel (i.e. from the basin outlet to the basin divide). The basin length is therefore measured along the longest flow path. Hence, it is considered a basic input parameter to compute shape parameters. L_b parameter is decisive in hydrological computation and increases as the drainage increases and vice versa [8]. Accordingly, basin length in the thirty one mini-watersheds varies between 1.35 km (MW 8) and 6.73 km (MW 9).

4.1.2 Linear parameters

The linear parameters which are considered in prioritization of watersheds through morphometric analysis are: bifurcation ratio, stream frequency, drainage density, length of overland flow, and texture ratio.

4.1.2.1 Bifurcation ratio (R_b)

R_b constitutes the ratio of the streams number of a given order to the number of streams of the next higher order [17]. The bifurcation ratio has been elaborated as an index of relief and dissection. Bifurcation ratios for drainage basins are often range between 2 for flat/rolling topography, and 6 for catchments controlled by geological structure, and where the drainage pattern is also highly distorted. By contrast, low values of R_b dominate watersheds less structurally disturbed, or catchments without any distortion of drainage system [19]. It is argued that a small range of variation in R_b values exists between different geologic and geomorphic regions, except where geological and structural controls exist. Eminent variation observed in the bifurcation ratios (R_b) of Wadi Kerak mini-watersheds(Table 2). MW no. 1, for example, has a minimum R_b of 2.0, while mini-watersheds nos.12, 13, and 15 have maximum R_b ratios of 5.75, 6.21, 6.21 respectively. The R_{bm} value for the entire W. Kerak is 5.3. It is obvious that R_b values are relatively high, mainly for the mini-watersheds occupied the middle part of the catchment (4-5, and >5).

4.1.2.2 Drainage density (D_d)

Drainage density refers to the closeness of spacing of channels. It is calculated as the total length of streams in a watershed per unit area, thus it is a measure of terrain dissection and runoff potential of the watershed. A high value of D_d would indicate a relatively high density of streams and hence, a quick stream response. High drainage density of a watershed is indicative of high runoff, and consequently a low infiltration rate. By contrast, low drainage density of a basin implies low runoff and high infiltration [45]. [19] postulated that low D_d occurs when basin relief is high as in the case of W. Kerak (B_h value is 1661 m).Other significant factors determining D_d are infiltration–capacity of the soil, and initial resistance of terrain against erosion. The poorly drained basins have a drainage density of 2.74, while a well-drained one has a density of 0.73, or one fourth as great [17]. The values of D_d for the thirty one mini-watersheds are relatively low, where the D_d values for twenty eight mini-watersheds range from 1.02 km/km^2 (MW no. 16) to 2.95 km/km^2 (MW no. 28) (Table 2), which implies the presence of highly dissected topography, steep slopes and permeable subsurface materials.

4.1.2.3 Stream frequency (F_u)

F_u is defined as the ratio of total number of streams (N_u) in a catchment to the watershed area (A). It represents the number of streams per unit of area [17]. Often, the value of stream frequency ranges from 3.91 to 9.99. The stream frequency value depends mainly on the lithology of the drainage basin and, resembles the texture of the drainage network. Stream frequency is positively correlated with D_d value of the basin, which means that the increase in stream population is connected with that of drainage density [46]. For small and large drainage basins, values of D_d and F_u are not directly comparable because they normally vary with the size of the drainage area. High F_u values indicate more percolation, and thus, more groundwater potential [47]. The value of stream frequency (F_u) ranges from 3.03 (MW 18) to 8.75 (MW 8) (Table 2), and the F_u value for the entire Wadi Kerak catchment is ≈ 4.

4.1.2.4 Texture ratio (T)

Texture ratio is computed as the ratio of total number of streams of the first order (N_1) to the perimeter (P) of the basin. It is one of the fundamental factors in morphometric analysis of a catchment. Texture ratio depends on lithology, infiltration capacity, and relief aspect of drainage basins [48]. The value of texture ratio ranges generally from 0.81 (MW no. 28) to 2.06 MW no. 9), and for the entire Wadi Kerak is 6.2, which denotes that the watershed is of relatively moderate runoff.

4.1.2.5 Length of overland flow (L_o)

L_o represent the length of water over the land surface before it is concentrated into defined stream channels. It is equal to half of drainage density [17]. The length of overland flow ascribes inversely to the average slope of stream channel [8], and is considered a significant independent parameters influencing hydrographic and hydrologic development of drainage basins [17,48]. The length of overland flow for the Wadi Kerak catchment is 1.279, and for the mini-watersheds ranges from 1.05 (MW no. 11) to 2.53 (MW no. 7) (Table 2).

4.1.3 Shape parameters

Shape parameters include elongation ratio, form factor, shape factor, circularity ratio, and compactness coefficient (ratio).

4.1.3.1 Form factor (R_f)

R_f represents the ratio of the area of the basin to the square of basin length [18]. It is elaborated to predict the intensity of the basin of a confined area. For a perfectly circular basin, it is suggested that the R_f parameter value to be less than 0.79 [49]. The smaller the value of form factor (<0.45), the more the basin will be elongated. The basin with high form factor is characterized with high peak flow of shorter duration. Whereas, an elongated sub-basin with a low form factor, has a low peak flow of longer duration. The R_f value for W. Kerak catchment is 0.165, and for the thirty one mini-watersheds ranges from a minimum of 0.14 (MW no. 25), which indicates the dominance of elongated shape for the mini-watersheds, thus characterized with flatter peak flow for longer duration.

4.1.3.2 Shape factor (B_s)

Shape factor is defined as the ratio of the square of the basin length to the area of the basin, and is in inverse proportion to form factor [5,17]. It delivers an indicator regarding the circular character of the drainage basin. The greater the circular character of the basin, the greater the fast response of the watershed to heavy rainstorm event [50]. The shape factor of W. Kerak is 6.050, whereas, the thirty one mini-watersheds exhibit a range of 1.87 to 6.99 (Table 2), which indicates that the elongated shapes dominate the mini-watersheds.

4.1.3.3 Elongation ration (R_e)

R_e represents the ratio between the diameter of the circle of the same area as presented by the drainage basin to the maximum basin length [20]. It has been reported that the values of R_e often vary between 0.6 and 1.0 over a wide range of geological and climatic conditions [19]. Values close to 1.0 depict regions with very low relief, whereas values in the range of 0.6-0.8 are often characteristic of catchments with dissected topography, high relief, and steep hillside-slopes. The low values of R_e indicate that a particular mini-watershed is more elongated than others. Where the R_e approaches 1.0, the shape of the drainage basin approaches a circle [20]. It has been stated that a circular basin is more efficient in runoff than an elongated one [51]. Based on R_e values, drainage basins were classified into five groups, i.e. circular (0.9-1.0), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and more elongated (<0.5). The elongated ratio of W. Kerak is 0.459, whereas values of R_e for the thirty one mini-watersheds range from 0.48 to 0.82 (Table 2). Thus, the mini-basins are of less elongated to oval shape.

4.1.3.4 Compactness coefficient (C_c)

C_c is described as the ratio of perimeter of catchment to circumference of circular area, which equals the area of the drainage basin [52]. It is known as the Gravelius index (GI). The C_c is independent of drainage basin area, and dependent only on slope steepness [17]. A circular basin yields the shorter time of concentration before the peak flow realized in the basin, and C_c>1.0 indicates more deviation from the circular nature [48]. Lower values of this parameter imply more elongation and high erosion. In the present investigation, the highest value of C_c is 1.74(MW 13), which means high erosion, while the lowest value is 1.16(MW 13), which denotes less erosion (Table 2).

4.1.3.5 Circularity ratio (R_c)

R_c is considered the ratio of basin area (A) to the area of circle having the same circumference as the perimeters of the basin [21]. R_c is controlled by the length and frequency of the streams, geological structures, morphology, land use/cover, climate, of the catchment. Drainage basins with a range of circularity ratios of 0.4 to 0.5, were described by [21], indicating that they are strongly elongated. High R_c values denote young, mature, and old stages of geomorphic development of drainage basin [46]. The circularity ratio values (0.44) of a drainage basin demonstrates Miller's range, which reveals that the watershed is elongated in shape, with low discharge of runoff, and high permeability of the subsoil materials. Similarly, if the circularity of the main basin is low, then the discharge will be slow as compared to the others, and so the possibility of erosion will be less [8]. The circularity ratio of W. Kerak is 0.241 whereas, R_c values for the thirty one mini-watersheds range from a minimum value of 0.32 (MW no. 13) to a maximum value of 0.74 (MW no. 25), which indicates a high possibility of rapid discharge and active erosion.

4.2 Prioritization of Mini-Watersheds Based on Morphometric Analysis

Recently, morphometric analysis was used for prioritization of watersheds for soil and water conservation at different scales: sub-watersheds, mini-watersheds, and micro-watersheds [3,8,4-7,2,9,11,53-58]. Erosion risk parameters pertained to linear and shape morphometric variables were employed for prioritizing watersheds [9]. The linear parameters are: Bifurcation ratio (R_b), Stream frequency (F_u), drainage density (D_d), length of overland flow (L_o), and texture ratio (T). Similarly, the shape factors include: form factor (R_f), compactness coefficient (C_c), shape factor (B_s), elongation ratio (R_e), and circularity ratio (R_c), It has been stated earlier that linear parameters have a direct relationship with erodibility. Therefore, the highest value of the linear parameters was ranked 1, second highest value ranked 2 and so on. By contrast, the shape have an inverse relation with linear parameters, hence, the lower their value, the greater the erodibility [54,8]. Consequently, the lowest value of shape parameter was rated as rank 1 and second lowest as rank 2 and so on. Compound factor(C_f)was computed by adding up all the ranks of linear parameters, as well as shape parameters and then dividing by the number of all parameters (which is here 10). From the group of mini-watersheds, the highest prioritized rank (score) was affirmed to mini-watersheds having the lowest compound factor and vice versa [8]. Fig. 5 illustrates the priority ranks for the thirty one mini-watersheds based on morphometric analysis. All mini-watersheds of W. Kerak were classified into five priority categories based on the range of compound factor (C_f) values [5]:

(i) Extremely high priority	(8.0-9.9)
(ii) Very high priority	(10.0-11.9)
(iii) High priority	(12.0-13.9)
(iv) Moderate priority	(14.0-15.9)
(v) Low priority	(16.0-17.9)

With respect to the thirty one mini-watersheds of Wadi Kerak, MW no. 2 is given rank 1 with the lowest compound factor at 9.0 (Table 3). It is succeeded by the mini- watershed nos. 3 and 19, as second and third respectively. The values of C_f and related ranks for all mini-watersheds are displayed in Table 3 and Fig. 5. By contrast, out of thirty one mini-watersheds, MW no. 2 is classified as extremely high priority, whereas MW nos. 3, 10, 19, 27 and 30 are ranked as very high priority. MW nos. 31, 29, 23, 17, 26, 25, 15, 8, and 5 are ranked as high priority. By contrast, MW nos. 28, 24, 20, 21, 22, 13, 14, 16, 9, 6, 7, and 4 are ranked as moderate priority (Table 3 and Fig. 5), MW nos. 18, 12, 11, and 1 are ranked as low priority. It can be concluded that fifteen mini-watersheds (48.4% of the total) are classified as extremely high, very high, and high priority.

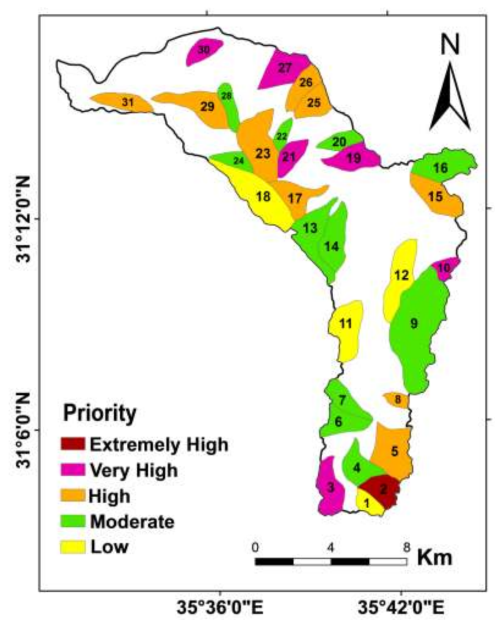

Fig. 5. Priority of mini-watersheds based on morphometric analysis

4.3 Prioritization of Mini-watersheds Based on Soil loss Modeling

The estimation of average annual soil loss (A) was calculated through full integration of the RUSLE parameters in a GIS environment, in order to compute soil loss rate. The generated soil loss map [1] was then classified into five categories for visual interpretation (Fig. 6): low, moderate, high, very high, and extremely high. The annual soil loss values range between 0 and 790 ton ha^{-1} $year^{-1}$, with a mean value of 64 ton ha^{-1} $year^{-1}$. 28.3% (54-16 km^2) of the W. Kerak watershed is under low soil erosion loss category, whereas 71.7% (136.54 km2) of the watershed has undergone of moderate, high, very high, and extremely high soil erosion loss. It is obvious that the estimated average annual soil loss rate in the watershed exceeds the acceptable soil loss tolerances.

Therefore, a priority plan for appropriate conservation measures should be adopted. High rates of soil erosion loss in W. Kerak is largely attributed to physical and cultural factors such as:

(i) The abundance of old degraded landslide complexes,

(ii) Repetitive deep and shallow landslides,
(iii) The influence of dense subsidiary faults and joints deviated from the Kerak–Al–fiha fault,
(iv) High rainfall intensity during the storm event (mm/hr^{-1}) probably due to climatic change,
(v) Land use changes and poor vegetation cover,
(vi) Lack of conservation measures,
(vii) Traditional cropping system and tillage practices (up–and–down the slope),
(viii) Remarkable increase in built–up areas and impervious road networks,
(ix) Deforestation (for fuel and charcoal–wood), overgrazing and destruction of vegetation cover [44].

Table 3. Calculation of compound factor and prioritized ranks based on morphometric parameters

Mini-basin	R_b	D_d	F_s	T	L_o	R_f	B_s	R_e	C_c	R_c	Compound factor	Prioritized ranks	Priority
1	21	24	8	26	22	10	20	9	19	4	16.3	24	Low
2	14	5	4	3	5	2	29	2	18	5	8.7	1	Extremely high
3	8	9	6	2	9	16	11	17	11	13	10.2	2	Very high
4	4	18	22	20	17	7	23	6	11	12	14	14	Moderate
5	8	14	23	8	14	6	24	5	13	11	12.6	9	high
6	15	17	20	23	16	12	18	11	8	15	15.5	21	Moderate
7	13	15	13	17	15	20	6	20	7	16	14.2	15	Moderate
8	21	13	1	18	13	4	27	4	21	2	12.4	7	High
9	5	25	29	1	23	17	10	16	9	14	14.9	18	Moderate
10	19	12	2	7	11	5	26	4	17	7	11	5	Very high
11	7	29	30	15	27	9	21	8	16	8	17	26	Low
12	3	28	26	12	26	21	5	21	6	17	16.5	25	Low
13	2	21	24	17	20	23	1	23	1	20	15.2	19	Moderate
14	10	16	27	15	16	19	7	19	12	12	15.3	20	Moderate
15	1	27	14	5	25	15	13	14	15	9	13.8	13	High
16	9	23	19	6	21	11	19	10	14	10	14.2	15	Moderate
17	16	7	18	21	7	5	25	4	3	19	12.5	8	High
18	9	26	31	17	24	22	3	22	2	18	17.4	27	Low
19	6	10	10	9	10	8	22	7	15	9	10.6	3	Very high
20	11	11	12	25	11	14	15	14	20	10	14.3	16	Moderate
21	15	2	11	14	2	13	17	12	18	4	10.8	4	Very high
22	21	22	3	24	21	17	9	16	17	7	15.7	23	Moderate
23	7	19	21	4	18	15	14	14	17	7	13.6	11	High
24	20	12	5	19	12	15	12	15	23	14	14.7	17	Moderate
25	13	18	16	11	17	1	30	1	22	1	13	10	High
26	12	20	9	10	19	15	14	14	15	9	13.7	12	High
27	7	3	25	13	3	3	28	3	17	6	10.8	4	Very high
28	18	4	15	27	24	18	8	18	10	14	15.6	22	Moderate
29	6	8	28	19	8	21	4	22	4	18	13.8	13	High
30	17	6	7	16	6	14	16	13	21	3	11.9	6	Very high
31	15	1	17	22	1	22	2	22	5	17	12.4	7	High

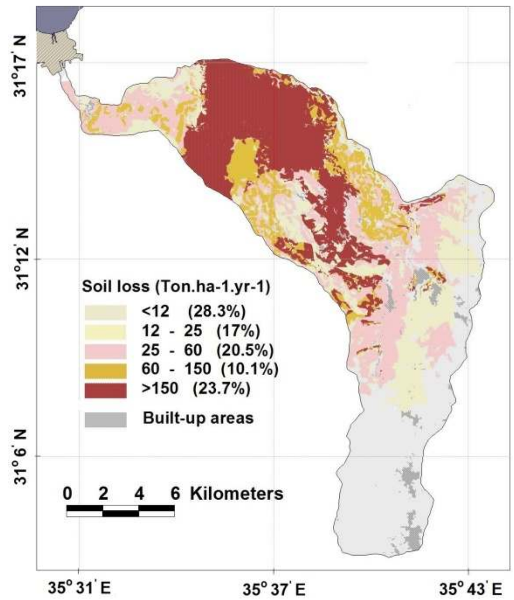

Fig. 6. Spatial distribution of soil erosion losses (Farhan & Nawaiseh 2015)

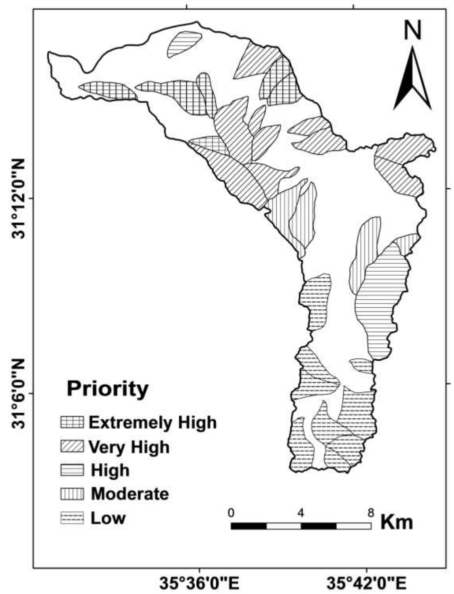

Fig. 7. Priority of mini-watersheds based on soil loss modeling

The annual soil loss (ton ha^{-1} $year^{-1}$) for the thirty one mini-watersheds was calculated and illustrated in Table 4. Similarly, categories of priority are displayed in Fig. 7. Fourteen mini-watersheds (48.4%) exhibit an average annual soil loss less than the average annual soil loss of W. Kerak catchment. Whereas sixteen mini-watersheds (51.6%) display an average annual soil loss greater than the average for W. Kerak. The results also revealed that the maximum average annual soil loss (157 ton ha^{-1} $year^{-1}$) occurred in MWno.31, while the minimum average annual. soil loss (8 ton ha^{-1} $year^{-1}$)was recorded in nine mini-watersheds (MW nos.1–8, and MW no.11) which are classified within the acceptable soil loss tolerance limits from 2 to 12 ton ha^{-1} $year^{-1}$ for the Mediterranean environments [59,42]. This means that 29% of the mini- watersheds are classified within the acceptable soil loss tolerance. Most of these mini-watersheds are part of the upper W. Kerak watershed, and represent the remnants of the Miocene-Pliocene erosion surface with a slope category of 0-5°. Four mini-watersheds experience moderate soil loss (MW no. 10 and nos. 12-14). By contrast, two mini-watersheds suffer from high soil erosion loss (MW no. 9 and no. 30), and ten mini-watersheds are categorized under very high soil erosion loss (MW nos. 15-29 and no. 27). Moreover, six mini-watersheds are classified under extremely high soil erosion loss (MW nos. 24-26; nos.28-29 and no. 31).

An integration of the results achieved based on the morphometric analysis method and soil loss modeling method was conducted through superimposition of the two layers /maps produced. Such a process makes it possible to identify the common mini-watersheds falling under each category of priority (Fig. 8). The correlation reveals that three mini-watersheds (MW no.27; no. 21, no.19) are the common mini-watersheds and ranked under very high priority. Similarly, two mini-watersheds are also common mini-watersheds (MW no.13; no.14) and are classified under moderate priority based on morphometric and soil loss modeling methods. Moreover, two mini-watersheds are also common (MW no.11; no.1) and ranked under the category of low priority based on morphometric analysis and soil loss methods. Four mini-watersheds (MW no. 31; no. 29; no. 26; no. 25) are categorized under extremely high priority based on soil loss modeling, and are classified under high priority based on morphometric analysis. In parallel, three mini-watersheds (MW no. 3; no. 17; no. 15) are ranked under very high priority based on the soil loss method, and categorized under high priority based on morphometric analysis. Equally, two mini-watersheds (MW no. 28; no. 24) are ranked under extremely high priority based on soil loss modeling, and of moderate priority based on morphometric analysis. Adding to that, mini-watershed no. 22, is ranked under very high priority based on soil loss modeling, and classified under moderate priority based on morphometric analysis method. The mini-watershed no. 9 is ranked under high priority based on soil loss modeling, and categorized under moderate priority based on morphometric analysis.

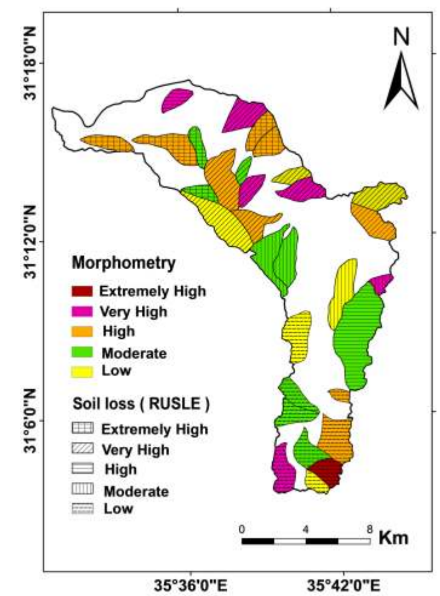

Fig. 8. Priority of mini-watersheds based on superimposition of morphometric and soil loss parameters

At the upper catchment of W. Kerak, several mini-watersheds are ranked under moderate/low priority based on both morphometric analysis and soil loss methods. It can be demonstrated that 50% of the total mini-watersheds can be categorized under moderate, high, very high, and extremely high priority based on both soil loss modeling and morphometric analysis. Therefore, these mini-watersheds should be prioritized for soil and conservation measures.

Different methods of conservation measures were suggested [44]. Among these are: (i)Protection of woodlands, and afforestation of bare lands, steep slopes, and landslide area; (ii)adoption of structural soil and water conservation measures (i.e., terraced farming using stone bunds–contour stone terraces, check dams and gully control, cropping system management) to reduce erosivity effects on soil loss. 27% of the farmers who live across W. Kufranja (northern Jordan) and received a questionnaire (regarding farmers' perception of soil erosion and conservation), believe that efficient land management is urgently needed to rehabilitate intensively exploited soil resources. Soil conservation measures should be integrated with technologies enhancing farming practices (i.e., rotation and contour plowing) of rainfed cultivation to reduce soil loss and improve crop productivity.

Table 4. Average annual soil loss (ton ha^{-1} year^{-1}) for the thirty one mini-watersheds of Wadi Kerak

Mini-watersheds	Soil erosion loss (ton ha^{-1} year^{-1})	Prioritized ranks	Priority
MW1	8	22	Low
MW2	8	22	Low
MW3	8	22	Low
MW4	8	22	Low
MW5	8	22	Low
MW6	8	22	Low
MW7	8	22	Low
MW8	8	22	Low
MW9	36	17	High
MW10	17	21	Moderate
MW11	8	22	Low
MW12	23	19	Moderate
MW13	21	20	Moderate
MW14	27	18	Moderate
MW15	70	15	Very high
MW16	76	13	Very high
MW17	83	10	Very high
MW18	86	9	Very high
MW19	78	12	Very high
MW20	83	10	Very high
MW21	89	8	Very high
MW22	107	7	Very high

Mini-watersheds	Soil erosion loss (ton ha^{-1} year^{-1})	Prioritized ranks	Priority
MW23	75	14	Very high
MW24	136	4	Extremely high
MW25	139	3	Extremely high
MW26	133	5	Extremely high
MW27	79	11	Very high
MW28	131	6	Extremely high
MW29	141	2	Extremely high
MW30	42	16	High
MW31	157	1	Extremely high

5. CONCLUSIONS

Land degradation due to high rates of soil erosion in the W. Kerak watershed has caused a serious increase in sediment yield of the wadi, particularly during intense rainfall storms. Thus, watershed prioritization is considered one of the most fundamental steps of watershed management and natural resources development. High bifurcation ratios for all mini-watersheds (4-5 and >5), and for the entire catchment (5.3) indicate the great influence of the Kerak–Al–fiha fault system on disturbing the mini-watersheds and the drainage pattern especially in the middle and lower parts of the catchment. Similarly, low drainage density values are dominant. D_d values vary from 1.02 km/km^2 (MW no.16) to 2.95 km/km^2 (MWno.28), which denotes low runoff, highly jointed and fissured permeable surface materials and weak rocks. The results of prioritization based on morphometric analysis showed that mini-watershed no. 2 has been ranked 1 with the lowest compound factor at 9.0, while mini-watersheds no. 3 and 19 are classified as the second and third respectively with low priority. By contrast, mini-watershed no. 2 is categorized as extremely high priority. Fifteen mini-watersheds (48.4% of the total) are classified as extremely high, very high, and high priority. Based on soil loss modeling, mini-watershed no.31 recorded the maximum annual soil loss (157 ton ha^{-1} year^{-1}), while the minimum annual soil loss (8 ton ha^{-1} year^{-1}) was dominant in nine mini-watersheds (MW nos. 1-8, and MW no. 11). However, the superimposition of the two thematic layers of morphometric analysis and soil loss modeling, showed that at least 50% of the mini-watersheds are categorized under moderate, high, very high, and extremely high priority. Therefore, these mini-watersheds must be given the highest priority for soil and water conservation measures, to ensure future sustainable agriculture. The present study demonstrated that the adopted methodology of watershed prioritization can be implemented by land developers and land use planners to conduct research on the Kerak Governorate level, where the data and software needed are available. GIS and RS tools and the RUSLE model are also simple and low cost techniques for prioritization of watersheds to help decision makers to formulate soil conservation plans at different levels of the watershed (sub-watersheds, mini-watersheds, and micro-watersheds).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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