Iraqi National Journal of Earth Science

www.earth.mosuljournals.com

Application of Rusle Model to Mapping the Soil Erosion Risk in Gebel Watershed

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Article information

Received: 18- Sep -2023

Revised: 20- Nov -2023

Accepted: 22- Feb -2024

Available online: 01- Jan – 2025

Keywords:
Erosion
RUSLE
Remote Sensing
NDVI
Gebel watershed

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ABSTRACT

The study has been carried out to mapping the risk of soil erosion in the Gebel watershed (Duhok Governorate, Kurdistan Region, Iraq) using the RUSLE model. All RUSLE factors (R, K, LS, C, and P) are computed as a raster's maps and used to calculate soil loss in ArcGIS software. The (R) factor map is computed from rainfall data and has a value ranging between (82.5 – 178) MJ mm ha^{-1} h^{-1} $year^{-1}$. Where the (K) factor is estimated from soil sampling, it has values ranging between (0.011 – 0.023) t h MJ^{-1} mm^{-1}. However, the (LS) factor values range between (0 – 1520). Based on NDVI (Normalized Difference Vegetation Index), a satellite image (LANDSAT 8) is employed to map the (C) factor, which has values ranging from 0.389 to 0.446. The average annual soil loss the in-study area is 1.52 $(ton/ha/year)$ which ranges from 0 to 1310 $tons/ha/year$. According to FAO and UNEP. (1984), soil erosion is classified into seven classes, and 76.17% of the total area has very slight soil erosion, and 19.45% of the watershed area has slight soil erosion, while the moderate soil loss rate is covers 3.19% of the total area. Finally, the other classes (High, Very High, Extremely, and Extremely High) represent 1.22% of the total area but have a large amount of soil loss (12708.87) ton per year. The results clearly show that most significant factor affecting soil loss (A) is LS factor, which has a very high significant correlation with soil loss (R^2=1)

DOI: 10.33899/earth.2024.143444.1146, ©Authors, 2025, College of Science, University of Mosul.

استخدام المعادلة العمومية لفقدان التربة المعدلة (RUSLE) لرسم خرائط مخاطر تعرية التربة في حوض كبيل المائي

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معلومات الارشفة

تاريخ الاستلام: 18- سبتمبر -2023

تاريخ المراجعة: 20- نوفمبر -2023

تاريخ القبول: 22- فبراير -2024

تاريخ النشر الالكتروني: 01- يناير -2025

الكلمات المفتاحية:

التعريه

المعادله العموميه لفقدان التربه

التحسس النائي

مؤشر الغطاء النباتي

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الملخص

أجريت هذه الدراسة في حوض كبيل بمحافظة دهوك، إقليم كردستان-العراق لرسم خريطة تبين خطر انجراف التربة باستخدام المعادلة العمومية لفقدان التربة المعدلة (RUSLE). تم تحويل جميع عوامل المعادلة (R وK وLS وC وP) الى خرائط نقطية (Raster) واستخدامها في برنامج (ArcGIS) لحساب التعرية في الحوض. فبخصوص العامل (R) تم ايجاد قيمها من بيانات هطول الأمطار، حيث تراوحت القيم بين (82,5 – 178) ميكا جول مم هكتار$^{-1}$ساعة$^{-1}$سنة$^{-1}$. وتم تقدير عامل (K) من تحليل عينات التربة وتراوحت القيم ما بين (0.011 – 0.023) طن هكتار مم$^{-1}$. أما قيم معامل الانحدار (LS) فقد تراوحت بين (0 – 1520). وبالاعتماد على مؤشر الاختلاف الخضري للغطاء النباتي (NDVI) و باستخدام بيان القمر الصناعي (LANDSAT 8) تم رسم خريطة للعامل (C)، والذي تراوح قيمها من 0.389 إلى 0.446. وبلغ معدل تعرية التربة السنوية في منطقة الدراسة 1.52 طن/هكتار/سنة. وبالاعتماد على تصنيف منظمة الأغذية والزراعة وبرنامج الأمم المتحدة للبيئة (1984). تم تصنيف تعرية التربة في حوض كبيل إلى سبع فئات، حيث ان 76.17% من المساحة الإجمالية للحوض تعاني من تعرية طفيفة جداً للتربة، و ان 19.45% من المساحة تعاني من تعرية طفيفة للتربة، في حين أن فئة التعرية المتوسطة يغطي 3.19% من المساحة الإجمالية. وباقي فئات التصنيف الأخرى (عالية، عالية جدًا، شديدة للغاية، عالية جدًا) تمثل 1.22% من إجمالي مساحة الحوض والتي لها قيمة عالية من فقدان التربة (12708.87) طن سنويًا. وأظهرت النتائج أن لعامل الانحدار (LS) اكبر تاثير في تعرية التربة (A)، والذي له علاقة معنوية عالية جداً مع تعرية التربة اذ بلغ قيمة معامل الارتباط (R^2=1).

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Introduction

According to (Shiferaw, 2011), a soil erosion is the biggest danger to food security in developing countries in Asia and Africa. The consequences of soil erosion are further exacerbated by human-caused factors such as major deforestation, overgrazing, agricultural intensification, and population expansion (Amsalu et al., 2007).

Soil erosion monitoring is an essential part of any kind of land conservation strategy. The evaluated soil erosion from the conventional method (experimental plots) is expensive and time-consuming. The researchers have been modeled the soil erosion for a long time, and the distinguished models are the Water Erosion Prediction Project (WEPP) (Nearing et al., 1989), the European Soil Erosion Model (EUROSEM) (Morgan, 1995), and the Universal Soil Loss Equation (USLE)(Wischmeier & Smith, 1978).

Mapping the risk of soil erosion is necessary for setting priorities for conservation efforts and putting appropriate soil management practices into place. One such successful and widely used model for determining soil erosion is the RUSLE model (Revised Universal Soil Loss Equation) that depends on several important factors, including rainfall erosivity, soil erodibility, slope length and steepness, cover management, and support techniques.

Due to several reasons, including steep slopes, heavy rainfall, and land use practices, the Gebel Watershed is well known for having soil erosion issues. Applying models that can quantify soil erosion risk and give spatially explicit information are essential for resolving this issue in order to inform land management choices and put in place sensible soil conservation measures.

The goal of this study is using the RUSLE model to evaluate the risk of soil erosion in the Gebel watershed. The study will estimate erosion rates, identify vulnerable regions, and produce soil erosion risk maps by combining spatial data layers inside a Geographic Information System (GIS) framework. These maps will be a great resource for stakeholders, policymakers, and land managers as they design sustainable land management plans then putting them into action.

Study area

The Gebel watershed is located in northern Iraq, Duhok Governorate in the Kurdistan Region. The research area is about 404.65 km^2, the region is situated between latitudes (36°35'13.96" N and 36°50'52.44" N) and longitudes, 43°49'40.65" E and 44°6'15.60" E, inside the 38N zone. (Fig 1).

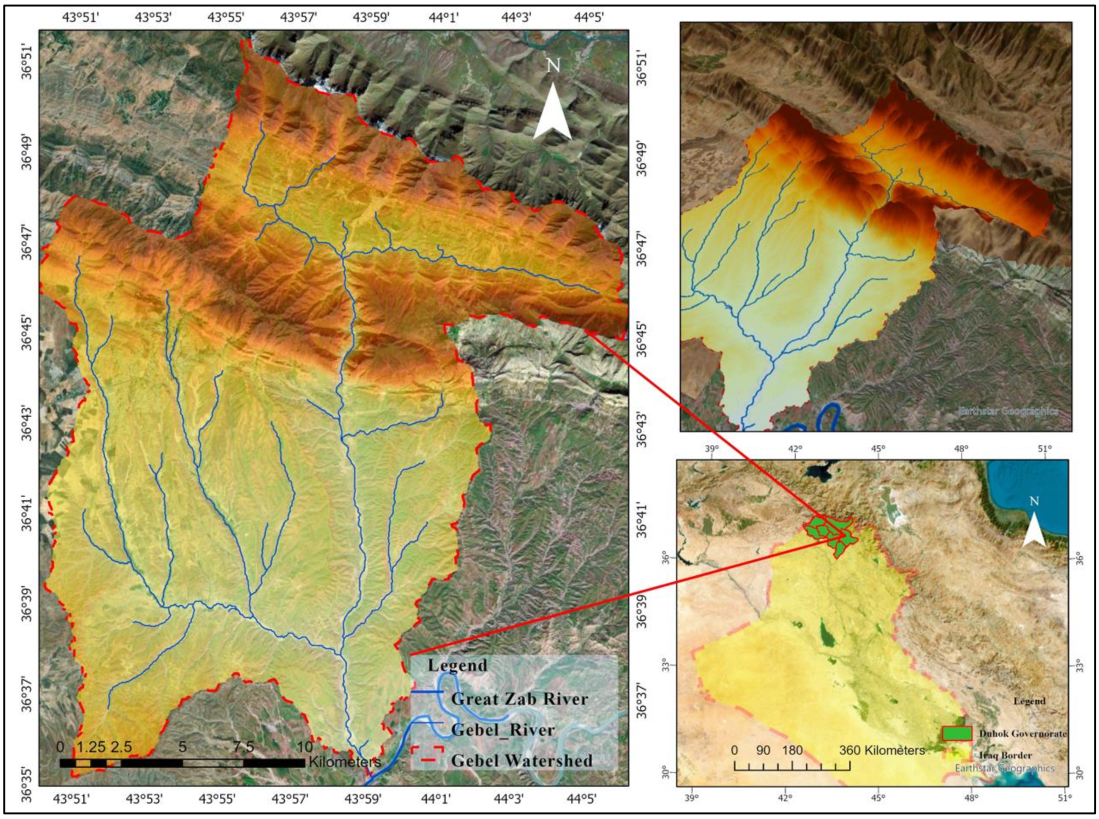

Fig. 1. Gebel watershed Location

The watershed's highest elevation point is 1603 m (a.s.l.), while the lowest elevation is 340 m (a.s.l.) at the outlet point. The Gebel River is the primary river in the watershed, which originates from mountains in the northern portion of the watershed moving to south area, and discharges into the Greater Zab River. The annual discharge of Gebel River at Zenta station is 100.39 million m^3/y. According to Sissakian (2013), the area is situated in a zone that has been heavily folded.

Mediterranean climate, which is dry and hot in the summer and cold and somewhat rainy in the winter, has an impact on the watershed. The wet season start from October to April, whereas the dry season lasts from the end of April until September. The average annual precipitation in the study area is 849.9 mm, that influenced by altitude, the high-altitude region has an annual rainfall reach of 1032 mm, and in the plain part was 587 mm (Fig. 2), the average annual temperature, daily evapotranspiration, annual average relative humidity, and average wind speed in the study area are (20.24 C◦, 5.77 mm, 44.91%, and 1.01 m/s) respectively (Salim, 2020).

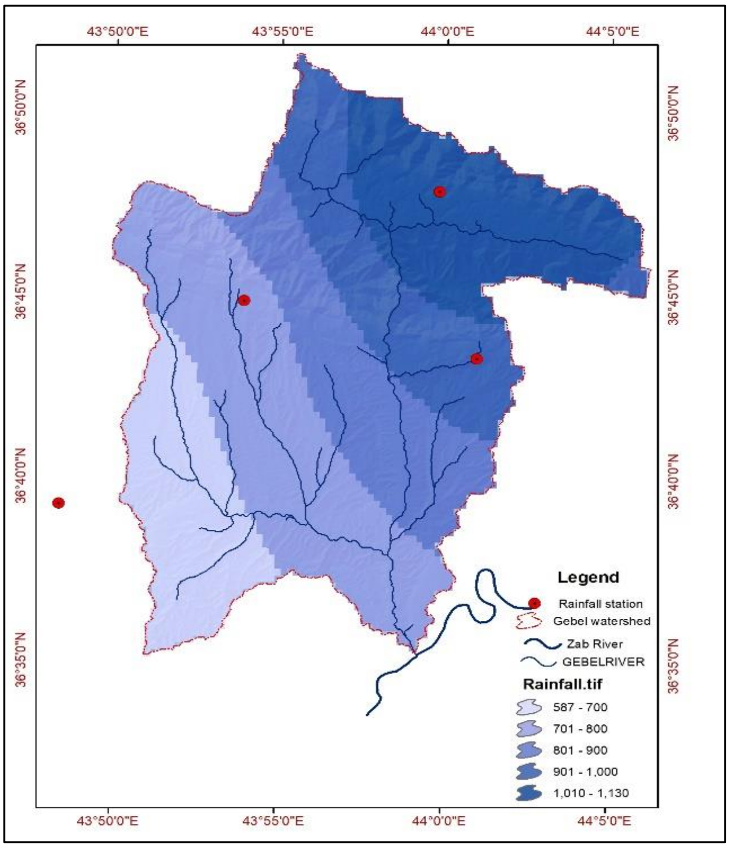

Fig. 2. Gebel watershed Rainfall

Materials and Methods

The RUSLE (Revised Universal Soil Loss Equation) is used in this study to forecast annual soil loss in the Gebel watershed. This model (RUSLE) is established by the United States Department of Agriculture, and most frequently utilized for both agricultural and forest watershed (Renard, 1997). The RUSLE equation (Eq.1) consists of five parameters (Wischmeier and Smith, 1978):

$$\boldsymbol{A = R \times K \times LS \times C \times P} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots (\mathbf{1})$$

Where:

$A = Annual\ soil\ erosion\ (metric\ t\ ha^{-1}yr^{-1})$.
$R = Rainfall\ Erosivity\ factor\ (MJ\ mm\ /t\ ha^{-1}yr^{-1})$.
$K = Soil\ erodibility\ factor\ (metric\ t\ ha^{-1}MJ^{-1}mm^{-1})$.
$LS = (L = length\ of\ slope\ in\ meter, and\ S = slope\ (\%))$.
$C = Vegetation\ factor$.
$P = Conservation\ and\ support\ practice\ factor$.

The RUSLE equation requires inputs gathered from various sources, (R factor from rainfall data, K factor from topsoil analysis, LS factor from DEM 12.5 m resolution, C factor from Landsat 8 image, finally *P* factor from field survey). Using spatial analysis tools in environment of GIS, all five-parameters (with the same coordinate system) are mapped as s raster. Figure (3) shows a schematic representation of the general methods followed in this investigation.

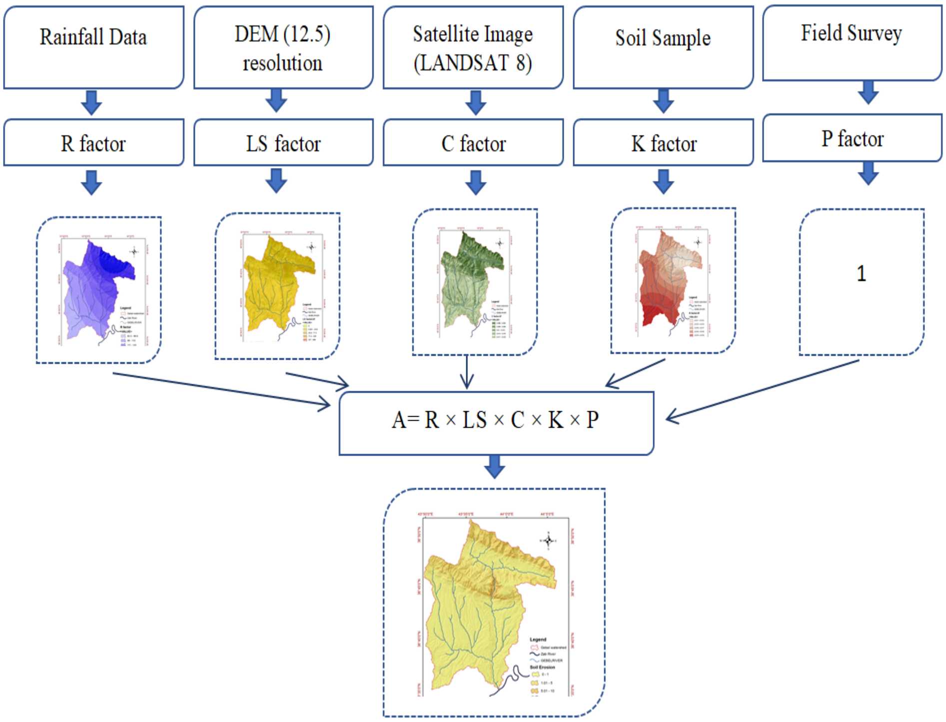

Fig. 3. Flowchart of the process.

Rainfall Erosivity (R factor)

The rainy erosivity (R factor) considers the influence of kinetic energy and runoff on erosion. (Wischmeier and Smith, 1978). The (R factor) attempts to measure the rainfall effect as well as the amount and attribution of runoff that is most probably linked with precipitation occurrences, and it is widely regarded as the most strongly correlated index to soil loss at several locations around the world (Hlaing et al., 2008). The study focuses on the real coincident of (R) with the geographical feature factors, particularly altitude, at ten study sites (Haji and Sulaiman, 2019). The equation proposed by Keya, (2020), which uses latitude, longitude, and annual precipitation as input variables, is used in the current study:

$$\mathbf{R = 1285.16 + 0.183 \times P - 18.475 \times Lat - 14.431 \times Long} \text{ ...... (2)}$$

Where

$\boldsymbol{R} = \boldsymbol{Rainfall\ Erosivity\ Factor}\ (\boldsymbol{MJ\ mm\ /t\ ha^{-1} yr^{-1}})$.

$\boldsymbol{P} = \boldsymbol{Annual\ rainfall}\ (\boldsymbol{mm})$

$\boldsymbol{Lat.} = \boldsymbol{the\ latitude\ point\ of\ the\ station}\ (\boldsymbol{degree})$

$\boldsymbol{Long.} = \boldsymbol{the\ Longitude\ point\ of\ the\ station}\ (\boldsymbol{degree})$.

Precipitation data are collected from 9 stations, inside and surrounding the Gebel watershed. Each station is represented by a point, and a raster map is extracted to calculate the (R) factor using the distance weighte inverse interpolation (IDW) technique in ArcGIS 10.8.1, where the (R) factors ranged between (82.5 – 178 $(\mathrm{MJ\ mm\ /t\ ha^{-1} yr^{-1}})$, as shown on the (Fig 4). Also from the map, we can note the high value of the R factor located at high altitude with high amount of annual rainfall, whereas the study result finds a very high significance correlation between R factor and both elevation and rainfall (R2=0.775 and 0.565) respectively.

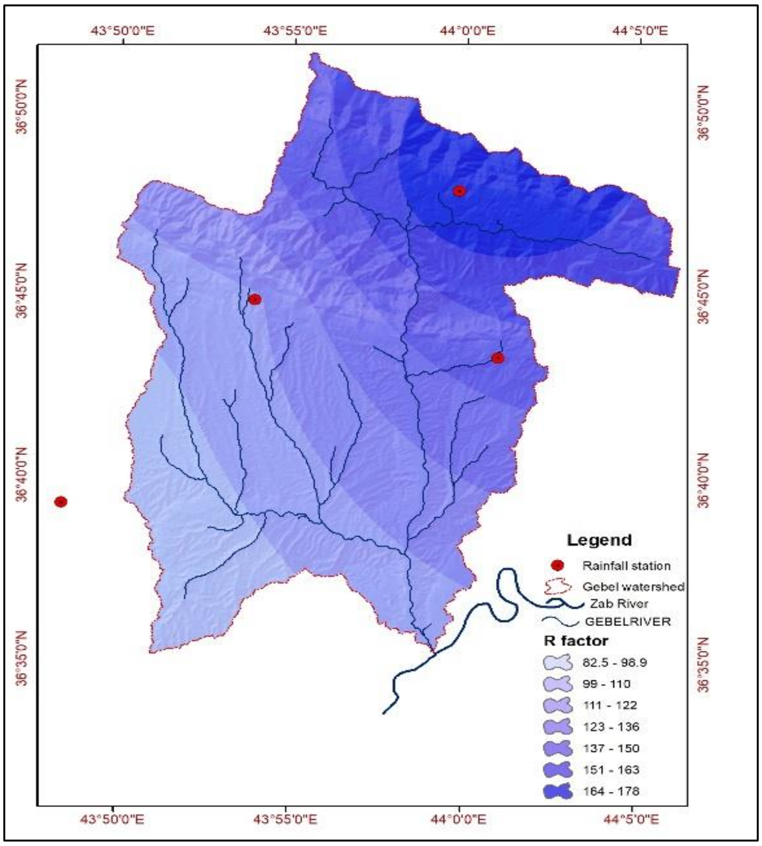

Fig. 4. Gebel watershed (R) factors map

Soil Erodibility (K factor)

The K factor assesses how easily runoff and rainfall can separate and move topsoil, which represents the rate of soil erosion due to the rainfall erosivity factor at each site within the study area (Koirala et al., 2019). Generally, the K factor values in clay type soils are low due to their resistance to all detachments. The K values of sandy soils are also low because of the high rates of infiltration, low runoff, and the difficulty of transporting sediment eroded from these soils. Silt loam soils have medium to high values because the particles of soil are relatively to comfortably detachable, and the infiltration is medium to low causing the runoff to be moderate to high, and the sediment is reasonably to easily transportable. The K values of the silt soils are the highest because they crust easily, resulting in high rates and quantities of runoff. The present study uses the multi-equation a cording to Neitsch et al. (2000) that are depends on the topsoil content:

$$\mathbf{K_{usle} = f_{csand} \times f_{cl-si} \times f_{orgc} \times f_{hisand}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

$$\mathbf{K_{Factor} = K_{usle} \times 0.1317}$$

$$\mathbf{f_{csand} = \left[0.2 + 0.3 \times \exp\left(-0.256 \times m_s \times (1 - \frac{m_{silt}}{100})\right)\right]}$$

$$\mathbf{f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3}}$$

$$\mathbf{f_{orgc} = \left(1 - \frac{0.25 \times orgc}{org_c + \exp[3.75 - 2.95 \times orgc]}\right.}$$

$$\mathbf{f_{hisand}} = (\mathbf{1} - \frac{\mathbf{0.7} \times (\mathbf{1} - \frac{\mathbf{m_s}}{\mathbf{100}}}{\left(\mathbf{1} - \frac{\mathbf{m_s}}{\mathbf{100}}\right) + \mathbf{exp}\left[-\mathbf{5.51} + \mathbf{22.9} \times (\mathbf{1} - \frac{\mathbf{m_s}}{\mathbf{100}})\right]})$$

Where:

K_{Factor} $(metric\ t/ha/MJ/mm)$ = Soil erosion susceptibility factor according to the modified general equation for erosion

K_{usle} = soil erosion susceptibility factor according to the unmodified general equation for erosion

$M_s\ =\ percentage\ of\ sand$

$M_{silt}\ =\ silt\ percentage$

$M_c\ =\ clay\ percentage$

$Orgc\ =\ percentage\ of\ organic\ matter$

$exp\ =\ Exponential.$

Applying the above equation on the seventeen soil samples taken from within and around the Gebel watershed as shown in Table (1), and using Arc GIS 10.8.1. A raster map of the K factor (map 5) is extracted using the spatial analyst extension, and according to the IDW tool. The map shows the K factor ranges from 0.011 to 0.023 in study area, and the high value is dominant in the southern part of the watershed due to the structure of the soil in the Gebel watershed.

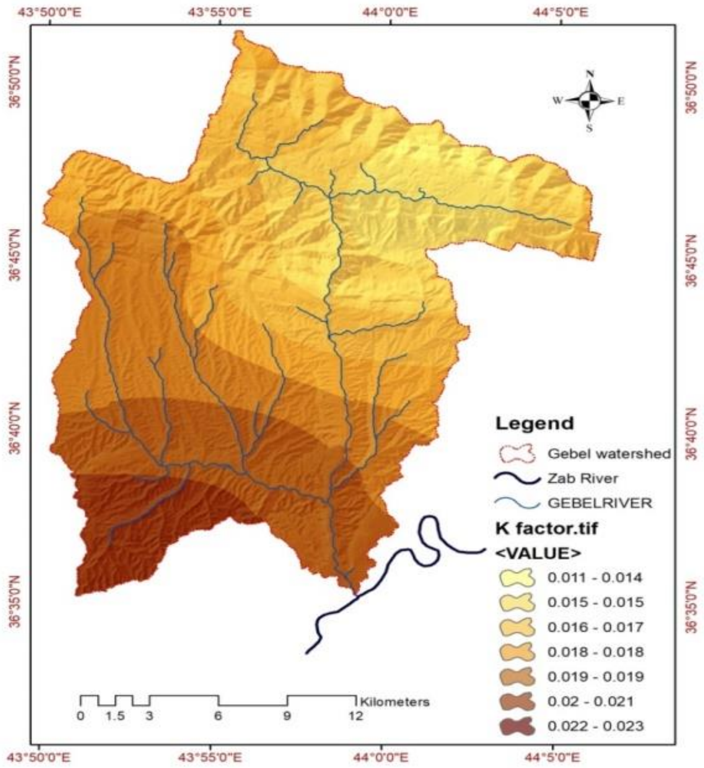

Fig. 5. Gebel watershed (K) factors map

Table 1: Soil sample structure and Soil erodibility (K) factors value in Gebel watershed

Soil Sample	Lat.	Log.	Sand % Ms	Silt % Msilt	Clay % Mc	Organic matter %	K Factor
1	36.7525	43.8915	14.63	41.28	44.09	2.29	0.019
2	36.7381	43.9307	31.6	31.24	37.6	3.45	0.016
3	36.7023	43.8021	19.68	31.18	49.14	1.63	0.017
4	36.7174	43.9703	42.96	19.44	37.6	1.43	0.016
5	36.7231	43.9975	40.24	23.08	36.68	1.86	0.015
6	36.6853	44.1688	33.83	31.77	34.4	0.35	0.021
7	36.629	44.1718	49.55	21.22	29.23	1.71	0.016
8	36.8118	43.9612	47.00	25.00	28.00	2.68	0.016
9	36.7961	43.9358	34.08	26.16	39.76	2.45	0.015
10	36.8406	43.8635	29.47	36.13	34.4	2.34	0.017
11	36.782	44.0199	62.40	5.28	32.32	1.65	0.011
12	36.7637	44.1228	29.47	36.13	34.4	2.24	0.017
13	36.6591	43.7399	37.76	35.64	26.6	0.22	0.022
14	36.5902	43.9722	36.53	37.23	26.24	1.12	0.020
15	36.582	43.8804	62.34	26.51	11.15	0.45	0.023
16	36.6595	43.9432	44.23	26.74	29.03	0.87	0.020
17	36.8644	44.008	28.43	36.78	34.79	1.54	0.018

Topographic factor (LS)

A site's topographic factor (LS) is a comparison between soil loss under certain conditions and soil loss at a site with a "standard" slope steepness of 9% and a slope length of 22.6 m. (Ganasri and Ramesh, 2016). The slope length (L) and slope steepness (S) are the two elements that make up the (LS). For present study, an equation of Ganasri and Ramesh, (2016) is assumed to estimate the (LS) factor.

$$\mathbf{LS} = \left[\frac{\mathbf{QaM}}{\mathbf{22.13}}\right]^{\mathbf{y}} \times (\mathbf{0.065} + \mathbf{0.045} \times \mathbf{S_g} + \mathbf{0.0065} \times \mathbf{S_g^2} \ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{4})$$

$LS = topography\ factor\ (slope\ length\ and\ steepness)$

$Y = exponent\ of\ a\ variable\ value\ of\ 0.2, 0.5$

$Qa = flux\ accumulation\ network$

$Sg = Regression\ of\ the\ network\ (in\ percent)$

$M = grid\ size\ (X, Y)$

By applying the above equation, the values of the coefficient (LS Factor) are calculated based on the digital elevation model (DEM) with 12.5 m resolution that is built in ArcGIS 10.8.1, and as a result, the values of the LS Factor are distributed into seven categories, and their values range between 0 and 1520 (Fig. 6). The high value of the LS factor is located in a deep valley within the mountainous area of the Gebel watershed.

Vegetation Cover (C factor)

The C factor is a complex component in preventing soil loss due to its ability to disperse raindrop kinetic energy, delaying surface runoff, and increasing infiltration capacity. (Acar et al., 2014). The C-factor is most significantly influenced by vegetation, the (C) value factor varies from 1 for completely barren land to 0 for land completely covered by water or trees. (Mengistu et al., 2015). However the optimum method for estimating the (C) factor with the RUSLE model is to use the NDVI (Normalized Difference Vegetation Index) (Wang et al., 2002). For present study, the equation of De Jong et al. (1998) has been used to calculate the (C) factor map.

$$\mathbf{C} = \mathbf{0.431} - (\mathbf{0.0805} \times \mathbf{NDVI}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(\mathbf{5})$$

$\boldsymbol{C = Vegetation\ factor}$

$\boldsymbol{NDVI = Normalized\ difference\ vegetation\ index}$

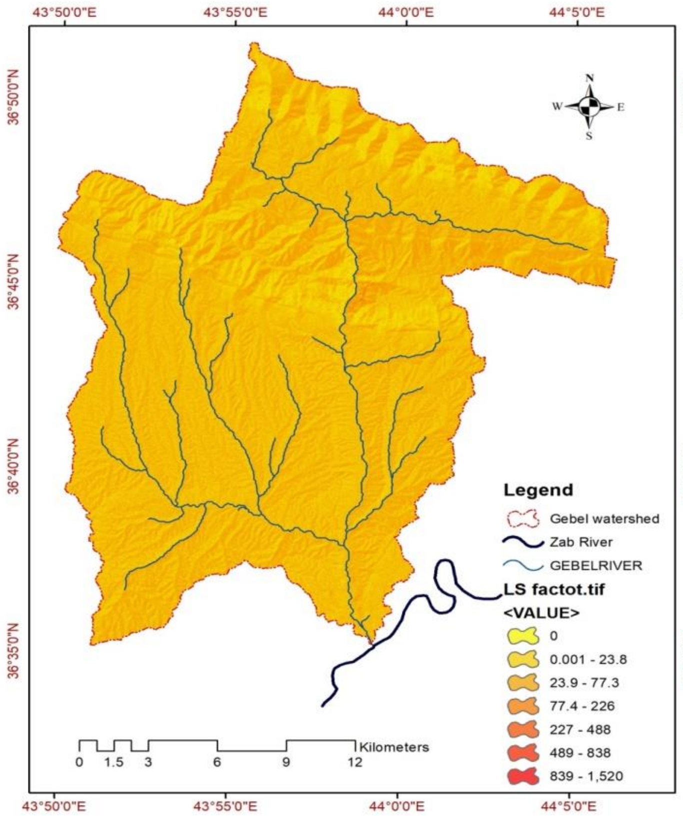

Fig. 6. Gebel watershed (LS) factors map

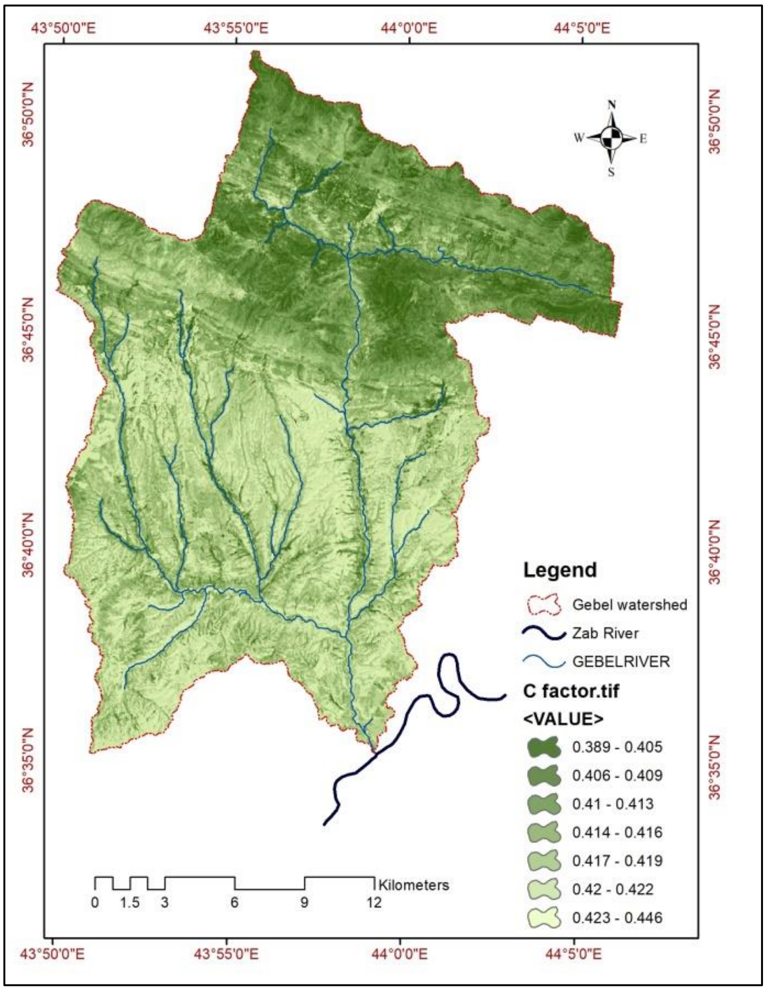

Fig. 7. Gebel watershed (C) factors map

Due to the vegetation's activity and rainfall season in spring (May), a satellite image (LANDSAT 8) in 22 May 2023 with a resolution of (30 x 30) meters is employed. By utilizing the equation and the Raster Calculate tool in ArcGIS 10.8.1, a raster map for the (C) factor is produced, the value of (C) factor is ranged from 0.389 to 0.446, as seen in the (Fig. 7), where the low value of (C) factor can be found in the area with high annual precipitation and in the riverbank too.

Supporting anti-erosion technique (P factor)

The supporting anti-erosion technique (P factor) is described as the ratio of soil erosion after a selective support implementation to the related soil erosion in normal land without any support (Samanta et al., 2016). There is absence of support implementation to control soil erosion in Gebel watershed. The entire watershed area has the value P = 1.

Results and Discussion

Annual Soil Loss (Soil Erosion)

There are traditional methods to measure soil erosion, but they are expensive and time-consuming (Amin and Romshoo, 2019). However, the (RUSLE) model has been used most recently because it is simple, easy to use, and requires less effort and data. Annual soil erosion is estimated by multiplying the RUSEL parameters (R, K, LS, C and P) factors with ArcGIS software environment. The values of soil erosion in Gebel watershed are range from 0 to 1310 $t\,ha^{-1}year^{-1}$ as a shown in Figure (8).

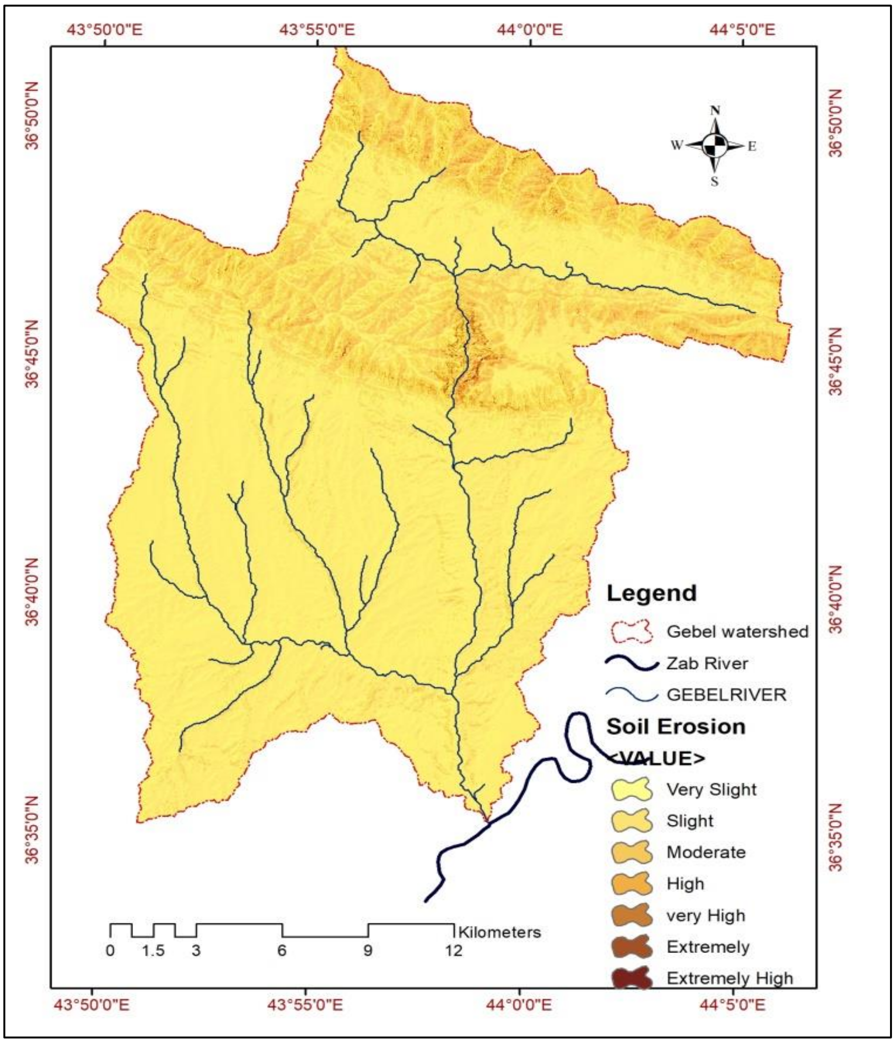

Fig. 7. The Soil erosion classes in Gebel watershed

The total annual soil loss in the study area is 61396.76 (t $year^{-1}$) with a mean of 1.52 (t ha^{-1} $year^{-1}$) and according to FAO and UNEP. (1984), the soil erosion is classified into seven classes (Table 2). The class one with very slight soil erosion is dominant in the area (30811.94 ha) covering 76.17% of total study area, this class is predominated in the southern area of watershed that has low value of (LS) and low amount of annual rainfall, also has moderately vegetation cover.

Table 2: Soil erosion (A) $t\ ha^{-1} year^{-1}$ **in Gebel watershed**

Soil loss classes (ton/ha/year)	Soil loss types	Area (ha)	Area %	Total Soil loss (ton/year)	Soil loss%
0 - 1	Very Slight	30811.94	76.15	15405.97	25.09
1 - 5	Slight	7870.76	19.45	23612.28	38.46
5 - 10	Moderate	1289.28	3.19	9669.63	15.75
10 - 20	High	380.67	0.94	5710.07	9.30
20 - 50	very High	96.02	0.24	3360.71	5.47
50 - 100	Extremely	11.93	0.03	894.39	1.46
100 <	Extremely High	3.89	0.01	2743.70	4.47
SUM		40464.50	100.00	61396.76	100.00
AVG				1.52	

The second class with slight soil erosion has a highest value of soil erosion (23612.28) (t $year^{-1}$) covering an area of 7870.76 ha representing 19.45% of watershed area. The increase of erosion in this class is due an increase the undulating area (slopes) and weak vegetation cover. The study results indicate that there is very high significant correlation between soil erosion and slope, also negative correlation between soil erosion and vegetation cover (C factor) as a shown in table (3).

Table 3: Correlation matrix (Pearson) of RUSLE factors

	A	R	K	LS	C	Rain	NDVI	Slope
R	-0.228							
K	-0.197	-0.175						
LS	1.000**	-0.228	-0.197					
C	-0.211	-0.255	0.633**	-0.210				
Rain	-0.366	0.565**	0.033	-0.366*	-0.090			
NDVI	-0.202	-0.213	0.904**	-0.202	0.639**	0.010		
slope	0.549**	0.122	-0.333	0.548**	-0.455**	-0.230	-0.351*	
Elevation	0.012	0.775**	-0.043	0.012	-0.219	0.421**	-0.061	0.573**

***** correlation is significant at the 0.01 level, * correlation is significant at the 0.05 level***

The Moderate soil erosion rate is ranged from (5 – 10) ($t\ ha^{-1} year^{-1}$) having 9669.63 (t $year^{-1}$) soil erosion in the study area covering 3.19% of the total watershed area. It suggests particularly to the areas with rolling landscape, mild rainfall, and stream banks, that located between the low zone and high zone of study area. The remaining classes (High, Very High, Extremely, and Extremely High) represent 1.22% of the watershed's total area, covering an area of about (492.51) hectares, but they face to significant annual soil erosion (12708.87 tons), due to location, because this classes are located in high zone elevation over tree line, with steep slope and high precipitation (rain and snow).where's the soil erosion (A) has very high significant correlation with both of LS factor and slope (R^2=1.000** and 0.549**) respectively. On the other side there are negative relationship between slope and C factor ($R^2 = -$ 0.455**). In addition the highest amount of precipitation falls on high elevation parts of the study area that has very high significant correlation ($R^2 = -0.421^{**}$).

Conclusion

This study has been carried out to estimate soil erosion in the Gebel watershed using RUSLE model approaches to the GIS environment. The results show that the average annual erosion in the watershed is 1.52 ($t\ ha^{-1} year^{-1}$), ranging from 0 to 1310 ($t\ ha^{-1} year^{-1}$). Aabout 76.17% of total area has very slight soil erosion and 19.45% of watershed area had slight soil erosion while the moderate soil erosion rate covers 3.19% of the total area of the watershed. The other classes (High, Very High, Extremely and Extremely High) are found in mountains at the northern part of the study area with high elevation and high value of (LS) factor, it represents 1.22% from total area. The soil erosion (A) has very high significant correlation with LS factor and slope (R2=1.000** and 0.549**) respectively

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