SPATIAL MAPPING AND ASSESSMENT OF SOIL ERODIBILITY USING GIS IN THE MIDDLE OF ERBIL PROVINCE

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ABSTRACT

This study aimed to estimate soil erodibility in the middle of Erbil province. The results of indirect methods were compared with the observed K-factor in order to determine the most suitable method. The tests were carried out for nine soil locations by taking samples from topsoil. Samples were analyzed for physicochemical properties. The soil in study area is mostly clay and silt clay. The analysis was performed using three assessment models of soil erodibility; the Erosion Productivity Impact Calculator (EPIC), Vaezi et al and Universal Soil Loss Equation (USLE) models. Soil erodibility for direct measured K values varied from 0.27 to 0.39 t h $MJ^{-1}mm^{-1}$ with standard deviation of 0.041 t h $MJ^{-1}mm^{-1}$. The statistical evaluation of the models for K-factor estimation showed that the EPIC and USLE nomograph models were the most suitable models for the studied area.

Keywords: soil erosion, soil erodibility, erodibility assessment, erodibility mapping.

رسم خرائط وتقييم قابلية التربة للتعرية باستخدام GIS في وسط محافظة أربيل

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المستخلص

الهدف من الدراسة هو تقدير قابلية التربة للتعرية في وسط محافظة أربيل. تمت مقارنة نتائج الطرق غير المباشرة مع عامل K المرصود من أجل تقدير الطريقة الاكثر ملائمة للدراسة. أجريت الفحوصات على نماذج للتربة السطحية المأخوذة من تسعة مواقع مختلفة من منطقة الدراسة. تم تحليل نماذج التربة للحصول على الصفات الفيزياوية و الكيمياوية، وكانت معظم ترب منطقة الدراسة تربة طينية (Clay) و غرينية طينية (Silty clay). انجز التحليل باستخدام ثلاثة موديلات تقييمية لقابلية التربة للتعرية: تأثير انتاجية التعرية الحاسوبي (EPIC)، نموذج (Vaezi et al)، ومعادلة فقد التربة العالمية (USLE). قابلية التربة للتعرية لـ(K) المقاسة مباشرة تراوحت بين (0.27) و (0.39) طن هكتار ميجاجول $^{-1}$ ملم$^{-1}$. وبانحراف معياري (0.048) طن هكتار ميجاجول $^{-1}$ ملم$^{-1}$. اظهر التقييم الاحصائي لموديلات تخمين عامل-K بان (EPIC) و مونوكراف (USLE) كانا من الموديلات الاكثر ملائمة لمنطقة الدراسة.

الكلمات المفتاحية: تعرية التربة، قابلية التربة للتعرية، تقييم القابلية التربة للتعرية، رسم الخرائط قابلية التربة للتعرية.

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INTRODUCTION

The process of erosion includes wearing down the top layer of soils and rocks. Erosion that is caused by geological processes plays a significant role in the natural development of both landscapes and physical ecosystems. It is an disagreeable form of erosion when it happens as accelerated or anthropic erosion because it can have an impact on soil quality and water resources. This kind of soil erosion is one of the most severe environmental issues that can occur anywhere, including cities. It can also cause socioeconomic problems. Furthermore, soil erosion delays rural development and sustainable soil use (9, 14, 24, 43). The Universal Soil Loss Equation (42) and it's revised versions are commonly used to predict soil loss and to plan soil conservation practies (17, 28, 32). The USLE is a statistically based water erosion model that takes into account the following variables: erosivity factor (R), erodibility factor (K), slope length factor (L), slope steepness factor (S), cover management factor (C), and support practice factor (P) (31). One of these factors, K-factor is essential for determining and/or predicting soil around the world (39, 43) and was found to be highly correlated with soil loss (8, 34). In modeling erosion, the erodibility of the surface horizon is taken into account. The K-factor demonstrations how soil is torn apart by raindrop splash and/or overland flow (42). The integrated effects of rainfall, runoff, soil characteristics, and soil profile characteristics on soil loss are referred to as erodibility (4, 29). The main soil characteristics that are impacted by soil erodibility are soil texture, including the amount of fine sand in addition to the typical content of sand, silt, and clay, soil structure, organic matter, and soil permeability (42). According to Brady and Weil (2008), the K-factor is influenced by the soil's detachability, runoff, infiltration, and the transportability of the sediment that is eroded from the soil (5).

Wischmeier et al., 1971 developed the nomograph method which is an analytic model; and formulated based on the indirect combination between soil physical properties and organic matter percentage (41). This model presents a graphical solution for determining soil erodibility and acceptable for surface soils; with less agglomeration and medium texture, not used for swelling clays, soils in which aggregate stability is more strong than primary particle size and soils with more than 4% organic matter (OM) (5, 27). Vaezi et al., 2008 concluded that erodibility for calcareous soils significantly reduces due to the robust effects of clay and lime on aggregate stability and infiltration rate, the fact that has not been sufficiently taken into account in USLE studies (36). During the last decade, several models based on integrated Geographic Information System (GIS) and Remote Sensing (RS) have been reported in some literature for predictive evaluation of soil erosion (10, 11, 22). Some studies demonstrated the advantage of Landsat spectral main indices based on land reflectances, such as Coloration Index, Form Index, Normalized Difference Vegetation Index, and Brightness Index for topsoil characterization. It can be noted, that GIS and RS techniques offer a exclusive chance to map, analyze, quantify, monitor, and in detail, the proceeding that assist to soil loss (21). McBratney et al., 2003 reported that the main erodibility factors can be possibly investigated and mapped with RS techniques. Dwivedi, 2001 used the Optical Satellite Imagery (OSI) method for soil mapping, mainly through the visual description of soil patterns. In the same way, soil classification by visual evaluation of OSI has been used to measure variances in soil erodibility (30, 33). Basied on Wischmeier and Smith, 1978's equations, it is possible to determine the relationship between soil classes and erodibility factor (5). The same equations can be used to determine the K-factor in the field, and obtained values will be extrapolated to the whole sampling area using by geostatistical methods. With these techniques, Landsat TM band 7 is allowable to replicateing the spatial distribution of K-factor (2, 38). Based on the above, this study was carried out to determine K-factor and mapping over Erbil city by examining the soil erodibility under simulated rainfall. While only a few studies on soil erosion have been carried out in Kurdistan Region (18).

MATERIAL AND METHODS

Study Area: The study was carried out in Iraqi Kurdistan, surrounding Erbil city and is bounded by latitudes 35°40′10″ and 36°39′22″ N and longitudes 43°29′68″ and 44°57′94″ E has a total area of about 7276 Km^2, see Figure 1. The study area is initiated with a mean annual rainfall of about 250 mm in the south and 550 mm in the northern parts. The area elevations greatly vary from high elevation in Safeen Mountain and downstream componet and range from (1950 to 202) m, respectively. The upper part of Erbil is covered by comprised forests with varying degrees of degradation ranging from completely treeless areas to thick forests. Oak is the dominant tree species. Furthermore, riparian forests can be found in the form of narrow strips along the main streams. The middle and lower parts are covered mainly by grazing lands covering various classes ranging from very poor to dense grazing lands. Dry farming is the dominant practice in the majority of the area. Wheat and barley are the principal crops. There are also scattered spots of irrigated lands close to the main streams, which are cropped with vegetables and fruit trees. Additional sources of irrigation water are springs, and shallow and deep wells (19). The soils are variable due to differences in contact, slope, runoff, parent materials, depth, and maturity (7, 13, 15). The existing soils have been either completely eroded or so shortened such that the diagnostic horizons of all orders in Entisoils are absent, particularly on steep slopes. The dominant soil groups are Xerothents and Rendolls which are overlying stony materials in the mountain area, Chromoxererts and calcixerolls in the intermountain valleys, and Torrifluvents adjacent to the main streams (3, 16).

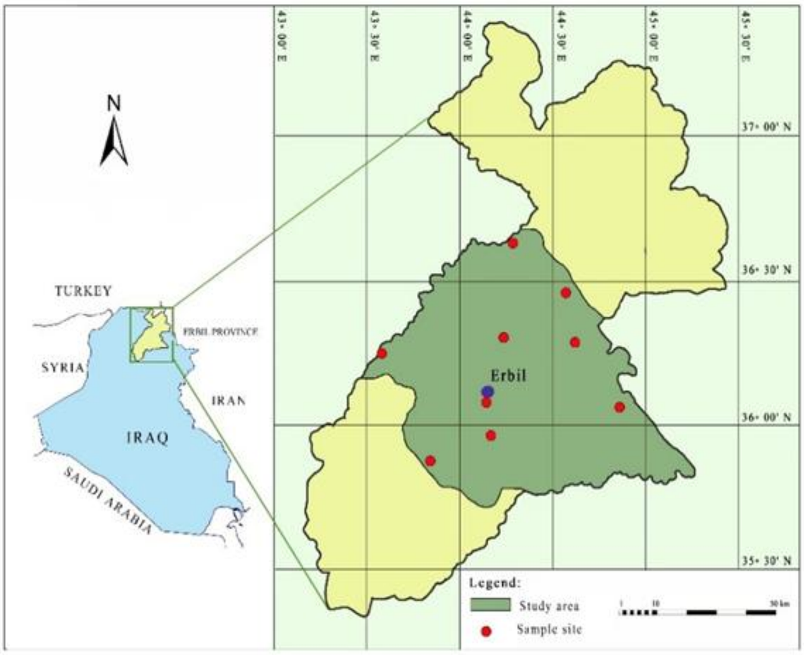

Figure 1. Location of the study including sample sites

Soil samples collected at 30-cm depth and followed nine points surrounding Erbil city. Physical properties of the soil samples were recognized using: *soil structure* by Visual Soil Evaluation (VSE) techniques (12), *soil hydraulic conductivity* by Blanco and Lal, 2008, *Particle size analysis* by Bouyoucous hydrometer method using sodium hexametaphosphate as the dispersant (35), *Soil texture* using the USDA soil textural triangle, *very fine sand (VFS)* by Panagos et al., 2014, *soil organic carbon* by Walkley-Black method (1). Furthermore, the amount of lime as the TNV (*Total Neutralizing Value*) was calculated by titrimetric method buffered at pH5; the neutralizing rate of carbonates with CH_3COOH. Table 1 lists the some selected physicochemical properties of the soil samples. Laboratory analysis revealed that they had a low OM and high potassium concentration. The soils were limey, moderate permeability, and textures were mostly clay (C) and clay loam (CL).

Table 1. Some selected soil characteristics of the soil samples

Sampling point	Coordinate		PSD (%)			TC	BD $g.cm^{-3}$	SP %	pH
	Latitude	Longitude	Sand	Silt	Clay				
Chra	36.612852	44.188018	34	27	39	CL	1.41	37	8.21
Dibaga	35.853056	44.034722	14	60	26	SL	1.46	37	7.95
Grdarasha	36.102222	44.001944	8	60	32	SCL	1.46	43	7.98
Khabat	36.263396	43.645389	28	39	33	CL	1.51	46	8.04
Koya	36.081014	44.597583	16	48	36	SCL	1.47	43	7.88
Malaomar	36.298611	44.118056	22	41	37	CL	1.44	43	8.2
Mamajalka	36.451395	44.383736	8	39	53	C	1.37	51	8.08
Qushtapa	36.001345	44.107591	18	52	30	SCL	1.52	43	8.16
Safeen	36.291205	44.414445	10	36	54	C	1.32	51	7.95

PSD; particle size distribution, TC; textural class, BD; bulk density, SP; saturated percentage

METHEDOLOGY

Rainfall simulator: The rainfall simulator was used to produce rainfall with 20 $mmhr^{-1}$ intensity that was designed with a 1–nozzle unit, the specifications are similar to the rainfall machine described by Mhaske et al., 2019. In this experiment, simulated rainfall was applied on the soil micro-plot (area=0.5 m^2), and used a slope of 9.8%. On each soil micro-plot, simulated rainfall events were conducted with 30-minute duration. Surface runoff was collected using a pail at the end of the rainfall events. After more than 24 hours of sedimentation, the sediment was collected in the pail, dried by air, and weighed. Total surface runoff and soil loss of each sample were then calculated, see Figure 2. In this study, K-factor was derived from the following equation which is extensively used in many studies (23, 26):

$$qs = aqr + b \qquad (1)$$

where qs is the sediment yield amount in g $m^{-2}min^{-1}$, qr is the runoff amount in mm min^{-1}, a and b are regression coefficients (a: g $m^{-2}mm^{-1}$; b: g $m^{-2}min^{-1}$), a is described K-factor.

USLE nomograph from soil analysis of the proportion of (silt + very fine sand), OM amount, soil structural class, and permeability class as described by Wischmeier et al., 1971. The generally used erodibility equation to allow quick calculation of K-factor without the need to follow the nomograph. The modified equation takes the form (42):

$$K=0.00021\times M^{1.14}\times(12-a)+3.25\times(b-2)+3.3\times10^{-3}(c-3)/100 \qquad (2)$$

Where; *M is the particle size, a= OM%, b= structure class, c= hydraulic conductivity class.*

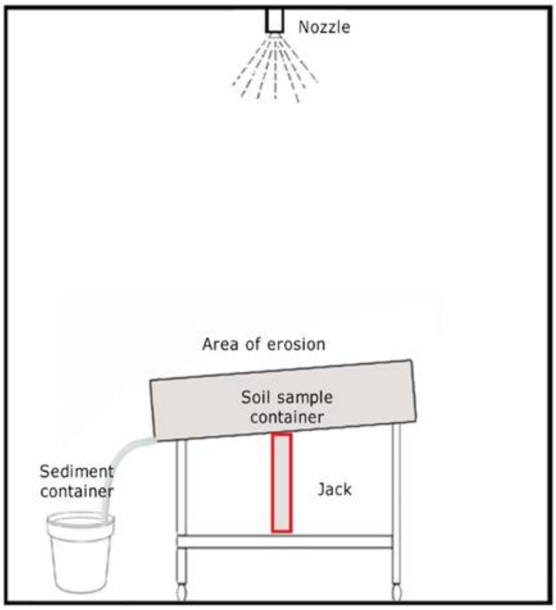

Figure 2. Cross-section view of the rainfall simulator (20).

EPIC model was used in K-factor calculation for the soil samples. The composition of soil particle size and Soil Organic Carbon (SOC) content were used to calculate the algebraic estimation of K-factor (40) as cited in Chen et al., 2011:

$$K = \left\{0.2 + 0.3 \exp\left[-0.0256 S_d \left(1 - \frac{S_i}{100}\right)\right]\right\} \times \left(\frac{S_i}{Cl+S_i}\right)^{0.3} \times \left[1 - \frac{0.25C}{C+\exp(3.72-2.95C)}\right] \times \left[1.0 - \frac{0.7SN}{SN+\exp(-5.51+22.9SN)}\right] \quad (3)$$

Where; *K is the soil erodibility factor in* $MghMJ^{-1}mm^{-1}$; S_d= *sand%*, S_i= *silt%, and Cl= clay%; C= SOC%;* $SN=(1-S_d/100)$. *The results were then divided by 0.1318 and converted to SI units* ($MghMJ^{-1}mm^{-1}$).

K-factor for calcareous soils, Vaezi et al., 2008 developed a relationship between K-factor and content of clay, lime and permeability for calcareous soils:

$K=0.0123 - 5.7\times10^{-5}$ CC- 5.2×10^{-5} TNV–0.00129PE (4)

Where; *CC= clay content%, TNV%, PE= permeability rate in* cmh^{-1}, *and K* ($t\ h\ MJ^{-1} mm^{-1}$).

Besides K-factor calculation of sampled soils, the performances of three equations that previously published were evaluated. The evaluation of methods was conducted in terms of some indicators such as R^2, MAE; mean absolute error, MAPE; mean absolute percent error and CRM; the coefficient of residual mass. After calculating the K-values, the ArcMap software was applied to map the spatial variability of erodibility over the study area using by Kriging interpolation method.

RESULTS AND DISCUSSION

Rainfall Simulation Study of Soil Erodibility (Observed K): The rainfall simulator developed at the Research Center of Erbil Polytechnic University was used to investigate the influence of soil characteristics on K-factor. A database was built using the quantity of eroded soil in the runoff plot to determine the mean K-factor for each soil samples. Table 2 shows the findings obtained for various soils, following as the procedure described in methodology section. The results for runoff, sediment yields, and sediment concentration, which are the averages of three repetitions, demonstrate that the soil loss reported on these soils ranges between 19.7 and 29.3 g, and that runoff and sediment concentration likewise vary amongst soils. It revealed that the total runoff of clay soils was significantly less than that of SC and SCL soils. Hence, the medium textural classes are more vulnerable to soil loss (25). Similar to the characteristics of runoff, the sediment yields also varied. Similar to the findings reported by Kamphorst in 1987, the sediment yields decreased as the clay content increased.As observed during the simulation runs and commonly described in the literature (18, 25), the typical pattern of sediment yield was one of initially large rates of loss, followed by decreasing rates with time.

Table 2. Average runoff, soil loss and sediment concentration measured on different soils

Soil sample	Textural name	Runoff (L)	Sediment (g)	Sediment concentration (g/L)
Chra	Silty Clay	29.3	249.4	8.5
Dibaga	Clay	22.8	196.5	8.6
Grdarasha	Silty Clay Loam	26.8	287.4	10.7
Khabat	Clay Loam	19.7	156.3	7.9
Koya	Clay	21.3	189.6	8.9
Malaomar	Clay	20.6	193.4	9.4
Mamajalka	Clay	22.6	218.4	9.7
Qushtapa	Silty Clay Loam	26.5	280.1	10.6
Safeen	Clay Loam	19.9	162.3	8.2

The slope of a linear function under net detachment conditions has been widely accepted as a measure of K-factor based on the link between sediment yield and runoff rate (26, 37). For each soil type, sediment yield (q_s) was a function of runoff rate (q_w), and the connection could be successfully fitted by the linear equation (1). The Grdarasha had the highest soil erodibility, whereas Khabat had the lowest, according to the link between runoff and soil loss. Haotian et al., 2015 also observed the same relationships between these variables in bare soil samples. Figure 3 illiterates how the sediment yield is affected by different levels of OM content and pH of the soil samples. Each point represents the mean value of three simulation runs. Wang et al., 2013 found that the OM and clay content are the principal factors that influence soil erodibility. According to Bonilla and Johnson, 2012 K-factor values must be precise and correlated with textural features and soil OM contents.

Indirect estimation of soil erodibility

K-factor can be calculated indirectly using models supplied with data on soil physical properties as input data: (Wischmeier and Smith, 1978), Eq. (2); (Williams and Renard, 1983), Eq. (3); and (Vaezi et al., 2008), Eq. (4). The inputs (Table 3) and outputs (Table 4) for the K-factor equations are given by soil type for each estimate technique. Table 4 lists the K-factor values obtained using three indirect methods in addition to a direct method of simulating rainfall. Equation (4) produced the highest results in spite of soil type. The K-factor values calculated by Equations (2, 3) were ranked third and fourth, respectively. The direct method determined the smallest K-factor value across all soil types.

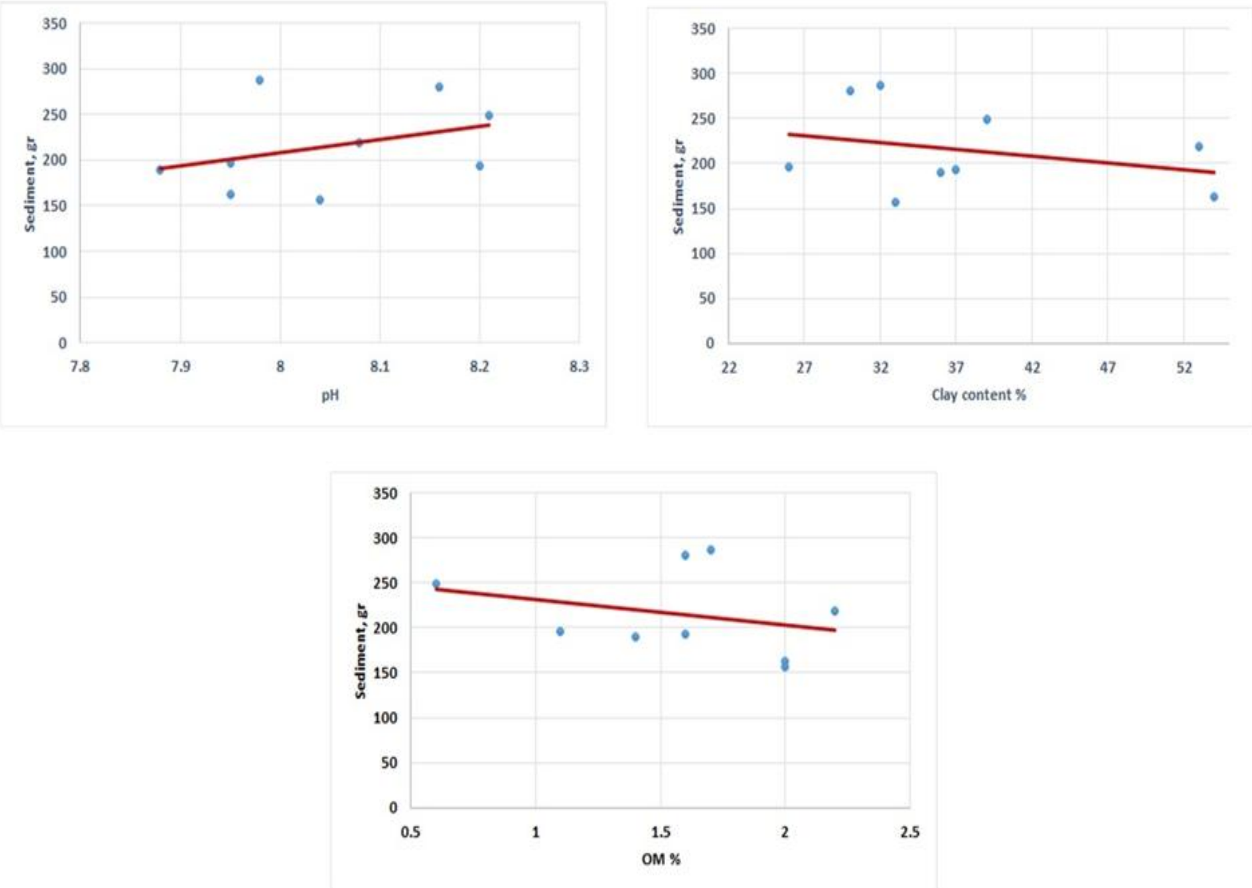

Figure 3. Sediment yield at different: (a) pH values, (b) clay content and (c) OM% contents

Table. 3. Summary of soil erodibility parameters by different methods

Soil	OC	SN	TNV	PE	S+ VFS	OM	SC	SHC
Chra	0.3720	0.66	16.74	2.46	33.8	0.6	4	4
Dibaga	0.6270	0.86	32.69	1.12	62.8	1.1	3	4
Grdarasha	0.9672	0.92	21.56	1.43	61.6	1.7	3	3
Khabat	1.1718	0.72	29.16	2.26	44.6	2.0	3	3
Koya	0.7998	0.84	16.28	1.64	51.2	1.4	3	3
Malaomar	0.9486	0.78	42.39	2.34	45.4	1.6	3	3
Mamajalka	1.2648	0.92	28.51	0.67	40.6	2.2	4	4
Qushtapa	0.912	0.82	15.55	1.48	55.6	1.6	3	4
Safeen	1.1346	0.90	2.290	0.58	38.0	2.0	4	4

OC is organic carbon in %, (SN=1-Sand/100), TNV is total neutralizing value in %, PE is permeability in cmh^{-1}, OM is organic matter in % SC is Structure class, SHC is soil hydraulic conductivity class. The very fine sand (VFS) fraction is estimated to be around 20% of the total sand fraction (27).

Based on Table 4, we found that the direct measured K-factor values varied from 0.27 to 0.39 t h MJ^{-1}mm^{-1} with standard deviation of 0.041 t h MJ^{-1}mm^{-1}. According to Hagos, 2004 the soils in the study area have a Moderate erodibility class. The K-factor estimated by EPIC model, Vaezi et al., 2008 and USLE nomograph varied from 0.27 to

0.40, 0.50 to 0.83 and 0.20 to 0.39 t h $MJ^{-1}mm^{-1}$, respectively.

Spatial Variation of soil erodibility

As a consequence, the estimated K-factor values have been used to create the erodibility map over the study area, see Figure 4. Except for the Vaezi et al.'s model, the other models were higher in the southern parts of the study area where the soil texture included silt content. Accordingly, these soils are more vulnerable to erosion. Panagos et al., 2014 also stated that the medium fine textural class has the highest mean values of the K-factor. Furthermore, the observed erodibility factor showed an increasing tendency from east to west, and from south to north, which is linked to the increase in the silt content in the same directions. This investigation of K-factor performed using USLE technique offered vital information on soil erosion estimate. This numerical value map can be a relevant tool for Integrated Soil Management (ISM).

Table 4. K-factor values determined by different methods

Soil	Soil erodibility (t h MJ^{-1} mm^{-1})			
	Rainfall simulator	EPIC model	Vaezi et al. (2008)	USLE nomograph
Chra	**0.31**	**0.27**	**0.60**	**0.20**
Dibaga	**0.30**	**0.40**	**0.77**	**0.39**
Grdarasha	**0.39**	**0.39**	**0.75**	**0.32**
Khabat	**0.27**	**0.29**	**0.60**	**0.20**
Koya	**0.31**	**0.36**	**0.73**	**0.24**
Malaomar	**0.33**	**0.32**	**0.50**	**0.20**
Mamajalka	**0.34**	**0.31**	**0.69**	**0.20**
Qushtapa	**0.39**	**0.36**	**0.79**	**0.31**
Safeen	**0.28**	**0.31**	**0.84**	**0.19**
Min	***0.27***	***0.27***	***0.50***	***0.20***
Max	***0.39***	***0.40***	***0.83***	***0.39***
Mean	***0.31***	***0.31***	***0.73***	***0.20***
S.D.	***0.041***	***0.043***	***0.103***	***0.067***
CV %	***0.132***	***0.134***	***0.141***	***0.331***

Comparison of the K determination methods

In the studied area, the EPIC and USLE nomograph models yielded the suitable K-factor for estimating soil erosion and sediment output. Both models have significant correlation indices and a percent bias (PBIAS 50%<), acceptable efficiency. The correlation (Figure 5) shows that K values obtained by both models could signify representing the same performances for determining soil erodibility factor. However, the Vaezi et al's model is not suitable for the study area because they overestimate K-factor values. In addition, the statistical evaluation showed that this model did not fit with observed data for K-factor. However, a number of statistical indices were used to evaluate the goodness-of-fit of investigated models. The fitting accuracy of models was determined by using the MAE, MAPE and CRM. The mean absolute percent of error varied from a minimum of 76.58 % for USLE nomograph model to as high as 214.07 % for the Vaezi et al's model. No model offered a MAPE of 30%< (Table 5).

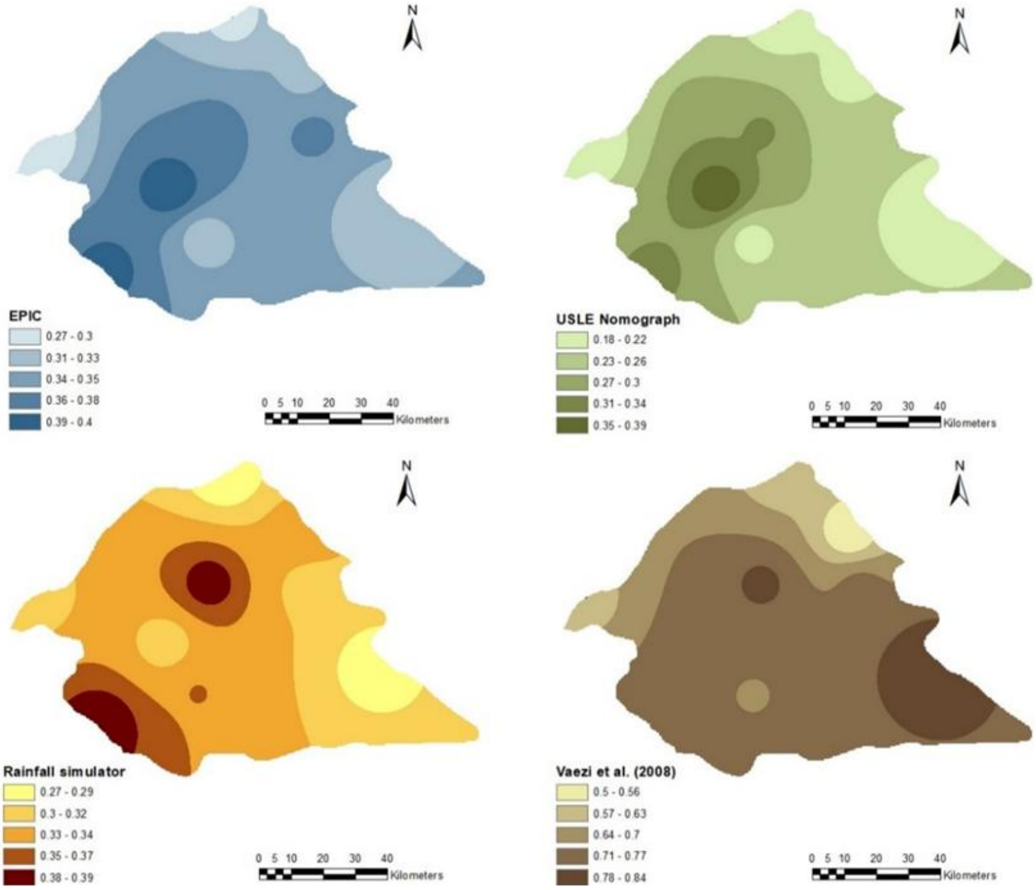

Figure 4. Spatial distribution of soil erodibility estimated as K-factor in the study area

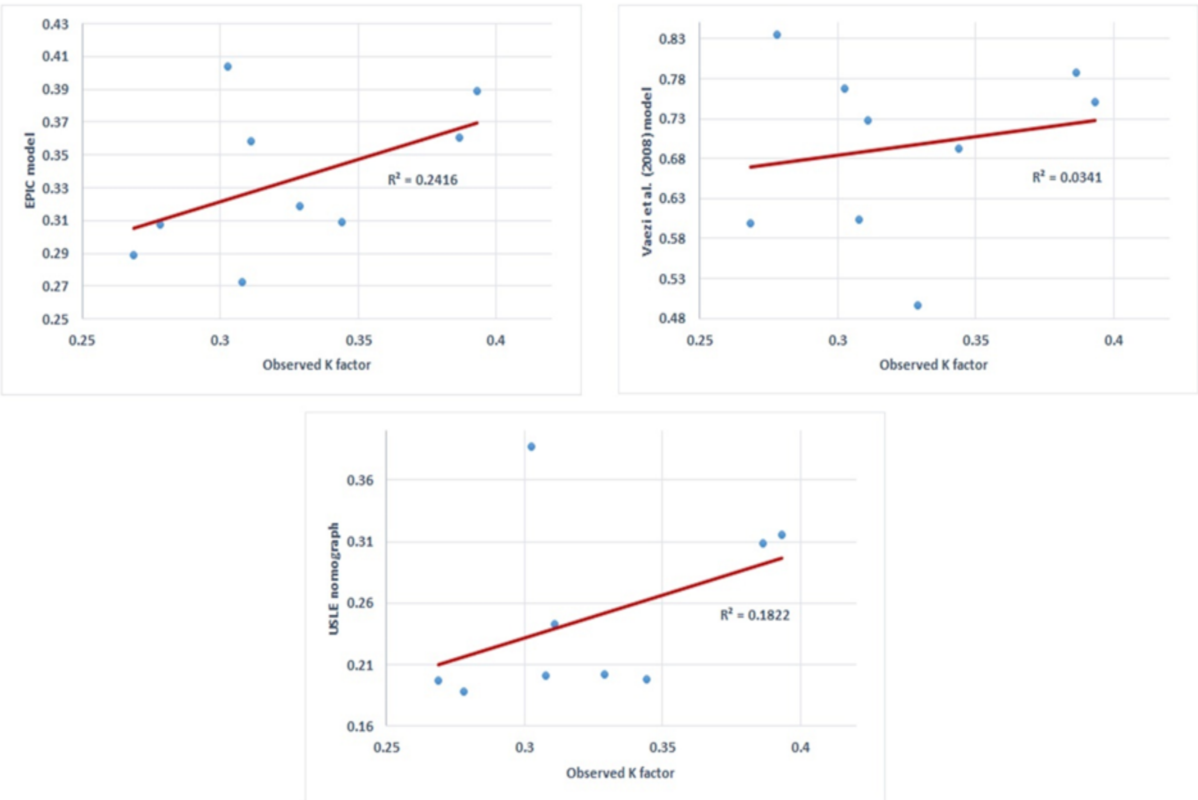

Figure 5. Measured K versus estimated K: (a) EPIC, (b) Vaezi et al and (c) USLE models

Table 5. Some statistical indices used for testing the performance models for predicting K values

Model	MAE	MAPE	CRM	R^2
EPIC	0.3342	102.84	-0.02992	0.2416
Vaezi et al	0.6957	214.07	-1.14394	0.0341
USLE nomograph	0.2488	76.58	0.23306	0.1822

CONCLUSIONS

In this study, the performance of different methods to estimate the K-factor was evaluated by comparing the sediment yield observed in the runoff plot. In addition, K-factor values were obtained from three experimental equations developed by Williams and Renard, 1983, Vaezi et al., 2008 and Wischmeier and Smith, 1978. As a whole, the soil erodibility is the most suitable parameter to estimate sediment yield and soil loss in the studied area which was obtained from the EPIC and USLE nomograph methods. Both methods present good correlation and acceptable efficiencies indexes. It suggested that using the simulating rainfall method to estimate K-factor and sediment predictions would be an alternative in data-scarce environments because the performance of this method is nearly satisfactory.

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