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Original Article

Comparison of Published and Proposed Models for Estimation of Soil Erodibility in a Semiarid Region

Tariq Hama Karim[1], Kamyar Mutalib Mohammed*[2]

[1]*Department of Surveying and Geomatics, Faculty of Engineering, Tishk International University, Erbil 44001, Kurdistan Region, Iraq.*
[2]*Department of Soil and Water, College of Agricultural Engineering Sciences, Salahaddin University-Erbil, Erbil 44001, Kurdistan Region, Iraq.*

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ABSTRACT
As the in-situ determination of the soil erodibility factor is in need of elaborate setting up and observation for lengthy periods of time, the use of pedotransfer functions is a good alternative for measurement at a large scale and is highly suitable for soil mapping. Therefore, a study was initiated to select the best model or index for estimating soil erodibility (K) based on soil properties under different land uses over the southern and middle parts of Erbil province. To achieve this goal, soil samples were obtained from the top 0.2 m at 30 locations within the study area. The most commonly used models and a proposed model were compared and ranked based on their power of predictability. The results indicated that 67% of the estimated soil erodibility by the reference method fell in the moderate and fairly high classes. It is also apparent from the displayed results that more than 73% of sampling sites have a dispersion ratio of more than 15% thereby indicating that the majority of the soils are highly vulnerable to erosion. Among soil erodibility indices, only Critical Level of Organic Matter (CLOM) exhibits the strongest correlation with K (r = 0.01). It was also observed that the truncated Wischmeier and Smith model has the highest predictability power for estimating K, followed by the proposed multiple linear models, while the Shirazi model exhibited the poorest performance. Further, the soil erodibility estimated by K6 and K2 exhibited better harmony with land use variation than that of the remaining models. It was also noticed that K gained the highest value at the north and tends to decrease from north to south.

Keywords: Soil erodibility, Model evaluation, Model building, Erodibility indices, Indirect estimation.

1 Introduction

Overexploitation of natural resources and conventional agricultural practices without conservation practices has led to severe soil erosion. Therefore, estimation of soil erosion has always been a key concern for soil conservation specialists and ecologists [1]. The acceleration of erosion as a natural process has become a big challenge as it gives rise to intensive land deterioration, environmental disturbance, and disorder of the socio-economic condition of the inhabitants [2,3]. Soil erosion measurement is a frustrating process on account of logistics and longer data series requirements. This is especially true in underdeveloped countries, with longer and the frequent data collection. The problems become more complicated in developing countries due to resource constraints [4]. Soil erodibility (K-factor) in the universal soil loss equation can be computed by the ratio of soil loss per unit rainfall erosivity and per unit area from a standard plot [5].

* Corresponding author
E-mail address kamyar.mohammed@su.edu.krd (Instructor).
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Soil erodibility is one of the vital parameters of erosion predicting models [6]. The measurement of this parameter is tedious and time-consuming in the field due to the vast cost of field setup and the time dedicated to frequent measurements. Accordingly, field measurements of the K-factor have been performed for limited reference soils [7]. Direct measurements of erodibility have been made on only a few benchmark soils. To find a remedy for this situation, Wischmeier and Mannering [8] originally proposed an erodibility model based on 15 soil properties and the interactions among them. Later on, soil properties were shrunk to only four properties, which were soil separates, soil organic content, soil structure, and permeability.

Because of many constraints and substantial uncertainties in in-situ measurement of K-factors, numerous empirical models have been suggested for indirect estimation of this parameter. For instance, Wischmeier & Smith [5] developed a model for indirect estimation of soil erodibility based on soil texture, organic content, structure, and permeability as input variables. Renard et al. [9] related soil erodibility to the mean geometric particle diameter of different textural classes and indicated that such models are useful for sites with limited data, especially when there is no gathered data on soil structure, soil permeability, soil organic content, and very fine sand. Also, Denardin [10] developed a regression model with M (the sum of silt and very fine sand multiplied by (100 – clay), structure code, the mean weighted diameter of particles less than 2 mm, and the ratio of soil organic content to the ratio of particles sandwiched between 1 and 2 mm. Furthermore, Sharpley and Williams [11] derived a model in the form of the product of four functions (A, B, C, and D).

Bonilla and Johnson [12] revealed that indirect methods can be employed to determine this factor and make such studies possible. Adhikary et al. [13] observed that the erodibility model that uses soil texture (particle size) and organic content exhibited better harmony with land use variation than erodibility models that depend only on soil separates. On the other hand, Anache et al. [14] revealed that soil properties such as texture, structure, organic content, and its chemical composition are significantly correlated with the susceptibility of soil to erosion. Based on these properties, a host of indices were also developed. These indices are a beneficial substitute for planning suitable treatment procedures in areas where the generation of soil erosion is a constraint. Among the most widely used indices are clay ratio, dispersion ratio, suspension ratio, ratio of clay content to moisture equivalent, etc. [15]. Chorley [16] developed an erodibility index based on a combination of permeability and shear resistance, while Wischmeier and Smith [17] suggested the K-factor depending on soil properties influencing dispersion and water transmission. The erosion index was also derived as an erodibility index based on Indian investigations [18]. The dispersion ratio value can be used as a good indicator for the vulnerability of soils to erosion [19]. The cutoff value of 15% for dispersion ratio can be considered as the cutoff value between erosive and non-erosive soils [20]. Remote Sensing accompanied with GIS is one of the powerful ways of soil mapping at different spatial and temporal resolutions [21].

Erodibility indices can support in diagnosing zones that are vulnerable to erosion, and protective measures can be planned accordingly. Furthermore, the models that are derived for a reference area are coherent with the soil features of that area, but they may not agree well with the features of the area under investigation. Therefore, the current study was initiated to target the following objectives: 1) To select the best soil erodibility index that is closely related to the susceptibility of soils to erosion over the study area; 2) to test the perfomance of the previuosly published and two proposed models for assessing soil erodibility, 3) to build a model for predicting soil erodability across the study area, and 4) to generate continous surfaces for soil erodibilty over the study area.

2 Materials and Methods

2.1 Description of the Study Area

The study area occupies nearly the southern and middle parts of Erbil Governorate. It spans a total area of approximately 9000 km^2 and covers several watersheds with different land uses. Geographically, it is situated between latitudes of 35.5000° N and 36.700° N and longitudes of 43.171° E and 44.8333°E. The area feeds the Greater Zab and the Lesser Zab rivers. The main watersheds within this area are: Koya, Hiran, Harir, Shaqlawa, Bastora, Bnaslawa, Qushtapa, Dibaga, and Makhmur. The dominant land uses encompassed agricultural (70%), grazing land (17%), and forest (13%).

The annual rainfall ranges from as low as 200 mm at Makhmur to as high as 900 mm at Shaqlawa. It has a unimodal distribution, and more than 95 % of the rainfall occurs between October and April. Contrarily, there is a water deficit over the remaining months of the year. The warmest and coldest months of the year are July and January, respectively.

On the basis of the classification scheme proposed by Koppen, the middle part of Erbil province (study area) is classified as temperate, dry summer, hot summer (CS_a). While the area located in the southern part of the study area falls within the arid, steppe, hot (BSh). However, Figure 1 shows the distribution of mean monthly rainfall and mean monthly air temperature over the months of the year at Erbil Meteorological Station.

Vegetation is diverse, with no mountain vegetation can be found over most of its southern part, even the smaller woody shrublets have been removed by plough, fuel gatherer, and wood cutter. Patches a deciduous shrub trees and artificial spots can be observed over its upper part, forming open plant communities. The plain has a high potential for agricultural production. Dry farming is practiced to a high extent. Wheat farming accounts for the majority of arable lands, followed by barley, faba bean, chick pea, and maize. There are also scattered spots of irrigated lands, mostly along the existing streams. They are cropped with vegetables and orchards. Unlike the southern part, most areas within the low and high zones are except for the intermountain valleys, have steep to very steep slopes. Accordingly, they are utilized for grazing, forest lands, and marginal lands.

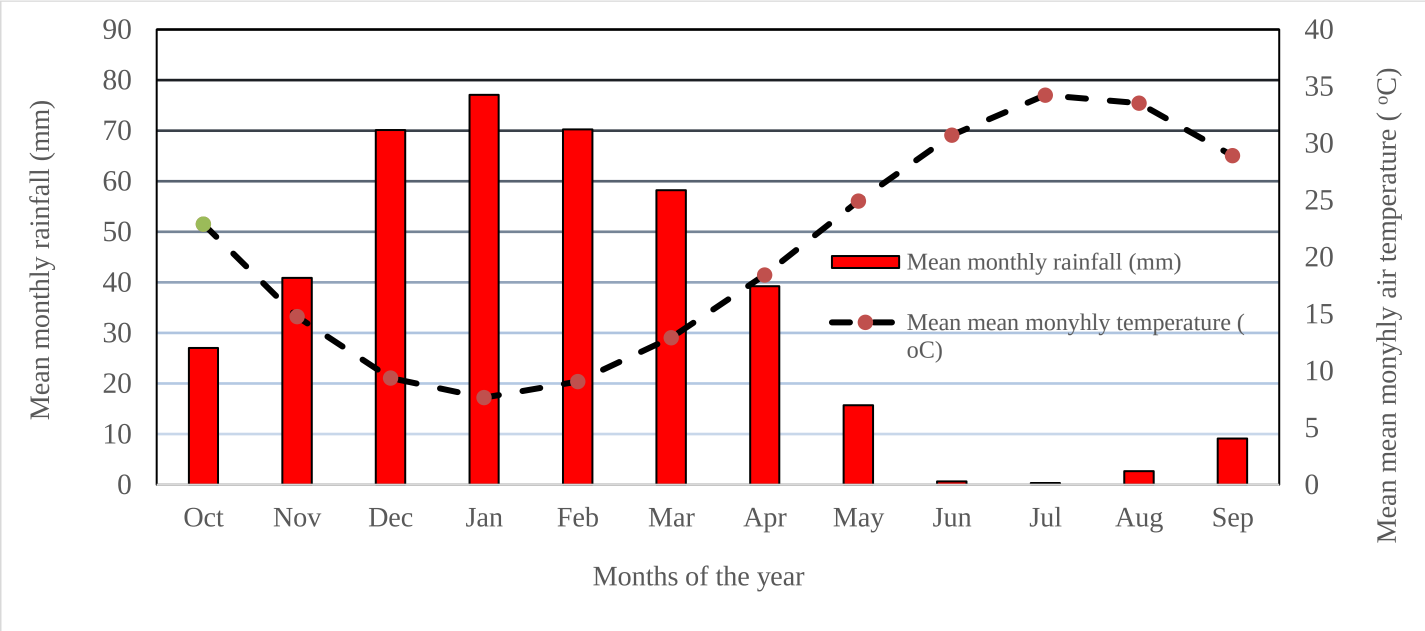

Figure 1: Distribution of mean monthly rainfall and mean monthly air temperature over the months of the year at Erbil meteorological station.

Tectonically, the southern parts are located within the foothill zone, while the areas surrounding the upper part are situated within the low folded zone. On the other hand, the mountainous area behind the upper part is located with high folded and thrust zones. Overall, the investigated area is underlain by various geological formations. The dominant rock formations encompass the Upper Bakhtiari, Lower Bakhtiari, Upper Fars, and Lower Fars.

Overall, the region can be considered as rough, broken, and stony lands. The mountains are mainly composed of limestone of different compositions. The existing soils have been either completely removed or so truncated that the diagnostic horizons of all orders other than Entisols are absent. The dominant soil groups than can be found over this area are: 1) Xerothents: a soil with a thin layer overlying stony or consolidated rocks, usually lime stone, 2) Rendolls: the soils with a dark brown or very dark brown to black granular surface layer of 15-20 cm in thickness overlying various kinds of limestone, 3) Chromoxererts: soils with a brown surface layer of about 20-40 cm grading into a lighter layer of lime accumulation [22]. Most of the existing soils at Erbil plain and the surrounding areas belong to Chromoxererts. This great group exists in the form of a deep profile, nearly free of rocks, medium potential to volume change, and has high agricultural potential. Additionally, there are scattered spots of red mud (Gercus formation), blue shales (Kolosh formation), and chalky soils (Shiranish formation) in the form of unconsolidated materials over steep slopes.

2.2 Sampling Strategy and Sampling Preparation

Prior to soil sampling, a field survey was made to estimate the level of soil erodibility and to postulate the soil characteristics. A Garmin portable GPS was employed to log the geospatial information. A total of thirty representative soil samples were collected from the top 0.2 m of different locations covering different land uses over the study area during the late spring season of 2023 (Figure 2 and Table 1). The soil structure was described visually after dropping representative clods from a height of about 1 m in the field [23]. The infiltration rate was also measured in the field using a double ring infiltrometer [24]. Upon bringing the soil samples to the laboratory, they were air-dried, gently ground to pass through a 2-mm sieve, and kept in plastic containers until use. The hydrology tool inside the Spatial Analysis Tools of ArcGIS, version 10.7, is used to delineate the basin boundaries, map the drainage networks, and extract topographic data [25].

2.3 Soil Erodibility Indices

Apart from soil erodibility modelling, several indices were also used to explore the proneness of soil to erosion.

2.3.1 Dispersion Ratio (DR)

It was determined by the procedure outlined by Akhtaruzzaman et al. [20] and calculated according to the following model:

$$DR = \frac{\mathrm{A}}{\mathrm{B}} \quad (1)$$

where A = % water-dispersible silt-plus-clay; B = % actual silt-plus-clay determined during particle size analyses with Calgon.

2.3.2 Clay Ratio (CR)

The calculation of this index was based on the following equation [7]:

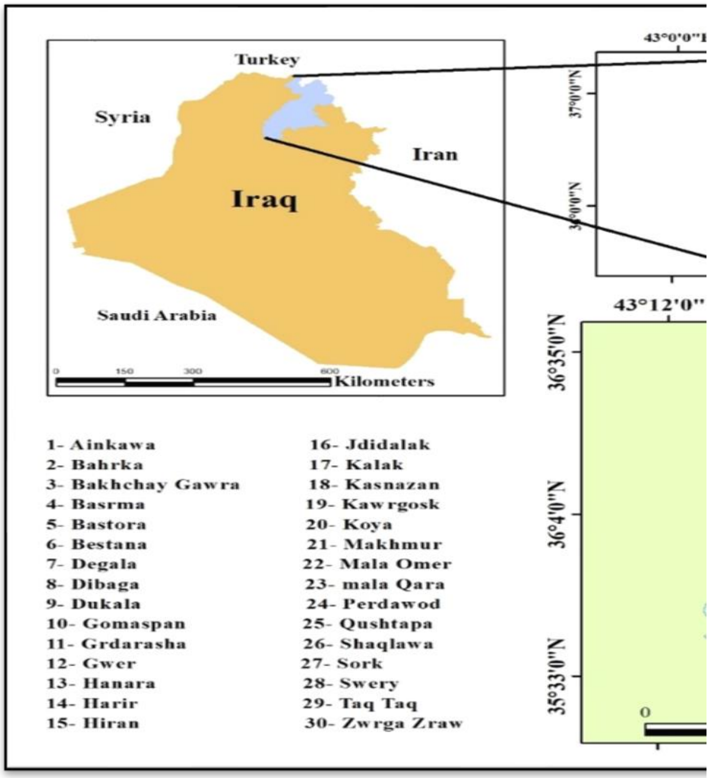

Figure 2: Location map showing the sampling sites.

$$CR = \frac{\%\,\text{silt} + \%\,\text{sand}}{\%\,\text{clay}} \tag{2}$$

2.3.3 Modified Clay Ratio (MCR)

Clay ratio was modified according to the following equation to better explain the variability of soil erodibility [26].

$$MCR = \frac{\%\,\text{silt} + \%\,\text{sand}}{\%\,\text{clay} + \%\,\text{organic matter}} \tag{3}$$

2.3.4 Structural Stability Index (SSI)

It was developed by Pieri [27] as an index of structural stability according to the following expression:

$$SSI = \frac{\%\text{Soil organic matter}}{\%\text{silt} + \%\,\text{clay}} \times 100 \tag{4}$$

The above equation was also used for the critical level of soil organic matter (CLOM).

Table 1: Sampling locations and types of land uses, along with their geographic coordinates.

No.	Sites	Latitude	Longitude	Types of land use
1	Ainkawa	36.2488°	43.9949°	Crop land
2	Bahrka	36.3663°	44.0175°	Crop land
3	Bakhchay Gawra	36.2201°	44.2306°	Grazing land
4	Basrma	36.5405°	44.3233°	Crop land
5	Bastora	36.3266°	44.2055°	Forest land
6	Bestana	36.0324°	44.1913°	Crop land
7	Degala	36.1742°	44.3911°	Grazing land
8	Dibaga	35.8375°	43.8272°	Crop land
9	Dukala	35.9363°	43.9516°	Crop land

10	Gomaspan	36.2731°	44.2974°	Crop land
11	Grdarasha	36.1088°	44.0122°	Crop land
12	Gwer	36.0988°	43.5442°	Crop land
13	Hanara	36.3005°	44.2376°	Forest land
14	Harir	36.5339°	44.3568°	Crop land
15	Hiran	36.2818°	44.5151°	Forest land
16	Jdidalak	35.9652°	43.8792°	Crop land
17	Kalak	36.2822°	43.6523°	Grazing land
18	Kasnazan	36.2174°	44.1786°	Grazing land
19	Kawrgosk	36.3521°	43.7871°	Crop land
20	Koya	36.0756°	44.6443°	Crop land
21	Makhmur	35.7838°	43.5547°	Crop land
22	Mala Omer	36.2866°	44.1241°	Crop land
23	Mala Qara	36.0081°	43.5398°	Crop land
24	Perdawod	36.0119°	43.9372°	Crop land
25	Qushtapa	35.9881°	44.0475°	Crop land
26	Shaqlawa	36.4255°	44.3616°	Crop land
27	Sork	36.4151°	44.3197°	Forest land
28	Swery	36.1604°	43.9028°	Crop land
29	Taq Taq	35.8797 °	44.5834 °	Crop land
30	Zwrga Zraw	35.9122°	43.8481°	Grazing land

2.4 Comparison of Previously Published Models for Assessing Soil Erodibility

The soil erodibility at each sampling point was assessed using the following formula by Wischmeier and Smith [5] as a reference model to check the power of predictability of previously published and proposed models.

2.4.1 Wischmeier and Smith, 1978 Model (Reference Model)

$$K_1 = 2.77x10^{-6}M^{1.14}(12 - OM) + 0.043(SC - 2) + 0.033(PC - 3) \quad (5)$$

K_1 = Soil erodibility (metric unit) from reference model

M = (% silt + % very fine sand) (100 - % clay)

OM = Soil organic matter content (%)

SC = Structure class code (-)

PC = Permeability class code (-)

2.4.2 Wischmeier and Smith, 1978, after Truncating the Permeability Term

$$K_2 = 2.77x10^{-6}M^{1.14}(12 - OM) + 0.043(SC - 2) \quad (6)$$

2.4.3 EPIC Model Developed by Sharpley and Williams [11]

$$K_3 = 0.1317AxBxCxD \quad (7)$$

$$A = 0.2 + 0.3\exp\left(-0.0256SAN(1 - \frac{SIL}{100})\right)$$

$$B = \left(\frac{SIL}{CLA + SIL}\right)^{0.3}$$

$$C = \left(1 - \frac{0.25\,C}{C + \exp(3.72 - 2.95C)}\right)$$

$$D = \left(1 - \frac{0.70\,SN1}{SN1 + \exp(-5.41 + 22.9SN1)}\right)$$

where: SAN = %Sand, SIL = % silt, CLA = % clay, C = % soil organic carbon and SN1 = (1-SAN/100).

2.4.4 Torri (Torri et al., 1997) [28]

$$K_4 = 0.0293\left(0.65 - D_g + 0.24\,D^2{}_g\right) * \exp(-0.0021\left(\frac{SOM}{C}\right) - 0.00037\left(\frac{SOM}{C}\right)^2 - 4.02C + 1.72C^2\right) \quad (8)$$

Where:

$D_g = \Sigma f_i \log(\sqrt{d_i d_{i-1}})$

Dg = The geometric mean diameter (mm)

d_i = The maximum diameter of the *i*th class (mm). The maximum diameters for sand, silt, and clay are 2, 0.05, and 0.002 mm, respectively

d_{i-1} = The minimum diameter of the *i*th class in mm. The minimum diameters for sand, silt, and clay are 0.05, 0.002, and 0.00005 mm, respectively

f_i = The mass fraction of the *i*th class (-)

SOM = % Soil organic matter

C = The mass fraction of clay (-)

K_4 = The soil erodibility in SI unit

2.4.5 Shirazi et al. (1988) [29]

$$K_5 = 7.594\left\{0.0034 + 0.0405\exp\left[-\frac{1}{2}\left[\frac{\log(Dg) + 1.659}{1.7101}\right]^2\right]\right\} \quad (9)$$

$$Dg(mm) = \exp(0.01\Sigma\, f_i \ln m_i)$$

where f_i = percent of soil separates, m_i = the arithmetic diameter of the particle size limit

Dg = Geometric mean diameter of the soil particles (mm)

2.4.6 The Proposed Pedotransfer Function during the Current Study

$$K_6 = 1.5173 - 0.0079SI - 0.0327CLOM - 0.0357FC \quad (10)$$

FC = 13.29 + 0.379 C by Karim [30]

where:

K_6 = Soil erodibility in metric units

SI = Silt content (%)

CLOM = critical level of soil organic matter (-)

FC = Water retention at -33kPa

C = % percent clay

2.5 Evaluation of Models Performance

The following metrics have been used to test the performance of the commonly used and proposed models to predict the soil erodibility [31,32]:

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(O_i - P_i) \quad (11)$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|O_i - P_i| \quad (12)$$

$$PE = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{O_i - P_i}{O_i}\right| x100 \quad (13)$$

$$MRSE = \sqrt{\frac{\Sigma\,(O_i - P_I)^2}{N}} \quad (14)$$

$$R = \frac{\Sigma\,(x_I - \bar{x})(y_I - \bar{y})}{\sqrt{\left(\Sigma x_i{}^2 - \frac{(\Sigma x_i)^2}{N}\right)\left(\Sigma y_i{}^2 - \frac{(\Sigma y_i)^2}{N}\right)}} \quad (15)$$

$$D = \sqrt{\frac{\Sigma\,(x_i - \bar{x})^2}{N}} \quad (16)$$

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O}_i)^2} \quad (17)$$

$$MSEc = \left[\frac{\Sigma[\,(P_i - \bar{P}) - (O_i - \bar{O})]^2}{N - 1}\right]^{-0.5} \quad (18)$$

$$d = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|O_i - \bar{O}| + |P_i - \bar{O}|)^2} \quad (19)$$

$$CRM = \frac{\sum O_I - \sum P_i}{\sum O_I} \quad (20)$$

where: N = number of data points; Oi = observed values; P_i = predicted values; $\bar{O}$= mean of observed values; $\overline{P}$ = mean predicted value; MBE = mean biased error; MAE = mean absolute error; MAPE = mean absolute percentage error; RMSE

= root mean square error; r = Pearson correlation coefficient; SD = standard deviation; NSE= Nash-Sutcliffe efficiency; RMSEc = Centered root mean square error; d = coefficient of agreement and CRM= coefficient of residual mass.

The degree of correspondence between the modeled and reference behavior was also quantified in terms of standard deviation. Root mean square error and the Pearson correlation coefficient are collectively considered as the main parameters of the Taylor diagram [33].

2.6 Generation of Continuous Surfaces for Soil Erodibility

To generate soil erodibility at unsampled locations, the values of soil erodibility of the geo-coded sampling points estimated by 6 soil erodibility models were interpolated by the IDW interpolation method in GIS Environment using ArcGIS Ver. 10.7. The outputs were used to generate maps for soil erodibility and presented in figures.

3 Results and Discussion

3.1 Basic Soil Characteristics

Table 2 presents the input variables required for estimating soil erodibility and other influencing properties for soil samples obtained at different locations and under different land uses over the study area. It is evident from the displayed results that the area under investigation is characterized by having a wide range of soil textures, varying from sandy loam to clay soils. The dominant soil textures are silt, clay loam and clay loam and silt loam. Table 2 also displays the descriptive statistics for these variables. As can be seen in Table 2 that the sand content varied from a minimum of 5.64% to a maximum of 57.21% with a mean of 22.16%; the silt varied between 30.66% and 64.72%, while the clay ranged between 9.90% to 45.41%, and it differed from 9.90% to 45.41% for clay content. It was also observed that the soil organic matter content ranged from as low as 0.48% to as high as 2.98% and for VFS from 0.68% to 8.04%, while the infiltration rate ranged between 1.1 and 8.76 cm hr^{-1}, water retention at – 33 kPa between 17.04% and 30.50% and lime equivalent varied from 26.5% to 47.5%. Regarding soil bulk density ranged between 1.16 and 1.42 Mgm-3and the mean weight diameter from 0.33 to 4.93 mm. Furthermore, the results showed that the sand content exhibited the highest coefficient of variation, CV (62.42%), followed by infiltration rate (61.14%) and Mean weight diameter, MWD (50.37%). Contrarily, the bulk density offered the least value for CV (4.67%), and lime equivalent offered the second lowest value (14.39%). Based on the classification scheme proposed by Wilding [34], each of sand, VFS, organic matter, infiltration rate, MWD, and dispersion ratio was put under a high class of variability (CV > 35%) (Table 3). In contrast, each of bulk density and equivalent lime was put under the low class of variability (CV < 15), while the rest of the study variables fell within the moderate class (15%< CV < 35%).

The skewness results revealed that with 2 exceptions, the skewness of the study variables is between -1 and 1, indicating that the data sets are normally distributed. Further, the negative and positive skewness indicate that the datasets tail to the left and to the right, respectively, on the horizontal axis. Additionally, it can be noticed that based on the obtained values of the kurtosis that there are some deviations from the normal distribution of the data sets.

Table 2: Some selected physical and chemical properties of the soils at different sites over the study area.

Site	Particle size distribution (%)			VFS (%)	Texture class	Bulk density ($Mg\ m^{-3}$)	Organic matter (%)	Infiltration rate ($cm\ hr^{-1}$)	Water retention at -33 kpa	MWD (mm)	Dispersion ratio	E-$CaCO_3$ Equivalent (%)	K (metric unit)
	Sand	Silt	Clay										
Ainkawa	12.35	45.95	41.70	4.53	SiL	1.31	1.53	2.72	29.09	1.38	16.55	39.10	0.26
Bahrka	8.19	53.67	38.15	1.53	SiCL	1.24	1.31	2.35	27.75	3.27	10.16	37.00	0.32
Bakhchay Gawra	20.66	44.21	35.14	2.47	CL	1.26	1.25	3.26	26.61	1.41	19.59	47.50	0.32
Basrma	23.49	38.35	38.16	1.69	CL	1.28	2.40	2.87	27.75	3.41	24.38	38.26	0.20
Bastora	26.23	36.77	37.01	2.99	CL	1.33	2.98	1.10	27.32	1.39	14.05	41.20	0.22
Bestana	13.94	48.75	37.31	4.06	SiCL	1.20	0.73	2.67	27.43	1.12	16.86	34.90	0.36
Degala	26.20	44.70	29.11	8.04	CL	1.24	1.09	2.15	24.32	2.40	32.29	43.30	0.44
Dibaga	48.50	35.08	16.43	5.55	L	1.42	0.63	4.99	19.52	3.66	40.24	37.00	0.33

Dukala	13.94	56.33	29.73	0.68	SiCL	1.36	1.06	1.92	24.56	3.67	16.86	32.80	0.42
Gomaspan	9.06	49.75	41.19	1.54	SiC	1.30	1.23	1.88	28.90	0.71	14.81	34.90	0.31
Grdarasha	12.93	52.25	34.82	3.51	SiCL	1.27	1.14	2.42	26.49	0.33	34.51	37.00	0.39
Gwer	18.95	53.08	27.97	2.72	SiCL	1.21	1.33	3.70	23.89	2.44	24.29	37.00	0.42
Hanara	5.64	57.02	37.34	0.95	SiCL	1.36	0.86	1.82	27.44	0.77	14.28	30.70	0.47
Harir	8.12	51.89	39.99	3.12	SiCL	1.26	1.12	3.05	28.45	1.02	22.56	37.00	0.35
Hiran	49.85	40.25	9.90	1.62	L	1.39	2.65	2.61	17.04	4.93	28.93	35.74	0.31
Jdidalak	11.96	64.46	23.57	5.87	SiL	1.28	0.89	3.16	22.22	2.74	22.36	32.80	0.55
Kalak	57.21	32.42	10.36	4.59	SL	1.32	1.64	8.76	17.22	-	48.44	30.70	0.35
Kasnazan	34.26	30.66	35.08	3.37	CL	1.33	1.47	1.16	26.59	4.06	28.37	43.30	0.22
Kawrgosk	20.69	50.21	29.11	5.11	CL	1.33	0.99	1.32	24.32	2.98	11.76	37.00	0.46
Koya	17.73	48.14	34.12	4.05	SiCL	1.34	1.41	1.47	26.22	4.57	30.23	43.30	0.39
Makhmur	11.85	57.18	30.97	5.67	SiCL	1.28	0.87	1.17	25.03	2.67	9.40	26.50	0.51
Mala Omer	19.71	35.15	45.14	4.12	C	1.32	0.65	1.95	30.40	1.04	24.52	32.80	0.23
Mala Qara	33.72	44.08	22.20	4.04	L	1.31	1.01	2.01	21.70	1.78	35.96	28.60	0.36
Perdawod	11.97	64.72	23.31	5.02	SiL	1.28	0.61	1.99	22.13	3.54	21.19	34.90	0.64
Qushtapa	13.92	49.19	36.89	5.35	SiCL	1.24	1.22	1.35	27.27	3.30	28.89	43.30	0.40
Shaqlawa	12.76	41.83	45.41	2.21	SiC	1.33	2.21	2.35	30.50	3.06	34.45	26.50	0.24
Sork	23.16	51.25	25.58	4.39	SiL	1.16	0.48	3.26	22.99	2.20	12.14	32.80	0.51
Swery	17.22	53.76	29.02	3.72	SiCL	1.23	1.18	1.98	24.29	4.75	18.78	37.00	0.47
Taq Taq	50.24	36.23	13.53	2.36	L	1.39	0.73	6.47	18.42	2.02	70.81	32.80	0.38
Zwrga Zraw	30.23	50.27	19.50	3.96	SiL	1.35	0.76	1.73	20.68	4.00	7.43	43.30	0.56

SiL = Silty Loam, SiCL = Silty Clay Loam, CL = Clay Loam, L = Loam, SiC = Silty Clay, SL = Sandy Loam, C=Clay

Table 3: Descriptive Statistics for the study input variables used for estimating soil erodibility.

Variable	Unit	Sample size (N)	Range	Min	Max	Mean	SD	Variance	CV (%)	Skewness	Kurtosis

MWD	Mm	30	4.6	0.33	4.93	2.56	1.29	1.66	50.37	0.09	- 0.98
Sand	%	30	51.57	5.64	57.21	22.16	13.83	191.28	62.42	1.24	0.72
Silt	%	30	34.06	30.66	64.72	47.25	8.90	79.15	18.83	-0.05	- 0.51
Clay	%	30	35.51	9.90	45.41	30.59	9.78	95.74	31.99	-0.62	- 0.35
VFS	%	30	7.36	0.68	8.04	3.63	1.68	2.81	46.25	0.32	0.20
Bulk density	Mg m^{-3}	30	0.26	1.16	1.42	1.30	0.06	0.00	4.67	-0.19	- 0.20
Organic matter	%	30	2.50	0.48	2.98	1.25	0.61	0.37	48.70	1.44	1.85
Infiltration rate	mm hr^{-1}	30	7.66	1.10	8.76	2.65	1.62	2.63	61.14	2.40	6.83
Dispersion ratio	%	30	63.38	7.43	70.81	24.50	13.19	174.04	53.84	1.63	4.09
Lime Equivalent	%	30	21.00	26.50	47.50	36.30	5.22	27.28	14.39	0.09	- 0.31
Soil erodibility	Metric unit	30	0.44	0.20	0.64	0.38	0.11	0.01	29.08	0.31	- 0.31

3.2 Descriptive Statistics of Soil Erodibility Estimated by Different Models

Table 4 exhibits the summary of statistics for the estimated values of soil erodibility by different formulas, namely Wischmeier and Smith, 1978 (K1), truncated Wischmeier and Smith (K2); EPIC (K3), Torri et al., 1997 (K4), Shirazi et al., 1988 (K5) and the proposed model (K6) during the current study. The soil erodibility dataset estimated by the Wischmeier and Smith (1978) model, which hereafter is referred to as the reference method, varied from a minimum of 0.197 to a maximum of 0.637 with a mean of 0.38 metric unit [(t/ha). $\frac{ha.hr}{metric\ ton.m.cm}$]. It can also be noticed that it ranges from 0.187 to 0.604 for the Truncated Wischmeier and Smith, from 0.231 to 0.431 for Shirazi et al., 1988, from 0.291 to 0.485 for Torri et al., 1987, from 0.300 to 0.559 for the EPIC, and from 0.179 to 0.596 metric unit for the proposed model. The results also disclosed that the reference method offered the highest range, followed by the Truncated Wischmeier and Smith (1978) model and the proposed model. In contrast, the Torri et al. [35] model offered the lowest range, followed by Shirazi et al. (1988) and EPIC models. Additionally. It can be observed from the results of Table 4 that the Truncated Wischmeier and Smith offered the highest coefficient of variation, CV (29.450%), followed by the reference method (29.083%) and the proposed model (27.406%). Contrarily, the Shirazi et al. [29] model gave the lowest value for CV (13.327%), followed by the Torri et al. [28] (13.625%) and the EPIC model (15.510%). The skewness results also revealed that, with one exception, the data generated by different models are sandwiched between -1 and 1, indicating that the generated data by most of the models follow a normal distribution. A dataset may be considered as normally distributed if the skewness value ranges from −1 to 1 [36].

Table 4: Descriptive Statistics for soil erodibility estimated by different models.

Model	N	Range	Min	Max	Mean	Standard Deviation	Variance	CV (%)	Skewness	Kurtosis
1. Wischmeier and Smith	30	0.440	0.197	0.637	0.380	0.110	0.012	29.083	0.311	-0.312
2. Truncated Wischmeier and Smith	30	0.417	0.187	0.604	0.367	0.108	0.012	29.450	0.089	-0.308
3.(Shirazi et al., 1988	30	0.200	0.231	0.431	0.394	0.053	0.003	13.327	-2.000	3.294

4.Torri et al., 1997	30	0.194	0.291	0.485	0.377	0.051	0.003	13.625	0.311	-0.468
5. EPIC model	30	0.259	0.300	0.559	0.439	0.068	0.005	15.510	-0.388	-0.484
6. Proposed model	30	0.417	0.179	0.596	0.379	0.104	0.011	27.406	-0.119	-0.015

3.3 Soil Classification Based on Estimated Soil Erodibility Index

Based on the estimated values of erodibility index, the soils of the investigated sites were categorized into different groups according to the scheme shown by Castro et al. [37] and the results are presented in Figure 3. It is apparaent from the displayed results that the fairly high class (0.33- 0.43) offered the highst frequency for the generated data of 5 out of 6 models. It can also be observed that the proposed model (K6) offered a distribution very close to a normal distribution, followed by the Wiscmeier and Smith [5] model (K1) and the truncated Wiscmeier and Smith (K_2).

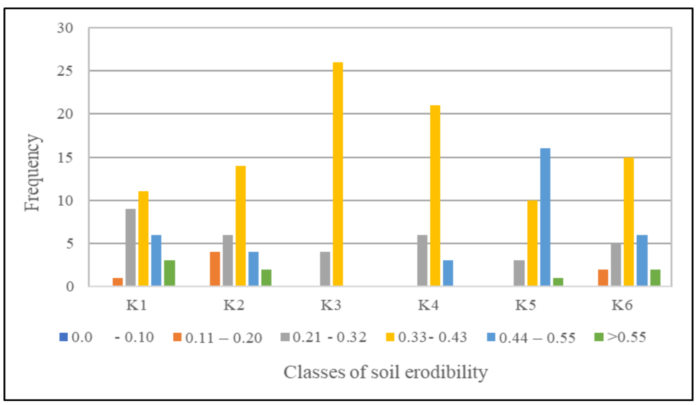

Figure 3: Frequency distribution of soil erodibility estimated by the K1 model.

Unlike these models, the estimated soil erodibility values estimated by some models, such as Sherazi et al. [29] (K3) and Torri et al. [35] (K4), were highly deviated from a normal distribution. It is also interesting to note that none of the studied soils fell in the very low class (0.0 - 0.10).

When the soils of the investigated area were classified into groups based on the estimated soil erodibility by the reference method, 67% of soils fell in the moderate (0.21- 0.32) and fairly high (0.33 - 0.43) classes. The results also indicated that 10% and 20% of the soils were in the high (0.44 -0.55) and very high (> 0.55) classes, respectively. On the other hand, it was noticed that about 3% and 0% of the study soils fell in low (0.10 - 0.20) and very low (0.00 - 0.10 m) classes, respectively.

To further confirm the authenticity of the distribution of the generated data by the applied models, a Box-Whisker plot was shown in Figure 4. As the median line of K6 and K2 is located at the center of the box, it indicates that these models produced more symmetrical data compared to the remaining models. The existence of some points outside the inner and outer fences of the K3 model is indicative of the presence of extreme points in the data sets of Shirazi et al. [29] model. Furthermore, it can be seen that the K1 model has the longest length, followed by K2 and K6. The length of the box is an indicator of data range; the longer the box, the wider the data range or variability.

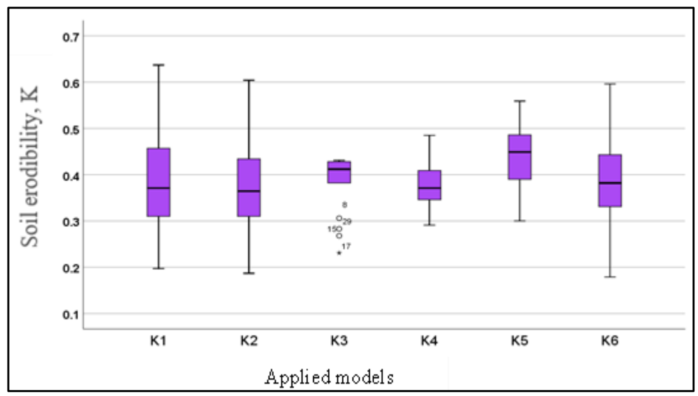

Figure 4: Representation of estimated soil erodibility by Box-Whisker plot.

3.4 Soil Erodibility Indices

In the current study, an additional attempt was made to determine 4 commonly used erodibility indices for identifying the proneness of the investigated soils to erosion (Table 5). These indices encompassed clay ratio (CR), Truncated clay ratio (MCR), dispersion ratio (DR), and critical level of soil organic matter content (CLOM). As can be noticed in Table 5, the estimated values fall in the following ranges: CR, 1.202 – 9.099; MCR, 1.146- 7.47; DR, 7.426 – 70.807; and CROM, 0.625 – 5.278. The lowest values for CR, MCR, DR, and CLOM were observed in Shaqlawa, Shaqlawa, Zwrga Zraw, and Sork, respectively. On the other hand, the highest values were observed in Hiran, Kalak, Taq Taq, and Hiran, respectively. The results also revealed that more than 96% of the investigated soils had CROM of less than 5, indicating that the majority of the soils have no stable structure and do not offer resistance to erosion [38]. It is also apparent from the displayed results that more than 73% of sampling sites have a dispersion ratio of more than 15% thereby indicating that the majority of the soils are highly vulnerable to erosion [26]. It is commendable to mention that the above study indices are appropriate to estimate the soil vulnerability to erosion, where physical measurement is very difficult.

Table 5: Some selected erodibility indices for different sites over the study area.

Site	Dispersion ratio	Clay ratio	Modified clay ratio	Critical level of organic matter
Ainkawa	16.552	1.398	1.349	1.742
Bahrka	10.158	1.622	1.568	1.431
Bakhchay Gawra	19.591	1.846	1.783	1.572
Basrma	24.379	1.620	1.524	3.136
Bastora	14.047	1.702	1.575	4.041
Bestana	16.857	1.680	1.648	0.846
Degala	32.293	2.436	2.348	1.471
Dibaga	40.241	5.087	4.899	1.223
Dukala	16.858	2.363	2.282	1.228
Gomaspan	14.813	1.428	1.386	1.348
Grdarasha	34.513	1.872	1.813	1.303
Gwer	24.292	2.575	2.458	1.641
Hanara	14.277	1.678	1.641	0.911
Harir	22.557	1.501	1.460	1.217
Hiran	28.928	9.099	7.180	5.278
Jdidalak	22.364	3.242	3.124	1.013
Kalak	48.440	8.650	7.470	3.826
Kasnazan	28.372	1.851	1.776	2.234
Kawrgosk	11.759	2.436	2.356	1.249
Koya	30.231	1.931	1.854	1.710
Makhmur	9.405	2.229	2.169	0.984
Mala Omer	24.524	1.215	1.198	0.806
Mala Qara	35.961	3.505	3.352	1.527
Perdawod	21.189	3.289	3.206	0.688
Qushtapa	28.892	1.711	1.656	1.418
Shaqlawa	34.446	1.202	1.146	2.533
Sork	12.138	2.909	2.855	0.625
Swery	18.777	2.445	2.349	1.430
Taq Taq	70.807	6.389	6.064	1.461
Zwrga Zraw	7.426	4.128	3.973	1.094

3.5 Pearson's Correlation Coefficient for the Relationship between Soil Erodibility and each of the Input Variables and Erodibility Indices

Table 6 presents the correlation coefficient between soil erodibility (K) estimated by the reference method (K1) and the input variables and some selected erodibility indices. As can be noticed in Table 6, each of silt, VFS, and MWD was positively correlated with soil erodibility. In contrast, the remaining variables were negatively correlated with K. It can also be observed that the correlation between K and clay content was negative and highly significant (r = - 0.415*). Similarly, its correlation with organic matter was negative and very highly significant (r = - 0.621**). Contrarily, the soil erodibility was positively and highly significantly correlated with each of silt and VFS.

Table 6: Pearson's correlation coefficient for the relationship between soil erodibility and each of the input variables and some selected erodibility indices.

Input variable	Sand	Silt	Clay	VFS	Bulk density	Organic matter	Infiltration rate	Lime equivalent	MWD
Pearson Correlation Coefficient	- 0.197	0.762**	- 0.415	0.389	- 0.247	- 0.621	- 0.064	- 0.132	0.176
Erodibility indices	Dispersion ratio		Clay ratio		Modified clay ratio		Critical level of organic matter		
Pearson Correlation Coefficient	- 0.220		0.129		0.181		- 0.532		

It is also obvious from Table 6 that each clay ratio and truncated clay ratio were found to be positively correlated with K, while it was negatively correlated with each of the dispersion ratio and critical level of organic matter (CLOM). Among these indices, only CLOM was high significantly correlated with K (r = - 0.532*) at N = 30 and P = 0.05. It is commendable to mention that the last index was considered as one of the input variables of the proposed model during the current study because of its strong correlation with K.

3.6 Soil Erodibility as Affected by Land Use

Table 7 displays the mean soil erodibility estimated by different models under different land uses. As can be seen in Table 7, irrespective of the type of model for K estimation and with one exception, the forest land offered the lowest value for K, while the cropland offered the highest value for K. It is noteworthy to indicate that land use type did not yield a significant difference in K. The estimated K values by some models, such as EPIC and the proposed one, exhibited better harmony with land use change compared to the estimated K value by the remaining model, indicating the appropriateness of the last two models (K5 and K6) for K estimation.

Table 7: Soil erodibility as affected by different land uses over the study area.

Land Use	Wischmeier and Smith	Truncated Wischmeier and Smith	Shirazi et al. (1988)	Torri et al. (1997)	EPIC model	Proposed model
Cropland	0.380	0.367	0.400	0.379	0.454	0.391
Forestland	0.378	0.361	0.377	0.366	0.421	0.358
Grazing land	0.379	0.372	0.382	0.378	0.390	0.344

3.7 Description of the Proposed Model during the Current Study

As mentioned earlier, one objective of the current study was to develop a model for estimating soil erodibility based on linear regression analysis. The result of this analysis indicated that the following model was the best model for predicting soil erodibility over the study area:

$$K6 = 1.517 - 0.0079\,\%\,Silt - 0.0327\,CLOM - 0.0357\,FC \quad N = 30 \quad R^2 = 0.884 \quad (21)$$

where: K6 = soil erodibility estimated by the proposed model

FC = Soil water retention at – 33 kPa.

It is evident from the above analysis that the variation in silt, CLOM, and FC accounted for more than 88% of the variation in soil erodibility. This is an indication of a good match between the estimated K by the proposed and the reference model. The maximum correlation between each pair of the input variables in this model was - 0.768. Multicollinearity analysis revealed that the condition number (CN) was 3.495, indicating that a low linear multicollinearity exists (CN < 20).

3.8 Evaluation of the Study Models for Estimating Soil Erodibility

Model evaluation was accomplished by comparing the estimated values by the reference method (K1) with the predicted values by K2, K3, K4, K5, and K6 models. To achieve this objective, the estimated values by the reference method were plotted versus the predicted values by each of these models in relation to line 1:1, and the results are portrayed in Figure 5. It can be discerned from the plotted figure that the K2 model offered the best performance, followed by the K6 model. The plotted points belonging to these 2 models fall on or close to the line 1:1 over the entire range of the estimated K values. The closeness of the slope of the linear relationship between soil erodibility estimated by the reference method and the estimated value by each of these models to unity is an indication of an acceptable match.

The closeness of the intercept of the linear relation is an additional indication of a good match between observed and predicted values. The high predictability power of the K2 model compared to the remaining models is due to the fact that K2 resembles the K1 model from all aspects except that the permeability term is removed from the K2 model. Furthermore, the permeability code of most of the study soils is 3 or close to 3. This will eliminate the effect of permeability on K prediction. Unlike K2 and K6 models, the remaining models offered poor performance with considerable deviations from the line 1:1.

To further confirm the predictability power of the applied models, a host of performance indicators were determined and presented in Table 8. Judging from mean biased error (MBE) and coefficient of residual mass (CRM), the K6 model neither overestimated nor underestimated the soil erodibility, while K2 and K4 underestimated the K value. In contrast, the K3 and K5 models overestimated the K values. Moreover, the results indicated that the K2 model offered the lowest values for mean absolute error (MAE) and root mean square error (RMSE), and K6 offered the second lowest values for these indicators. It was also observed that the K6 offered the lowest value for the mean absolute percentage error (MAPE = 4.867%), followed by the K2 model (MAPE = 5.133%). The reverse of these results is true for the remaining models. Judging from the coefficient of agreement (d) and Nash-Sutcliffe index, the K2 model also exhibited the highest power of predictability followed by the K6 model. It also presents the results of using multiple performance indicators [39].

Table 8: Some selected performance indicators to test the predictability power of the study models for estimating soil erodibility.

Performance Indicators	Model				
	Truncated Wischmeier and Smith	Shirazi et al. (1988)	Torri et al. (1997)	EPIC model	Proposed model
MBE	0.012	- 0.014	0.003	- 0.059	0.000
MAE	0.017	0.088	0.061	0.076	0.033
MAPE	5.133	30.384	17.520	25.428	4.867
RMSE	0.023	0.111	0.070	0.096	0.037
CRM	0.032	- 0.040	0.007	- 0.156	0.001
CV	6.148	29.240	18.420	25.161	9.735
D	0.988	0.427	0.800	0.738	0.969
NC	0.994	0.859	0.944	0.896	0.984

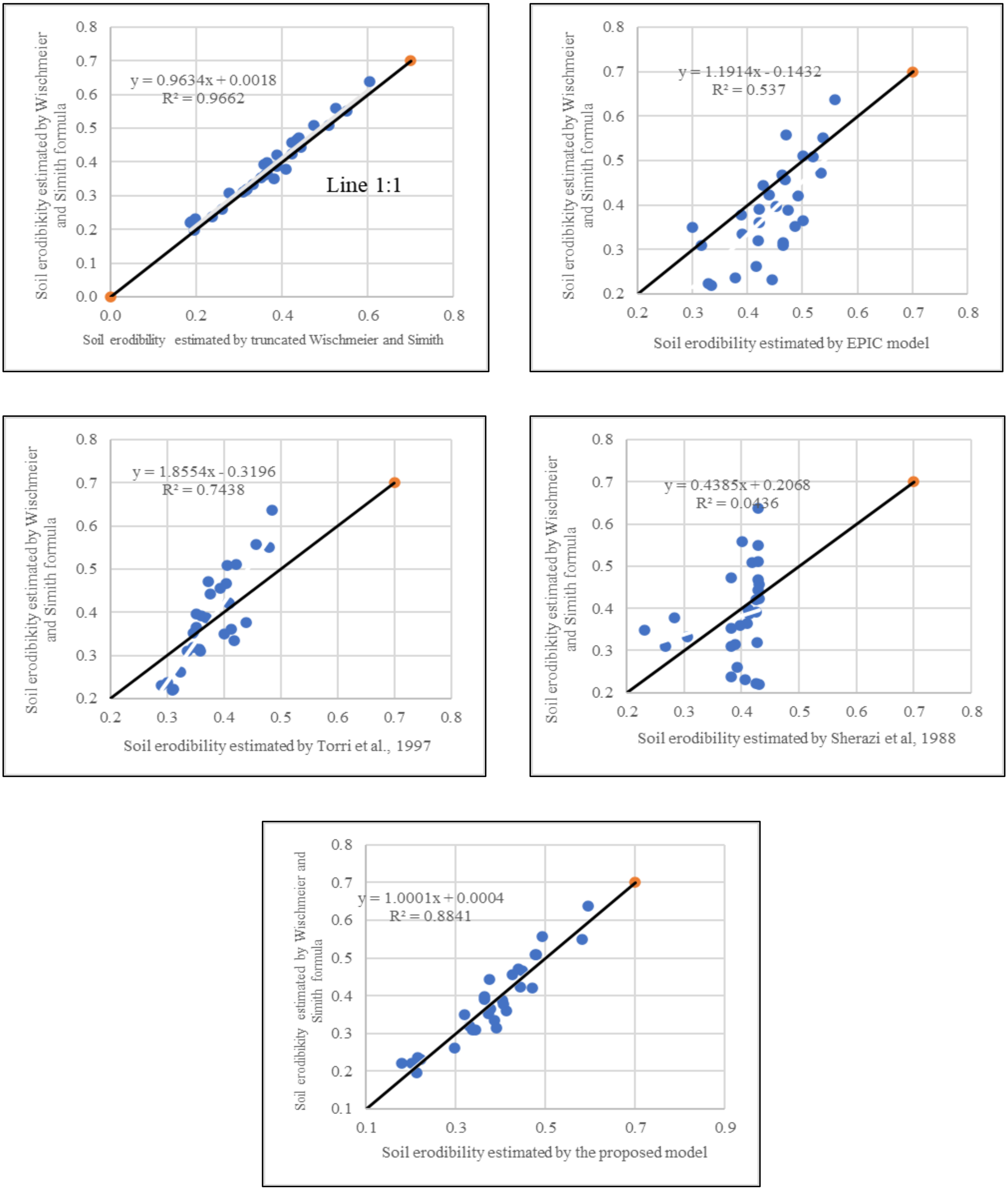

Figure 5: Plot of estimated soil erodibility by the different models versus the estimated values by Wischmeier and Smith, 1978.

A close evaluation of the applied models was also performed by using the Taylor diagram of Figure 6. The main objective was to show the consistency between the K values estimated by the K1 models and the estimated K values by the remaining models. In this figure, the K1 model was considered as the reference method. Six points were plotted, each representing a model. The coordinates of each point are its normalized standard deviation the its correlation with the reference model. As can be seen in the diagram, K2 is the closest point to the reference point, followed by K6, while the K3 model is the farthest point from the reference point. However, the applied models can be ranked in the following order according to their effectiveness or predictability power. However, the applied models can be ranked in the following order according to their effectiveness or predictability power: K2 > K6 > K4 > K5 > K3. It seems from the above results that the K2 and K6 models are the best candidates for predicting soil erodibility over the area under study. The advantages of these two models are ease of application and their low cost.

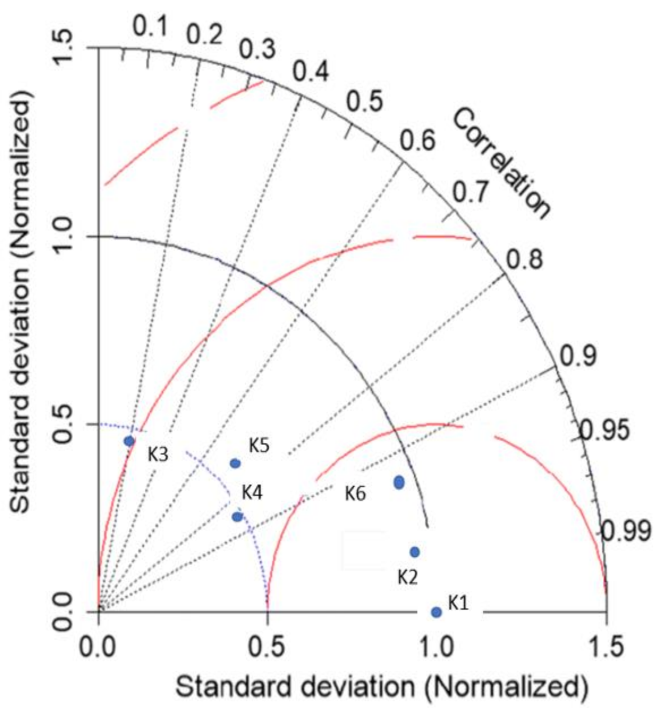

Figure 6: Taylor diagram to characterize the relationship between the tested models and the reference model.

3.9 Spatial Distribution of Soil Erodibility over the Study Area

After selecting the IDW as the best interpolation method, continuous surfaces were generated in a GIS environment for soil erodibility estimated by the applied models, and the results are displayed in Figure 7. Overall, it is obvious from Figure 7 that the K-factor values are the highest in the south and tend to decrease towards the north of the study area. A decrease in clay content, organic matter, and stable aggregates and an increase in silt content as one moves from north to south are responsible for such a trend. The results also indicated that drawn maps did not exhibit an obvious pattern for soil erodibility from east to west. It is also evident from Figure 7 that the applied models did not provide a similar spatial distribution. It is commendable to indicate that such type of study is important because it assists the researchers in developing suitable soil conservation measures that can preserve the integrity of the soil through reducing soil erosion and sedimentation [40,41].

Conclusions

The results of the current study indicated that the majority of the soil erodibility values estimated by the reference method fell in moderate and fairly high classes. It is also apparent from the displayed results that more than two-thirds of the sampling sites have a dispersion ratio of more than 15% indicating that the majority of the soils are highly susceptible to erosion. It can also be concluded from the results that the Truncated Wischmeier and Smith and the proposed models outperformed the Sherazi et al (1988), Torre et al (1997), and the EPIC models. Moreover, the soil erodibility estimated by the reference model has the highest value in the north and tends to decrease as one moves from north to south.

Authors' contributions

Tariq H. Karim: Supervision, Conceptualization, Methodology, Writing - original draft preparation. Kamyar M. Mohammed: Methodology, Formal analysis and investigation, Writing-review and editing, Resources.

Competing interests

The authors of this article declare no competing interests.

References

[1] Olaniya, M., Bora, P.K., Das, S. & Chanu, P.H. Soil erodibility indices under different land uses in Ri-Bhoi district of Meghalaya (India). *Scientific reports* **10**(1). 14986 (2020).

[2] Blaikie, P. *The political economy of soil erosion in developing countries*. Routledge. London. https://doi.org/10.4324/9781315637556 (2016).

[3] Lal, R. Soil degradation by erosion. *J. Land degradation and develop.* **12**(6), 519-539. (2001).

[4] Kusre, B. C., Bora, P. K., Rai, D., Singh, S., Tana, A. & Subba, S. Combating water scarcity through roof water harvesting: planning and design with stakeholders' perception in Sikkim (India). J. *Water Sci. and Techno.* Water Supply **17** (3), 799 – 810 (2017).

[5] Wischmeier, W.H. & Smith, D.D. *Predicting rainfall erosion losses: a guide to conservation planning* (No. 537). Department of Agriculture, Science and Education Administration (1978).

[6] Panagos, P., Meusburger, K., Alewell, C. & Montanarella, L. Soil erodibility estimation using LUCAS point survey data of Europe. *J. Environ. Modelling & Software* **30**,143-145 (2012).

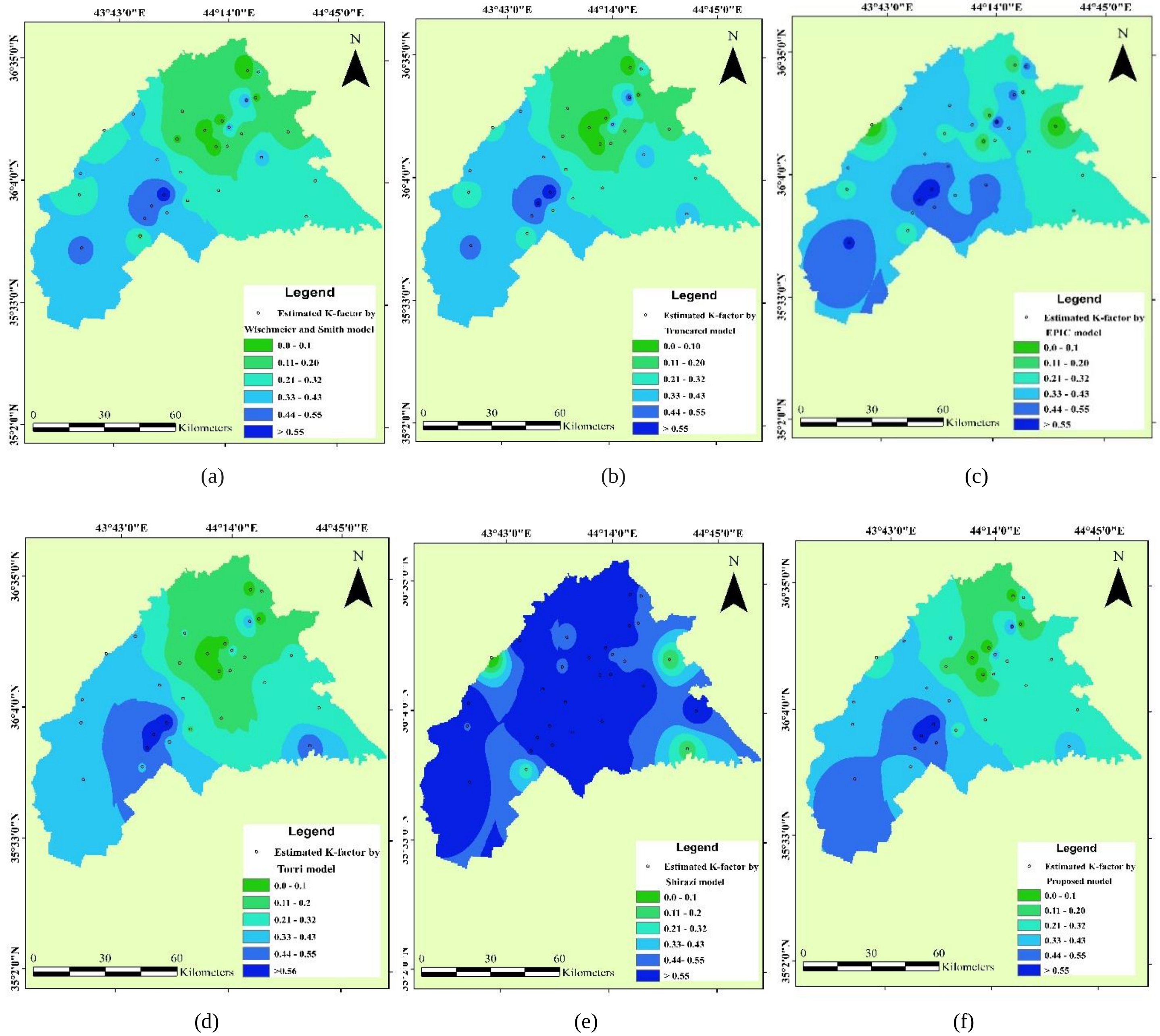

Figure 7 a, b, c, d, e, and f: Spatial distribution estimated by different models over the study area.

[7] Ezeabasili, A.C.C., Okoro, B.U. & Emengini, E.J. Relative erodibilities of some soils from Anambra basin. *Sky J. of Soil Sci. and Environ. Management* **8**, 83-90 (2014).

[8] Wischmeier, W.H. & Mannering, J.V. Relation of soil properties to its erodibility. *Soil sci. soc. of America J*. **33**(1), 131-137 (1969).

[9] Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., & Yoder, D.C. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).* USDA, Washington, DC. (1996).

[10] Denardin, J.E. Mean estimated erodibility of physical and chemical parameters (Doctoral dissertation, University of São Paulo) (1990).

[11] Sharpley, A.N. & Williams, J.R. eds. *EPIC-erosion/productivity impact calculator*: 1. Model documentation (1990)

[12] Bonilla, C.A. & Johnson, O.I. Soil erodibility mapping and its correlation with soil properties in Central Chile. *J. Geoderma* **189**, 116-123 (2012).

[13] Adhikary, P.P., Tiwari, S.P., Mandal, D., Lakaria, B.L. & Madhu, M. Geospatial comparison of four models to predict soil erodibility in a semi-arid region of Central India. *Environ. earth sci.* **72**, 5049-5062 (2014).

[14] Anache, J.A.A., Bacchi, C.G.V., Panachuki, E. & Sobrinho, T.A. Assessment of methods for predicting soil erodibility in soil loss modeling. *J. Geosciences* **34**(1), 32-40 (2015).

[15] Ravinder Kaur, R.K., Omvir Singh, O.S. & Gurung, H.P. *Soil erodibility indices-their development, use and efficiency testing on Indian soils: a review* (2003).

[16] Chorley, R.J. The geomorphic significance of some Oxford soils. *American J. of Sci.* **257**, 503-515 (1959).

[17] Wischmeier, W.H. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains, Guide for selection of practices for soil and water conservation. *United States Government Printing Office*. (1965).

[18] Sahi, B.P., Singh, S.N., Sinha, A.C. & Acharya, B. Erosion index—A new index of soil erodibility. *Journal of the Indian Soc. of Soil Sci.* **25** (1), 7-10 (1977).
[19] Singh, M.J. & Khera, K.L. Soil erodibility indices under different land uses in lower Shiwaliks. *Trop. Ecology* ***49*** (2), 113 (2008).
[20] Akhtaruzzaman, M., Roy, S., Mahmud, M.S. & Shormin, T. Soil Properties Under Different Vegetation Types in Chittagong University Campus, Bangladesh. *J. of forest and environ. Sci.* ***36***, 133-142 (2020).
[21] Mubammad Amin, I., Azeez, S.N. & Ahmad, I.H, Integration of Field Data and Online Satellite Images to Map Urban Change Pattern from 2003 to 2013, Case Study: Darbandikhan city, Kurdistan Region, Iraq. *Passer J. of Basic and Appl. Sci*, **4,** 25-30 (2022).
[22] Buringh, P. *Soils and soil conditions* in Iraq. Ministry of Agriculture, Bagdad, (1960).
[23] Nikolov, S.P. *Rainfall erosion in northern Iraq*. Baghdad, Iraq (1983).
[24] Michael A M. *Irrigation theory and practice*. 1st ed., Vikas publ. House DVT, Delhi (1978).
[25] Mohammed, K.M. Assessment of Morphometric and Hypsometric Analysis of the Ruste Basin Using Remote Sensing and Geographical Information System Techniques. *J. of Kirkuk University for Agri. Sci.* **14,** 1-19 (2023).
[26] Kusre, B.C., Ghosh, P. & Nath, K. Prioritization of soil conservation measures using erodibility indices as criteria in Sikkim (India) *J. of Earth System Sci.* **127**,1-13 (2018).
[27] Pieri, C. *Fertility of Savanna soils.* Thirty-Year Review of Agricultural Research and Development Sub-Saharan Africa. CIRAD-IRAT (1989).
[28] Torri, D., Poesen, J. & Borselli, L. Predictability and uncertainty of the soil erodibility factor using a global dataset. *J. Catena* **31** (1-2) 1-22 (1997).
[29] Shirazi, M.A., Boersma, L. & Hart, J.W. A unifying quantitative analysis of soil texture: improvement of precision and extension of scale. *Soil Sci. Soc. of America J.* **52**(1), 181-190 (1988).
[30] Karim, T. H. Models to predict water retention of Iraqi Soils. *J. of the Indian Soc. of Soil Sci.* (India). **47** (1), 6-19 (1999).
[31] Mello, C.D., Viola, M.R., Beskow, S. & Norton, L.D. Multivariate models for annual rainfall erosivity in Brazil. *J. Geoderma* **202**, 88-102, (2013).
[32] Anees, M.T., Abdullah, K., Nordin, M.N., Ab Rahman, N.N., Syakir, M.I. & Kadir, M.O. *One-and two-dimensional hydrological modelling and their uncertainties*. doi: 10.5772/intechopen.68924. In Flood risk management. IntechOpen. (2017).
[33] Taylor, K.E. Summarizing multiple aspects of model performance in a single diagram. *J. of geophysical research*: atmospheres **106** (7), 7183-7192 (2001).
[34] Wilding, L.P. Spatial variability: its documentation, accommodation and implication to soil surveys. *J. Soil spatial variability* **15**, 166-189 (1985).
[35] Torri, D., Sfalanga, M. & Del Sette, M. Splash detachment: runoff depth and soil cohesion. *J. Catena*, **14**(1-3), 149-155 (1987).
[36] Di Virgilio, N., Monti, A. & Venturi, G. Spatial variability of switchgrass (Panicum virgatum L.) yield as related to soil parameters in a small field. *Field crops research J.* **101**(2), 232-239 (2007).
[37] Castro, W.J., Lemke-de-Castro, M.L., de Oliveira Lima, J., de Oliveira, L.F.C., Rodrigues, C. & de Figueiredo, C.C. Erodibilidade de solos do cerrado goiano. Revista em Agronegócio e Meio Ambiente **4**(2) (2011).
[38] Pieri, C. Fertility of soils: *A future for farming in the West African savannah*. Springer Verlag, Berlin (1991).
[39] Abdulrahman, F.A. & Karim, T.H. Comparative Evaluation of Derived and Previously Published Models for Estimating Annual Runoff in the Mountainous Watersheds of Sulaimani Province. *Passer J. of Basic and Appl Sci*. **6**, 369-380 (2024). doi: 10.24271/PSR.2024.443072.1495
[40] Ahaneku, I.E., Ezinna, K.C., Orji, F.N., Alaneme, G.U. & Chukwudi, E.E. Spatial distribution of soil erodibility factors in erosion-prone areas in Umuahia, Southeast, Nigeria. *J. of Eng. Research* **13**, 1627-1637 (2024).
[41] Haji, G.Y., Mohammed, N.I. & Salim, J.I. Spatiotemporal Variations in Water Quality under Land Use/Land Cover in the Khabur River. Passer Journal of Basic and Applied Sciences, **8**, 382-391(2026).