



Spatial variability of soil erodibility factor using geo-statistics method in Duhok dam watershed, Kurdistan region, Iraq

Lida I.¹, Marwan B. I. Govay¹, Vahil I. H. Barwari¹, Omar A. O. Rekani¹

*1*Department of Soil and Water Sciences, College of Agriculture, University of Duhok, Duhok– Iraq
E-Mail address: lida.issazadeh@uod.ac

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Abstract

Soil erosion is one of the crucial problems in watershed and environmental management. It is obvious soil and water management can reduce soil losses and land degradation. One of the important factors in universal soil loss equation (USLE) to determine rate of erosion is soil erodibility factor. It is related to intrinsic properties of the soil properties. By determining and evaluating this factor, soil erosion can be decreased to minimum amount. Traditional methods such as regression models cannot estimate precision of variables and don't take spatial variability of soil properties. By using geo-statistical methods all changes in soil properties in distribution can be estimated with less error and high accuracy. In this research, by using 30 point of soil samples of Duhok dam watershed, the spatial variability of soil erodibility factor and some of soil properties such as percent of organic matter, particle size distribution and soil structure were obtained. Then graphical interpolation of soil properties was performed by using Kriging method. The statistical results showed that most variables had a normal distribution. Variability analysis on soil attributes according to soil erodibility, showed that exponential, spherical and linear to sill models was the most models to predict spatial variability of studied soil parameters. The Soil spatial variability pattern, is similar to silt and very fine sand pattern due to high effect of this factor on soil erodibility. According to the kriging map, soil erodibility in the east, south and north parts of the studied area is more than other parts. Soil erodibility in this location of research area based on estimation map showed need to more attention for conservation the soil and control erosion.

Introduction

The soil erodibility factor (K-factor) is a quantitative description of the inherent erodibility of a particular soil and it is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. The amount of soil erosion is generally estimated by EI_{30} in the standard plot with length 22.1 m and 9% gradient [1]. EI_{30} is R factor of USLE and it is the numerical descriptor of the ability of rainfall to erode soil. Many variables can interfere in soil erosion such as texture, amount of organic matter, size of soil particles, permeability and depth of impervious layer [2].

Soil spatial and temporal properties are varied because of complicated process interfere in soil formation and soil degradation. Five factors include climate, organisms, topography and parent material are so important in soil erodibility and cause different properties of soil in different locations [3]. While, estimating spatial and

temporal amount of soil erodibility factor, sediment load and deposition in dams for soil conservation is so important [4].

In soil classification, due to the multiple factors involved in soil formation process, determination of soil erodibility factor often not associated with the correct results especially in soil series [5]. For example, [6] investigated the spatial variability of soil erodibility in relation to soil types in north of Africa using 136 soil samples and the results showed that there are no changes in soil erodibility factor in comparison with FAO soil map in 1:125000 scale and this kind of maps just can be used in regional management with large scale. Also, in soil erosion and sedimentation studies, soil erodibility for each soil type devotes similar amount and this variable in this scale is considered as lumped model.

Soil erosion and sedimentation studies in different scales have been done in plots, sub basins and watersheds with some advantages and disadvantages. [7] Studied at spatial variability of USLE model by changing scales from large to small and by considering correction factor, the results showed that this factor just affected gradient value and other variables of model had unpredictable results. By comparison USLE and WEPP models results to estimate soil erosion and sedimentation in three different scales, it was observed no significant difference between the results of two models. Probably, it was related to soil sampling, measuring and analysis which leads to increase error and uncertainty in estimating variables. Therefore, it is necessary to find some methods before which determine spatial variability with uncertainty to have comprehensive decision [8]. Kriging interpolation method which is defined as unbiased estimator can predict accurate spatial and temporal variability for soil properties in non-sampled areas [9]. Soil characteristics variation also has spatial correlation. The concept of variance is a good indicator for spatial variability of soil properties because of effectiveness of soil variable on adjacent points. Geo-statistics method can estimate spatial and temporal variability of soil parameters.

The aim of this study is focused on evaluating, analyzing and determining spatial variability of soil erodibility factor by using kriging model of geo-statistics method and then preparing spatial distribution map of soil erodibility.

Materials and Methods

A. Study area

The current study is conducted in the Duhok dam watershed, Duhok province, Kurdistan region of Iraq (Figure 1). The study area covered 134.4 km², with mean annual precipitation 560 mm, and mean annual temperature 19.5°C. Elevation varies from 568 to 1367 m above sea level.

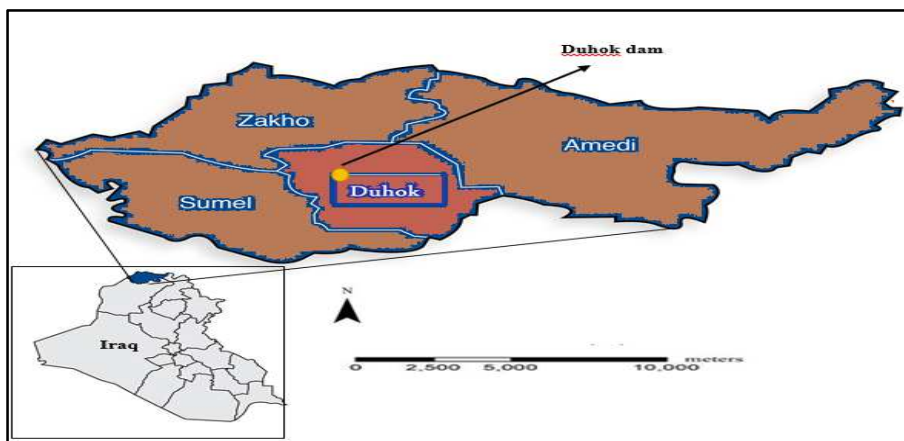


Figure-1: Location map for the Duhok dam watershed in Duhok Governorate, Kurdistan Region- Iraq

In this research, 30 samples of topsoil (0–20 cm deep) were randomly collected in Duhok dam watershed. Besides at each site, some soil properties such soil particle distribution, soil structure, soil permeability, percent of organic matter were measured. All soil samples were analyzed and the properties of soil related to soil erodibility factor were measured. Soil size distribution was estimated by using Klute method and wet sieving procedure. Soil organic matter was measured by the Walkly-Black method. Soil structure analysis has been done in the field based on size and shapes of soil aggregates. Also, soil permeability was measured by using double ring method in the field. The class codes for soil structure and soil permeability were determined based on the tables of Wischmeier and smith. K factor (soil erodibility factor) is susceptible to soil erosion depends on rainfall, soil structure, amount of organic matter and permeability. Wischmeier and smith [2] expressed K factor as follows:

$$K = [2.1 \times 10^{-4}(12 - OM)M^{1.14} + 3.25 (S - 2) + 2.5 (P - 3)]/100 \quad (1)$$

where K is the USLE soil erodibility factor, M is the product of percent of silt+very fine sand and the percent of all soil fractions other than clay, OM is soil organic matter content (%), S is the soil structure code, and P is the soil permeability code.

In order to convert K factor unit from American unit to standard unit, soil erodibility factor is multiplied by 0.1317. Unit of K factor in standard unit is ton in hour per mega joule in millimeter.

In order to qualify soil sample data, all soil parameters were analyzed and all statistical properties such as mean, coefficient of variation, Kurtosis and Skewness were obtained, then test of normality were done based on Shapiro-wilk analysis.

In geo-statistics method, analysis of spatial variability of data depend on statistics of semi variogram. Semi variogram can explain the structure properties of spatial variable. If variogram reach to the distinct level and has specific lag distance, then the assumption of accepting spatial variability is true. Semi variogram can be determined based on specific lag distance as follows:

$$\hat{\gamma}(h) = 1/2N(h) \sum_{a=1}^{N(h)} [z(u_a) - z(u_a+h)]^2 \quad (2)$$

Where:

$\hat{\gamma}(h)$ is the average sample semi variance to the distance h ,

$N(h)$ is the number of sample pair of points separated by the distance h and

$Z(u_a)$ is the value of variable in the point of sampling u_a .

For evaluating spatial variability of soil erodibility factor, Kriging method was used for each factor contribute to calculate soil erodibility factor. General equation of kriging method is as follows:

$$Z^*(xi) = \sum_{i=1}^n \lambda_i Z(xi) \quad (3)$$

Where:

$Z^*(xi)$: Estimated data,

$Z(xi)$: observed data,

(xi) : Location of observed data,

λ_i : weighted factor for each point

n : Number of estimated points

Kriging method is one of the interpolation methods which can determine uncertain data based on obvious data and sector variogram. This method is structured by weighted moving average and it is known as one of

the Best Linear Unbiased Estimator (B.L.U.E). This method can be applied when variable have normal distribution and if not, data should be normalized by converting data to another form such as logarithmic or root square. Then kriging method can be used for new changed data set.

Evaluating of kriging method for each factor, and estimating the results of spatial variability of K factor has been done by three statistical techniques, MAE (mean absolute error), MBE (mean bias error) and RMSE (root mean square error). When MAE and MBE are equal to zero or near to the nugget, it represents close simulation of reality and by receding from zero, less precision and high error will happen. Calculation of MAE and MBE are as follows:

$$MBE = \frac{\sum_{i=1}^n (R_s - R_0)}{n} \quad (4)$$

$$MAE = \frac{\sum_{i=1}^n |R_s - R_0|}{n} \quad (5)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (R_s - R_0)^2} \quad (6)$$

Where, R_s : Estimated data, R_0 : Observed data, n : Number of data.

Results and discussion

Table 1 shows the results of statistical analysis and normal distribution of soil parameters. Test of normality was obtained by Shapiro-wilk method. Particle size distribution parameter, percent of organic matter and erodibility factor had normal distribution, but permeability parameter and percent of silt do not show any adaptation with normality test. Therefore for designing semi variogram of soil permeability, they were normalized and converted to root square amount.

Table 1. Statistical descriptive and test of normality of soil parameters

parameter	Mean	Std. Deviation	Skewness	Kurtosis	Sig. Shapiro-wilk
K	0.02	0.01	0.42	0.39	.210
% Clay	40.61	1.02	-0.11	-1.09	.270
% Silt	34.78	6.88	2.24	7.96	.000
% Sand	24.67	8.83	0.64	-0.23	.055
% Very fine sand	9.86	3.53	0.64	-0.23	.055
% Organic matter	1.66	0.27	0.61	0.98	.325
Permeability rate (mm/h)	8.85	4.68	1.39	1.93	.002

Many model parameters were studied to choose the most appropriate model for each of soil property and the best semi-variogram that fits better experimental semi-variogram was selected.

Results of the semi variogram function for erosion variables are presented in table 2. Fitted model of semi variogram in soil erodibility factor and percent of clay is spherical. While, for percent of organic matter is linear to sill and for percent of silt and very fine sand is exponential model. Semi variogram in geo-statistics method is so essential. In this study, optimal distance to estimate soil erodibility can be considered 1770 meters.

Table 2. Results of the semi-variogram function modeling of erosion variables

Soil parameter	% clay	%silt+very fine sand	Organic matter	K factor
Model	spherical	exponential	linear to sill	spherical
Nugget	0	0.003	0	0.001
Sill	0.065	0.037	0.029	0.26
Range	2761	5380	910	1770

The cross-validation results of the mean values of the mean absolute error (MAE), mean bias error (MBE) and root mean square of error (RMSE) had an acceptable accuracy. Therefore the results of variogram indicate kriging is suitable to predict soil erodibility factor.

Table 3 illustrates the results of validation of kriging method to select to create prediction map.

Table 3. Results of the validation Kriging method the prediction map of soil erodibility factor

Variable	MAE	MBE	RMSE
K factor	0.007	0.002	0.010
% OM	0.313	0.067	0.515
% Clay	7.67	-1.07	9.713
% Silt + very fine sand	5.066	-0.763	6.959

Figures from 2 to 5 shows spatial pattern of percent of clay, organic matter amount, percent of silt + very fine sand and soil erodibility factor in the given area.

From the maps derived it could be seen some trends. Soils with higher clay content are in the north and southeast part of the study area. The organic matter content approximately had similar amount in whole parts of study area and it is close to 2 percent and just a small part of the area has high amount of organic matter. The percent of silt + very fine sand are vary from 40 to 56 percent. From the map derived for soil erodibility factor it could be seen that the higher values are mainly located in the east, south and north part and the ranges varies from 0.01 to 0.05. In this study the Soil spatial variability pattern, is similar to silt + very fine sand pattern due to high effect of this factor on soil erodibility. According to importance of K factor in USLE and other related soil erosion models, this map has a significant implication in modeling and prediction of erosion and aid in determination of location and kind of soil conservation practices.

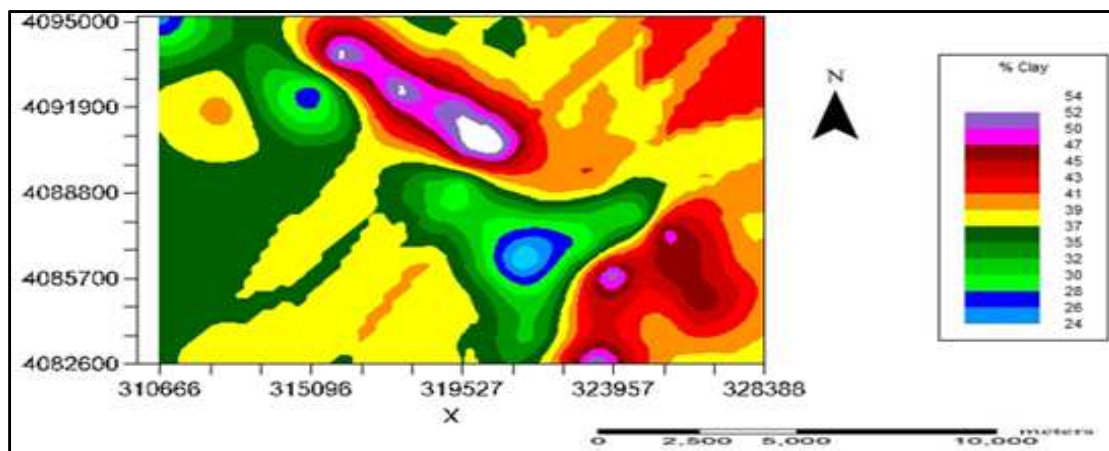


Figure-2: Map of predictor clay percent by Kriging method

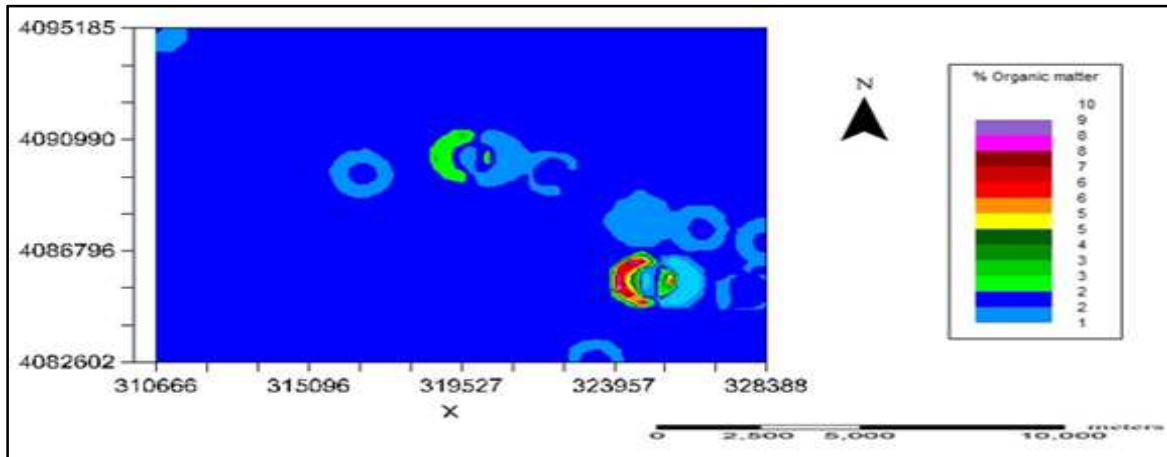


Figure-3: Map of predictor percent of organic matter by Kriging method

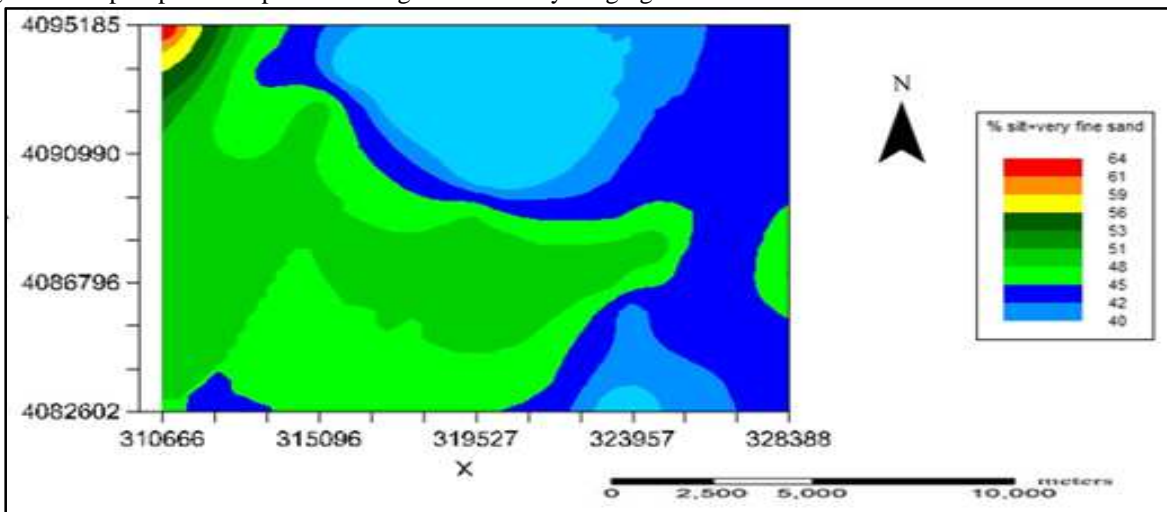


Figure-4: Map of predictor percent of silt + very fine sand by Kriging method

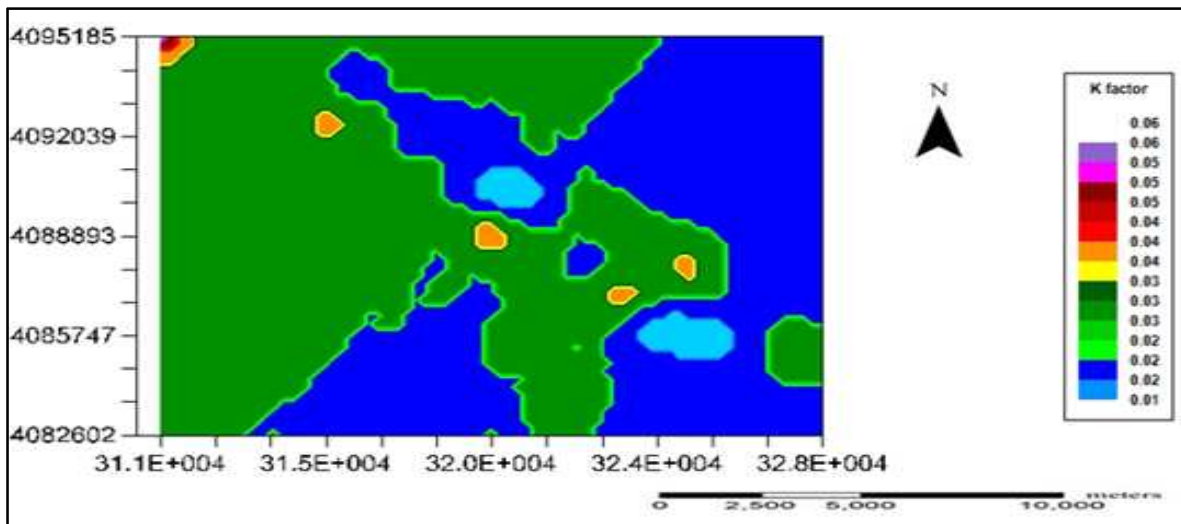


Figure-5: Map of predictor soil erodibility factor by Kriging method

Conclusion

The nomograph of USLE equation is an important method to calculate soil erodibility factor (k-factor). The result indicated the average estimated value of K-factor was 0.02, suggesting low amount of K-factor at Duhok dam watershed of Duok province, Kurdistan region of Iraq. The spherical function was the best semivariogram model to explain the spatial pattern of the estimated soil erodibility factor. The range of

spatial variation of K-factor was 1770 meter. Totally, the predicted soil erodibility factor was unbiased as the mean absolute error and mean bias error equals to zero and the root mean square was very low, that indicates better model performance and indicated Kriging method has the ability of zoning the soil erodibility factor of the studied area with high accuracy. The estimated soil erodibility factor had the highest values in the west and part of center and north, while the lowest values was observed in the east and part of the south. The results of this research can be applied to make recommendation of K-factor in future soil erosion and sedimentation studies of data scarce similar region to Duhok dam watershed of Duhok province in Kurdistan region of Iraq. Finally, the spatial pattern of the estimated K-factor accuracy of USLE nomograph of this area should be examined using direct measurement in standard plots under rainfall events.

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