Comparison of soil erodibility factor using fuzzy inference system and Wischmeier nemograph methods

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Abstract: Soil erodibility factor (K- factor) is one of the most important factors on USLE model. This factor is calculated on the basis of some soil properties such as soil texture (percentage of soil particles less than 0.1 mm and percentage of coarse sand particles larger than 0.1 mm), soil organic matter, soil structure and basic permeability of the soil profile. So far, various methods have been introduced for the measurement of K- factor. The objective of this research is to determine the soil erodibility factor using fuzzy rule base system. Sixty samples were collected from sixty homogenous units based on the Wischmeier`s nomograph method. After generating the fuzzy rules and calculating the soil erodibility factor, the results were compared with those of Wischmeier`s nomograph method. The results showed that the values of K- factor calculated by the fuzzy system are quite close to the values obtained by the USLE model and therefore, the fuzzy rule base model is introduced as the most suitable site selection strategy for determining soil erodibility factor.

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1. Introduction

Soil erosion is a major global environmental problem, having widespread and serious negative effects on agricultural production, infrastructure, water quality, biodiversity and promoting the emission of climate changing greenhouse gases (Pimentel et al., 1995; Lal, 1998; Lal, 2004). The Universal Soil Loss equation (USLE) remains the most popular tool for water erosion hazard assessment. However, the model has several shortcomings, two of which are likely to have prominent implications for the model results. First, the mathematical form of the USLE, the multiplication of six factors, easily leads to large errors whenever one of the input data is unspecified. Second, the USLE has a modest correlation between observed soil losses and model calculations, even with the same data that was used for its calibration (Sonneveld and Nearing, 2003). The term soil erodibility has a different meaning from soil erosion (Bybordi, 1993; Refahi, 1997). It is an expression of some inherent characteristic of soil susceptibility to erosion and of the soil particles to be separated from their base and transported to other locations. By definition, the soil erodibility factor is the average soil erosion in terms of ton/ha due to one unit of erosivity factors from a control plot (standard plot). A control plot would be 22.1m long with a 9% uniform slope and two consecutive years in fallow, without any plant cover and plowed down slopes (Refahi, 1997; Torri et al., 1997). Up to now, various methods of direct measurement and indirect prediction using models have been introduced for the measurement of the soil erodibility factor. The first method has good accuracy but it is cumbersome and expensive in the effort to predict the soil loss rates (Tran et al., 2002; Mitra and Scatte, 1998). The second method is Wischmeier`s nomograph method that it has low accuracy rather than the first method. So, this is the reason for improving the usage of model base included Wischmeier`s nomograph in USLE model.

This factor is calculated on the basis of soil texture, organic matter, soil structure and basic permeability of the soil profile in the USLE model and only based on soil texture in the RUSLE model (Wang et al., 2001). Some investigators have reported that using a fuzzy system to predict soil erosion would improve our ability to predict (Tran et al., 2002; Mitra and Scatte, 1998). Because of fuzzy inference system more closely resemble the way we think than do more explicit mathematical rules. Fuzzy logic programming can be used in two main ways: as a way of trying to model the behavior of a human expert, and as a way of relating a set of outputs to a set of inputs in a ‘model-free’ way- in ‘fuzzy inference method. Thus, a fuzzy logic system is flexible and transparent.

Fuzzy logic has not only made possible a more flexible and more realistic procedure in describing the relationship between the soil erodibility factor and the variables contributing to make up this factor, but it also overcomes the problems of uncertainty in the model parameters. The most important step in the fuzzy system is the expression of the process in the IF-THEN logic. It is quite important to be able to determine which entry would produce the largest output with the smallest incremental change (Bardosy and Duckstien, 1995; Mukaidono, 2001). The studies by Wischmeier and Manning showed that an incremental change in the percentage of silt often results in a considerable change in the value of the erodibility factor so that soils with 40-60% silt exhibit the greatest erodibility among the soils (Refahi, 1997). Another report indicates that a percentage figure for soil particles of less than 0.1 mm shows a good regression with the maximum run off as well as soil erosion among a vast number of soils examined (Barthes and Roose, 2002; Loch and Slater, 1998). Soil organic matter regression with the maximum run-off as well as soil erosion among a vast number of scatter is the second most important parameter that affects the soil erodibility factor. Soil organic matter positively affects on the stability of the soil permeability (Refahi, 1997). It is claimed that such rules more closely resemble the way we think than do more explicit mathematical rules. The objective of this research is to investigate the new topics of fuzzy system to predict the value of soil erodibility factor. The method of fuzzy system, USLE model with five parameters and data from wischmeier`s nomograph are used. In this paper, we consider the fuzzy system based on the singleton fuzzyfier, centeriod defuzzifier and minimum Mamdani`s inference engine.

2. Material and Methods

2.1 Study area

The research commenced in 2008 and ended in 2010. The study was carried out in Zayande-rood-olya watershed, chahar-mahal-va-bakhtyari province in Iran (Fig. 1) and is located between latitudes of 32°40′ and 32°42′ N and between longitudes of 50° 1′ and 50°37′ E which has the area about 83000 hectares. The soil moisture and temperature regimes of the region by means of Newhall software are Xeric and Mesic, respectively. The soils were classified according to USDA classification system (Soil Survey Staff, 2010) as belonging to the Alfisols, Entisols and Mollisols orders (USDA, 2010).

2.2 Fuzzy rules and modeling procedure

The USLE model is one of the most successful and widely applied erosion prediction tools for purposes of soil conservation and created by the Agricultural Research Service (ARS) of the USDA by Wischmeier and Smith (1965). The USLE predicts the long-term average annual rate of erosion on a field slope based on rainfall, soil type, topography, land cover and management practice. The USLE predicts soil loss due to sheet and rill erosion on a single slope and does not account for erosion due to other practices such as gully, wind or tillage erosion. Results of the USLE are reported in the in the metric System of units and the equation is represented as follows (Refahi, 1997):

$$A = R.K.LS.C.P \qquad (1)$$

Where: A is the potential long-term average annual soil loss in tons per ha per year, R is the rainfall energy-intensity factor in j.ton per ha, K is the soil erodibility factor, LS is the length- percent slope, C is the land cover factor and P is the crop management practice factor.

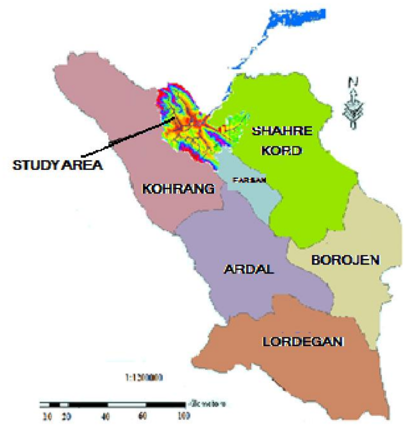

Figure 1. Location of the study area

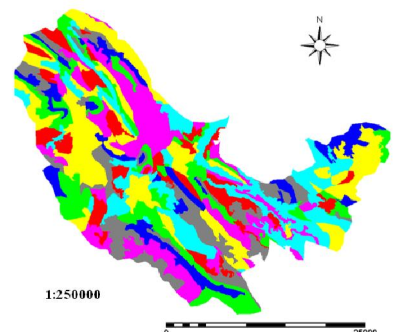

Figure 2: Homogeneous units in the study area

Determination of the soil erodibility factor (K-factor) in the USLE model depends on five parameters such as: percentage of soil particles less than 0.1 mm (FSS), percentage of coarse sand particles larger than 0.1 mm (CS), soil structure class (SC), permeability class and organic matter (OM) content. To determine the parameters, at first, the map was prepared using overlapping homogeneous regions of different geological layers, vegetation, physiographic units and geomorphological land forms in ILWIS software (Fig. 2). In each homogeneous region, soil samples in three replications were collected and finally sixty samples were collected from sixty homogenous units based on the Wischmeier`s nomograph method.

After obtaining the information of wischmeier`s nomograph, the fuzzy system was developed to determine the system output as K-factor with five inputs including percentage of particles smaller than 0.1 mm (FSS), percentage of coarse sand particles larger than 0.1 (CS), soil structure class (SC), soil infiltration (PC) and percentage of soil organic matter (OM). According to Table 1 (Wang, 1997; Bahrami et al., 2005) fuzzy system was produced. Fuzzy linguistic terms for these variables are as follow:

$A_{C.S}$ = {A1: etermely low, A2: very very low, A3: very low, A4: low, A5: less than medium, A6: medium, A7: less than high, A8: high, A9: very high, A10: very very high, A11: extermely high}

$B_{S.C}$ = {B_1: very low, B_2: low, B_3: less than medium, B_4: medium, B_5: less than high, B_6: high}

$C_{F.S.S}$ = {C_1: extremely low, C_2: very very low, C_3: very low, C_4: low, C_5: less than medium, C_6: medium, C_7: less than high, C_8: high, C_9: very high}

$D_{P.C}$ = {D_1: very low, D_2: low, D_3: less than medium, D_4: medium, D_5: less than high, D_6: high}

$E_{O.M}$ = {E_1: very low, E_2: low, E_3: less than medium, E_4: medium, E_5: high, E_6: very high}

$F_{K\text{-factor}}$ = {F_1: very low, F_2: very low, F_3: low, F_4: less than medium, F_5: medium, F_6: less than high, F_7: high, F_8: very high}

The fuzzy system has the following block diagram (Wang, 1997; bahrami et al., 2005) (Fig. 3). The design of the fuzzy system must include all of the four blocks in the diagram. Accordingly, we selected the singleton fuzzyfier, minimum Mamdani`s inference engine and centriod defuzzyfier. The singleton fuzzyfier will involve the smallest volume of calculations. It has been shown that using the singleton fuzzifier offers a reasonable accuracy with calculations and provides possibility of mathematical analysis. The centriod defuzzyfier gives the best accuracy with the system output compared to other defuzzifiers (Wang, 1997; bahrami et al., 2005). For derived analytical formula, we can select two approaches in the inference engine; the multiplier Mamdani and minimum Mamdani. Since the membership function is in the range of [0, 1], the first approach results in a few values for the K-factor with respect to the second approach.

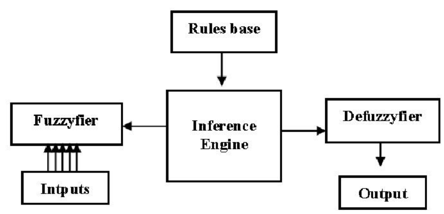

Figure 3: A block diagram of the fuzzy system

Table 1. The fuzzy system of inputs and output with the intervals

K-factor (SI)	OM (%)[1]	PC ($cm.h^{-1}$)[2]	FSS (%)[3]	SC[4]	CS (%)[5]
-0.15,0,0.15	-0.5,0,0.5	0,0.07,0.33	0,0.5,15	-0.005,0,0.5	0-0,005,0.02
0,0.05,0.15	0,0.5,2	0.075,0.33,1.015	5,15,25	0,0.5,1	0.005,0.02,0.045
0.05,0.15,0.25	0.5,2,4	0.33,1.015,3.3	15,25,40	0.5,1,2	0.02,0.045,0.095
0.15,0.25,0.4	2,4,6	1.015,3.3,8.185	25,40,55	1,2,3	0.045,0.095,0.15
0.25,0.4,0.6	4,6,8	3.3,8.185,12.145	40,55,65	2,3,4	0.095,0.15,0.21
0.4,0.6,0.8	6,8,10	8.185,12.145,13	55,65,75	3,4,5	0.15,0.21,0.26
0.6,0.8,1	-	-	65,75,85	-	0.21,0.26,0.3
-	-	-	75,85,95	-	0.26,0.3,0.34
-	-	-	85,95,100	-	0.3,0.34,0.36
-	-	-	-	-	0.34,0.36,0.45
-	-	-	-	-	0.36,0.45,0.585

[1] Percentage of organic matter, [2] Soil Permeability Class, [3] Soil particle size less than 0.1mm, [4] Soil Structure Code, [5]Percentage of Coarse Sand (0.1-0.02 mm)

For this reason we selected the minimum Mamdani`s inference engine. The membership functions for each of the above parameters are given in figures 4-9. It is obvious that the membership functions consist of overlap functions, which will increase the system accuracy. After deriving the membership functions for the inputs and output, the rule base should be develop. All rules are between input and output variables based on the effects soil erodibility factor. So, many configurations have been extracted to write these rules, then use IF and THEN, and linguistic variables that were mentioned above. The example of three fuzzy rules relating to soil erodibility factor is summarized and shown in Table 2.

Although this method is basically slow it is very accurate (Wang, 1997). Now we have a fuzzy system that can take the 5 inputs and give the K-factor.

Table 2. Fuzzy rules relating to soil erodibility factor

Rule No.	IF	particles larger than 0.1	and	structure class	and	particles smaller than 0.1	and	soil permeability	and	organic matter	THEN	erodibility factor
1	IF	EL	and	VL	and	H	and	L	and	L	THEN	VH
2	IF	EH	and	VH	and	EL	and	VH	and	VH	THEN	VVL
3	IF	M	and	M	and	VL	and	H	and	H	THEN	VL

(VVL=Very Very Low; EL= Extremely Low; VL= Very Low; L=Low; M= Moderate; H= High; VH=Very High; EH= Extremely High)

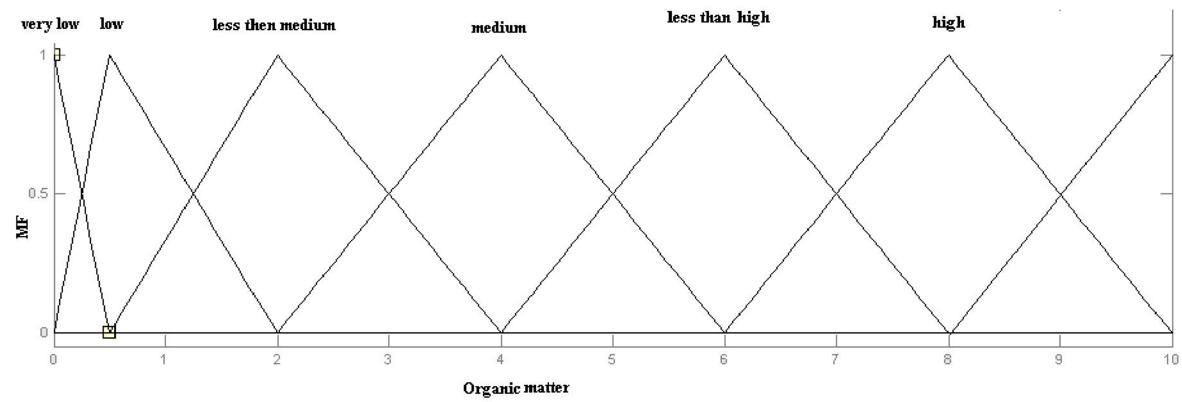

Figure 4. Fuzzy membership functions for organic matter

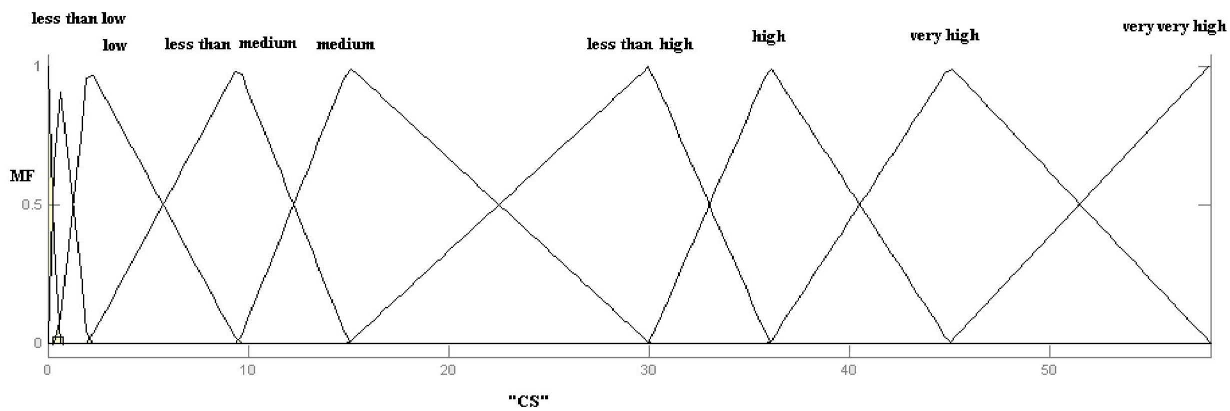

Figure 5: Fuzzy membership functions for soil structure

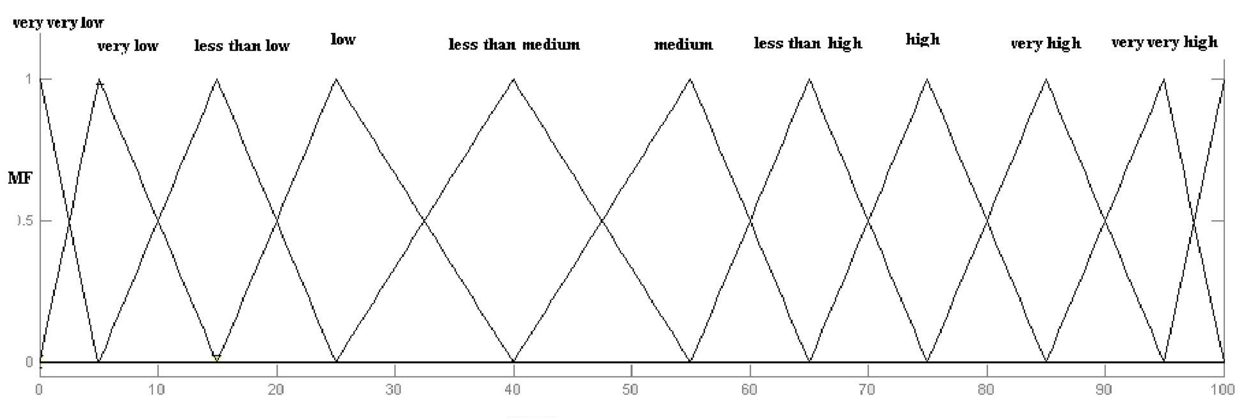

Figure 6: Fuzzy membership functions for percentage of particle less than 0.1 mm

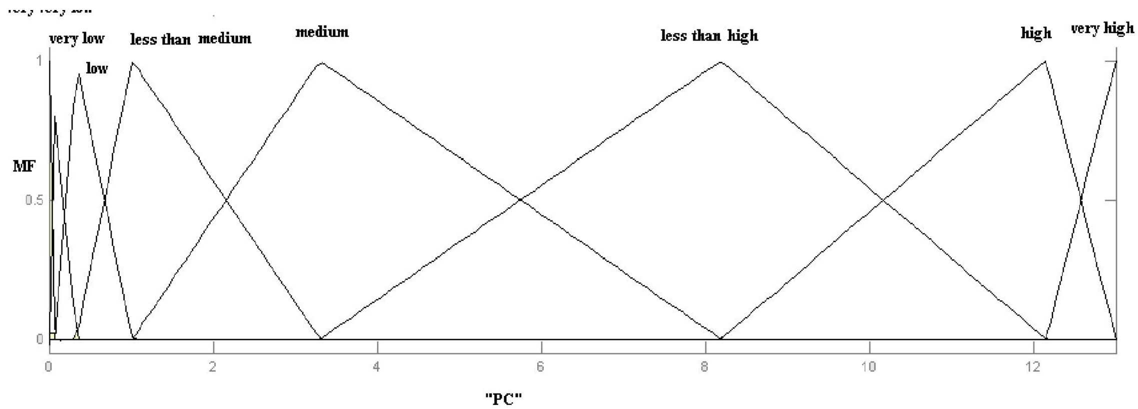

Figure 7: Fuzzy membership functions for permeability parameter

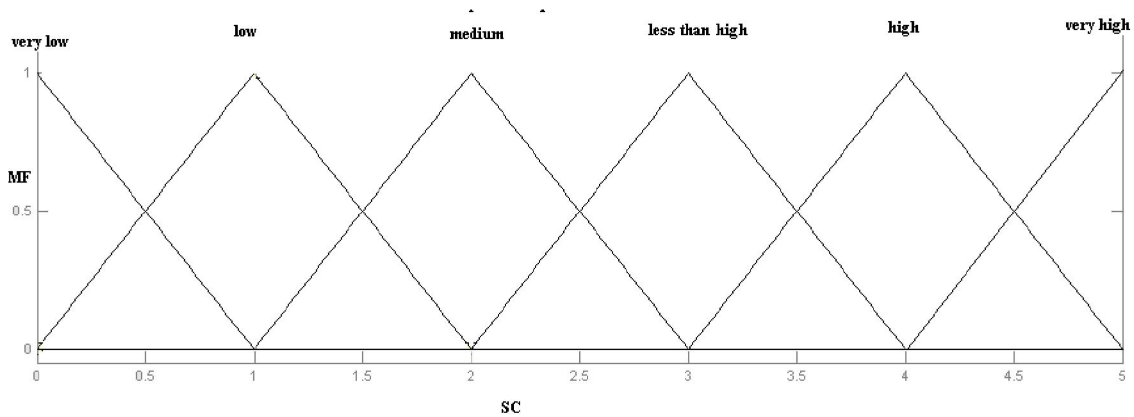

Figure 8: Fuzzy membership functions for percentage of sand particles larger than 0.1 mm

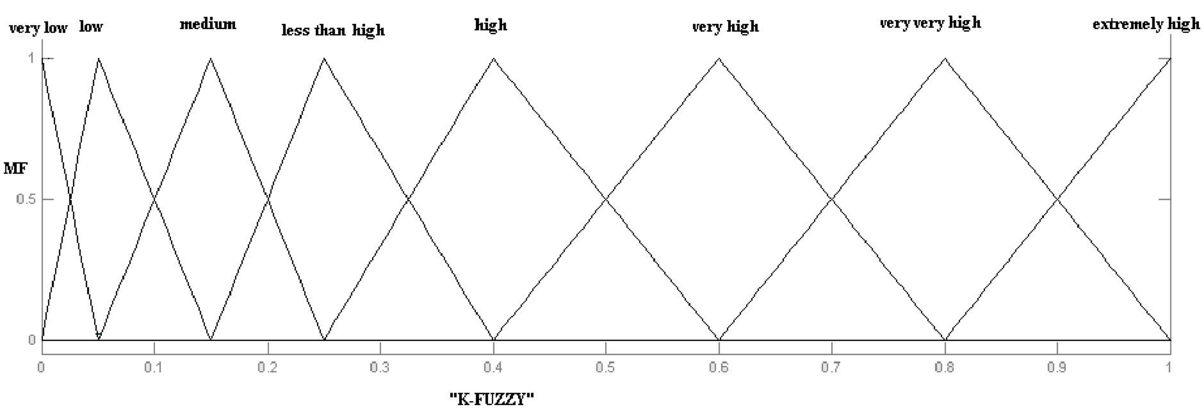

Figure 9: Fuzzy membership functions for soil erodibility factor (ton.ha.h/Mj.ha.mm)

3. Results and discussion

Ten experimental data have been chosen and applied to the fuzzy system in order to verify the performance of designed fuzzy system. Table 3 shows a summary of the result. In this table, the soil erodibility factor is given on the basis of the Wischmeier`s nomograph. The comparison in Table 3 indicates that the values of the soil erodibility factor calculated by the fuzzy system are quite close to the values obtained by the USLE model.

Where: K_FUZ and K_USLE are computed values of sample i, based on the fuzzy system and USLE model, respectively, and is the mean of measured values. The coefficient for our experiments produced the following value by applying the above formula to Table 3:

Predictions from the K wischmeier and fuzzy model (K-FUZ) were compared by calculating the coefficient of determination (R^2) defined by Nash and Sutcliffe (1970) which is calculated as follow:

$$R^2_{N-S} = 1 - \frac{\left[\sum_{i=1}^{N}((\text{KFUZZY}) - (\text{KUSLE}))^2\right]}{\left[\sum_{i=1}^{N}(\text{KFUZZY}) - (\text{K}\overline{\text{USLE}}\right]^2} \quad (2)$$

$$R^2_{N-S} = 0.998 \quad (3)$$

Table 3. The results of soil erodibility factors obtained with the fuzzy system and with the USLE model

No.	O.M (%)	PC	C.S (%)	F.S.S (%)	SC	K-USLE	K-Fuzzy
1	5.50	3	17.10	52.90	2	0.16	0.21
2	4.18	3	3.50	48.50	2	0.12	0.14
3	3.53	3	30.00	42.00	2	0.16	0.20
4	3.12	3	9.50	43.50	2	0.13	0.13
5	3.01	3	16.70	50.30	2	0.20	0.23
6	2.71	3	11.50	52.50	2	0.20	0.21
7	2.60	3	3.30	52.70	2	0.18	0.19
8	2.57	3	11.90	46.10	2	0.16	0.18
9	2.51	3	7.50	53.50	2	0.20	0.21
10	2.28	3	14.40	46.60	2	0.18	0.19

Bahrami et al. (2005) used a new method for determining the soil erodibility factor using fuzzy system. The K values obtained with this method were compared with those of USLE method. Kohli and Khera (2006) investigated the soil erodibility estimates using lab-scale simulated rainstorms in Punjab northern India. They compared their results with erodibility estimated using a nomograph, an empirical equation and a fuzzy k- frequency distribution generated by FUZKBAS program. The results showed that the measured soil erodibility was significantly correlated with nomographic estimates of soil erodibility when steady state infiltration rate was used to delineate the permeability classes. The value of soil erodibility at maximum membership obtained from fuzzy K-frequency distributions and the value at fuzzy centroid determined by FUZKBAS were also significantly correlated with measured soil erodibility. Estimated K values were considerably higher than the measured K values. Torri et al. (1997) developed a multiple regression equation and a procedure based on fuzzy logic and fuzzy mathematical theories using the program FUZKBAS, which describes the frequency distribution of observed K- factor for a given soil data. A multiple regression equation accounted for only 41% of the observed variance, because of the large unexplained variance and the best predictor (valid only for 207 data points) was characterised by a $r2 = 0.41$, which is fairly low and gives unreliable predictions. They showed that by using fuzzy mathematics erosion risk or erodibility classes can be drawn in a more natural way than simply using subjective class limits.

As we observed the result of fuzzy system, coefficient of determination between two models (K-USLE and K-Fuzzy) is near to 1 (R2=1) and fuzzy system can be used instead of Wischmeier`s nomograph to predict soil erodibility factor. In this paper, we achieved a greater generality with the Wischmeier`s nomograph based on fuzzy system because the fuzzy system does not require the real model of K-factor and so has more flexibility. Also, good performance of the designed system has been shown by validated experimental data. In the fuzzy system, we can combine some inputs and make new input. Also, we have a rule base that can be developed by new data and therefore high accuracy is achievable. The fuzzy system provides a base for more studies such as neglecting any input without losing accuracy in the estimation of the soil erodibility factor. The experimental values of the five parameters of the Wischmeier`s nomograph have errors at various steps of laboratory work caused by the instruments and human error. The fuzzy system model can be a practical way to obtain a more general method to determine the soil erodibility factor in the world. In this regard, a greater value base and more accurate interval of inputs and output yield more a accurate value for the K factor. Therefore, we have applied experimented data to the rule base of fuzzy system where the Wischmeier`s nomograph is not practical, and so we have designed a more generally applicable model.

4. Conclusion

The fuzzy system with the singleton fuzzyfier, the minimum Mamdani`s inference engine and centriod defuzzyfier is able to calculate the soil erodibility factor quite accurately. Comparing the value calculated using the designed fuzzy system with K values obtained from the USLE model showed that the fuzzy logic based modeling for determination of the soil erodibility factor is superior to the traditional statistical approaches and suggests a promising new direction for other empirically-based modeling needs. It has made possible a more flexible and more realistic procedure for describing the relationship between soil erodibility factor and the variables contributing to make up this factor.

5. Acknowledgement

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