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WATERSHED SEDIMENT YIELD PREDICTION FOR SOILS CONTAINING ROCK FRAGMENTS*

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Abstract Estimates of soil erosion and sediment yield from watersheds are needed to select the best management practices for sediment yield abatement and protection of water quality. The 'ANSWERS' model predicts sediment yield from agricultural watersheds for individual rainfall events. Conventional values of the soil erodibility factor, *K*, for soils containing rock fragments may result in an overestimation of sediment concentration present in the runoff. In this study, the effect of *K* factor adjustment to predict a more accurate sediment yield by the ANSWERS model was investigated. The value of the *K* factor was adjusted for the volumetric fraction of rock fragment. This resulted in a higher level of agreement between the predicted and observed values of sediment concentration in the watershed runoff. Therefore, it is concluded that the volumetric fraction of rock fragment should be determined for watershed soils containing rock fragments and be applied for modification of published *K* values.

Keywords – ANSWERS model, soil erodibility factor, watershed erosion

1. INTRODUCTION

Soil is one of the most valuable resources in agricultural production. As soil erosion is a selective process with respect to particle size, the higher fraction of nutrients, organic matter, and fine colloidal particles are lost from the soil and transported to the standing waters by runoff flow.

Estimates of soil erosion and sediment yield from watersheds are needed to select the best management practices for reducing sediment yield and improve water quality. Mathematical models are used to predict runoff and sediment transport from various agricultural watersheds. The ANSWERS (Areal Nonpoint Watershed Environment Response Simulation) model predicts sediment yield of runoff from small agricultural watersheds [1-3]. This prediction is based on the Universal Soil Loss Equation (USLE) proposed by Wischmeier and Smith [4]. In this model, the soil erodibility factor, K, is one of the key parameters which depends on the soil particle size fractions (silt, fine sand, and sand), organic matter, soil structure and soil hydraulic conductivity. However in the procedure for *K* factor determination, the effect of rock fragment (gravel) in soils is not considered, although some soil series in the rangelands contain considerable amounts of rock fragments in the soil surface [5, 6] which prevent the effects of rain drop impacts. The surface of these rangeland areas is usually sparsely vegetated, low in litter cover, and moderately covered with rock fragments larger than 5 mm [7, 8]. These investigators showed that the erosion rate decreased exponentially with the increasing percentage of rock cover. They also concluded that the effects of rock fragment cover on rangeland erosion can be described by the cover-management factor C of the USLE.

Rock fragments protect the soil from erosion mainly by attenuating rain drop impact and reducing surface runoff. This protection is in proportion to the surface coverage by rock fragments [9]. McCormack *et al*. [10] proposed a procedure to adjust the *K* factor for soils in order to account for rock fragments. This is because rock fragment content is a soil property and it is more appropriate to adjust the *K* factor, rather than the *C* factor which is related to cultural practices.

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The original soil *K* factor [4] was used in the 'ANSWERS' model for the simulation of hydrologic response in a small watershed. The watershed contained rock fragments in the soil surface layer. The results were not in a close agreement with the observed values of sediment concentration in runoff water [2]. Therefore, the *K* factor for the soils in this study might have been adjusted according to McCormack *et al*. [10].

In the present study, the effect of the *K* factor adjustment for soils containing rock fragments in a small agricultural watershed in the Badjgah area (Fars province, I.R. Iran) was investigated for a more accurate prediction of sediment concentration in runoff water simulated by the 'ANSWERS' model.

2. MATERIALS AND METHODS

The 'ANSWERS' model was applied using data from a small agricultural watershed located at the Agricultural College of Shiraz University, Shiraz, I.R. or Iran [2, 11, 12]. This small agricultural watershed has a drainage area of 4.83 ha and short term of concentration of 15 minutes due to steepness and small size. However, its size was reduced to 3.62 ha with no change in its concentration time [12]. The watershed has an average slope of 2.6% with a minimum and maximum slope of about 0.2 and 4.8%, respectively. A topographic map of this watershed is shown in Fig. 1. This small agricultural watershed was used because it is representative of the major portion of the watersheds of Fars province in south of I.R. Iran.

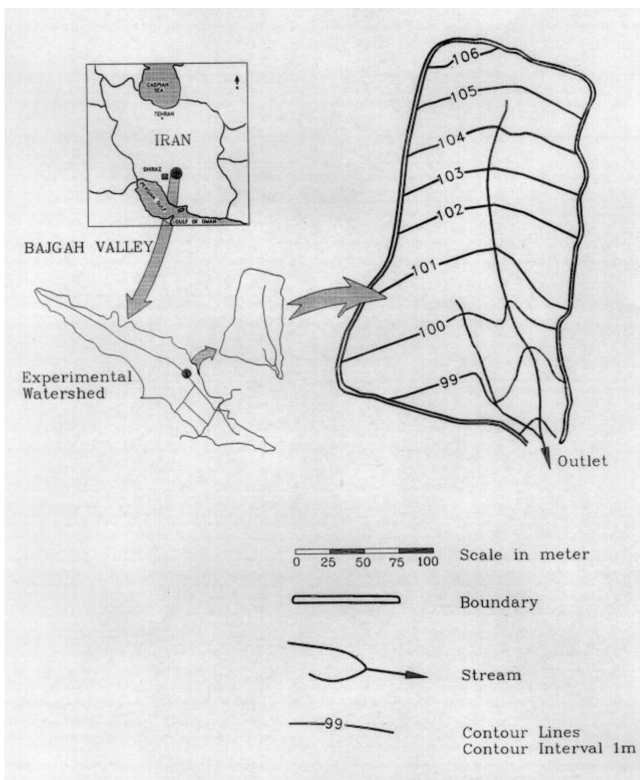

Fig. 1. Location of the experimental watershed in Bajgah valley in the north of Shiraz and its contour map

Precipitation occurs primarily from November to May each year with 400 mm y^{-1}, and rainfall events fit the *B* (intermediate) distribution type of storm [13]. The experimental watershed contains two soil types; Kuye-Asateed (loamy-skeletal over fragmental, carbonatic, mesic, Fluentic, Xerothents) sandy loam lies in the upper portion of the watershed and Ramjerdi (fine, mixed, mesic, Fluentic, Xerochrepts) clay loam in the lower portion. Some physical properties of soils are shown in Table 1. A parshall flume with a throat width of 15 cm was installed at the outlet of the watershed to measure the runoff flow rate from the site. As the flow was measured, water samples were taken for laboratory measurement of the suspended solid materials.

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Table 1. Some physical properties of the soils

Soil series	Area ha	Particle size, %				Field* capacity %	Total porosity cm^3/cm^3	Infilt-ration capacity mm/h	Erodi-bility factor (K)	Modified K
		Clay	fine silt	coarse silt	sand					
Kuye-Asateed	1.70	13	7	40	40	74.0	0.48	4.5	0.4	0.24
Ramjerdi	3.13	29	6	41	24	45.0	0.38	8.3	0.5	-

(*) Saturation percentage

Different storms during 1988, 1994, and 1997 were selected to simulate the response of the watershed shown in Table 2.

Table 2. List of selected storms used in this study

Storm date	Depth mm	Duration h	Mean storm intensity mm/h	Max. storm intensity mm/h	Reference
Feb. 18, 1988	26.4	7.0			Amin-Sichani
Feb. 25, 1988	49.5	15.7			*et al.*[2]
March 5, 1988	16.5	3.7			"
Nov. 15, 1994	19.5	9.3	2.35	6.0	Rajaee [11]
Feb. 4, 1995	34.5	10.0	3.43	7.5	"
Feb. 6, 1995	31.3	12.3	3.05	6.0	"
Jan. 16, 1997	7.5	12.0			Garosi [12]
March 23, 1997	60.3	29.7			"
March 28, 1997	19.3	9.3			"

A grid system of 25 m was adapted on the watershed to simulate the rainfall events. The rainfall data used were recorded from the Agricultural College weather station located about one kilometer from the watershed. The storm events used in this study are representative of those received in this region of the I. R. of Iran. Representative plots of each soil type were completely saturated in order to measure the field capacity of the soils. This was determined by taking samples after two days. Infiltration capacity of the soils was determined by the double ring infiltrometer method.

The volumetric fraction of rock fragment content was determined by taking 75 cylindrical samples (Inside diameter of 200 mm and height of 200 mm) in which the soil particles greater than 2 mm as rock fragments were weighted. Bulk density of the rock fragments was determined by inserting some weighted oily rock fragments in a graduated cylinder containing water. The displaced volume of water was considered as volume of the rock fragments. The rock fragments are almost uniformly distributed in depth of 0-200 mm, therefore the measured mean rock fragments for the depth of 0-200 mm may be considered as soil surface rock fragments.

An average of rock bulk density of 2.09 g cm^{-3} was obtained and using this value, the mass of surface soil rock fragments was converted to volume, and the average volumetric fraction of rock fragments (R_f) was finally determined to be approximately 0.40.

The *K* values were calculated from a nomograph of the Agricultural Handbook 537 [4], (Table 1) using particle size distribution of the soils of the watershed under study. The original *K* values were then proposed to be modified as $(1-R_f)K$ and used in the 'ANSWERS' model for simulation of sediment yield, and their comparison with observed values of sediment concentration in runoff water show that the K value was reduced by about 40%.

Channel size and specifications were determined through direct measurements using the topographic map of the watershed. Other pieces of information were extracted from the 'ANSWERS' user's manual [14] according to the given tables. The upper part of the watershed was planted by rainfed wheat in 1988 [2], while the lower part was fallow. However, in the 1994-1997 period the whole watershed was under fallow to obtain maximum soil erosion.

The improvement in sediment prediction of the model by using the adjusted *K* values for rock ragments was further evaluated by calculating the following error parameters

$$EF=\left\{\sum_{i=1}^{n}(M_i-\overline{M})^2-\sum_{i=1}^{n}(M_i-S_i)^2\right\}/\sum_{i=1}^{n}(M_i-\overline{M})^2, \quad RMSE=\left[1/n\sum_{i=1}^{n}(M_i-S_i)^2\right]^{0.5}(100/\overline{M})$$

where

$$\overline{M}=(1/n)\sum_{i=1}^{n}M_i, \quad CRM=\left[\sum_{i=1}^{n}M_i-\sum_{i=1}^{n}S_i\right]/\sum_{i=1}^{n}M_i, \quad ME=\max|M_i-S_i|_{i=1}^{n}$$

in which *EF* is the efficiency of the model for prediction, *RSME* is the relative mean square error in %, *CRM* is the coefficient of residual mass, *ME* is the maximum error (the maximum difference between measured and simulated values of sediment concentration in runoff in mg l^{-1}), S_i is the simulated values of sediment concentration in runoff, and $\overline{M}$ is the mean of measured sediment concentration in runoff.

3. RESULTS AND DISCUSSION

A sample of simulated and observed values of sediment yield for the February 6, 1995 storm is depicted in Fig. 2. It is shown that the adjusted *K* factor by rock fragments fractions with values lower than that for soils without rock fragments resulted in sediment concentration in runoff in mg l^{-1}, very close to those of the observed values. Similar results were obtained for the other storm events studied.

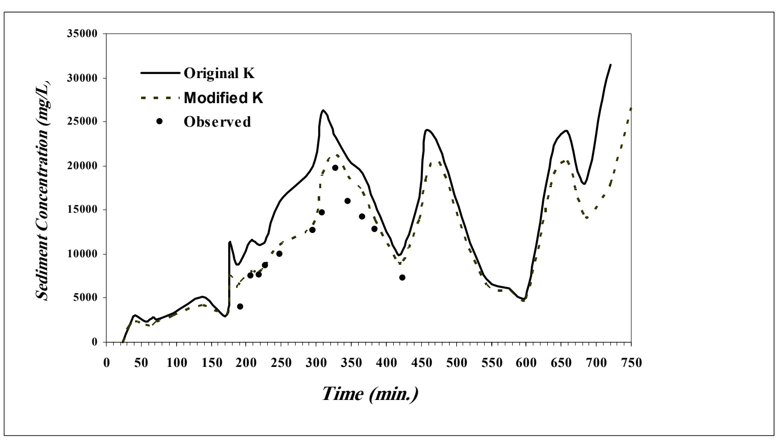

Fig. 2. Simulated and observed values of sediment yield for February 6, 1995 storm

The observed and predicted values of sediment concentration in runoff for the adjusted and original values for *K* were correlated. Their regression equations and coefficient of determinations are shown in Fig. 3. The Slope of the regression equation for the adjusted value for *K* was lower (1.07) than that for the original value for *K* (1.24) and approached unity. Furthermore, the coefficient of determination of the adjusted value for *K* was higher (0.97) than that for the original value for *K* (0.84). Therefore, by using the adjusted value for *K* the accuracy of the model for predicting sediment concentration in runoff flow was increased considerably.

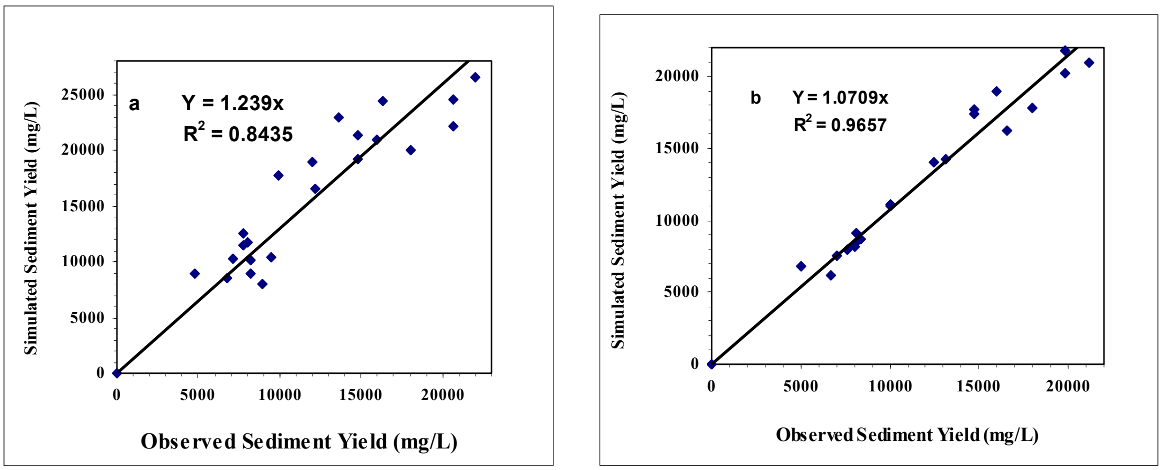

Fig. 3. Relationship between observed and simulated sediment yield for February 6, 1995 storm (a-original, b-modified)

The results of regression analyses between observed and predicted sediment concentration in runoff for the adjusted and original values for *K* of other storm events studied are shown in Table 3. The overestimation of sediment concentration for the original value for *K* was as high as 55% (slope of regression equation of 1.55). The overall regression equation and the coefficient of determination between the observed and predicted sediment concentration in runoff for the adjusted and original values for *K* are shown in Fig. 4. The results indicated that by adjusting the value for *K* by volumetric rock fraction improves the model results for sediment concentration in runoff, and a nearly one to one correlation (slope of 1.05) between the observed and predicted values was obtained (Table 3). Furthermore, the average coefficient of determination increased from 0.83 to 0.97 (a minimum of 0.51 to a maximum of 0.99).

Table 3. Regression equation and coefficient of determination between the observed and predicted sediment concentration in runoff flow (mg/*l*) for different storm events and values for K

Storm date	Regression equation		Coefficient of determination R^2	
	Original K	Adjusted K	Original K	Adjusted K
Feb. 18, 88	y=1.55x	y=1.28x	0.88	0.91
Feb. 25, 88	y=1.20x	y=1.09x	0.70	0.89
March 5, 88	y=1.31x	y=1.27x	0.79	0.89
Nov. 15, 94	y=1.13x	y=1.01x	0.78	0.91
Feb. 4, 95	y=1.28x	y=1.05x	0.87	0.93
Feb. 6, 95	y=1.24x	y=1.07x	0.84	0.97
Jan. 16, 97	y=1.27x	y=1.00x	0.79	0.91
March 23, 97	y=1.25x	y=0.97x	0.51	0.99
March 28, 97	y=1.30x	y=1.07x	0.93	0.98

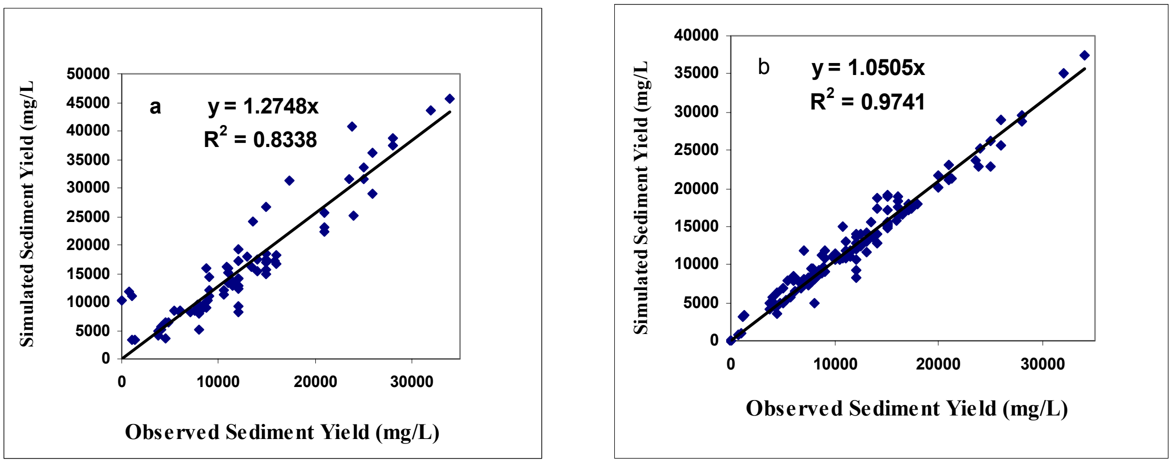

Fig. 4. Relationship between observed and simulated sediment yield for all storms (a-original, b-modified)

The effect of rock fragment percentage on the erosion rate reduction has also been shown by [1, 6, 15]. Although they stated that the effect of rock fragment cover on rangeland erosion can be described by *C* factor (cover-management factor) of the USLE, the results of this study indicated that since rock fragment content is a soil property, it is more appropriate to adjust the *K* factor, as stated by McCormack *et al*. [10].

The results of model improvement evaluation are shown in Table 4. The *EF* of the model was improved for all the rainfall events, but this improvement was not considerable for two out of nine rainfall events. The same trends were observed for the *RMSE*, *CRM* and *ME*.

Table 4. The results of error improvement calculation for the model

Rainfall	EF		RMSE (%)		CRM		ME (mg l^{-1})	
Events	Orig.	Adj.	Orig.	Adj.	Orig.	Adj.	Orig.	Adj.
Feb. 18, 88	0.158	0.680	87.5	49.9	-0.629	-0.442	7059	2487
Feb. 25, 88	-2.53	-1.82	137.5	122.9	-1.39	-1.17	12384	11333
March 5, 88	-7.3	-5.9	131.1	118.1	-0.73	-0.65	18236	16938
Nov. 15, 94	0.85	0.92	13.2	9.6	-0.18	-0.08	4916	4811
Feb. 4, 95	0.70	0.96	29.4	10.5	-0.32	-0.05	6311	4765
Feb. 6, 95	0.05	0.93	36.6	10.0	-0.37	-0.08	11682	3934
Jan. 16, 97	0.30	0.71	39.5	25.5	-0.18	0.04	16887	12889
March 23, 97	0.38	0.98	43.1	7.0	-0.48	0.02	11036	2128
March 28, 97	0.70	0.97	48.9	14.8	-0.29	-0.08	13831	4001

4. CONCLUSIONS

An original value of *K* factor for soil erodibility caused an overestimation of sediment concentration in runoff when applied to the 'ANSWERS' model. A small agricultural watershed in the Badjgah area (Fars province) with soil-containing rock fragments was used for the tests. Adjusting the soil erodibility factor *K* by multiplying the original value for *K* by (1-R_f), in which R_f is the volume rock fragment fraction, resulted in a decrease in soil value for *K*. This resulted in a more accurate prediction of sediment concentration in runoff flow from the 'ANSWERS' model. Therefore, it is concluded that R_f should be determined for soils containing rock fragments and this parameter should be used in *K* estimation for such soils by modifying the original published values for *K*.

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