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INCORPORATING ROCK FRAGMENTS IN SOIL EROSION MODELS: A CASE STUDY, THE *ANSWERS* MODEL*

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Abstract– Many researchers have incorporated the effects of rock fragments in soil erosion studies to improve the prediction of erosion by raindrop impact and overland flow. According to the Box-Simanton approach, the effect of rock fragments should be incorporated into the crop factor of USLE, C, whereas the Poesen-McCormack and Sepaskhah *et al*. approaches include the rock fragments in the soil erodibility factor K. For this study we investigated which approach was most suitable for our research basins. This study is based on a comparison of observed sediment concentration data out of a representative agricultural watershed in the south of Iran with the output of ANSWERS model. Preliminary results reveal that there is no meaningful statistical difference between the Poesen-McCormack and Box-Simanton approaches. Nevertheless, when the runoff coefficient exceeded 0.3, the Poesen-McCormack approach was more accurate, but under high antecedent soil moisture conditions, the Box-Simanton approach gave more accurate results. Finally, a comparison of the Sepaskhah et al. approach with other methods showed that, in general, the Sepaskhah et al. method is more practical and reliable than the other approaches.

Keywords – Rock fragments, ANSWERS, soil erosion, erodibility factor (K), crop and management factor (C), USLE

1. INTRODUCTION

In most soil erosion studies, particles larger than 5 mm are considered rock fragments [1, 2]. The role of rock fragments in protecting the soil surface against raindrop impacts is well known and has been well documented since 1943 [3, 4]. Rock fragments in the soil and on soil surfaces significantly influence infiltration, runoff, moisture storage, and land use [5-7]. Rock fragments protect a soil surface by 1) a reduction in soil erodibility by protecting the soil surface against raindrop impact and overland flow detachment, 2) a reduction of soil surface sealing, and 3) retardation of overland flow which results in lowering its shear stress and transport capacity [8]. Therefore, it is necessary to incorporate the role of rock fragments in soil erosion models, increasing the accuracy of the estimation of soil loss from arable lands and watersheds.

2. BACKGROUND

The removal of rock fragments caused increase of both runoff volume and rate and soil loss of a watershed [3, 4, 9]. Nyssen *et al.* [1] found that reducing surface rock fragments cover from 20% to 0% resulted in a threefold increase of soil loss.

Several studies have been carried out to investigate how size [10], shape [11], and position [12] of rock fragments affect soil erosion.

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There are several ways to incorporate the effect of rock fragments in calculation and modeling of soil loss and sediment transport out of watersheds. Poesen [13] and McCormack *et al*., [14] stated that the percentage of rock fragments is a soil property, and that it would be correct therefore, to include the effect of rock fragments on the amount of soil loss in models such as USLE soil erodibility factor (K), rather than in a cover and management factor (C). By definition, K is the average annual soil loss from bare fallow with cultivation up and down the slope on an area 22.1 m long and 1.83 m wide with a 9% slope gradient divided by the average annual sum of rainfall erosivity (R). Cover and management factor (C) is defined as the ratio of the average annual soil loss from the cropped area to that from the bare fallow cultivation up and down the slope condition. Poesen [13] and McCormack *et al*., [14] have adopted Table 3 of McCormack *et al.*, [14] for obtaining rock-based K value based on volume of rock fragments, through converting the K values obtained from Agriculture Handbook No. 537 [15]. This table was the basis of determination of K based on the Poesen-McCormack (PM) method in our study. Entering the K value of soil particles less than 2 mm [15] and the percentage volume of rock fragments into Table 3 of McCormack *et al*. [14], hence, the K value associated with the Poesen-McCormack (PM) method is obtained.

Conversely, Box and Meyer [16] and Simanton *et al.*, [17] suggested that rock fragments act as a surface mulch cover, and so that their effect should be reflected in the C factor of USLE, they propose that the Zero-canopy curve in Fig. 6 of Agriculture Handbook No. 537 [15] must be taken into account. This figure was used in our study to determine the C based on the Box-Simanton (BS) method.

Recently, Sepaskhah *et al.*, [18] proposed adjusting K value for rocky soils as follows. Multiplication of the original value of K [15] and (1-R_f), in which R_f is the volume rock fragment fraction in topsoil, returns the adjusted K value. They reported that the adjusted soil erodibiity factor results in a closer agreement between observed values of sediment concentration using the ***ANSWERS*** model as a prediction tool for sediment concentration.

In the present study, four approaches for incorporation of rock fragments in the ***ANSWERS*** model to determine the most reliable one are: PM (Poesen-McCornack); BS (Box-Simanton), ES (Sepaskhah *et al.*, [18]), and IN or Integrated (Ahmadi [19]) are applied; the latter of which is a new approach.

3. MATERIALS AND METHODS

a) The ANSWERS model

ANSWERS (***A***real ***N***onpoint ***S***ource ***W***atershed ***E***nvironmental ***R***esponse ***S***imulation), is a deterministic, distributed parameter, event-based model developed to simulate the hydrologic behavior, sediment yield and sediment concentration of agricultural watersheds [20]. Its primary application is in planning and evaluating various strategies for controlling pollution from intensively cropped areas [21, 22]. The hydrologic concepts behind the ***ANSWERS*** were originally developed by Huggins and Monke [23] for estimating runoff rate in a watershed by considering the process of interception, infiltration, and surface storage. Afterwards, Dillaha [24], Beasley and Huggins [20], and Amin [25] modified the model to deal with other hydrologic processes and water quality such as erosion, drainage, and pollutant transport. A watershed which is to be modeled should be divided into a network of squares elements. Variables which are defined for each element are slope, soil characteristics (porosity, moisture content, field capacity, infiltration capacity, soil erodibility factors, USLE K factor), crop variables (covering, interception capacity, USLE C factor), surface variables (roughness and surface retention) and channel variables (width and roughness). This model uses the data of any rainfall event with user selected time steps, taking into account spatial and temporal variability of rainfall. The continuity equation is the basic equation for runoff calculation. More details on ***ANSWERS*** are discussed in Beasley and Huggins [20].

Many researchers throughout the world have conducted some studies on the ***ANSWERS*** model and agreed that the model can predict the runoff rate very close to the observation [25-32]. However, almost all of the above studies have demonstrated that the model prediction of sediment concentrations is not very close to those of observations. In some watersheds, ***ANSWERS*** has underestimated the sediment concentration [28, 33] while Bhuyan *et al*., [34], Walling *et al*., [35], and Moehansyah *et al*., [36] reported an overestimation in sediment concentration. It is therefore concluded that erosion subroutine of the ***ANSWERS*** may need some modifications. However, erosion prediction in a watershed is difficult due to the complexity of large heterogeneity. So far, few erosion models have been relatively acceptable in predicting watershed sediment yield [36, 37]. Due to variability and uncertainty of erosion data under field or watershed conditions, an error in model prediction up to 50% has been chosen as acceptable by researchers [36, 37].

b) The study area

The 3.62 ha study basin is located at the College of Agriculture of Shiraz University, approximately 15 km north of Shiraz city on the Badjgah Plain (29^o 50' N and 52^o 46' E) in southern Iran. The Badjgah Plain has a dry, mesothermal climate, with little or no rainfall during winter [30]. The average annual rainfall average is 414 mm, which generally falls from November to May. The other months are warm and dry. The soil in the basin consists of two soil series: Ramjerdi, a fine, mixed, mesic, Fluventic Xerochrepts; and Kuye Asatid, a loamy-skeletal over fragmental, carbonatic, mesic, Fluventic Xerorthents), with a clay loam and loam texture for the top 25 cm. The Ramjerdi series, which is formed on Piedmont alluvial plains, covers 16% of the watershed area, while the Kuye Asatid series, formed by Alluvial-Colluvial fans, covers the remaining area of the watershed [38]. During the time of the study, the surface of the watershed was fallow in order to achieve the maximum runoff and erosion rate. Table 1 shows some physicochemical properties of the watershed soil series [38].

Table 1. Particle size distribution and selected chemical properties of watershed soil series

Soil seires	Depth,cm	Particle size distribution			Chemical		
		Sand,%	Silt,%	Clay,%	OM %	CaCo3 %	pH
Kuye asatid	0-20	40	47	13	2.2	28.1	7.9
	20-55	40	36	24		46.5	7.9
Ramjerdi	0-25	24	47	29	0.7	32.8	8
	25-70	23	39	38	0.6	34.7	8.2

c) Available data

Data for eleven storms from 1993 to 1998 were used for simulation. Sediment concentration data for the storms were collected by Rajaee [31], Garosi [30], and Estakhri [29] at the outlet of the watershed where two 15 cm and 23 cm Parshall flumes were installed in series. Table 2 shows the characteristics of the selected rainfall events.

d) Sediment concentration simulation

In order to simulate the sediment concentration in the watershed during the rainstorms, the original version of the ***ANSWERS*** model (version 4.840801) was used [20, 27]. The erosion algorithm of ***ANSWERS*** uses the empirical relationships described by Meyer and Wischmeier [39] for rainfall detachment rate (Eq. 1), and Foster [40] for overland flow detachment rate (Eq. 2) respectively, as follows:

$$\mathrm{DETR} = \mathrm{C}_1 \times \mathrm{CDR} \times \mathrm{SKDR} \times \mathrm{A} \times \mathrm{R}^2 \quad (1)$$

$$\mathrm{DETF} = \mathrm{C}_2 \times \mathrm{CDR} \times \mathrm{SKDR} \times \mathrm{A} \times \mathrm{SL} \times \mathrm{Q} \quad (2)$$

where *DETR* is the rainfall detachment rate ($kg\ min^{-1}$); *DETF* is the overland flow detachment rate, ($kg\ min^{-1}$); *CDR* is the crop and management factor (C in the USLE equation); *SKDR* is the Soil erodibility factor (K in the USLE equation); *A* is the area (m^2) impacted by rainfall; *R* is the rainfall intensity ($mm\ min^{-1}$); *Q* is the discharge ($m^3\ min^{-1}$); *SL* is the slope steepness; and C_1, and C_2 are empirical coefficients.
To incorporate the effect of rock fragments, the *CDR* (C, crop and management factor) and *SKDR* (K, soil erodibility factor) in Eqs. (1) and (2) should be adjusted following the appropriate method.

Table 2. Rainfall events and runoff properties used in the simulation

Date	Rainfall depth (mm)	Average rainfall intensity (mm/h)	Observed runoff (mm)	Runoff coefficient
20/12/1993	15.75	0.61	5.76	0.37
5/2/1994	34.5	3.34	12.06	0.35
7/2/1994	28.5	2.25	8.64	0.30
17/1/1996	28.00	2.05	2.73	0.10
24/3/1996	60.3	0.03	5.82	0.10
29/3/1996	19.25	2.06	5.91	0.31
14/12/1997	22.25	1.76	2.23	0.10
20/12/1997	28.75	1.92	4.75	0.17
5/1/1998	55.25	5.72	28.28	0.51
11/2/1998	46.00	2.27	10.56	0.23
1/3/1998	14.25	1.29	2.54	0.18

e) Measuring the amount of rock fragments

To determine the effect of rock fragments on runoff and sediment yield, the percentage by weight, volume, and areal cover of the rock fragments scattered on the watershed soil surface and within the 5 cm topsoil layer of the watershed must be determined.

Only particles larger than 5 mm were taken into account because Simanton *et al.*, [17], Abrahams and Parson [41], Wijdenes *et al.*, [42], Poesen *et al.*, [2], and Nyssen *et al.*, [1] suggest that particles smaller than 5 mm could be considered a part of the fine fraction of the soil since such particles are moved easily by rill and interrill flow.

Areal cover of rock fragment was determined using the point-count method [43] in which at five randomly-located places in each soil series a 50 cm squared metal frame was laid on the soil surface and a transparent plate with the same size inserted in the frame. Rock fragments larger than 5 mm were determined visually and traced on the transparent plate. Rock fragment cover (RFc) was estimated using the following equation [1]:

$$\mathrm{RFc}(\%) = \frac{n_p}{n_t} \times 100 \quad (3)$$

where n_p is the number of observations with a rock fragment present, and n_t is the total number of observations.

For the adjustment of K, all rock fragments both on the surface and in the first 5 cm of the topsoil are required. At the same points where the surface cover was measured, particles larger than 5 mm were removed by hand to determine the mass of the soil surface rock cover. The top 5 cm of soil [16, 17] surrounded by the metal frame was collected and transported to the laboratory for mechanical sieve analysis of particles larger than 2 mm. The bulk density of the surface rock fragments was determined for calculation of the volume. The results of the average amount of rocks measured at each sampling site are shown in Table 3. In this table each value is the average of 5 samples.

Table 3. Rock fragment areal cover and volume

Soil series	Areal cover of particles > 5mm, %	Volume of particles > 2mm the topsoil layer, %	Total volume of rock fragments, %
Ramjerdi	12.31	11.16	12.58
Kuye asatid	24.56	21.17	24.37

The following procedures were used to include the effect of rock fragments in the ***ANSWERS*** erosion model based on the values of Table 3:

1) Adjustment of the C factor based on the areal cover of a rock fragment > 5 mm on the soil surface (Box-Simanton approach). This adjustment was carried out using Fig. 6 of Wischmeier and Smith [15].

2) Adjustment of the K factor based on the volume of a rock fragment >5 mm on the soil surface and the volume of rock fragments >2 mm in the top 5 cm of the soil layer (Poesen-McCormack approach). In this case, Table 3 of McCormack *et al*., [14] was used for determining the adjusted K value.

3) Combining the surface rock cover in the C factor, and the topsoil rock fragments in the K factor, (Integrated approach of Ahmadi [19]).

4) Adjusting the K value calculated from the Wischmeier and Smith [15] nomograph (Sepaskhah *et al.*, [18] approach).

f) Determination of K and C factors

Total volume of rock fragments (>2 mm in the topsoil layer plus >5 mm on the soil surface) were 12.58% and 24.37% for the Ramjerdi and Kuye Asatid series, respectively. Table 4 shows the adjusted K and C values for the different approaches. However, one should note that a specific amount of rock fragments does not result in a similar decreasing effect on the K or C value. For example, in general, a 20% rock fragment may decrease K by 10 % (based on PM method) or C by 15% (based on the BS method). So, in Eqs. (1) or (2) the value of the term "$CDR \times SKDR$" may vary in different methods of considering rock fragments for a specific amount of rock fragments.

Table 4. K and C values for each soil series according to different approaches

	C	C	K	K
Method	Ramjerdi	Kuye Asatid	Ramjerdi	Kuye Asatid
Box-Simanton	0.5	0.5	0.4	0.5
Integrated	0.5	0.5	0.31	0.3
Poesen-McCormack	0.68	0.93	0.27	0.26
Sepaskhah et al.	0.68	0.93	0.35	0.38

It is worthy to mention that incorporating the effect of rock fragments in the ***ANSWERS*** model has no effect on the simulation of runoff rate. The governing equations of runoff rate simulation are Manning and continuity in which rock fragments are not included. The algorithm of the ***ANSWERS*** model is developed in such a way that the SED subroutine (in which sediment concentration is calculated) called the FILT subroutine, i.e. runoff rate is computed first, and sediment concentration is calculated, thereafter, based on the runoff rate. Equations (4) and (5) show the sediment transport capacity equations, which are directly related to runoff rate. As was noted before, the ***ANSWERS*** model simulate the runoff rate very well [25-32].

$$TF=161\times S\times Q^{0.5} \quad \text{if} \quad Q\leq 0.046\ m^2/min \tag{4}$$

$$TF=16320\times S\times Q^{2} \quad \text{if} \quad Q> 0.046\ m^2/min \tag{5}$$

Where

TF is sediment transport capacity, *kg/(m.min)*; *Q* is flow discharge (runoff rate) per width unit, m^2/min, and *S* is slope steepness, *%*.

g) Statistical analysis

El-Sadek *et al.,* [44] and Homaee *et al.*, [45] used statistical criteria to determine model performance. These criteria were used to evaluate the accuracy of the proposed approaches. More details on these criteria can be found in Homaee *et al.,* [45].

1. Mean Absolute Error (MAE)

$$MAE=\frac{\sum_{i=1}^{n}\left|O_i-P_i\right|}{n}$$

where, O_i is the observed value, P_i is the predicted value, and n is the number of data points.

2. Root Mean Square Error (RMSE)

$$RMSE=\frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(O_i-P_i\right)^2}}{\overline{O}}$$

where $\overline{O}$ is the mean of the observed values.

3. Nash-Sutcliffe coefficient (CNS)

$$EF=\frac{\sum_{i=1}^{n}\left(O_i-\overline{O}\right)^2-\sum_{i=1}^{n}\left(P_i-O_i\right)^2}{\sum_{i=1}^{n}\left(O_i-\overline{O}\right)^2}$$

The CNS ranges from minus infinity to 1, with higher values indicating better agreement. If the CNS is negative, the model prediction is worse than the mean observation or, in other words, a negative CNS value results when there is a greater difference between observed and predicted values than between observed and the mean of observed values [34]. Sometimes this criterion is called the “model efficiency”.

4. Coefficient of Residual Mass (CRM)

$$CRM=\frac{\sum_{i=1}^{n}O_i-\sum_{i=1}^{n}P_i}{\sum_{i=1}^{n}O_i}$$

The CRM has a maximum value of 1. If the CRM is negative, the model overestimates.

5. Coefficient of Determination (CD)

$$CD=\frac{\sum_{i=1}^{n}\left(O_i-\overline{O}\right)^2}{\sum_{i=1}^{n}\left(P_i-\overline{O}\right)^2}$$

The CD describes the ratio of the scatter of the simulated values and the observed values around the average of the observations. A CD value of 1 indicates that the simulated and observed values match perfectly.

6. Maximum Error (ME)

$$ME = \max\left|O_i - P_i\right|$$

The ME shows the maximum difference between the predicted and observed values in a series of data.

4. RESULTS AND DISCUSSIONS

Figure 1 shows the observed and predicted sediment concentrations for the rainfall event of 17/1/1996 obtained with the Box-Simanton and Sepaskhah *et al.,* [18] approaches. Clearly, there is no close agreement between observed and predicted sediment concentration for either approach. The model underestimates the sediment concentration during the early parts of the simulation time (0-200 min). From 500 to 750 min, however, the predicted sediment concentration is in a closer agreement with the observed data. Figure 2A and 2B illustrates the best fitted regression line for the rainfall event of 17/1/1996 with the Box-Simanton and Sepaskhah *et al.*, [18] approaches, respectively. The regression line with low R^2 value does not cover the predicted sediment concentrations well. The wide prediction interval also shows that observed and predicted sediment concentrations are not in acceptable agreement.

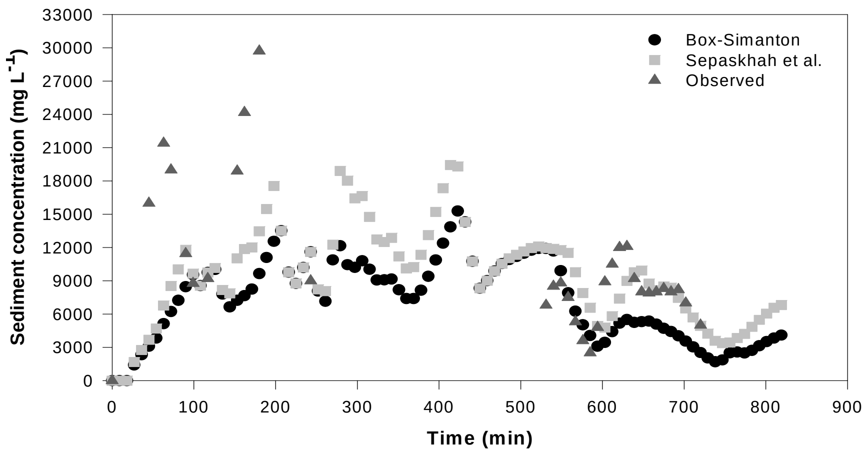

Fig. 1. Comparison between observed and predicted values of sediment concentration for the Box-Simanton and Sepaskhah *et al*. [44] approaches, rainfall event 17/1/ 1996

Comparison between Poesen-McCormack, Box-Simanton, and Integrated approaches: Table 5 summarizes the statistical criteria for the Poesen-McCormck (PM), Box-Simanton (BS), and Integrated (IN) approaches for 11 rainfall events. For seven events, the BS approach gave the most accurate results. The Poesen-McCormack approach showed the closest agreement between observed and simulated values of sediment concentration for two events of 7/2/1994 and 11/2/1998, whereas the Integrated approach provided the best results for 5/2/1994 and 20/12/1993. It can be concluded that when the runoff coefficient is greater than 0.3, considering the rock fragments in the K factor provide more accurate results, it seems that measuring or computing runoff coefficient is necessary before modeling the erosion rate in stony soils.

Rock fragments in the soil or on the soil surface affect some soil physical and hydraulic properties such as hydraulic conductivity, and infiltration is directly related to the saturated hydraulic conductivity [46]. It was mentioned that for rainfall events having runoff coefficient greater than 0.3, rock fragments in the K factor provide more accurate results. Since K factor is of soil physical properties, it can be concluded that rock fragments have a restricted infiltration rate in the case of runoff coefficients greater than 0.3. This conclusion agrees well with the results of Mehuys *et al*., [5], Dunn and Mehuys [47], and

Brakensiek and Rawls [46] who found that saturated hydraulic conductivity decreased with increasing rock fragment content. So, for a runoff coefficient greater than 0.3, the rock fragments likely led to the reduction of the soil hydraulic conductivity. Thus, for watersheds with rock fragments in or on the soil surface, runoff coefficient must be evaluated first.

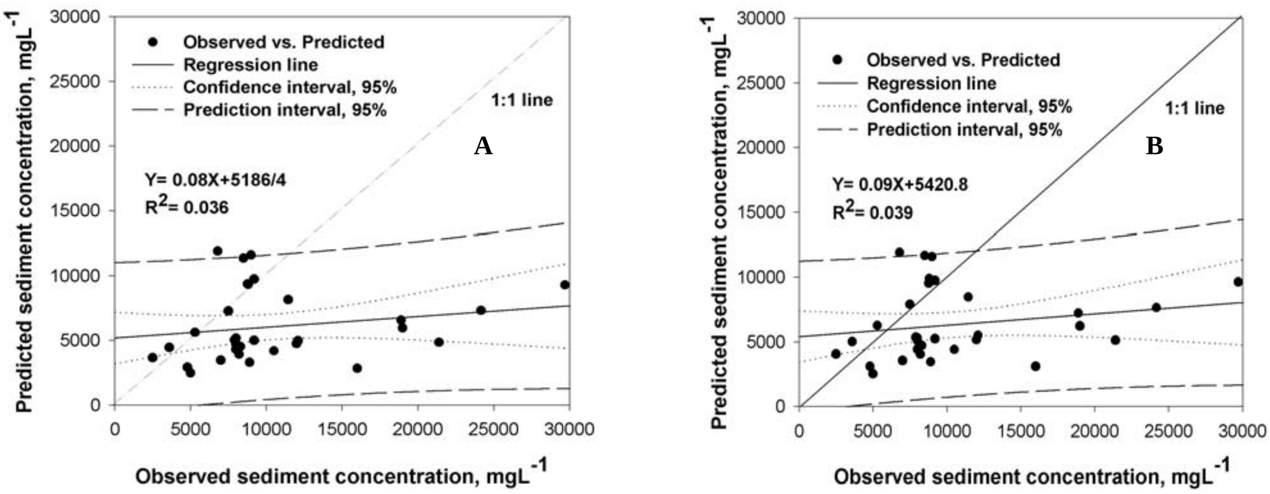

Fig. 2. The regression line, confidence and prediction interval (95%) for the Box-Simanton (A) and Sepaskhah *et al.*, [44] (B) approaches, rainfall event 17/1/ 1996

Nevertheless, there are some exceptions e.g., in the case of the rainfall event of 5/1/1998, although the runoff coefficient is 0.51, the Box-Simanton method was found to be the most appropriate approach. The average intensity of this rainfall was the highest (I_{ave}=5.72 mm h^{-1}) (Table 2), but rainfall intensity was much more than the infiltration capacity [2]. For this storm, rock fragments likely should be considered as mulch cover and the Box-Simanton approach has to be applied. The same situation probably happened for the storm of 29/3/1996. This storm has a runoff coefficient of more than 0.3, so the Box-Simanton approach provides the most accurate results. During this particular rainfall event, rainfall ceased and after 200 min started again. Hence, the high runoff coefficient is likely caused by the high antecedent soil moisture conditions resulting from the first part of the rainfall. Rainfall intensity during the second part of this storm was twice (3.88 mm hr^{-1}) the overall average rainfall intensity (2.06 mm hr^{-1}). It is therefore concluded that whenever the soil moisture content is high or near saturation, the effects of rock fragments should be incorporated in the C factor because rock fragments may act as mulch cover in these conditions.

Since the C factor generally addresses the mulch effect of rock fragments in preventing raindrop impact on soil particles, it is concluded that the soil surface might be mostly inundated, which has decreased or diminished the effect of the surface cover of rock fragments on soil erosion. Also, even with relatively low rainfall intensities, large volumes of runoff were generated (Table 2). This can be interpreted as indicating that the surface rock fragments should be partially to fully embedded in the topsoil layer, which according to Poesen [48], Poesen *et al.*, [12], and Poesen *et al.*, [8] limits infiltration and acts as a barrier, or mulch which prevent the direct and indirect rainfall infiltration. Visual observations in the experimental watershed support this conclusion.

According to Table 5, the CRM is negative for the first three storms. Runoff coefficients for these three storms are more than 0.3, which implies that ***ANSWERS*** underestimates sediment concentration unless the runoff coefficient is more than 0.3.

A t-test (**α=0.05**) comparing the means of two groups of equal size [49] reveals that there is no significant and meaningful difference between the results of Box-Simanton and Poesen-McCormack approaches. This implies that both ideas about considering the rock fragments in the erosion models likely give similar results of sediment concentration.

Table 5. Comparison between different approaches based on statistical criteria

Date	Approach	ME	RMSE	CNS	MAE	CRM	CD
20/12/1993	*Sepaskhah et al. (ES)*	5988.6	1.27	-2.3	2102.73	-0.73	0.39
	Box-Simanton(BS)	3902.6	0.9	-0.65	1544.85	-0.15	1.24
	Integrated(IN)	3655.4	0.78	-0.24	1248.48	0.18	2.81
	Poesen-Mc Cormack(PM)	4018.6	0.91	-0.69	1588.61	-0.29	1.14
5/2/1994	*Sepaskhah et al. (ES)*	6223.1	1.62	-12.89	3978.78	-1.49	0.07
	Box-Simanton(BS)	3946.1	0.89	-3.21	2120.81	-0.73	0.25
	Integrated(IN)	2123.1	0.45	-0.08	1024.11	-0.15	1.76
	Poesen-Mc Cormack(PM)	4069.1	0.94	-3.65	2227.48	-0.79	0.23
7/2/1994	*Sepaskhah et al. (ES)*	4266	2.7	-17.29	1940.69	-2.24	0.05
	Box-Simanton(BS)	4970	3.22	-25.03	2348.77	-2.71	0.04
	Integrated(IN)	3721	2.31	-12.38	1620.77	-1.87	0.08
	Poesen-Mc Cormack(PM)	2492	1.46	-4.36	957.15	-1.04	0.2
17/1/1996*	*Sepaskhah et al. (ES)*	20071	0.7	-0.51	5383.01	0.4	1.46
	Box-Simanton(BS)	20071	0.7	-0.51	5383.01	0.4	1.46
	Integrated(IN)	23760	0.87	-1.33	7390.55	0.68	0.64
	Poesen-Mc Cormack(PM)	20425	0.72	-0.58	5468.23	0.43	1.33
24/3/1997*	*Sepaskhah et al. (ES)*	11586	0.66	-0.78	7310	0.61	0.53
	Box-Simanton(BS)	14456	0.77	-1.42	8419.78	0.7	0.46
	Integrated(IN)	17289	0.88	-2.2	9566	0.8	0.38
	Poesen-Mc Cormack(PM)	14750	0.78	-1.53	8618.56	0.72	0.44
29/3/1997*	*Sepaskhah et al. (ES)*	14883	0.47	0.27	6325.23	0.21	1.98
	Box-Simanton(BS)	18647	0.62	-0.24	8085.95	0.36	1.47
	Integrated(IN)	24474	0.8	-1.05	10650.2	0.57	0.82
	Poesen-Mc Cormack(PM)	19095	0.63	-0.3	8305.18	0.37	1.4
14/12/1997*	*Sepaskhah et al. (ES)*	13258	0.53	0.12	6140.3	0.45	0.9
	Box-Simanton(BS)	16456	0.67	-0.41	7940.55	0.58	0.72
	Integrated(IN)	19624	0.84	-1.2	10019.8	0.74	0.55
	Poesen-Mc Cormack(PM)	16799	0.69	-0.49	8175.73	0.6	0.7
20/12/1997*	*Sepaskhah et al. (ES)*	9050	0.78	-1.18	3551.21	-0.27	0.33
	Box-Simanton(BS)	6236	0.71	0.34	2057.55	0.11	0.83
	Integrated(IN)	10768	1.36	-1.43	5000.91	0.7	1.28
	Poesen-Mc Cormack(PM)	10726	1.4	-1.58	5302	0.61	1.33
5/1/1998*	*Sepaskhah et al. (ES)*	13637	0.46	-8.13	8005.88	0.43	0.12
	Box-Simanton(BS)	16569	0.61	-14.96	10976.4	0.58	0.07
	Integrated(IN)	19461	0.76	-23.89	13908.8	0.74	0.04
	Poesen-Mc Cormack(PM)	16867	0.62	-15.79	11280.3	0.6	0.06
11/2/1998	*Sepaskhah et al. (ES)*	13810	0.44	-1.92	5016.86	0.32	0.3
	Box-Simanton(BS)	14709	0.55	-3.48	6748.93	0.45	0.24
	Integrated(IN)	14370	0.69	-6.1	9102.97	0.66	0.15
	Poesen-Mc Cormack(PM)	12231	0.52	-3.06	6613.01	0.48	0.27
1/3/1998*	*Sepaskhah et al. (ES)*	10115	0.73	0.08	4230.14	0.39	0.84
	Box-Simanton(BS)	10574	0.79	0.02	4439.4	0.53	1.08
	Integrated(IN)	11119	0.92	-0.34	5289.3	0.71	1.02
	Poesen-Mc Cormack(PM)	10773	0.8	-0.02	4534.57	0.55	1.07

*: For these dates the BS approach gave the most accurate results compared to PM and IN approaches

Comparison of Sepaskhah *et al.* [18] with the other approaches: The statistical results show that the Sepaskhah *et al.*, [18] approach is generally more accurate for simulating the sediment concentration and yield (Table 5), and t-test (α=0.05) comparing the means of two groups of equal size [49] indicated a significant difference between the results of the Sepaskhah *et al.*, [18] approach and the other methods. We therefore suggest that the Sepaskhah *et al.*, [18] approach should be used for the adjustment of K values for erosion modeling. Since the Sepaskhah *et al*., [18] approach requires data on the volume percentage of rock fragments in the 5-cm topsoil layer, which is time-consuming, especially in large areas, it is suggested that this method is used only where an accurate prediction of sediment concentration is desired; otherwise the much simpler to use Box-Simanton approach may be adequate .

5. CONCLUSION

Four approaches for incorporating the effect of rock fragments in soil erosion models have been evaluated. The results showed that the approach of Sepaskhah *et al.*, [18] provides the most accurate results. Results of t-tests indicate that there is no significant difference between the Poesen-McCormack and Box-Simanton approaches.

However, none of the approaches gave a good simulation of sediment concentration and this shows that more modifications should be applied to this model. Recent researches on the ***ANSWERS*** model failed to simulate the sediment [34, 35, 36]. Because of the basic algorithm of the ***ANSWERS*** model, the rock fragments were not considered in the infiltration and runoff process. Edwards *et al.*, [50], Dunn and Mehuys [47], and Flint and Childs [51] reported that rock fragments in the soil profile affect the soil water content and infiltration rate and it is recommended that for future researches this option be considered in erosion modeling. Also, Wallach *et al.*, [52], showed that neglecting the relationship between the infiltration rate and overland flow depth causes some errors in the prediction of surface runoff rate and depth. Therefore, it is suggested that future studies on erosion modeling consider this fact. Not neglecting this relationship may somehow affect the simulation of sediment concentration in the watershed.

In this study it was found that when the runoff coefficient exceeded 0.3, the rock fragments in the K factor seemed to provide the best results. When the runoff coefficient was less than 0.3 or under high antecedent soil moisture condition, it is preferable to include the effect of rock fragments in the C factor. These results are, however, site specific and therefore, should be evaluated in other watersheds under different conditions of soil and rainfall to better understand the impact of spatial variability of rock fragment characteristics in soil erosion modeling. More research on the effect of rock fragments on soil erosion modeling are recommended.

Because of the complex nature of erosion and sediment and also the large heterogeneity of watersheds, it is a challenge and a hard way to access a model which can simulate the sediment concentration well and satisfactorily, and much more research is needed [36].

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REFERENCES

1. Nyssen, J., Haile, M., Poesen, J., Deckers, J. & Moeyersons, J. (2001). Removal of rock fragments and its effect on soil loss and crop yield, Tigray, Ethiopia. *Soil Use and Management, 17,* 179-187.

2. Poesen, J., van Wesemael, B., Bunte, K. & Benet, A. S. (1998). Variation of rock fragment cover and size along semiarid hillslopes: a case study from southeast Spain. *Geomorphology, 23*, 323-335.
3. Lamb, J. J. & Chapman, J. E. (1943). Effects of surface stones on erosion, evaporation, soil temperature, and soil moisture. *Journal of American Society Agronomy, 35*, 567-578.
4. Huberty, M. R. (1944). Compaction in cultivated soils. *Transaction of American Geophysics Union*, *25*, 896-899.
5. Mehuys, G. R., Stolzy, L. H., Letey, J. & Weeks, L. V. (1975). Effect of stones on the hydraulic conductivity of relatively dry desert soils. *Soil Science Society of American Proceeding, 39*, 37-42.
6. Miller, F. T. & Guthrie, R. L. (1984). Classification and distribution of soils containing rock fragments in the united states. *In:* J. D. Nichols, P. L. Brown, and W. J. Grant (Eds.), Erosion and Productivity of Soils Containing Rock Fragments. SSSA Special Publication No. 13, Madison, WI. pp. 1-6.
7. Van Wesemael, B., Poesen, J. & de Figueiredo, T. (1995). Effects of rock fragments on physical degradation of cultivated soils by rainfall. *Soil & Tillage Research, 33*, 229-250.
8. Poesen, J., Torri, D. & Bunte, K. (1994). Effects of rock fragments on soil erosion by water at different spatial scales: a review. *Catena, 23*, 141-166.
9. Grant, W. J. & Struchtemeyer, R. A. (1959). Influence of the coarse fraction in two Maine potato soils on infiltration, runoff and erosion. *Soil Science Society of American Journal, 25*, 391-394.
10. Poesen, J. & Lavee, H. (1991). Effects of size and incorporation of synthetic mulch on runoff and sediment yield from interrills in a laboratory study with simulated rainfall. *Soil & Tillage Research, 21*, 209-223.
11. Lavee, H. & Poesen, J. (1991). Overland flow generation and continuity on stone-covered soil surfaces. *Hydrological Processes, 5*, 345-369.
12. Poesen, J., Ingelmo-Sanchez, F. & Mucher, H. (1990). The hydrological response of soil surfaces to rainfall as affected by cover and position of rock fragments in the top layer. *Earth Surface Processes and Landforms*, *15*, 653-671.
13. Poesen, J. (1987). Transport of rock fragments by rill flow- a field study. *Catena Supplement, 8*, 35-54.
14. McCormack, D. E., Young, K. K. & Darby, G. M. (1984). Rock fragments and the K factor of the Universal Soil Loss Equation. *In:* J. D. Nichols, P. L. Brown, and W. J. Grant (Eds.), Erosion and Productivity of Soils Containing Rock Fragments. SSSA Special Publication No. 13, Madison, WI. pp. 73-81.
15. Wischmeier, W. H. & Smith, D. D. (1978). Predicting rainfall erosion losses. USDA Handbook No. 537. Science and Education Administration. 58 p.
16. Box, J. E. & Meyer, L. D. (1984). Adjustment of the Universal Soil Loss Equation for cropland soils containing coarse fragments. ***In:*** J. D. Nichols, P. L. Brown, and W. J. Grant (Eds.), Erosion and Productivity of Soils Containing Rock Fragments. SSSA Special Publication No. 13, Madison, WI. pp. 83-90.
17. Simanton, J. R., Rawitz, E. & Shirley, E. D. (1984). Effects of rock fragments on erosion of semiarid rangeland soils. ***In:*** J. D. Nichols, P. L. Brown, and W. J. Grant (Eds.), Erosion and Productivity of Soils Containing Rock Fragments. SSSA Special Publication No. 13, Madison, WI. pp. 65-72.
18. Sepaskhah, A. R., Amin, S. & Estakhri, R. (2004). Watershed sediment yield prediction for soils containing rock fragment. *Iranian Journal of Science and Technology, Transaction B, 28*, 145- 151.
19. Ahmadi, S. H. (2002). Modification of the ANSWERS's soil detachment equations and its effect on runoff and sediment in watershed. M.Sc. Thesis, Shiraz University, Shiraz, Iran, 412 p.
20. Beasley, D. B. & Huggins, L. F. (1982). ANSWERS user's manual. Department of Agricultural Engineering, Purdue University, West Lafayette. IN. 47907. USA. 55 p.
21. Amin, S. (1989). Prediction of runoff and sediment from agricultural watersheds by mathematical model. I: Introducing "ANSWERS". *Iran Agricultural Research, 8*, 75-92.
22. De Roo, A. P. L., Hazelhoff, L. & Burrough, P. A. (1989). Soil erosion modeling using ANSWERS and Geographical Information System. *Earth Surface Processes and Landform, 14*, 517-532.

23. Huggins, L. F. & Monke, E. J. (1966). The mathematical simulation of small watersheds. Technical Report 1. Water Resources Research Center, Purdue University. West Lafayette, IN. 130 p.
24. Dillaha, T. A. (1981). Modelling the particle size distribution of eroded sediments during shallow overland flow. M.Sc. Thesis, Purdue University, West Lafayette, IN. 92 pp.
25. Amin, S. (1982). Modeling of phosphorous transport in surface runoff from agriculture watersheds. Ph.D. Thesis, Purdue University, West Lafayette, IN. 157 pp.
26. Amin, S. & Engel, B. A. (1990). Prediction of runoff and sediment from agricultural watersheds by mathematical model. II: Watershed simulation. *Iran Agricultural Research*, *9*, 1-16.
27. Beasley, D. B., Huggins, L. F. & Monke, J. M. (1980). ANSWERS: A model for watershed planning. *Transaction ASAE. 23*, 938-944.
28. Breve, M. A., Thomas, D. L., Sheridan, J. M., Beasley, D. B. & Mills, W. C. (1989). A preliminary evaluation of ANSWERS in the Georgia Coastal Plains. ASAE Paper No. 89-2044. ASAE St. Joseph, MI.
29. Estakhri, R. (1999). Use of different infiltration equations in ANSWERS model and its effect on prediction of runoff and sediment. M.Sc. Thesis, Shiraz University, Shiraz, Iran. 246 p. [In Persian]
30. Garosi, A. (1997). Modification of the ANSWERS model for prediction of Sediment Delivery Ratio (SDR) in a small agricultural watershed. M.Sc. Thesis, Shiraz University, Shiraz, Iran. 144 p. [In Persian]
31. Rajaee, Sh. (1996). Determination of clay enrichment ratio in runoff sediment from agricultural watershed in college of Agriculture, Shiraz University. M.Sc. Thesis. Shiraz University, Shiraz, Iran. 71 p. [In Persian]
32. Razavian, D. (1990). Hydrologic responses of an agricultural watershed to various hydrologic and management conditions. *Water Research Bulletin, 26*, 777-785.
33. Purschwitz, M. A. (1981). Using ANSWERS on Indiana and Texas watersheds with four element sizes. M. Sc. Thesis, Purdue University, West Lafayette, IN. 95 pp.
34. Bhuyan, S., Kalita, P. K., Janssen, K. A. & Barnes, P. L. (2002). Soil loss predictions with three erosion simulation models. *Environmental Modeling & Software*, *17*, 137-146.
35. Walling, D. E., He, Q. & Whelan, P. A. (2003). Using ^{137}Cs measurement to validate the application of the AGNPS and ANSWERS erosion and sediment yield models in two small Devon catchments. *Soil & Tillage Research*, *69*, 27-43.
36. Moehansyah, H., Maheshwari, B. L. & Armstrong, J. (2004). Field evaluation of selected soil erosion models for catchment management in Indonesia. *Biosystems Engineering, 88*, 491-506.
37. Kothyari, U. C., Tiwari, A. K. & Singh, R. (1994). Prediction of sediment yield. *Journal of Irrigation and Drainage Engineering*, *120*, 1122-1131.
38. Solhi, M. (1988). Genetical, morphological, physico-chemical study and classification of soils in Badjgah region in Fars province. M.Sc. Thesis, Shiraz university, Shiraz, Iran. 140 p. [In Persian]
39. Meyer, L. D. & Wischmeier, W. H. (1969). Mathematical simulation of the processes of soil erosion by water. *Transaction ASAE, 12*, 754-758.
40. Foster, G. R. (1976). Sedimentation, general. Proceedings of the National Symposium on Urban Hydrology, Hydraulics, and Sediment Control, University of Kentucky, Lexington, KY. pp. 129-138.
41. Abrahams, A. D. & Parsons, A. J.. (1991). Relation between infiltration and stone cover on a semiarid hillslope, southern Arizona. *Journal of Hydrology. 122*, 49-59.
42. Wijdenes, D. O., Poesen, J., Vandekerkhove, L. & de Luna, E. (1997). Chiselling effects on the vertical distribution of rock fragments in the tilled layer of a Mediterranean soil. *Soil & Tillage Research, 44*, 55-66.
43. Daniels, R. B., Gamble, E. E., Bartelli, L. J. & Nelson, L. A. (1968). Application of the point-count method to problems of soil morphology. *Soil Science, 106*, 149-152.
44. El–Sadek, A., Feyen, J. & Berlamont, J. (2001). Comparison of models for computing drainage discharge. *Journal of Irrigation and Drainage Engineering, 127*, 363-369.

45. Homaee, M., Dirksen, C. & Feddes, R. A. (2002). Simulation of root water uptake I. Non-uniform transient salinity using different macroscopic reduction functions. *Agricultural Water Management. 57*, 89-109.
46. Brakensiek, D. L. & Rawls, W. J. (1994). Soil containing rock fragments: effects on infiltration. *Catena, 23*, 99-110.
47. Dunn, A. J. & Mehuys, G. R. (1984). Relationship between gravel content of soils and saturated hydraulic conductivity in laboratory tests. ***In:*** J. D. Nichols, P. L. Brown, and W. J. Grant (Eds.), Erosion and Productivity of Soils Containing Rock Fragments. SSSA Special Publication No. 13, Madison, WI. pp. 55-63.
48. Poesen, J. (1986). Surface sealing as influenced by slope angle and position of simulated stones in the top layer of loose sediments. *Earth Surface Processes and Landforms, 11*, 1-10.
49. Snedecor, G. W. & Cochran, W. G. (1967). Statistical methods. The Iowa State University Press, Sixth edition, 593 p.
50. Edwards, W. M., Germann, P. F., Owens, L. B. & Amerman, C. R. (1984). Watershed studies of factors influencing infiltration, runoff, and erosion on stony and non-stony soils. ***In:*** J. D. Nichols, P. L. Brown, and W. J. Grant (Eds.), Erosion and Productivity of Soils Containing Rock Fragments. SSSA Special Publication No. 13, Madison, WI. pp. 45-54.
51. Flint, A. L. & Childs, S. (1984). Physical properties of rock fragments and their effect on available water in skeletal soils. ***In:*** J. D. Nichols, P. L. Brown, and W. J. Grant (Eds.), Erosion and Productivity of Soils Containing Rock Fragments. SSSA Special Publication No. 13, Madison, WI. pp. 91-103.
52. Wallach, R, Grigorin, G. & Rivlin (Byk), J. (1997). The errors in surface runoff prediction by neglecting the relationship between infiltration rate and overland flow depth. *Journal of Hydrology, 200*, 243-259.