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Large scale evaluation of single storm and short/long term erosivity index models

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Abstract: Rainfall erosivity of the Revised Universal Soil Loss Equation (RUSLE) is influenced by the type, amount, and intensity of storm. In this research, rainfall data from 18 recording rain gauge stations were collected and analyzed. Further, their single storm, daily, monthly, and annual erosion indices were calculated and estimated by different models. Duration of each rainfall was divided into 15 min intervals. Intensity and energy of each interval, maximum rainfall intensity of 30 min, total energy of each rainfall, and erosivity index of every single storm were calculated. Furthermore, Cooley's model for single storm was evaluated and its coefficients were estimated. For daily rainfall erosion index prediction, Richardson's model was assessed and its coefficients were also estimated. A new power model based on monthly rainfall was proposed in order to predict monthly rainfall erosion index. For the estimation of the annual rainfall erosion index, the Arnoldus model was evaluated and its coefficients were estimated. The coefficients for all equations were also determined using multiple regression. According to the calibrated Arnoldus model, an iso-rainfall erosion index map was drawn for the studied area consisting of 150 rain gauge information. The results indicated that models of Cooley, Richardson, Arnoldus, and the newly proposed model for monthly rainfall erosion index provide a reasonable agreement with the rainfall characteristics of the studied area.

Key words: Rainfall erosivity, RUSLE, single storm

Introduction

Soil is the most important component of natural resources and is also the most effective factor in the economy of each region that is threatened by erosion. Assessments of soil erosion are needed to evaluate contaminant mobility (Johansen et al. 2003), conservation soil organic carbon (Breshears and Allen 2002), evaluation of runoff and hydrology (Beeson et al. 2001; Wilson et al. 2001; Johansen et al. 2003), and utilization of land management (Hastings et al. 2003). Based on the results of research conducted in Turkey, soil erosion is an important issue in this country (Bayramin et al. 2002; Yılmaz et al. 2005; Bayramin et al. 2006). Therefore, assessment of factors causing soil erosion or controlling its severity is necessary.

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Kırnak (2002) reported that, according to the results of research conducted by Türkseven and Ayday (2000), the Universal Soil Loss Equation (USLE) model worked well in Turkey. The USLE was originally developed based on the information obtained from 10,000 field plots to predict the long term average annual soil loss from some agricultural areas (Wischmeier and Smith 1965). It was later extended to cover the whole United States (Wischmeier and Smith 1978). RUSLE is extensively used to assess the degree of rill and interrill erosions. All parameters of this equation can be determined using regional conditions, relevant curves, and corresponding tables. However, the rainfall erosivity factor of RUSLE should be calculated from the rainfall pattern or from the long term continuous rain record information.

The most common approach for estimating rainfall erosivity uses the interaction between the storm energy (E) (MJ ha^{-1}) and the highest continuous 30 min rainfall intensity (I_{30}) (mm h^{-1}). The multiple products of these factors equal rainfall erosivity, noted as EI_{30}. The parameter EI_{30} has been shown to be a better predictor of sediment yield than rainfall depth (Foster et al. 1982). The predictor is commonly used to model soil loss as well as sediment yield (Renard et al. 1997). Computation of the erosion index (*EI*), which is basic to the determination of the rainfall runoff erosivity factor R of the Revised Universal Soil Loss Equation (RUSLE), is tedious and time consuming and requires continuous records of rainfall intensity (Diodato 2004). Consequently, various researchers have introduced some models to calculate the rainfall erosivity index using the rainfall data that are available at rain gauge stations (Ateshian 1974; Wischmeier and Smith 1978).

Bullock et al. (1990) stated that several years' duration of rainfall intensity data are needed to calculate the R factor. Bagarello and D'Asarro (1994) found that the erosion index of a single storm is only related to the amount of rainfall, and derived an equation with power of 1.54 for the erosion index of the Mediterranean area. They also developed a model for the erosion index in terms of rainfall amount and the maximum intensity of 30 min. Another rainfall erosion index model was presented for estimating erosion losses from individual rainfall events (Foster et al. 1981). Ateshian (1974) and Cooley (1980) developed 2 empirical equations for estimating EI_{30} from rainfall amounts for storms of different types and durations.

Hadda et al. (1991) expressed the relationship between rainfall erosion index (*REI*) and daily rainfall depth in the form of a model with random and deterministic components. Selker et al. (1990) also developed a model for the rainfall erosivity index based on daily rainfall. They also evaluated another model for the erosivity index that has been developed based on the hourly precipitation. Richardson et al. (1983) developed a model to estimate the daily rainfall erosion index from daily rainfall amounts. Their model includes both deterministic and random components. Bullock et al. (1990) reported that the erosion index calculated by the Richardson model was more reliable than EI_{30} calculated by hourly data in southern Saskatchewan. Elsenbeer et al. (1993) reported that the Richardson model can properly predict the rainfall erosivity from daily rainfall amount.

Posch and Rekolainen (1993) derived a power equation to estimate *REI* on daily rainfall because of a lack of continuous rainfall data in Finland. They also reported that variation of *REI* was very small all over the country. Although the *REI* varied from station to station, the variation in coefficients at different stations was negligible. Variation in *REI* was due to the rainfall intensity variation, which is a normal phenomenon. On the other hand, the slight variation in model coefficients indicated that the model had very good compatibility for the area of study to predict *REI*.

Renard and Freimund (1994) developed a model to estimate monthly erosion index from average monthly rainfall. De Santos Loureio et al. (2001) estimated the EI_{30} index from monthly rainfall data for the south of Portugal. In the Mediterranean environment, 3 erosive periods were identified. The first period extends from July to October, the second erosive period has a duration of 2 months, from May to June, and the third erosive period extends from November to April, with values of erosivity 87.8 MJ mm ha^{-1} h^{-1}, 0.10 Mg ha^{-1} month^{-1}, and 17.5 MJ mm ha^{-1} h^{-1}, respectively (López Vicente et al. 2008).

Wischmeier (1962) computed the annual erosion index for 1700 stations in the USA, and prepared isoerodent maps. Wischmeier and Smith (1978) computed the rainfall erosion index and they prepared an isopluvial map. Kinnell (2003) compared USLE with modified USLE (USLEM) equations. Because the USLEM includes the product of runoff ratio and EI_{30} value as the event erosivity index, it is more efficient in estimating soil loss.

The relationship between annual rainfall and erosivity is similar only in certain years. This confirms the extreme variability of rainfall patterns in Mediterranean areas (Le Bissonnais et al. 2002; Renschler and Harbur 2002). Ateshian (1974) used the 2 year, 6 h rainfall to estimate the annual rainfall erosion index. Diodato (2004) obtained a power equation ($r^2 = 0.867$) involving the annual erosion index ($EI_{30\text{annual}}$) in the Mediterranean part of Italy.

Arnoldus (1977), using monthly and annual rainfall, calculated annual rainfall erosion index, and obtained satisfactory results for 164 stations in the USA and 14 stations in West Africa. Hussein (1986) delineated the isoerodent map for Iraq by applying the Arnoldus model (1977). In this map, the erosion index varied from 5 SI units in the South and South Western parts to 700 SI units in north Iraq. Sepaskhah (1994) used the Arnoldus model (1977) and provided the isoerodent map of Iran using the rainfall data from all weather stations in the country. According to this map, the values of erosion index ranged from 500 to 1900 SI units. Bayramin et al. (2006) computed rainfall erosivity using the Fournier index and reported that rainfall erosivity had high variation in Turkey.

This study was aimed to the calculate rainfall erosion index for different rain gauge stations in northwest Iran. The second objective was to develop and evaluate single storm, daily, monthly, and annual rainfall erosivity index models for estimating EI_{30} from the single storm, daily, monthly, and annual rainfall information. Further, it was aimed to prepare iso-rainfall erosion index map for the study area.

Materials and methods

Extensive data from 18 chart type rain gauge stations in the Uremia lake basin (northwest Iran) were collected to calculate EI_{30}. These data were obtained from different weather stations located in the Uremia lake basin. The basin covers an area of 50,862 km^2 and located at 44°, 14′ to 47°, 56′ east longitude and 35°, 40′ to 38°, 30′ north latitude. Its mean elevation from the sea level varies between 1270 and 3707 m.

To calculate the rainfall erosion index, any storm with at least 12.7 mm or with the intensity of more than 24 mm h^{-1} during a period of 15 min was considered an erosive event. An interval longer than 6 h is necessary between 2 storms to consider it a distinct event (Wischmeier and Smith 1978). Any storm not meeting this condition was eliminated from the EI_{30} calculation process. Therefore, the rainfall hyetographs were divided into 15-min periods and the intensities were calculated. Rainfall kinetic energy was obtained using equations 1 and 2 (Foster et al. 1981).

$$ei = 0.119+0.0873\log_{10} i \qquad i \le 76 \text{ mm h}^{-1} \qquad (1)$$

$$ei = 0.283 \qquad i > 76 \text{ mm h}^{-1} \qquad (2)$$

where ei is kinetic energy of 1 unit of rainfall (MJ ha^{-1} per mm) and i is rainfall intensity (mm h^{-1}).

To calculate each interval energy, the values of ei were multiplied by the amounts of relevant interval rainfall. In order to run the computation process on a computer, a program in Quick Basic language (EI.bas) was written. In this program data from 18 weather stations consisting of 15 min rainfall, date of rainfall events, and beginning and ending time of a rainfall were used. It was assumed that the time interval between 2 consequent rainstorms was equal or less than 6 h, and the ending time of rainstorm and each year were designated in the input data. The output were the date of rainfall event, beginning time of rainfall, rainfall amount, duration of rainstorm, the maximum 15 and 30 min intensities, kinetic energy of unit rainfall, total kinetic energy of each storm (MJ ha^{-1}), and the storm erosion index (MJ mm ha^{-1} h^{-1}).

The EI_{30} for an event is the product of E and the maximum 30 min intensity (EI_{30}) for the event. Rainfall amount, duration of single storm, the maximum 30 min intensity, kinetic energy, and the single storm erosivity index all were calculated using the EI.bas program for all chart type rain gauge recorders in the study area. Calculating rainfall erosion index needs a lot of initial information and is a time consuming process; therefore, the Cooley, Richardson, Monthly, and Arnoldus models were examined for estimating the single storm, daily, monthly, and annual erosion index, respectively. The Equation 3 as the general form of Cooley's model indicating the relationship between single storm erosion index and relevant storm amount and duration.

$$EI_S = \frac{\alpha P^{\beta}}{D^{\gamma}} \tag{3}$$

where EI_S is single storm erosion index (MJ mm ha^{-1} h^{-1}), P is rainfall amount (mm), D is duration of rainfall (h), and α, β, and γ are model regression coefficients.

In order to evaluate Cooley's model, EI_{30}, P, and D for each storm event in all stations were calculated. For estimating the daily rainfall erosion index, the model suggested by Richardson et al. (1983) was also calibrated and evaluated. Therefore, total erosive daily rainfall of 18 rain record stations in the Uremia Lake Basin was collected and their daily rainfall erosion indices were calculated by Equation 4 (Richardson et al. 1983)

$$EI_D = aP^b + \varepsilon \tag{4}$$

where EI_D is daily rainfall erosion index (MJ mm ha^{-1} h^{-1}), P is daily rainfall amount (mm), a, and b are regression coefficients of Richardson's model. aP^b is the deterministic component and ε is the random component of the relationship.

The ε parameter for a given observation is the difference between the observed EI_D and predicted EI_D, using the deterministic part of the model. This evaluation also involved comparison of the model parameters (a and b) and the rainfall erosion index reported by other researchers (Sepaskhah and Sarkhosh 2005). The parameters of EI_D and rainfall amount (P) were calculated for each day and each station since its establishment. The regression between EI_D and P gave the coefficients a, b, ε and their statistical characteristics.

To determine the monthly rainfall erosion index, the model proposed by Sepaskhah and Sarkhosh (2005) was evaluated. They estimated monthly EI_{30} values (MJ mm ha^{-1} h^{-1}), based on relevant monthly maximum daily rainfall (mm) in southern Iran according to Equation 5

$$EI_{MS} = (a + (bP_{24})^2)^2 \tag{5}$$

where EI_{MS} is the monthly rainfall erosion index (MJ mm ha^{-1} h^{-1}), P_{24} is the maximum 24 h rainfall at the relevant month (mm), a and b are regression coefficients of the model; the value of a coefficient is dependent on the elevation and the b coefficient value was constant and equal to 0.004. In this study, a new model was proposed and is explained by Equation 6

$$EI_M = aP_M^b \tag{6}$$

where EI_M is the monthly rainfall erosion index (MJ mm ha^{-1} h^{-1}), P_M is the monthly rainfall at the relevant month (mm), and a and b are regression coefficients of the model.

In this study, for the evaluation of the proposed model, EI_M and P_M were calculated for each month in all stations since their establishment. For estimating the annual erosion index, the Arnoldus model was used in the form of Equation 7 (Arnoldus 1977)

$$EI_A = a\left(\sum_{i=1}^{n} \frac{Pi^2}{P}\right)^b \tag{7}$$

where EI_A is the average annual erosion index (metric units), Pi is the average monthly rainfall (mm), P is the average annual rainfall (mm), n is the number of rainy months, and a and b are regression coefficients of the model.

Hussein (1986) calibrated the Arnoldus model in the metric system as shown in Equation 8:

$$EI_A = 0.297\left(\sum_{i=1}^{n} \frac{Pi^2}{P}\right)^{1,93} \tag{8}$$

A logarithmic regression was used to estimate the constant coefficients of this model. Constant coefficients and statistical characteristics of these models were provided for all stations of the study area.

Average values of the monthly and annual rainfall for 150 stations covering the entire study area, calculated Arnoldus model coefficients, and the geographical information were used to determine erosivity values of each station. Then using the obtained information and the Uremia lake basin map information, the iso-rainfall erosion index was developed for the entire study area. The single storm erosivity index values (EI_S) versus P, the amount of rainfall (mm), and D duration of rainfall (h) based on Cooley's model were entered to SAS software and the regression coefficients α, β, and γ and statistical characteristics of the model were calculated for each station. The same as single storm erosivity index, the daily, monthly, and annual rainfall erosivity model parameters entered to SAS software, and statistical characteristics and their calibrated form were derived.

Results

Based on results shown in Table 1, the maximum average annual rainfall and the erosivity index were obtained from Saqqiz and Sarab stations, respectively. Duncan's multiple range tests showed that there was a significant difference between the average amount of rainfalls and erosivity indices at different stations (Table 1).

The calibrated form of each station and the suitable form of the total area study of Cooley's, Richardson's, and Arnoldus models as well as the proposed model for the single storm, daily, monthly, and annual rainfall erosion index are presented in Table 2.

In the Cooley's multiple linear regression, between EI_S of each storm were taken as the dependent variable and P and D of the same storm as independent variables. The results indicated that regression coefficients α, β, and γ were not considerably varied among the stations. Calculations were performed to find out if there is any internal correlation between the coefficients (α, β, and γ) using accessible parameters, such as the height of each station. It was found that the coefficients are not statistically correlated.

The daily rainfall erosion index for each weather station located in the Uremia lake basin were calculated based on equations proposed by Foster et al. (1981) using the EI.bas software. There were 5800 days in which the rainfall was erosive. Because of the huge volume of data sets in this respect, it is impossible to show them in this article. The calibrated form of daily *REI* model (Richardson et al. 1983) is given in Table 2. As can be seen in Table 2, the *a* coefficient varied from 0.12 to 0.37, and *b* coefficient from 1.47 to 1.83 for different study stations.

Table 1. The geographical specifications of different stations and means comparison of their annual rainfall and erosivity index

Stations	Longitude	Latitude	Annual rainfall (mm)	EI
Saqqiz	46°16′	36°14′	482.0 a	242.2 cd
Ushnuvyeh	45°03′	37°02′	458.2 ab	294.7 bc
Mahabad	45°43′	36°46′	407.7 b	232.2 d
Naghadeh	45°23′	36°58′	350.3 c	203.3 de
Qaleh Jouq	44°28′	39°17′	341.9 c	339.4 b
Uremia	47°03′	37°33′	338.8 c	232.5 d
Lighvan	46°26′	37°50′	331.3 c	323.0 b
Maragheh	46°14′	37°24′	330.0 c	158.2 ef
Nowruzlu	46°12′	36°54′	310.0 cd	156.0 ef
Sarab	47°31′	37°56′	292.6 cde	399.2 a
Shahindez	46°33′	36°40′	288.4 cde	174.4 ef
Alishah	45°50′	38°09′	256.6 def	74.3 h
Qaraziaaddin	45°01′	38°53′	253.5 def	151.2 ef
Salmas	44°47′	38°12′	252.1 def	89.4 gh
Malakan	46°07′	37°08′	243.0 ef	84.6 gh
Azarshahr	54°57′	37°47′	239.6 ef	136.7 fg
Tabriz	46°22′	38°04′	236.4 ef	162.6 ef
Polnavaei	46°15′	38°35′	220.6 f	137.4 fg

Table 2. The obtained form of single storm, daily, monthly and annual rainfall erosivity index model

Stations	Elev.	Single storm	Daily	Monthly	Annual
Polnavaei	1050	$EI_S = \frac{0.14P^{2.4}}{D^{0.93}}$	$EI_D = 0.13P^{1.77}$	$EI_M = 0.15P_m^{1.47}$	$EI_A = 1.12(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.32}$
Qaraziaaddin	1090	$EI_S = \frac{0.14P^{2.4}}{D^{0.91}}$	$EI_D = 0.12P^{1.81}$	$EI_M = 0.14P_m^{1.49}$	$EI_A = 1.68(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.22}$
Qaleh Jouq	1285	$EI_S = \frac{0.15P^{2.3}}{D^{0.74}}$	$EI_D = 0.19P^{1.71}$	$EI_M = 0.22P_m^{1.42}$	$EI_A = 1.12(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.45}$
Alishah	1330	$EI_S = \frac{0.14P^{2.3}}{D^{0.78}}$	$EI_D = 0.25P^{1.47}$	$EI_M = 0.95P_m^{0.9}$	$EI_A = 1.19(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.11}$
Azarshahr	1340	$EI_S = \frac{0.14P^{2.3}}{D^{0.78}}$	$EI_D = 0.17P^{1.64}$	$EI_M = 0.29P_m^{1.28}$	$EI_A = 1.21(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.27}$
Mahabad	1344	$EI_S = \frac{0.15P^{2.3}}{D^{0.81}}$	$EI_D = 0.13P^{1.71}$	$EI_M = 0.37P_m^{1.26}$	$EI_A = 1.89(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.14}$
Malakan	1350	$EI_S = \frac{0.15P^{2.4}}{D^{0.88}}$	$EI_D = 0.16P^{1.70}$	$EI_M = 0.1P_m^{1.64}$	$EI_A = 0.30(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.47}$
Nowruzlu	1350	$EI_S = \frac{0.15P^{2.4}}{D^{0.98}}$	$EI_D = 0.19P^{1.63}$	$EI_M = 0.31P_m^{1.3}$	$EI_A = 1.14(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.22}$
Uremia	1360	$EI_S = \frac{0.14P^{2.3}}{D^{0.87}}$	$EI_D = 0.15P^{1.63}$	$EI_M = 0.24P_m^{1.33}$	$EI_A = 1.45(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.26}$
Salmas	1380	$EI_S = \frac{0.13P^{2.3}}{D^{0.81}}$	$EI_D = 0.13P^{1.72}$	$EI_M = 0.15P_m^{0.46}$	$EI_A = 0.25(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.55}$
Shahindez	1395	$EI_S = \frac{0.15P^{2.3}}{D^{0.88}}$	$EI_D = 0.19P^{1.62}$	$EI_M = 0.29P_m^{1.31}$	$EI_A = 1.21(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.25}$
Maragheh	1465	$EI_S = \frac{0.14P^{2.3}}{D^{0.81}}$	$EI_D = 0.17P^{1.63}$	$EI_M = 0.46P_m^{1.16}$	$EI_A = 1.63(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.13}$
Tabriz	1470	$EI_S = \frac{0.15P^{2.3}}{D^{0.77}}$	$EI_D = 0.25P^{1.74}$	$EI_M = 0.86P_m^{1.19}$	$EI_A = 2.49(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.15}$
Ushnuvyeh	1480	$EI_S = \frac{0.14P^{2.3}}{D^{0.87}}$	$EI_D = 0.13P^{1.64}$	$EI_M = 0.22P_m^{1.33}$	$EI_A = 1.26(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.26}$
Saqqiz	1480	$EI_S = \frac{0.15P^{2.3}}{D^{0.86}}$	$EI_D = 0.19P^{1.59}$	$EI_M = 0.19P_m^{1.41}$	$EI_A = 0.97(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.25}$
Naghadeh	1565	$EI_S = \frac{0.14P^{2.4}}{D^{0.90}}$	$EI_D = 0.14P^{1.67}$	$EI_M = 0.33P_m^{1.25}$	$EI_A = 0.54(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.44}$
Sarab	1750	$EI_S = \frac{0.16P^{2.2}}{D^{0.67}}$	$EI_D = 0.37P^{1.51}$	$EI_M = 0.41P_m^{1.38}$	$EI_A = 0.81(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.58}$
Lighvan	2200	$EI_S = \frac{0.16P^{2.2}}{D^{0.62}}$	$EI_D = 0.15P^{1.83}$	$EI_M = 0.31P_m^{1.46}$	$EI_A = 1.15(\sum_{i=1}^{n} \frac{Pi^2}{P})^{1.43}$
average		$EI_S = \frac{0.15P^{2.31}}{D^{0.83}}$	$EI_D = 0.17P^{1.68}$	$EI_M = 0.33P_m^{1.28}$	$EI_A = 1.19(\sum_{i=1}^{12} \frac{Pi^2}{P})^{1.31}$

The relationship between EI_M and monthly rainfall, based on the proposed model, was evaluated to attain a simple model for EI_M. The obtained results showed that the coefficients of this model had a limited variation. In addition, there was no relationship between these coefficients and the available parameters of the stations. Coefficient a varied from 0.098 to 0.948 and coefficient b varied from 0.46 to 1.64.

To estimate the annual rainfall erosion index for the study area, long term yearly and monthly rainfall data and the relevant yearly rainfall erosion index for 18 rain gauge stations were computed. These data were used to evaluate the Arnoldus model (1977) as reported by Hussein, (1986) and its coefficients were computed using logarithmic regression SAS software.

For annual *REI* coefficient a varied from 0.25 to 2.49, and b ranged from 1.11 to 1.57. These variations did not follow a specific trend and did not show any correlation with accessible factors. Therefore, the mean values of 1.19 and 1.31 were adapted to a and b coefficients, respectively.

For preparing the iso-rainfall erosion index of the Uremia lake basin, information from 150 rain gauge stations was used. The long term annual rainfall erosion index (EI_A) was calculated for each station (using the calibrated Arnoldus model). By entering the data of geographic parameters of each station and relevant EI_A in to the SDRMAP software, the iso-rainfall erosion index of the basin was obtained.

Afterwards, the mentioned data were sent to the AUTOCAD software using a digitizer, and the final map with corrected boundaries was prepared. Iso-rainfall erosion index lines were depicted using geographic latitude, and longitude of each station, long term average of EI_A, and SDRMAP software. The Figure shows the iso-rainfall erosion index of the Uremia lake basin based on the modified Arnoldus model for the study area.

Discussion

Since rainfall intensity, duration, and frequency varied at different spatiotemporal settings, there was no specific relation between rainfall erosion index and annual rainfall at different stations (Table 1). These variations have been reflected in the coefficients of models developed for erosivity index (Table 2). Therefore, for calculating the rainfall erosion index, an appropriate model should be used for each station depending on the available rainfall information.

In this investigation, α coefficient was estimated to be in the range of 0.13 to 0.16 by evaluating Cooley's model. Since the variation of the estimated values for α was very low, the average value of 0.15 was adopted for α in the general equation. The β coefficient varied between 2.23 and 2.39. The average value of 2.31 was then chosen. This was very close to the range of 1.5 to 2.2 that was reported by Ateshian (1974) and Cooley (1980). The range of γ coefficient varied from 0.63 to 0.98 with the average value of 0.83. Therefore, values of 0.15, 2.31, and 0.83 can be applied for α, β, and γ coefficients in the derived model, respectively.

Statistical characteristics of the derived model showed that it can be considered a reasonably good predicting model for calculating the single storm erosion index. Because R^2 values varied from 0.990 to 0.996, the mean square of regression at all stations was also highly significant ($P < 0.01$). Therefore, the mean values of 0.15, 2.31, and 0.83, for α, β, and γ coefficients, respectively, are recommended for the general form of the Cooley's model for the entire study area. Cooley (1980) tested his model for different patterns of rainfall in the USA and introduced the coefficients of the models for each storm type. Since the type of storm of this area has not been determined, the variation of α, β and γ should be evaluated after determining the type of storms.

The mean values of the ε in the Richardson's model are very close to zero. However its standard deviation ranges from 0.24 to 0.56 and the values are almost normally distributed. The standard error of ε parameter varied from 0.01 to 0.40 and the mean R^2 value was 0.85. The chi square (χ^2) analysis indicated that the daily *REI* for all study stations were significant at the confidence level of 99%. The mean square of regression at all study stations was also highly significant ($P < 0.01$).

The result of regressions between a and b parameters with accessible parameters including elevation of each station showed that they were not statistically correlated. These results resemble the findings of Richardson et al. (1983) and Elsenbeer et al. (1993). Consequently, the Richardson equation

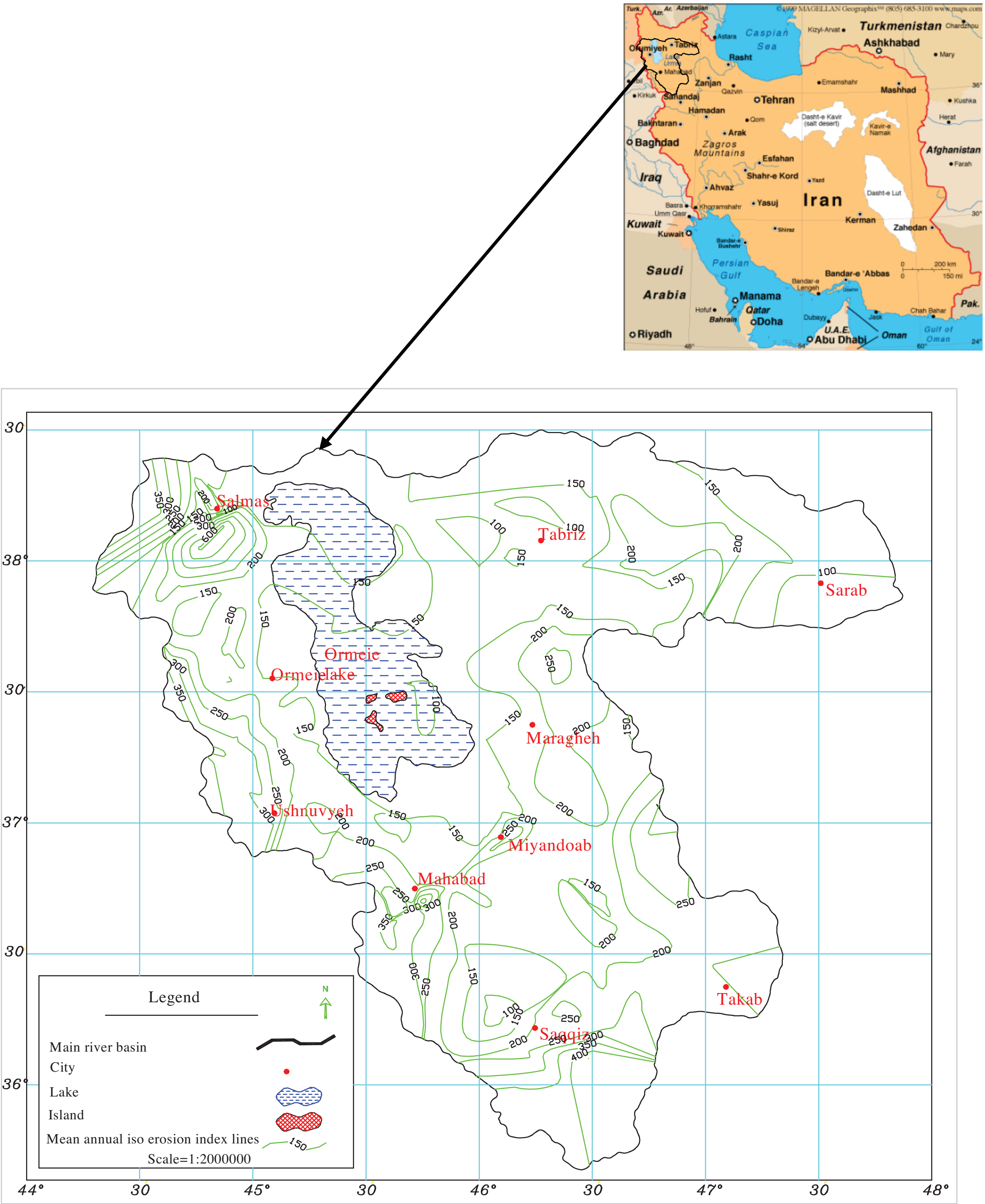

Figure. Isorainfall erosivity index in the Uremia lake basin.

can be recommended as an efficient method to estimate the daily *REI* for the Uremia lake basin with 0.17 and 1.68 for the coefficients *a* and *b*, respectively.

To estimate the monthly rainfall erosion index (EI_{MS}), the model developed by Sepaskhah and Sarkhosh (2005) was also tested. In this model, the *a* parameter varied from 2.57 to 5.23 and *b* from 0.00077 to 0.013. It was also found that there was no correlation between these coefficients and the available parameters of the stations. Based on the results reported by Sepaskhah and Panahi (2007), the range of *a* coefficient varied from 0.33 to 10.57, and *b* coefficient from 0.001 to 0.23. However, in our study, these coefficients had remarkable variations within the stations and, hence, application of this model is not reliable for our study area.

Estimated EI_M from the proposed model was evaluated using the chi square test and the mean square regression method. Results showed that the erosion index was highly significant ($P < 0.01$) based on both tests. Tomas et al. (1990) developed a model to calculate EI_M for USLE using daily rainfall. This model can calculate the EI_M based on the relevant month and its maximum rainfall, and the difference between the maximum daily rainfall and rainfall of the corresponding month. Since the parameters of this equation had high variation at different years, it was not evaluated in this study.

The calibrated form of the Arnoldus model for the study area was obtained as $EI_A = 1.19(\sum_{i=1}^{12} \frac{Pi^2}{P})^{1.31}$. The values of annual rainfall erosion indices obtained for all 18 stations and tested by chi square were highly significant ($P < 0.01$).

According to the Figure, rainfall erosion indices varied from 65 to 618 SI unit, which were much lower than those reported by Wischmeier and Smith (1978) and Narain et al. (1994). Therefore, there is little variation in the R factor across the basin and so the model will be more sensitive to other management factors.

Conclusions

Estimating the single storm erosion index model, similar to that proposed by Cooley's model, was developed for the study area. The variation of coefficients of this equation was very low. Therefore, the mean values of 0.15, 2.31, and 0.83 were recommended for the constant coefficients (α, β, and γ) of the general form of Cooley's model.

For daily rainfall erosivity estimation, a power function model was derived for the study area. Results of this investigation were the same as the results reported by Richardson et al. (1983) and Elsenbeer et al. (1993). Due to the compatibility of the Richardson model for the study area, it can be recommended as an efficient model to estimate the daily rainfall erosivity index with the values of 0.17 and 1.68 for the coefficients *a* and *b*, respectively.

For monthly rainfall erosivity estimation, a new simple power model in which the monthly EI_M may be estimated from relevant monthly rainfall was proposed. The results showed that the coefficients of this model had a limited variation, and there was no relationship between these coefficients and the available parameters of the stations. Averages of 0.33 and 1.28 for intercept and *b* coefficients were obtained and recommended, respectively.

For the annual rainfall erosivity estimation, the Arnoldus model was evaluated and calibrated for the study area. Averages of 1.19 and 1.31 are appropriate for the *a* and *b* coefficients. According to the Arnoldus model with calibrated coefficients, an annual iso-erosivity map was drawn for the study area. This map indicated that the annual rainfall erosivity indices varied from 65 to 618 SI units, which were much lower than those reported for other regions. Therefore, there was a slight little variation in the R factor across the Uremia lake basin in such a way that the RUSLE model was more sensitive to the other management factors.

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