Iranian Journal of Science & Technology, Transaction B, Engineering, Vol. 31, No. B2, pp. 237-248
Printed in The Islamic Republic of Iran, 2007

"Research Note"

ESTIMATING STORM EROSION INDEX IN I.R. IRAN*

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Abstract– The Revised Universal Soil Loss Equation (RUSLE) is used for predicting soil erosion. Rainfall erosivity (EI) in this equation is related to storm type, amount and intensity so it should be determined from rainfall characteristics. In the present research, data from 180 recording rain gauge stations throughout the I.R. of Iran were analyzed and single storm, daily, monthly and annual erosion indices were calculated and estimated by different simple models. For the single storm erosion index, the models $EI=\alpha P_e^{\beta}/D^{\gamma}$ and $EI=pP_e^{\ q}$ were modified. Coefficients of these simple models were found to be elevation, longitude and latitude dependent. Therefore, multiple regression equations were used to estimate these coefficients based on the elevation, longitude and latitude of the stations. For the daily erosion index, a power function based on daily rainfall is presented. The values of coefficients for this equation were dependent on the elevation, longitude and latitude of stations and they are estimated by the given multiple regressions. For the monthly erosion index, a simple model based on the monthly maximum daily rainfall was proposed. The values of the coefficients for this equation were also determined by the given multiple regression equations. The coefficients of the Arnoldus model was modified for the study region to estimate the annual erosion index using monthly and annual rainfalls. The coefficients of this model are elevation, longitude and latitude dependent and are estimated by multiple regression equations. According to the simple model, for the monthly erosivity estimation with modified coefficients the annual iso-erosivity map was drawn for the study region. The range of annual erosivity for the study region was similar to those reported for a neighbor country (i.e., Iraq).

Keywords– Rainfall event EI_{30}, daily EI_{30}, monthly EI_{30}, annual EI_{30}

1. INTRODUCTION

The Universal Soil Loss Equation (USLE) [1] has been widely used in many countries to predict rainfall soil erosion. This equation has been revised by Renard *et al*. [2] and modified by Kinnell and Risse [3] by introducing the runoff factor in it. In all these equations, the rainfall factor, R, is the sum of all erosion indices (EI) of single storms for a given period (daily, monthly or annual).

The EI ($MJ.mm.ha^{-1}.h^{-1}$) index for an event is the product of total storm energy, E ($MJ.ha^{-1}$) and maximum 30-min intensity I_{30} ($mm\ h^{-1}$):

$$EI=(E)(I_{30}) \tag{1}$$

Unfortunately, the calculation of EI is tedious and time-consuming and requires a continuous record of rainfall intensity. Therefore, many authors, including Brown and Foster proposed simplified relationships for estimating the rainfall erosivity [4].

In particular, a number of equations relating daily rainfall amounts, h, to the EI were proposed. These relationships have the following general form:

$$EI=ah^b \tag{2}$$

in which a and b are coefficients [5]. The coefficient usually shows both temporal and spatial variabilities [6]. Since the b exponent can be considered as a process parameter, it should be nearly constant. The value

*Received by the editors November 20, 2004; final revised form July 3, 2006.
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of this exponent is obtained by a theoretically based approach approximates 2 [7]; however, empirical approaches resulted in b values ranging from 1.5 to 2.2 [6, 8, 9, 10]. Furthermore, the b=1.81 was derived by Richardson *et al*. [6] for 11 locations, east of the Rocky Mountains in the United States. This value was also applied in different geographic areas [11]. Bagarello and D'Asaro [5] for 32 Sicilian locations and three additional locations in the continental south of Italy obtained b values between 1.22 and 2.08 and proposed an average value of 1.54.

The relationship between event rainfall amount, P_e, duration, D, and EI was proposed by Ateshian [8] and Cooley [10] as follows:

$$EI=\alpha P_e^{\beta}/D^{\gamma} \tag{3}$$

in which α, β and γ are constants, P_e is the precipitation and D is the storm duration. The values of α, β and γ were not determined for Iran's rainfall data.

Bagarello and D'Asaro [5] presented a relationship between EI_{30} (MJ mm ha^{-1} h^{-1}) and the amount of rainfall for each event (h, mm) as follows:

$$EI_{30}=pP_e^{q} \tag{4}$$

Where p and q are constants.

Wischmeier and Smith [1] used a minimum of 22 years of precipitation intensity data and then had 22 values of EI_{30} to obtain the average values for each of the 12 months. Selker *et al*. [12] assumed uniform daily rainfall during a month and estimated the monthly erosivity index by an equation similar to Eq.(2), with different values of a.

Wischmeier [13] proposed the following equation for annual erosivity index:

$$EI=0.417\ P_6^{2.17} \tag{5}$$

in which P_6 is mean 6-hour rainfall (mm). Equation (5) was used as a way to predict values of EI when data were missing. Therefore, it is of limited use. Wischmeier and Smith [1] used individual raingage data in the United States and computed EI_{30} for all storm events. Summing the EI_{30} of events for each year resulted in yearly EI_{30} to draw the iso-erosivity map for the United States. Similar equations have been reported by Ateshisn [8], Cooley [10] and Cooley *et al*. [14].

Furthermore, Sepaskhah and Sarkhosh [15] calculated the EI_{30} of rainfall events in each month and correlated these values with the monthly maximum daily rainfall. They presented the following equation for monthly EI_{30} values (MJ mm ha^{-1} h^{-1}) based on the monthly maximum daily rainfall (mm) in the southern region of the I.R. of Iran:

$$EI_{30}=(a'+b'P_{m24}^{2})^{2} \tag{6}$$

Where the value of b' was equal to 0.004 and the value of a' was dependent on the elevation (H, m) as follows:

$$a'=1.316+0.00027H \tag{7}$$

where H is the elevation (m).

Arnoldus [16, cited in 17] modified Fournier's index and proposed an equation for the estimation of annual erosivity index as follows:

$$EI=0.297\left(\sum_{i=1}^{n} P_i^{2}/P\right)^{1.93} \tag{8}$$

in which EI is the annual erosivity index, $MJ.mm.ha^{-1}.h^{-1}$, p_i is the mean monthly rainfall, mm, P is mean annual rainfall, mm, and n is 12 months. Hussein [17] and Renard and Freimund [4] used Eq. (8) to draw the iso-erosivity index map for Iraq and the United States, respectively.

Sepaskhah [18] tested Eq. (8) for data of a single recording station in the southern region of the I.R. of Iran (Fig. 1) and found their coefficients quite different from those reported by Arnoldus [16, cited in 17].

Furthermore, Sepaskhah and Sarkhosh [15] used the data of five recording stations and modified Eq. (8) as follows:

$$EI_{30}=a''(\sum_{i=1}^{n} p_i^2/P)^{b''} \quad (9)$$

Where the value of b'' was 1.27 and the value of a'' was presented as:

$$a''=(1.537\text{-}8.688\times10^{16}\exp(-P_{a24})) \quad (10)$$

where P_{a24} is the annual maximum daily rainfall (mm).

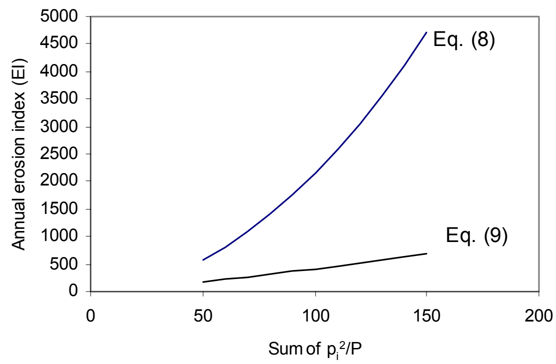

Fig. 1. Relationships between EI_{30} and sum of p_i^2/P (p_i is monthly rainfall and P is annual rainfall)

Renard and Freimund [4, cited in 19] presented a relationship between annual EI (MJ mm ha $^{-1}$ h^{-1}) and rainfall (P, mm) as follows:

$$EI=a'''P^{b'''} \quad (11)$$

Where a and b are constants.

Most of the mentioned simple models might be of regional interest, and have not been verified or tested in other areas extensively, especially in arid and semi-arid regions.

The objective of this study is to verify and develop simplified models for estimating the single-storm, daily, monthly and annual EI in the I.R. of Iran using data from 180 recording rain gauge stations with a record length of up to 25 years.

2. MATERIALS AND METHODS

The data for this study (tipping bucket recording rain gage, daily and monthly rainfalls) were obtained from 180 recording rain gage stations which were collected by Water District Organizations in different provinces of the I.R. of Iran. The stations were located between 44°, 28'- 62°, 35' longitudes and 25°, 42'- 38°, 35' latitudes. The elevation of the stations ranged between –28 to 2580 m above mean sea level. Records of periods of 1 to 25 years, ranging from 1966 to 1990 were considered for these stations. Storms with amounts greater than 12 mm were selected in order to calculate the single-storm EI from time-intensity recordings according to Wischmeier and Smith [1]. Furthermore, storms with amounts of 10-12 mm with intensities greater than 15 mm h^{-1} were considered in the EI calculations. These were considered as event erosivity. The sum of events erosivity of rainfall occurring in a 24 h period was considered daily erosivity. The sum of daily erosivity calculated in a month was considered monthly erosivity. The sum of monthly erosivity calculated in a year was considered annual erosivity.

The maximum mean annual rainfall (1820.2 mm, with 17 years of data) occurred at the Anzali station (-28 m altitude, 49.47 degree E longitude and 37.47 degree N latitude) and the minimum mean annual rainfall (76.6 mm, with 6 years of data) occurred at the Zahedan station (1400 m altitude, 60.88 degree E longitude and 29.63 degree N latitude).

The rainfall duration of each event on the recording rain gage graph was divided into 15 minute intervals and the rainfall intensity for this time interval was calculated. Then, the energy for each interval was calculated by the following equation in SI units [1, 20].

$$e_i = 0.119 + 0.0873 \log i, \qquad \text{for } i \leq 76 \text{ mm h}^{-1} \tag{12.1}$$

$$e_i = 0.283, \qquad \text{for } i > 76 \text{ mm h}^{-1} \tag{12.2}$$

where e_i is the energy per unit of rainfall, MJ mm^{-1} ha^{-1}, and i is the rainfall intensity for each interval, mm h^{-1}. Then, the values of e_i were multiplied by the amounts of rainfall for each interval in order to calculate the rainfall energy for each. By summing these values, the total energy of the rainfall (E) was calculated. Based on the 15 minute rainfall intensities, the maximum 30 minute rainfall intensity (I_{30}) was determined. Then, EI_{30} was calculated by multiplying E by I_{30}.

In order to derive an estimating procedure for EI, the calculated event, daily, monthly and annual erosivities were used in Eqs. (2), (3), (6) and (9) and the coefficients of these equations were determined. In these analyses, only stations with more than four years of data were used. Furthermore, relationships between coefficients of Eqs. (2), (3), (6) and (9) and elevations, longitudes and latitudes of stations were determined by multiple regression analysis using SPSS software.

3. RESULTS AND DISCUSSON

a) Event erosivity index:

The relationships between event EI (MJ.mm.ha^{-1}.h^{-1}) and event rainfall (mm) and duration (h) according to Eq. (3) were determined. By this analysis the value of α, β, and γ in Eq. (3) for rainfall events of the I.R. of Iran were obtained. The range of values for α, β and γ are shown in Table 1. This relationship was not obtained for some stations with less than four years of data. The values of α, β and γ coefficients were dependent on the station elevation and location. Therefore, multiple regressions between α, β and γ and station elevation (EL, m), longitude (LONG, degree) and latitude (LAT, degree) were obtained by SPSS software as follows:

$$\alpha = -5.6147\times10\text{-}4(EL) + 2.361\times10\text{-}2(LAT) + 1.04\times10\text{-}3(LONG) \tag{13}$$
$$(\pm2.4\times10^{-5}) \qquad (\pm3.15\times10^{-3}) \qquad (\pm1.87\times10^{-3})$$
$$R^2=0.94, \quad MSE=0.0404, \quad p<0.0001$$

$$\beta = 1.35\times10^{-4}(EL) + 3.5149\text{x}10^{-2}(LAT) + 1.9066\times10^{-2}(LONG) \tag{14}$$
$$(\pm3.0\times10^{-5}) \qquad (\pm4.3\times10^{-3}) \qquad (\pm2.5\times10^{-3})$$
$$R^2=0.98, \quad MSE=0.0712, \quad p<0.0001$$

$$\gamma = 1.3998\times10^{-4}(EL) - 1.2486\times10^{-2}(LAT) + 1.8304\times10^{-2}(LONG) \tag{15}$$
$$(\pm3.0\times10^{-5}) \qquad (\pm3.4\times10^{-3}) \qquad (\pm2.0\times10^{-3})$$
$$R^2=0.76, \quad MSE=0.0451, \quad p<0.0001$$

The standard errors of the regression coefficients are in parentheses. The mean value of β may be considered as 2.0, which is in the range of 1.5-2.2 as reported by Ateshian [8] and Cooley [10].

Table 1. Minimum, maximum, mean and standard deviation of α, β and γ for Eq. (3)

Coefficient	Minimum	Maximum	Mean	Standard deviation
α	0.0061	4.209	0.478	0.563
β	1.024	3.919	2.042	0.418
γ	0.0364	1.806	0.770	0.266

The relationships between EI (MJ mm ha $^{-1}$ h^{-1}) and event rainfall (mm) according to Eq. (4) were determined. The range of values for p and q are shown in Table 2. The mean values of p and q for southern Italy were 0.332 (range of 0.66-0.944), and 1.548 (range of 1.23-2.082) as reported by Bagarello and D'Asaro [5]. The value of p in Table 2 is different from that reported by these investigators for Italy.

By an appropriate software for regression analysis, multiple regression between p and q and station elevation (EL, m), longitude (LONG, degree) and latitude (LAT, degree) were obtained as follows:

$$p=1.6417\times10^{-5}(EL)+4.378\times10^{-3}(LAT)+1.3685\times10^{-2}(LONG) \quad (16)$$
$$(\pm2.3\times10^{-5}) \quad (\pm3.1\times10^{-3}) \quad (\pm1.8\times10^{-3})$$
$$R^2=0.95,\quad MSE=0.0405,\quad p<0.0001$$

$$q=-5.663\times10^{-5}(EL)+1.628\times10^{-2}(LAT)+1.684\times10^{-2}(LONG) \quad (17)$$
$$(\pm4.0\times10^{-5}) \quad (\pm5.5\times10^{-3}) \quad (\pm2.9\times10^{-3})$$
$$R^2=0.95,\quad MSE=0.1099,\quad p<0.0001$$

Table 2. Minimum, maximum, mean and standard deviation of p and q for Eq. (4)

Coefficient	Minimum	Maximum	Mean	Standard deviation
p	0.0001	5.688	0.956	1.011
q	0.183	5.081	1.417	0.497

b) Daily erosivity index:

In order to derive an estimating procedure of the daily EI from the daily rainfall, the relationship between daily EI and daily rainfall as Eq. (2) was determined by regression analysis. The daily EI was the summation of events of EI that occurred in each day. The variation for coefficients of a and b are given in Table 3. Richardson *et al*. [6] tested Eq. (2) for 22 stations in the eastern states of the USA. They reported a range of 1.59-1.99 for values of b with an average value of 1.81. They also indicated that the values of the natural logarithm of a (ln a) were dependent on the thermal and spatial conditions. The values of ln a were reported –2.81 to –0.99 and –2.04 to –0.24 for cold and warm seasons, respectively. These values for b and ln a are somewhat different from those obtained for our study (Table 3). The values of ln a and b for the southern region of the I.R. of Iran were reported as 1.61 and –0.86 [15], which are somewhat different from those reported in Table 3.

Table 3. Minimum, maximum, mean and standard deviation of lna and b for Eq. (2)

Coefficient	Minimum	Maximum	Mean	Standard deviation
lna	-7.464	2.362	-0.54	1.503
b	0.120	3.704	1.363	0.492

By SPSS software, multiple regression between ln a and b and station elevation (EL, m), longitude (LONG, degree) and latitude (LAT, degree) was performed and the following equations were obtained:

$$\ln(a)=(-0.101517)\mathrm{Log}(EL+25)-1.164163(LAT)^{05}+1.603166(LONG)^{05} \quad (18)$$
$$(\pm0.127) \quad (\pm0.379) \quad (\pm0.28)$$
$$R^2=0.86,\quad MSE=3.561,\quad p<0.0001$$

$$b=(-6.27\times10^{-2})\mathrm{Log}(EL+25)+2.28\times10^{-2}(LAT)+1.86\times10^{-2}(LONG) \quad (19)$$
$$(\pm2.24\times10^{-2}) \quad (\pm6.0\times10^{-3}) \quad (\pm3.6\times10^{-3})$$
$$R^2=0.93,\quad MSE=4.056,\quad p<0.0001$$

c) Monthly erosivity index:

For the estimation of monthly EI several relationships were tested. In this analysis the event erosivities the occurred in a month were summed to calculate the monthly erosivity. The most appropriate relationship for monthly EI estimation was obtained by a regression analysis between monthly EI

(MJ.mm.ha^{-1}.h^{-1}) and monthly maximum daily rainfall (mm) as Eq. (6). The variation for coefficients of Eq. (6) (a\`and b\`) for all stations are shown in Table 4. A similar equation for the estimation of monthly EI was presented by Sepaskhah and Sarkhosh [17] for the southern region of the I.R. of Iran with an average value of 4.981 and 0.00399 for a\` and b\`, respectively which are close to those in Table 4.

Table 4. Minimum, maximum, mean and standard deviation of a\` and b\` for Eq. (6)

Coefficient	Minimum	Maximum	Mean	Standard deviation
a\`	0.33	10.57	4.597	2.142
b\`	0.001	0.023	0.005167	0.004081

By SPSS software, multiple regression between a\` and b\` and station elevation (EL, m), longitude (LONG, degree) and latitude (LAT, degree) was performed and the following equations were obtained:

$$a`=[1.879\times10^{-3}\text{Log}(EL+25)-3.303\times10^{-2}(LAT)+7.523\times10^{-2}(LONG)]^{4/3} \quad (20)$$
$$(\pm6.75\times10^{-2}) \quad (\pm1.93\times10^{-2}) \quad (\pm1.1\times10^{-2})$$
$$R^2=0.90, \quad MSE=1.064, \quad p<0.0001$$

$$b`=[-1.92\times10^{-3}\text{Log}(EL+25)+2.53\times10^{-2}(LAT)^{0.5}+5.2\times10^{-2}(LONG)^{0.5}]^{8} \quad (21)$$
$$(\pm2.7\times10^{-3}) \quad (\pm8.4\times10^{-3}) \quad (\pm6.1\times10^{-3})$$
$$R^2=0.99, \quad MSE=0.00158, \quad p<0.0001$$

d) Annual erosivity index:

The coefficients of Eq. (9) were determined and the results for all stations are shown in Table 5. The values of a'' and b'' for 164 stations in west Africa were reported as 0.297 and 1.93 [16]. The mean value of b'' (Table 5) that was obtained herein was similar to that reported by Arnoldus [16], but the values of a'' were quite different. The ranges of $\ln a''$ and b'' for the southern region of the I.R. of Iran were reported as –6.41 to 0.263 and 1.087 to 2.226, respectively, which are in the limits of those in Table 5.

Table 5. Minimum, maximum, mean and standard deviation of a'' and b'' for Eq. (9)

Coefficient	Minimum	Maximum	Mean	Standard deviation
$\ln a''$	-24.95	4.606	-3.279	5.709
b''	0.075	7.546	2.018	1.372

By SPSS software, multiple regression between $\ln a''$ and b'' and station elevation (EL, m), longitude (LONG, degree) and latitude (LAT, degree) was performed and the following equations were obtained:

$$\ln a''=\{[1.65\text{x}10^{-1}\text{Log}(EL+25)+9.74\text{x}10^{-2}(LAT)+1.15\text{x}10^{-1}(LONG)]^{4/3}-25\} \quad (22)$$
$$(\pm1.3\text{x}10^{-1}) \quad (\pm3.31\text{x}10^{-2}) \quad (\pm1.69\text{x}10^{-2})$$
$$R^2=0.98, \quad MSE=2.28, \quad p<0.0001$$

$$b''=[-3.25\text{x}10^{-3}\text{Log}(EL+25)+1.55\text{x}10^{-2}(LAT)+1.25\text{x}10^{-2}(LONG)]^{4} \quad (23)$$
$$(\pm1.36\text{x}10^{-2}) \quad (\pm3.46\text{x}10^{-3}) \quad (\pm1.77\text{x}10^{-3})$$
$$R^2=0.98, \quad MSE=0.0246, \quad p<0.0001$$

The coefficients of Eq. (11) were determined and the results for all stations are shown in Table 6. By SPSS software, multiple regression between lna” and b” and station elevation (EL, m), longitude (LONG, degree) and latitude (LAT, degree) was performed and the following equations were obtained:

$$\ln a''=\{[1.67\times10^{-1}\text{Log}(EL+25)+79.53(LAT)^{-1}+68.6(LONG)^{-1}]^{2}-30\} \quad (24)$$
$$(\pm4.97\times10^{-2}) \quad (\pm9.983) \quad (\pm23.977)$$
$$R^2=0.99, \quad MSE=0.3165, \quad p<0.0001$$

$$b''=-2.47\times10^{-2}\text{Log}(EL+25)+2.0\times10^{-2}(LAT)+1.26\times10^{-2}(LONG)]^4 \quad (25)$$
$$(\pm1.30\times10^{-2}) \quad (\pm3.3\times10^{-3}) \quad (\pm1.65\times10^{-3})$$
$$R^2=0.99, \quad MSE=0.0218, \quad p<0.0001$$

Table 6. Minimum, maximum, mean and standard deviation of $\ln a''`$ and $b''`$ for Eq. (11)

Coefficient	Minimum	Maximum	Mean	Standard deviation
$\ln a''`$	-58.8	3.851	-7.186	8.937
$b''`$	0.199	10.21	2.126	1.463

e) Model validation for monthly and annual erosiviesy

Validation of Eqs. (6) and (21) should be made by a series of data that have not been used in obtaining these Equations. For validation of Eqs. (6), (20) and (21), for the estimation of monthly erosivity, the monthly maximum daily rainfall of 47 stations with less than 4 years of data which were not used in obtaining these Equations were used in Eq. (6) by using Eqs. (20) and (21) for determination of a` and b`. Then the estimated monthly erosivity was accumulated to obtain annual erosivity. Finally, the estimated and measured annual erosivity and 1:1 line were plotted in Fig. 2. The linear regression between measured and estimated annual erosivity was obtained as follows:

$$EI_e=13.58+0.982(EI_m) \quad (26)$$
$$R^2=0.99, \quad SE=40.942, \quad p<0.0001$$

Where, EI_m and EI_e are the measured (calculated from raingage records with time-intensity recording) and estimated annual erosivity by summing the monthly erosiosivities obtained from Eq. (6) for 12 months. The slope for Eq. (26) is close to one and its intercept is not different from zero. Therefore, the presented simple model for the estimation of the monthly erosivity from the monthly maximum daily rainfall (Eq. 6) is quite accurate.

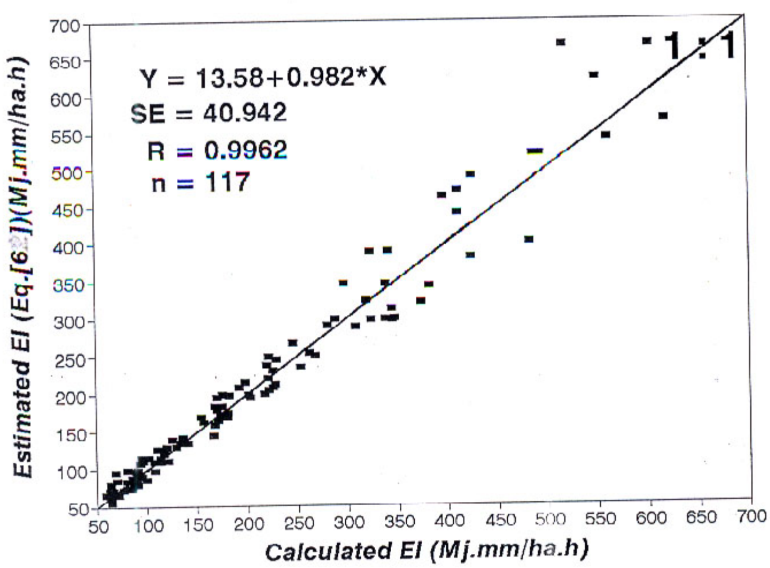

Fig. 2. Relationship between measured and estimated annual erosivity indices
by summing the results of Eq. (6) for 12 months

For validation of Eqs. (11), (24) and (25), for the estimation of annual erosivity, the annual rainfall of 47 stations with less than 4 years of data which were not used in obtaining these Equations were used in Eq. (11) by using Eqs. (24) and (25) for the determination of $a''`$ and $b''`$. Then, the estimated and measured erosivities and 1:1 line were plotted in Fig. 3. The linear regression between measured and estimated annual erosivities was obtained as follows:

$$ET_e=22.06+0.986(EI_m) \quad (27)$$
$$R^2=0.997, \quad SE=23.5, \quad p<0.0001$$

The slope of Eq. (27) is close to one and its intercept is not different from zero. Therefore, the presented simple model for the estimation of the annual erosivity from annual rainfall (Eq. (11)) is quite accurate.

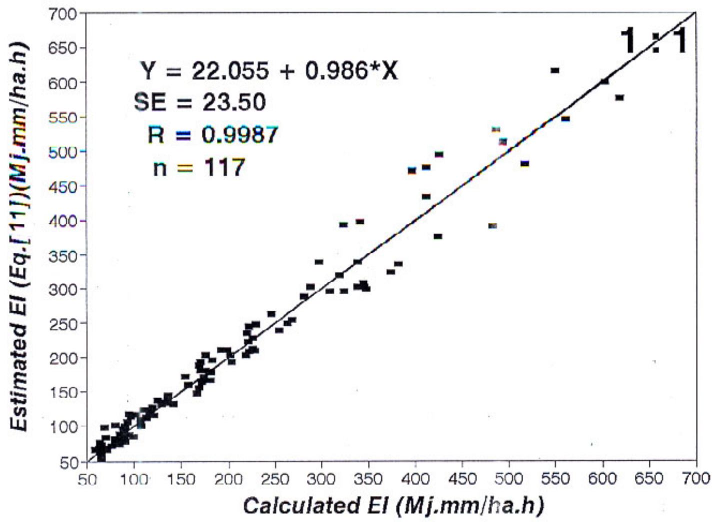

Fig. 3. Relationship between measured and estimated (Eq. 11) annual erosivity indices

f) Erosivity index for snowfall area

The effect of snowfall on the erosivity index may be ignored for small amounts of snowfall as suggested by Wischmeier and Smith [1]. For considerable amounts of snowfall, Wall *et al*. [21] as reported by Madramootoo *et al*. [22] presented the following equation for the estimation of the erosivity index:

$$ET_a=(WP)EI+EI \quad (28)$$

Where EI_a is the mean equivalent annual erosivity index for both rainfall and snowfall, EI is the mean annual erosivity index estimated based on the amount of all precipitation as rainfall, and WP is the ratio of snowfall to total annual precipitation. The annual precipitation of 61 stations consisted of rainfall and snowfall with different mean ratios of snowfall to total precipitation of 0.03 to 0.49. These ratios were used in Eq. (28) for the estimation of EI_a. The values of EI in Eq. (28) were estimated by using Eq. (6). The values of coefficients in this equation were estimated by Eqs. (20) and (21). The annual rainfall erosivity index was obtained by summing the monthly rainfall erosivity indices.

g) Iso-erosivity map:

The estimated values of EI_a for the stations with more than four years of data were used to draw the iso-erosivity map by SPSS software for the study region (Fig. 4). Due to a small interval of contour lines for erosivity, the iso-erosivity map for the Caspian sea (region I) and the Zagros mountain (region II) regions are not clear. Therefore, the iso-erosivity maps for these regions with greater contour intervals were presented in Figs. 5 and 6 separately. The minimum and maximum EI (50.7 and 7555.4 $MJ.mm.ha^{-1}.h^{-1}$, respectively) were estimated for stations with lowest (173 mm) and highest (1275 mm) amounts of annual rainfall, respectively. The minimum and maximum EI for Iraq (a western neighbor) were reported to be 45 and 6900 MJ mm ha^{-1} h^{-1}, respectively [17], which are similar to those for the I.R. of Iran. The minimum and maximum annual EI for the United States were reported as 70 and 5500 MJ.mm.ha^{-1}.h^{-1}, respectively [1]. However, Renard *et al*. [2] reported larger values than those reported by Wischmeier and Smith [1]. The maximum value of EI is lower than those obtained for the study region. Excluding the Caspian sea region, the EI values ranged from 50.7 to about 2000 MJ mm ha^{-1} h^{-1} which is less than those reported for the USA and Iraq, while the reported soil erosion per unit area is higher than those countries. Therefore, it may be concluded that the rainfall erosivity factor for the study region is less effective in soil erosion, and soil loss occurrence is more related to scarce vegetation cover.

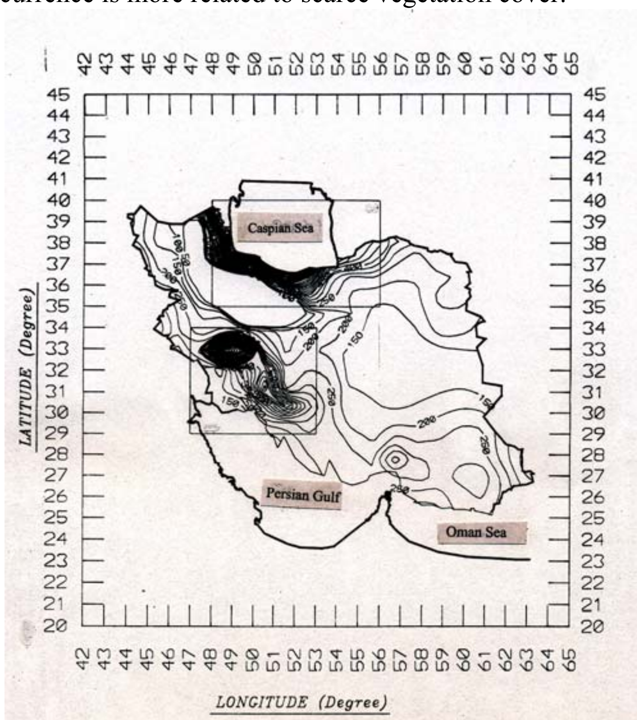

Fig. 4. General iso-erosivity map for the study area

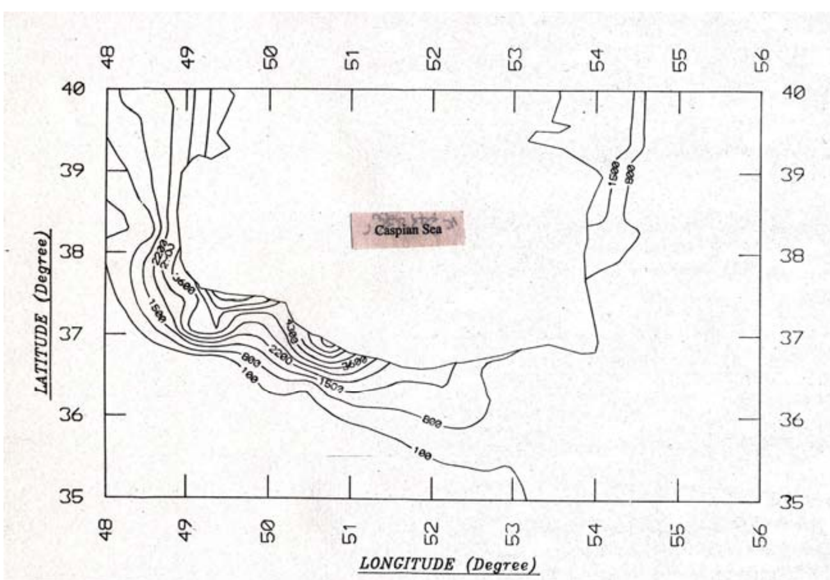

Fig. 5. Iso-erosivity map for specific area (region I)

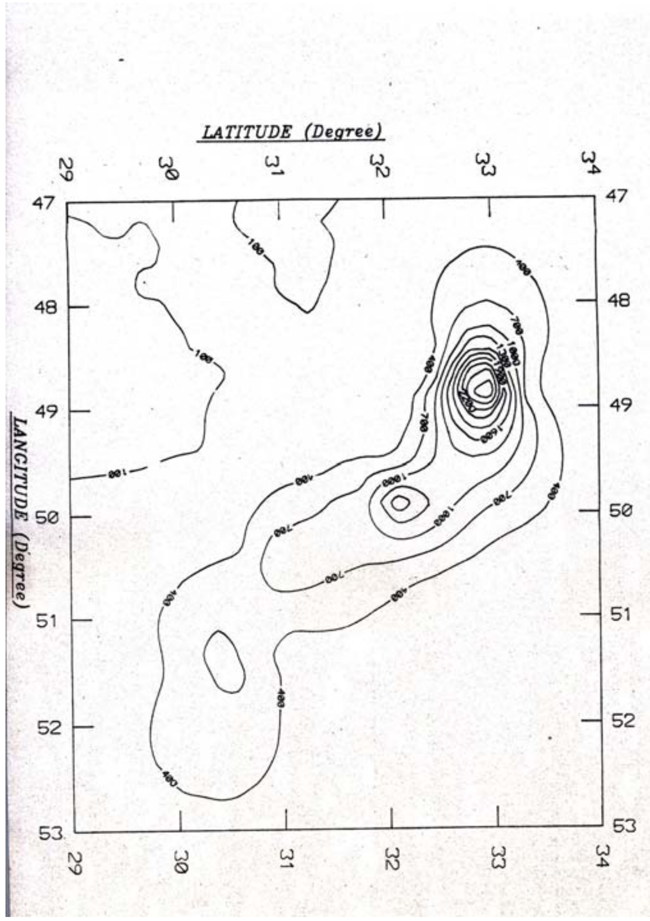

Fig. 6. Iso-erosivity map for specific area (region II)

4. CONCLUSION

A model with three coefficients for rainfall event erosivity estimation similar to that proposed by Ateshian [8] and Cooley [16] was proposed for the study region. The coefficients of this equation were found to be elevation and position (longitude and latitude) dependent. A simple model with two coefficients for rainfall event erosivity estimation similar to that proposed by Bagarello and D`Asaro [5] was proposed for the study region. The coefficients of this equation were found to be elevation and position (longitude and latitude) dependent.

For daily rainfall erosivity estimation a power function ($EI=ah^b$) was proposed for the study region. For the determination of coefficients (a and b), different multiple regression equations with elevation, longitude and latitude as variables were presented.

For the monthly erosivity estimation a simple model ($EI=(a`+b`P_{m24}^2)^2$) as proposed by Sepaskhah and Sarkhosh [15] was fitted to the study region in which the monthly EI may be estimated from the monthly maximum daily rainfall. For the determination of coefficients (a` and b`) different multiple regression equations with elevation, longitude and latitude as variables were presented.

For annual rainfall erosivity estimation the Arnoldus model was modified for the study region. Multiple regression equations were presented to estimate the a'' and b'' coefficients as a function of elevation, longitude and latitude. Furthermore, the annual rainfall erosivity was estimated by a power function ($EI=a''`h^{b''`}$) of annual rainfall (mm), in which $a''`$ and $b''`$ were estimated by multiple regression equations with elevation, longitude and latitude as variables.

The proposed simple models for monthly and annual erosivities were validated with some measured values from 47 stations. The results indicated that they are appropriate for the estimation of erosivity.

According to the simple model for monthly erosivity estimation with modified coefficients, an annual iso-erosivity map was drawn for the study region. The range of annual erosivity for the study region was similar to those reported for a neighbor country (i.e., Iraq).

Acknowledgements- This research was supported in part by project No. 70-AG-693-378 from the Shiraz University Research Council.

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