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Research Article

Investigating rainfall erosivity indices in arid and semiarid climates of Iran

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Abstract: The rainfall erosivity index is one of the most important factors influencing soil erosion. For this reason, investigating the accuracy of rainfall erosivity indices is very important in different climatic regions. The objective of this research was to investigate different rainfall erosivity factors and determine the most appropriate ones for use in the central and northeastern parts of Iran. For this reason, necessary data were collected from 92, 6 and 10 soil erosion research plots in Khorasan Razavi, Semnan and Isfahan provinces, respectively. The rainfall intensities were recorded, as was the sediment yield associated with storm events, and 63 different erosivity indices based on rainfall intensity were computed for these soil erosion research stations. The results demonstrated that the $\sqrt{P} \times I_{30}^2$, $\sqrt{P} \times I_{60}^2$, and $\frac{(P \times t)^2}{\sqrt{d}}$ rainfall intensity-based indices had the most significant correlations, with results of 0.740 ($P < 0.01$), 0.651 ($P < 0.01$) and 0.976 ($P < 0.01$) for sediment yield in Khorasan Razavi, Semnan, and Isfahan, respectively. These selected rainfall intensity-based indices were also computed for synoptic stations. Rainfall erosivity indices, based on the amount of rainfall, were also computed for all soil erosion research plots and synoptic and climatic stations. The results showed that mean annual rainfall displayed a significant correlation with selected rainfall intensity-based indices ($r = 0.83$ and 0.99, $P < 0.01$) in the synoptic stations of Semnan and Khorasan Razavi, and the modified Fournier index showed a significant correlation with selected rainfall intensity-based indices ($r = 0.90$, $P < 0.01$) in Isfahan. Selected regression models were used to estimate the rainfall intensity-based indices at stations without intensity data in the studied provinces.

Key words: Experimental plot, Khorasan Razavi, rainfall amount-based indices, rainfall erosivity, rainfall intensity-based indices, Semnan

Introduction

Soil degradation resulting from erosion by stormwater is perceived as one of the main climate-related problems worldwide since it has large environmental and economic impacts, especially in agricultural areas (Arshad and Martin 2002). One of the most important factors in soil erosion by water is the erosive potential of raindrop impact. The rainfall erosivity factor (*R*) in the Universal Soil Loss Equation (USLE) is generally recognized as one of the best parameters for the prediction of the erosive potential of raindrop impact (Loureiro and Coutinho 2001).

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The subject of rainfall erosivity has been studied worldwide, and various properties of raindrops, such as intensity, velocity, size, and kinetic energy, are among the most frequently used parameters to develop erosivity indices. The $A_r I_m$ (rainfall amount × maximum intensity), EI_{30} (rainfall energy × maximum 30-min intensity), and $KE > 1$ (total kinetic energy of all of the rain falling at more than 25 mm h^{-1}) indices are the most important rainfall erosivity indices. These 3 indices were introduced by Lal (1976), Wischmeier and Smith (Salles et al. 2002), and Hudson (Nanko et al. 2004), respectively, and are suggested for use in certain geographical locations with specific climatic and local conditions.

The empirically based EI_{30} index, which is frequently used, has a number of limitations and requires adaptation for different climatic regions (Sukhanovski et al. 2002). This index has been widely tested, adopted, and used in some countries and regions in which rainfall is mainly characterized by its moderate to high intensity (Yin et al. 2007). In the arid and semiarid regions of Iran, rainfalls with mainly low to moderate intensity and raindrop erosion are more important than the erosion caused by runoff due to poor vegetation canopy cover. Generally, water erosion in the arid and semiarid regions of Iran is characterized by a large variability in the erosive storm. Hence, investigating the event-based rainfall erosivity factors is essential for accurately predicting erosion.

Many studies around the world have focused on selecting appropriate rainfall erosivity factors. In Spain, Nicolau (2002) found some factors, such as rainfall volume I_{30} and I_{60} (maximum 60-min intensity), that had high correlations with sediment and runoff amounts on artificial slopes in a Mediterranean environment. Sharifah Mastura et al. (2003) also showed that some rainfall parameters such as EI_{60} (rainfall energy × maximum 60-min intensity) and I_{60} could be used as the best linear estimators for explaining soil splash erosion in the Tekala River catchment in Malaysia. Abu Hammad et al. (2005) found that in a region with a Mediterranean climate, the total kinetic energy of rainfall has a better correlation with the amount of soil loss compared to EI_{30}, I_{30}, and rainfall duration. Additionally, Yang et al. (2010) found that I_{60} had the most significant correlation with the amount of soil loss on bare and sloppy land in southeast Yunnan in China.

However, a direct computation of rainfall erosivity factors requires long-term data for both the amount and intensity of rainfall. High-resolution rainfall measurement at small time steps as well as the accurate computation of the rainfall erosivity of each storm are the common requirements of rainfall erosivity factors (R) in the USLE model, making its calculation costly and time-consuming (Diodato 2005). In such a situation, more readily available types of parameters (rainfall amount-based indices) such as monthly or annual rainfall data could be utilized to predict rainfall erosivity indices.

Diodato (2005) developed some equations involving the annual EI_{30} and rainfall parameters such as annual rainfall and maximum daily rainfall for a Mediterranean region in Italy. Salako (2007) introduced power functions between EI_{15} (rainfall energy × maximum 15-min intensity) and EI_{30} indices with the amount of daily rainfall in southern Nigeria. In this research, EI_{15} was introduced as the appropriate rainfall erosivity index for tropical climates. An erosivity map was also produced by Shamshad et al. (2008) for Pulau Penang in Peninsular Malaysia; this was based on the work of Munka et al. (2008) to find the relations between the EI_{30} and Fournier indices.

In most Iranian watersheds, there is not sufficient recorded rainfall data, which is necessary to compute rainfall erosivity indices. Therefore, in most soil erosion studies, EI_{30} is assumed to be a valid erosivity index, and it has rarely been tested and adopted for different climatic regions. Hemmati (2007) introduced EI_{60}, $KE > 5$ (total kinetic energy of rainfall at more than 5 mm h^{-1} intensity), and I^2 [I is the summation of partial storm intensities (mm h^{-1})] as the appropriate rainfall erosivity indices for Kermanshah, Markazi, and Zanjan provinces in Iran, respectively. Sharifan (2008) measured the annual EI_{30} index for synoptic stations of Gorgan and formulated relations between this index and some rainfall amount-based indices such as daily and annual rainfall. Hakimkhani et al. (2008) used the modified Fournier index of Arnoldus (Yuksel et al. 2008) to estimate the R factor and prepare the rainfall erosivity map for the Namak Lake basin in Iran.

The objectives of this research were to investigate different rainfall intensity-based indices in order to derive an appropriate index for arid and semiarid regions in Iran, and to introduce a simple calculation method for a rainfall intensity-based index using rainfall amount-based indices.

Materials and methods

Study areas

This study was conducted at 3 soil erosion research stations in the Khorasan Razavi, Semnan, and Isfahan provinces of Iran.

The Sanganeh soil erosion research station is located 100 km northeast of the city of Mashad in Khorasan Razavi Province. This study area extends from 35°30′N to 38°15′N and from 54°0′E to 61°13′E, covering an area of 30 ha. The mean annual rainfall is about 250 mm and the area features arid and semiarid climates and an average elevation of 700 m above sea level. This site includes 92 soil erosion plots in 25 groups that are 2 m in width and 5, 10, 15, 20, and 25 m in length. A 0.2-mm tipping bucket rain gauge is also installed to measure the amount and the intensity of rainfalls.

The Jashloobar soil erosion research station is located 55 km northwest of the city of Semnan in Semnan Province. This station comprises 2485 ha and extends between 35°45′N and 35°48′N and between 53°7′E and 53°12′E. The climate of the station is cold and semiarid, with a mean annual rainfall of 293 mm and an elevation of 2727 m above sea level. A total of 6 soil erosion plots are installed in this station, each with a size of 1.8 × 22.1 m, as is a recording rain gauge with a constant measuring period of 10 min.

The Zayandehrood soil erosion research station is located 110 km west of the city of Isfahan in Isfahan Province. This station extends between 32°43′N and 32°41′N and between 50°40′E and 50°42′E. The mean annual rainfall of this station is 350 mm, with a cold steppe climate, and the elevation of the station ranges between 2050 and 2100 m above sea level. There are 10 soil erosion plots of 1.8 × 22.1 m and a recording rain gauge with a constant measuring period of 30

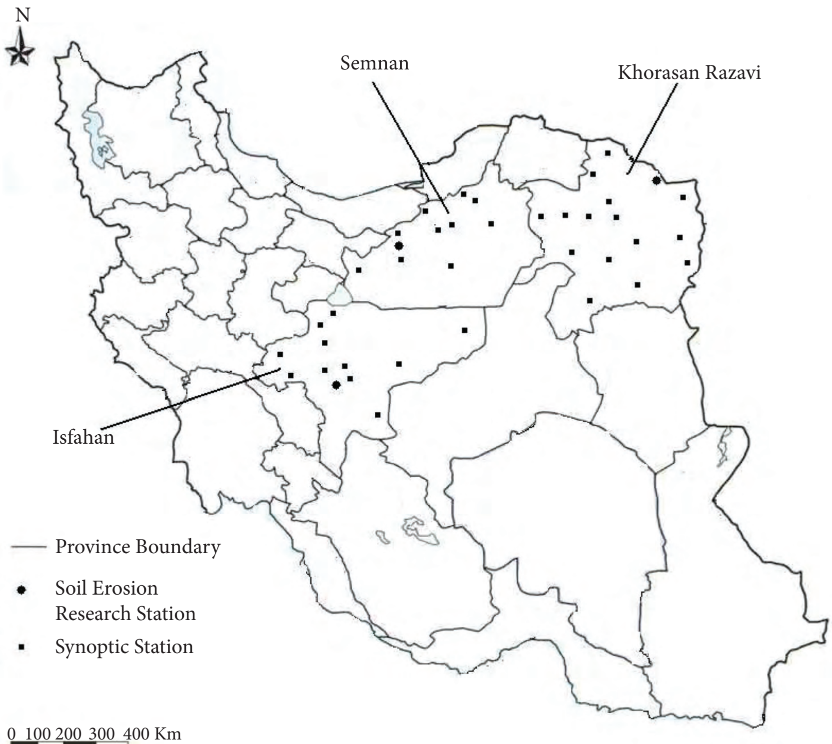

Figure. The location of the soil erosion research and synoptic stations within 3 provinces of Iran.

min at this station. The Figure shows the location of the soil erosion research stations in the studied provinces.

Data acquisition

Data collection was conducted from 8 April 2006 to 12 May 2009 at the Sanganeh soil erosion research station. Fifteen rainfall events within 27 rainy days were monitored and the volume of runoff and the amount of sediment collected in the tanks at the bottom end of the soil erosion plots were measured. The data were monitored at the Jashloobar soil erosion research station from 13 April 2008 to 24 April 2010, and 11 rainfall events during 18 rainy days were observed and associated runoffs and sediment yields were measured. At the Zayandehrood soil erosion research station, the monitoring of 10 rainfall events and the associated runoffs and sediment yields took place from 25 January 1996 to 5 May 1997. After each rainfall, the runoff and sediment in the collection tanks were mixed and a 2-L sample was sent to the laboratory in order to measure the amount of soil erosion. Table 1 shows the average amounts of soil losses from the plots after each rainfall event at the research stations. At Sanganeh station, because of the different lengths of the plots, the amounts of collected sediment from plots were calculated per square meter.

Rainfall erosivity indices

From the literature, various rainfall intensity indices were collected for computing and investigating information from the 3 soil erosion research stations. These indices were classified into 10 different groups based on their parameters. Table 2 shows these indices and provides a description of their parameters.

Computing rainfall intensity-based indices for soil erosion research stations

Selection of the appropriate index among different indices in each province was done based on studying the correlations between a given index and the soil loss amount after rainfall events. Thus, our study required the use of stations with recording rain gauges and experimental plots for collecting the soil loss amounts. However, there was only one station with both a recording rain gauge and experimental plots in each province. Daily rainfall data were collected from recording rain gauges installed at the research stations. These data were used to measure 10 different groups of erosivity indices (Table 2). The data were analyzed in order to quantify the total storm depth; the highest continuous storm intensity periods for 5, 10, 15, 30, 60, and 120 min; and storm energy. The total energy of each storm (*KE*) also was calculated by 13 different equations. These equations were as follows:

$KE_1 = 11.87 + (8.73 \times \log(I))$ Wischmeier and Smith (Salles et al. 2002) (1)

$KE_2 = 8.95 + (8.44 \times \log(I))$ Marshal and Palmer (Salles et al. 2002) (2)

$KE_3 = 9.81 + (11.25 \times \log(I))$ Zanchi and Torri (Salles et al. 2002) (3)

$KE_4 = 9.81 + (10.6 \times \log(I))$ Onaga, Shirai, and Yoshinaga (Salles et al. 2002) (4)

$KE_5 = 35.9 \times (1-(0.559 \times (\mathrm{Exp}(-0.034 \times I))))$ Cutinho and Tomas (Salles et al. 2002) (5)

$KE_6 = 38.4 \times (1-(0.538 \times (\mathrm{Exp}(-0.029 \times I))))$ Cerro et al. (Salles et al. 2002) (6)

$KE_7 = 29.22 \times (1-(0.894 \times (\mathrm{Exp}(-0.047 \times I))))$ Kinnell (Salles et al. 2002) (7)

$KE_8 = 8.95 \times (8.73 \times (\log(I))$ Brandt (Salles et al. 2002) (8)

$KE_9 = 36.8 \times (1-(0.691 \times (\mathrm{Exp}(-0.038 \times I))))$ Jayawardena and Rezaur (2000) (9)

$KE_{10} = 36.65 \times (1-(\frac{0.6}{I}))$ Nyssen et al. (2005) (10)

$KE_{11} = 28.3 \times (1-(0.52 \times (\mathrm{Exp}(-0.042 \times I))))$ Van Dijk et al. (2002) (11)

$KE_{12} = 10.2 \times (1-(8.9 \times (\log(I))$ Alizadeh (2009) (12)

$KE_{13} = 29 \times (1-(0.72 \times (\mathrm{Exp}(-0.05 \times I))))$ Brown and Foster (Salles et al. 2002) (13)

Table 1. The average amount of sediment (g L^{-1}) from experimental plots after each individual rainfall event at the research stations.

Sanganeh*		Jashloobar		Zayandehrood	
Date of rainfall event	Soil loss amount	Date of rainfall event	Soil loss amount	Date of rainfall event	Soil loss amount
8 Apr 2006	0.04	13 Apr 2008	7.13	25 Jan 1996	4.80
16 Nov 2006	0.09	20 May 2008	1.28	22 Feb 1996	1.39
18 Dec 2006	0.11	3 Nov 2008	15.86	5 Mar 1996	1.63
26 Feb 2007	0.04	6 May 2009	4.61	24 Mar 1996	3.46
4 Mar 2007	0.03	8 Jun 2009	4.49	14 Apr 1996	5.37
12 Apr 2007	2.11	19 Jun 2009	16.62	11 Feb 1997	9.00
8 Dec 2007	0.49	30 Aug 2009	15.00	23 Feb 1997	4.23
17 Dec 2007	0.10	17 Sep 2009	7.73	15 Mar 1997	1.39
4 May 2008	0.65	3 Nov 2009	60.06	18 Apr 1997	2.14
12 Feb 2009	0.30	9 Apr 2010	5.05	5 May 1997	3.46
2 Mar 2009	0.09	24 Apr 2010	0.99		
25 Mar 2009	0.15				
31 Mar 2009	0.08				
20 Apr 2009	0.73				
12 May 2009	0.74				

*At Sanganeh station, because of the different lengths of plots, the amount of collected soil loss from plots was calculated per square meter.

For other indices, the kinetic energy, as one of the parameters, was calculated using Wischmeier and Smith's method (Salles et al. 2002):

$$E = 11.87 + 8.73\, Log_{10} I \tag{14}$$

where E is total kinetic energy of rainfall (J m^{-2} mm^{-1}) and I is the rainfall intensity (mm h^{-1}). Furthermore, D_{50} (median drop size) was included in some indices and was measured by the Laws and Parson equation (Salles et al. 2002) as follows:

$$D_{50} = 1.238 \times I^{0.182} \tag{15}$$

where D_{50} is the median drop size (mm) and I is the rainfall intensity (mm h^{-1}).

To explore the relationship between the rainfall intensity-based indices and soil loss amounts, further simple linear regressions were calculated after rainfall events to determine the average amount of soil losses from plots against individual rainfall erosivity indices. In this study, only the effect of the R factor on soil loss was studied; the effects of other parameters in the USLE, such as the K factor, were assumed to be fixed.

Computing the rainfall amount-based indices at climatology stations

Climatology stations with long-term data were selected to measure the rainfall amount-based indices. Daily rainfall records of periods of 1 to 25 years, ranging from 1981 to 2005, were considered for Khorasan Razavi and Isfahan provinces, while periods of 1 to 20 years, ranging from 1986 to 2005, were considered for Semnan Province. Finally, after ignoring the stations with limited data (<10 years), 78, 48, and 30 climatology stations were considered for Khorasan Razavi, Isfahan, and Semnan, respectively. Quality controls of the daily, monthly, and annual rainfall data were done at all stations. For example, very low or very high rainfall amounts were compared with neighbor station data. The double mass curve test (Alansi et al. 2009) was also used to

Table 2. Computed rainfall erosivity indices at the soil erosion research stations.

No.	Index	Description
1	$I_5, I_{10}, I_{15}, I_{30}, I_{60}, I_{120}$	I is the maximum rainfall intensity at different base times (mm h^{-1})
2	$KE_1, KE_2, KE_3, KE_4, KE_5, KE_6, KE_7, KE_8, KE_9, KE_{10}, KE_{11}, KE_{12}, KE_{13}$	KE is the total kinetic energy of rainfall (J m^{-2} mm^{-1}) as calculated by different equations
3	$EI_5, EI_{10}, EI_{15}, EI_{30}, EI_{60}, EI_{120},$	E is the total kinetic energy calculated by the Wischmeier & Smith equation (J m^{-2} mm^{-1})
4	P_{10}, P_{20}, P_{30}	P is the amount of rainfall with maximum intensity and different base times (mm)
5	$KE \times \sqrt{d}, KE \times d, KE \times \sqrt{d^2}, \frac{KE}{\sqrt{d}}, \frac{KE}{d}, \frac{KE}{d^2}$	d is the median raindrop size (mm)
6	$P \times \sqrt{I_{30}}, P \times I_{30}, P \times I_{30}^2, \sqrt{P} \times \sqrt{I_{30}}, P \times \sqrt{I_{30}^2}$ $P \times \sqrt{I_{60}}, P \times I_{60}, P \times I_{60}^2, \sqrt{P} \times \sqrt{I_{60}}, P \times \sqrt{I_{60}^2}$ $P \times I_{7.5}$	P is the total rainfall amount (mm) and is maximum 7.5-min intensity (mm h^{-1})
7	$KE > 1, KE > 2.5, KE > 5,$ $KE > 10, KE > 25$	KE is the total kinetic energy of all rain falling at more than 1, 2.5, 5, 10, and 25 mm h^{-1}
8	$P, d \times P, d^2 \times P, \sqrt{P \times t}, \frac{(P \times t)^2}{\sqrt{d}}, \sum (P \times I),$ $\sum (P \times I) \times d, d \times I$	t is the duration of rainfall (h) and is the rainfall intensity (mm h^{-1}) is the summation of the multiplication of partial rainfall amounts by related intensities ($mm^2.hr^{-1}$) $\sum (P \times I)$ is the summation of the multiplication of partial rainfall amounts by related intensities
9	R_{10}, R_{20}, R_{30}	R is $\sum (P \times I)$ multiplied by I_{10}, I_{20}, and I_{30}
10	$I^{1.5}, I^2$	I is the summation of the partial intensities of storms (mm h^{-1})

check the consistency of data and an inverse-distance weighting method was used to fill in missing data. A total of 7 rainfall amount-based indices (mm) were used in this study. These indices included mean annual rainfall (P_{yr}), standard deviation of annual rainfall ($\sigma_{P_{yr}}$), maximum monthly rainfall ($P_{m.max}$), standard deviation of maximum monthly rainfall ($\sigma_{P_{m.max}}$), Fournier (*F*) (Munka et al. 2008), modified Fournier (*M.F*) (Yuksel et al. 2008), and Ciccacci (*Ci*) (Grauso et al. 2007). The Ciccacci index is the mean annual rainfall amount multiplied by the mean standard deviation of monthly rainfalls. Eqs. (16) and (17), respectively, show the Fournier and modified Fournier indices.

$$F = \frac{p^2}{P} \tag{16}$$

where *p* is the mean maximum rainfall amount (mm) and *P* is the mean annual rainfall depth (mm).

$$MF = \frac{\sum_{i=1}^{12} p_i}{P} \tag{17}$$

where p_i is the mean rainfall amount (mm) for month *i* and *P* is the mean annual rainfall depth (mm).

Computing selected rainfall intensity-based indices and rainfall amount-based indices in synoptic stations

Selected rainfall erosivity factors, as the appropriate indices at the Sanganeh, Jashloobar and Zayandehrood stations were measured at synoptic stations with long-term data for both rainfall amounts and intensities. Records of periods of 1 to 25 years, ranging from 1977 to 2001, were considered for 15, 10, and 11 stations in Khorasan Razavi, Semnan, and Isfahan, respectively. The Figure shows the location of synoptic stations in the studied provinces. On an annual basis, the *R* value (rainfall erosivity index) was taken to be the summation of values over the storms in an individual year as a Brown and Foster equation (Martinez et al. 2009):

$$R = \frac{1}{n}\sum_{j=1}^{n}\sum_{k=1}^{mj}(r)_k \tag{18}$$

where *r* is rainfall erosivity for any individual event, *j* is the index for the number of years used to compute the average, *k* is the index of the number of storms in each year, *n* is the number of years to obtain the average *R*, and m_j is the number of storms in each year. In addition, mean annual rainfall amount-based indices were measured for all of the selected synoptic stations in each province. Linear regression equations were then obtained for the appropriate rainfall intensity-based and rainfall amount-based indices.

Results

Table 3 shows the correlation coefficients (r) between rainfall intensity-based indices and soil loss amounts at soil erosion research stations in 3 provinces. The rainfall indices that most significantly correlated with the quantity of soil loss were $\sqrt{P} \times I_{30}^2$, $\sqrt{P} \times I_{60}^2$, and $\frac{(P \times t)^2}{\sqrt{d}}$, respectively at the Sanganeh, Jashloobar and Zayandehrood stations (according to their correlation coefficients). Although rainfall amount showed a weak correlation with soil loss amount at the Sanganeh and Jashloobar stations, multiplying $\sqrt{P}$ by I_{30}^2 and I_{60}^2, rather than *P*, I_{30}, and I_{60} alone, improved correlations with the soil loss amount. However, erosivity indices that included both rainfall amount and I_{30} and I_{60} were superior to those that included only the rainfall amount at these stations. At the Zayandehrood station, the results were different because the *P* index showed a better significant correlation rather than the I_{30} and I_{60} indices. It was also noted at this station that $P \times \sqrt{I_{30}}$ and $P \times \sqrt{I_{60}}$ showed better correlations with soil loss amount when compared to the I_{30} and I_{60} indices only.

At the Zayandehrood station, the *KE* indices (different equations of kinetic energy) showed better significant correlations compared to other stations; multiplying *KE* by I_{30} and I_{60}, however, resulted in weak and nonsignificant correlations with the soil loss amount. The results for the other 2 stations were inverse in this case because the correlations of I_{30} and I_{60} with soil loss amount were better; thus, EI_{30} and EI_{60} showed better correlations with soil loss amounts than other *KE* indices alone. The threshold intensity for rainfall erosivity was different among the 3

Table 3. The correlation coefficients between rainfall intensity-based indices and the amount of soil loss at the soil research stations.

No.	Station			
	Index	Sanganeh	Jashloobar	Zayandehrood
1	I_{max5}	0.634**	-	-
2	I_{max10}	0.655**	0.395	-
3	I_{max15}	0.631**	0.488	-
4	I_{max30}	0.725**	0.621*	0.131
5	I_{max60}	0.685**	0.642**	0.224
6	I_{max120}	-	0.552	0.322
7	KE_1	0.155	0.610*	0.744**
8	KE_2	0.261	0.611*	0.737**
9	KE_3	0.336	0.612*	0.730**
10	KE_4	0.314	0.612*	0.732**
11	KE_5	0.275	0.612*	0.736**
12	KE_6	0.229	0.611*	0.740**
13	KE_7	0.582	0.624*	0.650**
14	KE_8	0.075	0.592	0.753**
15	KE_9	0.013	0.615*	0.761**
16	KE_{10}	0.333	0.625*	0.724**
17	KE_{11}	0.292	0.601*	0.770**
18	KE_{12}	0.041	0.616*	0.754**
19	KE_{13}	0.404	0.626*	0.708**
20	EI_5	0.580	-	-
21	EI_{10}	0.610*	0.449	-
22	EI_{15}	0.585	0.568	-
23	EI_{30}	0.715**	0.630*	0.532
24	EI_{60}	0.666**	0.631*	0.603**
25	EI_{120}	-	0.574	0.594
26	P_{30}	0.728**	0.624*	0.031
27	P_{20}	0.611*	0.609*	-
28	P_{10}	0.638**	0.395	-
29	$KE \times d$	0.526	0.602*	0.718**
30	$KE \times d^2$	0.605*	0.595	0.696**
31	$KE \times \sqrt{d}$	0.400	0.607*	0.731**

Table 3. (Continued).

32	$\frac{KE}{\sqrt{d}}$	0.016	0.634*	0.760**
33	$KE \times d^{-2}$	0.060	0.581	0.816**
34	$KE \times d^{-1}$	0.040	0.610*	0.777**
35	$P_{7,5}$	0.560	-	-
36	P_{30}^{2}	0.735**	0.634*	0.377
37	P_{30}	0.685**	0.637*	0.557
38	$P\sqrt{I_{30}}$	0.453	0.636*	0.670**
39	$\sqrt{PI_{30}}$	0.719**	0.643**	0.385
40	$\sqrt{PI_{30}^{2}}$	0.740**	0.636*	0.188
41	PI_{60}	0.572	0.637*	0.632**
42	$P\sqrt{I_{60}}$	0.267	0.631*	0.705**
43	$\sqrt{PI_{60}}$	0.643**	0.650**	0.509
44	$\sqrt{PI_{60}^{2}}$	0.706*	0.651**	0.393
45	PI_{60}^{2}	0.683**	0.640**	0.527
46	$KE > 1$	0.162	0.612*	0.133
47	$KE > 2.5$	0.307	0.567	0.708**
48	$KE > 5$	0.522	0.394	0.608**
49	$KE > 25$	0.271	0.520	-
50	$KE > 10$	0.606*	0.367	-
51	P	0.036	0.574	0.800**
52	$\sqrt{P} \times t$	0.056	0.363	0.927**
53	$\sum (P \times I)$	0.595	0.605*	0.552
54	$d \times P$	0.091	0.593	0.765**
55	$(d)^2 \times P$	0.462	0.589	0.736**
56	$d \times I$	0.526	0.540	0.530
57	$(\sum (P \times I) \times d$	0.597	0.594	0.553
58	R_{30}	0.684**	0.607*	0.395
59	R_{20}	0.672**	0.616*	-
60	R_{10}	0.563	0.486	-
61	$I^{1.5}$	0.455	0.538	0.526
62	I^2	0.362	0.524	0.516
63	$\frac{(P \times t)^2}{\sqrt{d}}$	0.046	0.316	0.976**

*P < 0.05 and **P < 0.01

stations because the $KE > 10$ ($P < 0.05$), $KE > 1$ ($P < 0.05$), and $KE > 2.5$ ($P < 0.01$) indices showed good correlations with soil loss amounts at the Sanganeh, Jashloobar, and Zayandehrood stations, respectively. Multiplying D_{50} by P and KE (with low powers) further resulted in high correlations with soil loss amounts at the Zayandehrood station. In indices that included kinetic energy (KE) and D_{50}, the highest significant correlations with the soil loss amount were related to ($KE \times d^2$), $\frac{KE}{\sqrt{d}}$ ($r = 0.606$, $P < 0.05$), and $\frac{KE}{d^2}$ ($r = 0.816$, $P < 0.01$), respectively, at the Sanganeh, Jashloobar and Zayandehrood stations.

Table 4 shows the regression relationships between appropriate rainfall intensity-based and rainfall amount-based indices, as well as their correlation coefficients. The mean annual rainfall showed good significant correlations (r = 0.83 and 0.99) in Semnan and Khorasan Razavi, respectively, and the modified Fournier index showed a correlation of r = 0.90 in Isfahan. Thus, related equations were used to measure the appropriate indices at climatology stations in the 3 provinces. Table 5 shows the minimum and maximum amounts of appropriate indices among the climatology stations in these provinces.

Table 4. The relationships and correlations between appropriate rainfall intensity-based indices and rainfall amount-based indices.

Province	No.	Relationship	Correlation coefficient (r)
Khorasan Razavi	1	$R_1 = -41.44 + 15.08\ P_{yr}$	0.99**
	2	$R_1 = 1900 + 10.84\ \sigma_{P_{yr}}$	0.15
	3	$R_1 = 307.28 + 58.51\ P_m$	0.89**
	4	$R_1 = 1337.8 + 76.99\ \sigma_{P_m}$	0.50
	5	$R_1 = 801.36 + 142.08\ F$	0.61**
	6	$R_1 = 603.73 + 107.64\ F_{mod}$	0.96**
	7	$R_1 = 710.41 + 0.71\ Ci$	0.89**
Semnan	1	$R_2 = 736.64 + 8.34\ P_{yr}$	0.83**
	2	$R_2 = 1039.3 + 17.10\ \sigma_{P_{yr}}$	0.82**
	3	$R_2 = 744.54 + 39.65\ P_m$	0.81**
	4	$R_2 = 581.77 + 85.39\ \sigma_{P_m}$	0.68**
	5	$R_2 = 923.95 + 152.78\ F$	0.68**
	6	$R_2 = 659.05 + 66.78\ F_{mod}$	0.75**
	7	$R_2 = 139.87 + 0.46\ Ci$	0.70**
Isfahan	1	$R_3 = 57{,}536 + 390.77\ P_{yr}$	0.89**
	2	$R_3 = 79{,}985 + 520.48\ \sigma_{P_{yr}}$	0.85**
	3	$R_3 = 53{,}781 + 1795\ P_m$	0.87**
	4	$R_3 = 84{,}110 + 1584.8\ \sigma_{P_m}$	0.83**
	5	$R_3 = 61{,}661 + 6583.2\ F$	0.84**
	6	$R_3 = 46{,}970 + 3240.6\ F_{mod}$	0.90**
	7	$R_3 = 85{,}200 + 21.989\ Ci$	0.87**

R_1, R_2, and R_3 are $\sqrt{P} \times I_{30}^2$, $\sqrt{P} \times I_{60}^2$, and $\frac{(P \times t)^2}{\sqrt{d}}$ indices respectively. ** P < 0.01.

Table 5. The minimum and maximum amounts of appropriate indices among climatology stations.

Khorasan Razavi							
Minimum				Maximum			
Station	Mean rainfall amount (mm)	Mean sea level (m)	Amount ($\sqrt{mm}\ mm^2 h^{-2}$)	Station	Mean rainfall amount (mm)	Mean sea level (m)	Amount ($\sqrt{mm}\ mm^2 h^{-2}$)
Azadvar	143.25	984	1746.06	Ghar Moghan	355.36	1900	4945.10
Semnan							
Minimum				Maximum			
Station	Mean rainfall amount (mm)	Mean sea level (m)	Amount ($\sqrt{mm}\ mm^2 h^{-2}$)	Station	Mean rainfall amount (mm)	Mean sea level (m)	Amount ($\sqrt{mm}\ mm^2 h^{-2}$)
Ghoosheh	116.73	1280	1710.17	Tarzeh	929.79	1930	3178.51
Isfahan							
Minimum				Maximum			
Station	Mean rainfall amount (mm)	Mean sea level (m)	Amount ($\sqrt{mm}\ mm^2 h^{-2}$)	Station	Mean rainfall amount (mm)	Mean sea level (m)	Amount ($\sqrt{mm}\ mm^2 h^{-2}$)
Garmeh	85.69	950	89052.43	Ghaleh Sorkh	337.67	2512	201368.39

Discussion

According to Table 2, the $\sqrt{P} \times I_{30}^2$ and $\sqrt{P} \times I_{60}^2$ indices generally showed the highest significant correlation coefficients (P < 0.01) among all of the studied indices at the Sanganeh and Jashloobar stations, respectively. Hemmati (2007) investigated rainfall erosivity indices based on rain gauge data and soil loss amounts in the Markazi and Kermanshah provinces of Iran, which feature arid and semiarid climates, respectively. He concluded that, among the studied indices, $\sqrt{P} \times I_{30}^2$ showed good correlations with soil loss amounts as the second and third indices, respectively, in Markazi and Kermanshah.

According to Wischmeier and Smith, because storm energy per unit of rainfall does not vary greatly with rainfall intensity, total storm energy is almost directly proportional to rainfall amount (Hussein et al. 1994). For this reason, an erosivity index of the form $P \times I_{30}$ may give better correlations with soil loss amounts in the studied regions than the EI_{30} index. Foster et al. (1982) concluded that erosivity factors that include terms for volume and rate of rainfall and runoff are better than the EI_{30} index. The major advantage of an erosivity factor that includes runoff terms is the reduction of large overestimates of soil loss when the runoff is negligible and rainfall amounts and rates are great (Kinnel 2007). Conceptually, the EI_{30} index accounts for the effect of runoff on erosion best when the soil surface is impervious (Kinnel 2007). According to the mean recorded rainfall amounts (7.91 and 9.23 mm, respectively) and the mean intensities (5.00 and 2.94 mm h^{-1}), the importance of raindrop impact in soil erosion is generally more than that of runoff at the Sanganeh and Jashloobar stations. Zheng et al. (2005) pointed out that lower rainfall amounts and intensity (rainfall amount < 15 mm or I_{30} < 10 mm h^{-1}) generated lower runoff discharge as well as corresponding transport capacity, resulting in lower sediment yields and erosion rates. Thus, the importance of runoff in soil erosion compared to raindrop erosion is limited. Similarly, the mean recorded rainfall amounts and I_{30} at the 3 stations were less than 15 mm and less than

10 mm h^{-1}, respectively. Duan et al. (2006), based on correlations between rainfall factors and runoff and sediment amounts, stated that the $P \times I_{30}$, $P \times I_{60}$, and $P \times I_{10}$ indices are the main factors influencing soil erosion when rainfall amount and intensity are lower. Generally, at the Jashloobar and Sanganeh stations, the I_{60} and I_{30} indices were respectively shown to provide better significant correlations with the soil loss amount when compared to other maximum intensities. Therefore, all erosivity indices that include I_{60} and I_{30}, such as EI_{30}, P_{30}, and R_{30} at Sanganeh and EI_{60} and I_{60} at Jashloobar, also showed better correlations with soil loss amounts. Hussein et al. (1994), also studying the rainfall erosivity indices in the arid and semiarid climates of northern Iraq, found that I_{60} and I_{30} showed better correlations with soil loss compared to I_5 and I_{10}.

At the Sanganeh station, which showed low rainfall intensity (>1 mm h^{-1}) and high rainfall intensity (>25 mm h^{-1}), the correlation with soil loss amounts decreased. Thus, 10 mm h^{-1} is the effective rainstorm intensity with respect to soil erosion at this station. However, at the other 2 stations, it seems that low rainfall intensities (>1 and >2.5 mm h^{-1}) showed better correlations with soil loss amounts.

Rainfall and soil surface characteristics are important factors for threshold intensity in raindrop erosion. Because of the important role of direct raindrop impact, vegetation cover may also provide mechanical protection to the soil against erosion by absorbing the energy of the falling drops and generally reducing the drop sizes that reach the ground (Haj-El Tahir et al. 2010). This is very important, especially in arid and semiarid regions with poor vegetation cover and sensitivity to erosion. Vegetation cover on a soil surface actually increases the threshold intensity. Furthermore, an increase in splash erosion can be attributed to the decrease in runoff depth. Erpul and Çanga (1999) pointed out that thicker runoff layers diminished the beating action of raindrops and that increased soil shear strength or cohesion with surface sealing decreased the soil detachment. The average individual recorded rainfall intensities were 5.00, 2.94, and 4.20 mm h^{-1}, respectively, at the Sanganeh, Jashloobar, and Zayandehrood stations. This range of intensities, according to the rain rate classification of Tokay and Short (Dunkerley 2008), can be described as "moderate intensity" ($2 < I < 5$ mm h^{-1}). However, these intensities are very low when compared to rainfall intensity in tropical regions.

The averages of D_{50} (mm) were 1.48, 1.45, and 1.59 mm, respectively, at the Sanganeh, Jashloobar, and Zayandehrood stations. Thus, the importance of D_{50} (median raindrop diameter) in the rainfall erosivity at the Zayandehrood station is higher than at other stations. Ellison reported that the quantity of soil splash increased with drop size, drop velocity, and rainfall intensity (Sharifah Mastura et al. 2003).

As seen in Table 3, the relationships between selected indices based on intensity and indices based on rainfall amounts were studied and the appropriate relationships were selected. Based on intensity data (10 years) from a synoptic station in Gorgan, Sharifan (2008) studied the relations between annual R and other rainfall parameters. He showed that $R_{yr} = 1.22 \times 10^{-3} \times \frac{P_y^{2116}}{T^{0.122}}$ (r = 0.98) can be used to measure the annual R. In this equation, R_{yr} is the annual rainfall erosivity, P_y is the annual rainfall amount, and T is the return period. Khorsandi et al. (2010) also measured the long-term average of the mean EI_{30} at some synoptic stations in the northern part of Iran and investigated the relations between EI_{30} and some indices based on rainfall amount. They found that $EI_{30} = -223.30 + 214.548\ FI_{mod}$ ($r = 0.79$) can be used to predict the EI_{30} at climatology stations without rainfall intensity data. In this equation, FI_{mod} is the modified Fournier index.

Logically, using an approach that improves the accuracy of the estimation of event soil loss for the unit plot condition will improve the prediction of annual soil loss. To do this, the EI_{30} index must be replaced by one that is better-suited to predicting event erosion. In addition, predicting the rainfall intensity-based indices by the rainfall amount-based indices is very inexpensive and requires little time at stations without rainfall intensity data. In the future, it is suggested that long-term data from recording rain gauges and soil loss amounts from experimental plots be investigated at several stations in each province by using rainfall erosivity indices. In predicting the factor in all regions of each province, rainfall erosivity maps should also be produced and regions at high risk of erosion should be recognized.

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