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ORIGINAL ARTICLE

Evaluation of Spatial Variations of the Best Rainfall Erosivity Index for Iran, Khouzestan

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ABSTRACT

Rainfall erosivity is the ability of rainfall to detach the soil particles. This study was conducted to evaluate spatial variability of rainfall erosivity indices in Khouzestan Province. The spot informational indices (EI30, AIm, KE>1 and Onchev indices) in 74 stations were changed into regional information through Interpolation methods(Radial Basis Functions, Inverse Distance Weighted, Kriging and Cokriging).Results indicate that cokriging have least error and most correlation with determining coefficient of 0.89, 0.89, 0.48 and 0.49 for EI30, AIm, KE>1 and Onchev indices . Based on the correlation relationships between the basins specific sediment yield (in basins dominating the sedimentation stations) and mean indices of EI30, AIm, KE>1 and Onchev, EI30 index with correlation coefficient of 0.98 (P<0.01) is selected as the appropriate rainfall erosivity index. Based on the prepared map on the basis of Cokriging method with secondary variable of maximum mean monthly rainfall, the east and northeastern regions presented the highest values of EI30 index, while the southern and western regions showed the lowest values of EI30 index. The annual rainfall erosivity(EI30) ranged from 404 to 3064 Mj.mm.ha-1.h-1.y-1.

Key words: Rainfall erosivity, Geostatistics, CoKriging, Interpolation.

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INTRODUCTION

Rainfall erosivity has a determining role in the universal soil loss equation. Among the natural factors affecting soil erosion, rainfall erosivity has a paramount importance. Rainfall erosivity is defined as the aggressiveness of the rain to cause erosion [1].The analysis of different parts of water erosion seems necessary as we consider other properties effective on erosions as constant; the amount of soil loss is directly proportional to the amount of rain erosive. In essence, the rainfall erosivity index represents the climate influence on water related soil erosion [2]. Rainfall erosivity, kinetic energy or the power of erosive factors (such as rain and runoff of it) is for the transfer of soil particles [3]. Rain erosive term was proposed by Wischmeier and smith in 1958 to consider the effect of climate on raw erosion [4]. Rain erosion can be determined by two methods of direct measurement and indices [3,5].Direct measurement method is a good method to determine the rain erosive power that is used by measuring the amount of splash. Due to the fact that direct measurement of rain erosive power for all the rainfalls is hard and time-consuming, the numerous investigators [4,6,5] by simultaneously measurement of the amount of splash or soil loss and rainfall properties and making relationship between them found the indices based on the rainfall properties. By these indices and without these indices and direct measurement the rain erosive power can be determined for different regions. Rainfall erosivity indices are divided into two indices based on kinetics energy and rainfall intensity and indices based on rainfall available data. In the first group rain intensity or kinetics energy or both of them are used to some extent in erosivity index. The most famous indices of this group are EI_{30} [4] AIm [6], KE>1 [5] and $P/\sqrt{t}$ [8]. One of the drawbacks of the indices based on kinetics energy and rainfall intensity is that they require the long –term statistics (above

20 years) of rain intensity (with short interval) of weather stations equipped with rain gauge [4]. As there is not such statistics in most of the countries especially for long-term periods, the investigators by rainfall available statistics that are seen in rain gauge stations, could provide more simple indices. These indices are obtained through either regional analysis of sediment yield or by having correlation with EI_{30} index [9]. The most famous indices of this group are Fournier index and modified Fournier index [10, 11]. By selecting a good index and calculating its values as point method in weather stations, we can draw rain erosive maps as regional. Erosive maps as the most important information source can be a considerable aid for watershed managers and agriculture experts to provide soil conservation, erosion control and land management strategies. To convert local data to regional data and providing rainfall erosivity different interpolation methods are applied. There are different methods for data interpolation including Spline [12,13, 14], weighted moving average [15, 12], Regression methods [15] and other geostatistics methods [16, 17]. These methods depending on the type of variable, the number and data scatter and the condition of the studied region have different precision and the best method should be selected before interpolation and providing map. As more changes of natural phenomena such as rainfall is dependent on time and place, classic statistics in which the difference of two points in space is independent from the place and time distance, cannot interpret the changes as effective. So, many investigators investigated the changes of different phenomenal by geostatistics. In geostatistics the difference of phenomena is investigated considering the place and time and the samples are not considered separated from each other but adjacent samples are dependent to each other to certain distance. The main goal of geostatistics is giving a mathematical model to describe dependence and place similarity between samples. By geostatistics technique we can create a continuous level of statistical properties of known points. Khouzestan province is located in the western south of Iran and due to its especial climatic conditions, has poor vegetation cover and high erosive potential. The knowledge of annual distribution of rain erosive index as one of the most important data sources can determine the erosion hazard in Khouzestan province.

MATERIALS AND METHODS

The study area

Khouzestan Province is located in the western south of Iran between 47º 41' to 51º 39' eastern longitudes and 29º 58' to 33º 04' northern latitude. Mean annual rainfall in this region is 265 mm. The average annual temperature is varied from 14.9ºC in cold season to more than 31.2 °C in warm season. The dominant climate of the province, as according to modified De Martonne system is arid and hyper arid climate that covers about 64.6 % of the area of the province.

Selecting pluviograph stations, rain gauge and sediment gauge

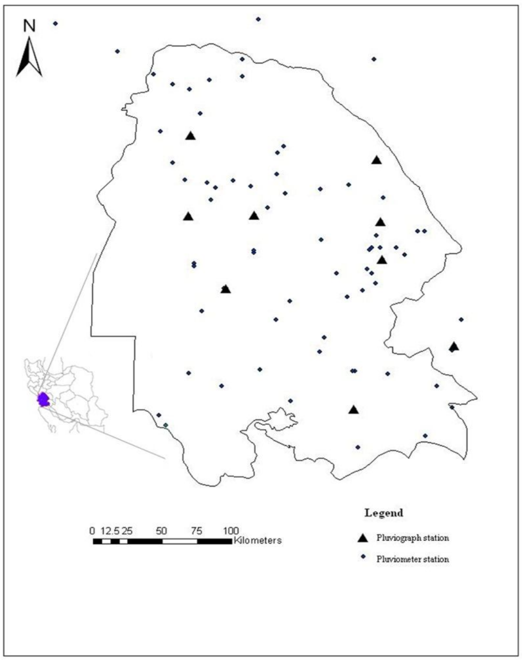

Figure 1- Study area and location map of the pluviograph and pluviometer stations in Khouzestan province in Iran

In order to consider the climate changes in EI_{30} index and get to an appropriate conclusion, data of rainfall intensity of at least 20 years is needed. In this research the statistics of 74 rain gauge stations with the statistical period of 21 years were used. The quality of statistics of each of the selected stations is done through investigating the high and very low level of daily rainfall and its comparison with some of the adjacent stations. If unusual values are observed, they are reduced or removed. Homogeneous statistical investigation is done by double mass method and run test [18]. Rain intensity data was not available at every of the stations in Khouzestan province, therefore, to assess the rain Kinetic energy based indices, used from 10 min interval rain intensity data from pluviograph(nine stations). Specifications along with geographical coordinates of pluviometer and pluviograph stations made use of in this research are presented in Figure 1.

Rainfall erosivity indices

In this paper four indices based on kinetic energy and rainfall intensity such as EI_{30} [4], AIm [2], KE>1[5] and P/√t [8] are calculated for 9 recording rain gauge by having rainfall intensity data with the interval of 10 min in statistical periods. The details and the method of calculation of the indices are presented in the followings.

$$EI_{30} = (E)\ (I_{30}) \qquad (1)$$

$$E = 11.87 + 8.73 \log I_r \qquad (2)$$

Where EI_{30} is rainfall erosivity index, E is the total storm kinetic energy (MJ $mmha^{-1}$), I_{30} is the maximum 30 min rainfall intensity (mmh-1) and I_r is the rainfall intensity in r period. KE>1 index was calculate similar method of calculation EI_{30} index but KE>1 is an ersivity index that consists of the total kinetic energy of all the rainfall at more than 25 $mmhr^{-1}$. This intensity is the practical threshold separating erosive from non-erosive rain [5].

$$AIm = (A)\ (Im) \qquad (3)$$

Where AIm is Lal's index, A is the amount rainfall in storm (mm) and Im is the maximum 7.5 min rainfall intensity (mmh^{-1}). Due to non-access to one minute's intensity rainfall records for calculating the maximum 7.5 min rainfall intensity, the 10 minute maximum rainfall was taken as the basis.

$$R = \frac{P}{\sqrt{t}} \qquad (4)$$

Where R is universal index (Onchev's index), is quantity of rainfall ≥9.5 mm with i≥0.180 mm/min (mm) and t is duration of rainfall with i ≥0.180 mm/min. Also, rainfall available indices such as Fournier index (F), Modified Fournier index (MF), Ciccacci (pδ where δ is the standard deviation of monthly rainfall), average annual rainfall (P), maximum daily rainfall (Pmax24), maximum monthly rainfall (Pmaxm), standard deviation of monthly rainfall (Pstdm) and standard deviation of annual rainfall (Pstdy) were calculated for 65 rain gauge stations and 9 recording rainfall stations with the statistical period of 21 years. The list of the indices and properties of recording rainfall stations are indicated in table 1

.

Table 1- The value of EI_{30}, KE>1, AIm and P/√t indices of pluviograph stations

station	latitude	longitude	EI_{30} ($Mj.mm.ha^{-1}.h^{-1}.y^{-1}$)	AI_m (mm^2/h)	KE>1 ($J.m^{-2}.y^{-1}$)	p/√ t (mm/h)
Dehmolla	30°30'N	49°40'E	551	4751	845	12.6
Gotvand	32°15'N	48°49'E	988	7151	769	2.43
Ahvaz	31°20'N	48°41'E	959	7670	1039	0
Arab hasan	31°51'N	48°53'E	715	5636	679	6.5
Dezfoul	32°24'N	48°23'E	1174	5655	717	6.67
Bagh-malek	31°33'N	49°52'E	1543	13523	1118	3.43
Idenak	30°57'N	50°25'E	1770	13287	1182	0
Izeh	31°49'N	49°51'E	1756	13774	1383	2.74
Abdolkhan	31°50'N	48°23'E	608	4391	593	3.04

The estimation of EI_{30}, KE>1, AIm and P/√t in pluviometer stations

In order to estimate indices EI_{30}, AIm, KE>1, and P/√t in pluviometer stations, regression between EI_{30}, AIm, KE>1, and P/√t and readily available rainfall indices such as Fournier index (F), Modified Fournier index (MF), Ciccacci index, mean annual precipitation (P), maximum daily rainfall (Pmax24), maximum monthly rainfall (Pmaxm), maximum mean monthly rainfall(P_{maxmm}), monthly rainfall standard deviation (Pstdm) and annual rainfall standard deviation (Pstdy) were analyzed using multiple linear regressions.

Interpolation methods

In this research to convert point data to regional data and providing rainfall erosivity map, different methods of interpolation such as Inverse Distance Weighted with different powers, Spline, Kriging and Co-Kriging methods are being analyzed. To select the best interpolation method to convert point data to regional data, Cross-Validation technique is used. The assessment criterions are the amount of the given methods error including Mean Absolute Error (MAE), Root Mean Squared Error (RMSE). The calculation methods of these criterions are as the followings:

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}\left|(Z^*(x_i) - Z(x_i)\right| \quad (5)$$

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}\left[Z^*(xi) - Z(xi)\right]^2}{n}} \quad (6)$$

Where,

MAE: Mean Absolute Error, RMSE: Root Mean Squared Error, Z*(Xi): The estimated values, Z (Xi): The observed values, n: The number of observed variables.

RESULTS AND DISCUSSION

In table 1 the values of EI_{30}, KE>1, AIm P/√t indices are shown in 9 recording rain gauge stations. The results of this research show that values of P/√t were zero in some stations during statistical period of this research. This shows that in the mentioned stations during the record period, there wasn't any rainfall more than 9.5 mm with the rainfall intensity of equal or more than 10.8 mmh^{-1}. The descriptive statistics of indices and rainfall properties in pluviograph stations are investigated during the statistical period and are shown in table 2.

Table 2- Descriptive statistics of the indices and rainfall properties in pluviograph stations

index	mean	Standard deviation	Cv%	min	max	range	skewness	Kurtosis
EI_{30} ($Mj.mm.ha^{-1}.h^{-1}.y^{-1}$)	1118	474	42	551	1770	1219	0.34	-1.525
AI_m (mm^2/h)	8427	3963	47	4391	13774	9382	0.618	-1.726
KE>1 ($J.m^{-2}.y^{-1}$)	925	267	28	593	1383	790	0.482	-0.972
p/√ t (mm/h)	4.17	3.9	93	0	12.69	12.69	1.261	1.844
Maximum daily rainfall(mm)	115	28	24	70	141	71.5	-0.677	-1.346
Maximum monthly rainfall(mm)	280	120	42	137	522	384	0.931	0.778
annual rainfall standard deviation	139	56	40	78	228	150	0.579	-1.302
Maximum mean monthly rainfall(mm)	89	37.5	42	45	140	95	0.333	-1.773
Modified Fournier index (mm)	68	30	44	36	108	72	0.313	-1.87
Height of station	260	310	119	20	764	744	0.909	-1.292

Table 3- Correlation between indices based rainfall intensity and available indices of rainfall in pluviograph stations

Index	P_{max24}	P_{maxm}	Std_y	P_{maxmm}	MF	H
EI_{30}	0.78**	0.88**	0.93**	0.97**	0.96**	0.92**
AI_m	0.75*	0.83**	0.91**	0.91**	0.90**	0.95**
KE>1	0.75*	0.63*	0.78*	0.76*	0.73*	0.85*
p/√ t	-0.59*	-0.40	-0.35	-0.39	-0.38	-0.35

After evaluating regression models based on coefficient of determination and standard error(table 3), four regression models are selected for the estimation of EI_{30}, KE>1, AIm and P/√t indices. The details of the selected regression models are explained in the followings.

$EI_{30} = 327.65(P_{max24}) + 800.377(P_{maxmm}) + 32.188\,(H) - 5606.239 \quad R^2 = 0.96$ (8)

$AI_m = 8.83(H) + 33.79(P_{max24}) + 4.606\,(P_{maxm}) + 930.346 \quad R^2 = 0.95$ (9)

$KE>1 = -7.129(MF) + 1.086(H) + 4.982(P_{max24}) + 522.3 \quad R^2 = 0.87$ (10)

$p/\sqrt{t} = -0.00278(H) - 0.0922(Pmax24) + 0.0206(Pstdy) + 12.667 \quad R^2 = 0.36$ (11)

where, H is stations height. By using of these four models, indices were estimated in 65 rain guages stations. In next step, the spot informational indices (EI_{30}, AI_m, KE>1 and Onchev indices) were changed into regional information through Interpolation methods. According to table 4, Cokriging have least error and most correlation with determining coefficient of 0.89, 0.89, 0.48 and 0.49 for EI_{30}, AI_m, KE>1 and p/√ t. In contrast, the highest mean absolute error and the least correlation between estimated values and observed values are belonging to Thin Plate Spline interpolation method.

Table 4- The evaluation results of different interpolation methods

Interpolation method	EI_{30}			AI_m			KE>1			p/√ t		
	MAE	RMSE	R^2	MAE	RMSE	R^2	MAE	RMSE	R^2	MAE	RMSE	R^2
Cokriging	140	184	0.89	1119	1465	0.89	141	222	0.48	1.57	2.03	0.49
Ordinary kriging	219	312	0.69	1751	2543	0.67	187	273	0.22	2.16	2.68	0.18
Completely regularized spline	207.8	313	068	1807	2483	0.68	186	273.4	0.21	2.07	2.56	0.20
Spline with tension	207.6	313	0.68	1810	2484	0.68	186.9	273.3	0.21	2.07	2.55	0.20
Multiquadratic	211.6	311	0.69	1763	2526	0.67	201	290	0.19	2.36	2.88	0.15
Inverse Multi quadratic	217	325	0.66	1837	2539	0.66	183.3	267.2	0.24	2.05	2.57	0.19
Thin plate spline	260	385	0.56	1983	2839	0.61	244	347	0.15	2.82	3.49	0.10
IDW1	216	316	0.68	1695	2406	0.70	264	178	0.26	1.9	2.47	0.25
IDW2	211	307.5	0.69	1678	2404	0.70	261	178	0.29	2.11	2.58	0.23
IDW3	217	314	0.68	1721	2465	0.69	268	184	0.29	2.3	2.78	0.19

In table 6 correlation between EI_{30}, KE>1, AIm and P/√t indices (interpolated by cokriging) with the specific sediment yield of upstream basins of sediment gauge stations are presented. According to this table, correlation of four indices based on rainfall intensity and kinetic energy with specific sediment yield of sediment gauge stations besides having a high value are significant. High correlation between average indices based on kinetic energy and sediment yield in upstream basins of sediment gauge stations in the areas show that soil loss resulting from rainfall erosion and the creating droplets direct impact is the most important factor of sediments creation in Khouzestan province. According to the table 6 EI_{30} and AIm with the correlation coefficient of 0.98 and 0.97 (R) have the highest correlation with specific sediment yield. In contrast, KE>1 with the correlation coefficient of 0.96 has the less correlation with specific sediment yield. As it was said before, to calculate KE>1 index, there is a threshold for rainfall intensity in which splash amount is ignorable for the amounts less than it. So, rainfall events with the intensity of less than 25mmh-1 are deleted and they are not in the calculations, while to calculate EI_{30} and AIm index, there is not such a condition and kinetic energy of all rainfall is considered 7.5 or 30 min. As the numbers of rainfall events with the intensity of more than 25 mm per hour in studied region are very limited, in some of the studied stations during record period the amount of this index is considered as zero. Thus, we can say that this index is suitable for tropical areas that are usually with rains with the intensity of more than 25 (mmh-1). For other climates in which most of erosion rains are with the intensity of less than the mentioned number, it is not a good index (Hudson, 1971). Results indicate the greatest correlation between specific sediment yield, and AIm and EI_{30} indices with correlation of 0.98 and 0.97 respectively ($P \leq 0.01$). As EI_{30} index is the most common indices used around the world and most of the researchers in different parts of the world made the rainfall erosivity map according to this index. So, in this research EI_{30} index is the basis of rainfall erosivity map in Khouzestan province (Figure 2).

Table 5- The values of EI_{30}, KE>1, AIm and P/√t (cokriging method) and Specific sediment yield in sediment gauge stations

p/√ t (mm/h)	KE>1 ($J.m^{-2}.y^{-1}$)	AI_m (mm^2/h)	EI_{30} ($Mj.mm.ha^{-1}.h^{-1}.y^{-1}$)	Specific sediment yield($T/km^2/yr$)	station
3.96	974	10122	1367	206.46	Ahvaz
3.67	1084	12520	1545	530.46	Poleshaloo
4.87	987	9937	1382	362	Payepol
0.519	1345	18960	2524	2080	Idenak
3.21	1028	11776	1543	875	Tele zang

Table 6- The correlation between EI_{30}, KE>1, AIm, P/√t and specific sediment yield in sediment gauge stations

p/√ t (mm/h)	KE>1 ($J.m^{-2}.y^{-1}$)	AI_m (mm^2/h)	EI_{30} ($Mj.mm.ha^{-1}.h^{-1}.y^{-1}$)	Variable
0.94 **	0.96 **	0.97 **	0.98 **	Specific sediment yield($T/km^2/yr$)

*, significant at P≤0.05; **, significant at P≤0.01

Fitted model on semivariogram of experimental in CoKriging and Ordinary Kriging was spherical that minor range is varied from 120 Km to 161 and major range is varied from 314 km to 343 km in cokriging and ordinary kriging methods respectively. Sill values in Ordinary Kriging and Co-Kriging method are equivalent with 441250 and 408020 (MJ.mm.ha-1.h-1.y-1)2. A nugget effect value is varied from 12178 in ordinary Kriging to 1900 in CoKriging method. In CoKriging method, used as maximum mean monthly rainfall an auxiliary variable. Figure (2) shows the erosivity map of EI_{30} in Khouzestan province by Co-Kriging method (having the highest accuracy amount between common interpolation methods).

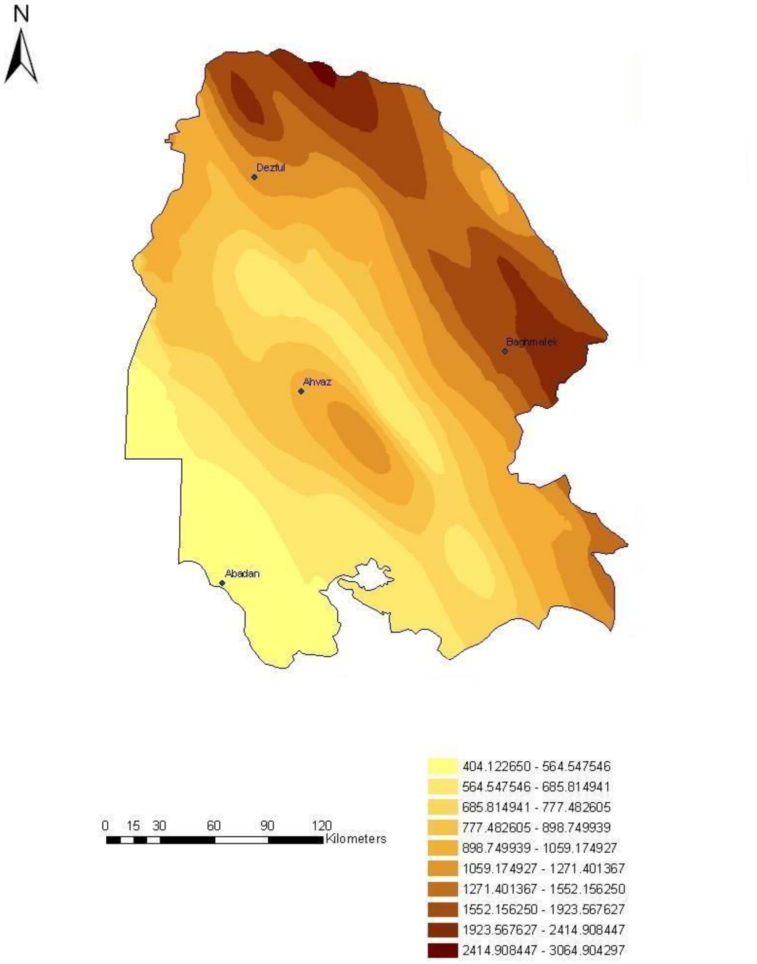

Fig 2- Rainfall erosivity map (EI30 index)

CONCLUSION

The results of this research show that value of Hudson index and P/√t were zero in some stations during statistical period of this research. This shows that in the mentioned stations during the record period, there wasn't any rainfall more than 9.5 mm with the rainfall intensity of equal or more than 10.8 mmh^{-1}. Considering the high correlation of AI_m and EI_{30} with the specific sediment yield, we can conclude that these two indices are good indices to show the rainfall erosivity power in Khouzestan province.

In interpolation discussion, the results of the research indicated that using Co-Kriging method increases accuracy and decreases mean absolute error in comparison with other methods such as ordinary Kriging and it causes that the error of rainfall erosivity index estimation decrease considerably in the areas without rainfall intensity records. As it can be seen in figure 2 the least amount of EI_{30} are 404 in the north and east of Khouzestan province and the highest amount of EI_{30} as 2414 $Mj.mm.ha^{-1}.h^{-1}.y^{-1}$ are located in the South and west of Khouzestan province.

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