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The Determination of the Best Rainfall Erosivity Index for Namak Lake Basin and Evaluation of Spatial Variations

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ABSTRACT

In order to evaluate the spatial variations of rainfall erosivity index in Namak Lake basin, Lal, EI_{30}, Hudson and Onchev indices are calculated for 16 pluviograph stations and 3 stations in the proximity of Namak lake basin with the statistics period of 16 to 26 years. Then, among Lal, EI_{30}, Hudson and Onchev a dependent variable and other indices and rainfall available properties such as Fournier index, modified Fournier index, annual rainfall and the maximum monthly rainfall are considered as independent variable or regression equation. According to Coefficient of determination and standard error of different regression models, four models are selected to estimated EI_{30}, Lal, Hudson and Onchev indices in the stations not equipped with rainfall intensity data. The correlation relationship was made between the average EI_{30}, Lal, Hudson and Onchev indices with the especial sediment yield of the basins. Results indicate the greatest correlation between specific sediment yield, and AI_m and EI_{30} indices with correlation coefficients of 0.84 ($P \leq 0.01$). To prepare the final map of rainfall erosivity by using of EI_{30} index, interpolation methods like: usual Kriging, Co-Kriging, inverse distance weighted with different powers, Spline and Fuzzy Kriging were assessed. In Fuzzy Kriging method, values of estimated EI_{30} indices by regression relations in 121 pluviograph stations were used as Fuzzy numbers and the estimated EI_{30} values in pluviograph stations were used as precise numbers. It can be concluded that Fuzzy Kriging method can reduce 15 % of Mean Absolute Error and was selected as an appropriate interpolation method for preparing the rainfall erosivity map in Namak Lake basin.

KEY WORDS: EI_{30}; Inverse Distance Weighted; fuzzy kriging; interpolation.

1- INTRODUCTION

Rainfall erosivity is one of the determining parameters in the universal soil loss equation. Rainfall erosivity is the potential ability for rainfall to cause soil loss (Silva, 2004). 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 (Yu, 1998)

Rainfall erosivity, kinetic energy or the power of erosive factors (such as rain and runoff of it) is for the transfer of soil particles (Lal and Elliot, 1994). Rain erosive term was proposed by Wischmeier and smith in 1958 to consider the effect of climate on raw erosion (Wischmeier and Smith, 1978). Rain erosion can be determined by two methods of direct measurement and using indices (Lal and Elliot, 1994; Hudson, 1971). 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 (Weischmeier and Smith, 1978; Lal, 1976; Hudson, 1971; Salles and Poesen, 2000) 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.

Generally 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}

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(Wischmeier and Smith, 1978), AI_m (Lal, 1976), KE>1 (Hudson, 1971) and P/√t (Onchev, 1985). 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 (Wischmeier and Smith, 1978). 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 (Yu and Rosewell, 1996). The most famous indices of this group are Fournier index and modified Fournier index (Morgan, 1995; Arnoldus, 1980). 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 (Price *et.al*, 2000; Hutchinson, 1998; Jeffery *et.al*, 2001), weighted moving average (Naoum and Tsanis, 2003 ; Price *et al*, 2000), Regression methods (Naoum and Tsanis, 2003) and other geostatistics methods (Goovarets, 2000; Atkinson and Lloyd, 1998). 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. Application of geostatistics such as Kriging is restricted when the number of measured data is less or it is imprecise. To remove this problem, the data set can be completed by the estimation of fuzzy data by experts and the error causing from the environmental data due to the presence of random variables, incomplete statistics(the lack of precision in measurement), approximated estimations instead of measurement (due to financial or technical issues), the incomparability of the statistics (difference in measurement or the variable conditions of observations), using quality information instead of quantity information (due to financial or technical issues), incomplete knowledge of the expert or the descriptive nature of the information obtained from the expert can be considerably reduced (Salski, 1992).

This Kriging method in which fuzzy data is used is called fuzzy Kriging. Fuzzy Kriging for the first time was proposed by Bardossy (Bardossy, *et. al*, 1989). Indeed, Fuzzy Kriging is the modified form of Ordinary Kriging methods in which the measurement data and the estimations of the experts (defined as fuzzy numbers) are used. In this method there is not a defined boundary between information and this feature reflects the natural properties continuity better (Diamond, 1989).

Namak lake basin is located in the central part of Iran and due to its especial climatic conditions, has poor vegetation cover and high erosive potential. The knowledge of seasonal and annual distribution of rain erosive index as one of the most important data sources can determine the erosion hazard in Namak lake watershed basin.

2- MATERIALS AND METHODS

2-1- The study area

Namak Lake basin or saline basin and Jajrud are one of the local watershed basins in Iran. This basin is located in the southern part of central Alborz between 48º 8' to 52 º 8' eastern longitudes and 33º 0' to 36º 30' northern latitude. Its minimum height is 800m and maximum height is 4375m.

Mean annual rainfall in this region is decreasing from about 700 mm in western and northern highland to less than 100 mm in eastern desert and Namak Lake. The average annual temperature is varied from less than 5ºC in highland regions to more than 17.5 °C around Namak Lake. The dominant climate of the region, as according to modified De Martin system is dry climate that covers about 44.8 % of the area of the basin (JAMAB, 1999).

2-2- Selecting pluviograph stations, rain gauge and sediment gauge

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. There were no records of it in some stations, so in this research stations with statistical records of more than 15 years were chosen. The sum of synoptic, climatology, recording rain gauge and reservoir rain gauge in Namak lake basin are about 400 stations. In this research the statistics of 121 rain gauge stations with the statistical period of more than 15 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 immediately. Homogeneous statistical investigation is done by double mass method and run test (McCuen, 1996). Rain intensity data was not available at every of the stations in Namak Lake basin, therefore, to assess the rain Kinetic energy based indices, use was made of 10 min interval rain intensity data from pluviograph. Twelve of the stations belonged to Metrological Organization and the rest to Ministry of Energy. In addition, and because the number of pluviograph stations was limited, data from 3 stations of Semnan, Shahrood, and Esfahan, adjacent to Namak Lake basin, were also used. Specifications along with geographical coordinates of pluviometer and pluviograph stations made use of in this research are presented in Figure 1. Of sediment gauge stations in Namak Lake, 13 stations were used.

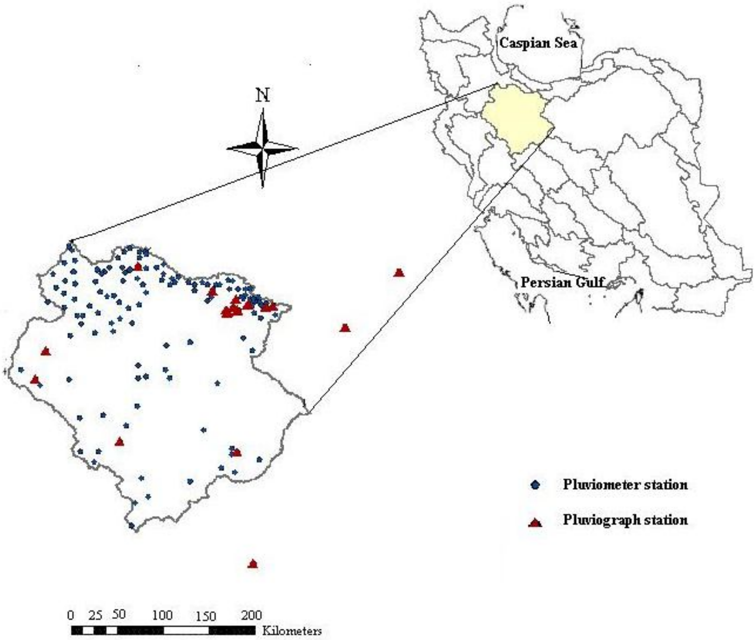


Figure 1- Study area and location map the pluviograph and pluviometer stations in Namak lake basin in Iran

Table 1-characteristics of pluviograph stations in Namak lake basin

No	Station	Longitude	latitude	Period (year)	Elevation (m)	Annual rainfall (mm)
1	Arak	49°46'E	34°6'N	26	1708.00	345.69
2	Isfahan	51°40'E	32°37'N	15	1590.00	124.44
3	North aban	51°28'E	35°43'N	20	1250.00	388.40
4	Ab-Ali	51°59'E	35°46'N	23	2450.00	525.30
5	Tehran Pars	51°53'E	35°45'N	15	1500.00	378.00
6	Tehran Mehrabad	51°19'E	35°41'N	26	1190.80	224.57
7	Dushan Tape	51°20'E	35°42'N	16	1209.20	263.27
8	Karaj damp	51°6'E	35°57'N	20	1588.00	395.29
8	Latiyan damp	51°38'E	35°48'N	15	1600.00	410.00
10	Semnan	53°23'E	35°33'N	21	1130.80	145.39
11	Shahrood	54°57'E	36°25'N	24	1345.30	177.32
12	Gazvin	50°00'E	36°15'N	20	1278.30	323.81
13	Kashan	51°27'E	33°59'N	20	982.30	133.05
14	Saadabd house	51°37'E	35°47'N	15	1548.20	416.60
15	Kolak chal	51°27'E	35°51'N	18	2250.00	559.27
16	Tasfiyekhane kan	51°18'E	35°44'N	22	1320.00	467.13
17	Hamedan	48°32'E	34°51'N	17	1749.00	324.37
18	Nozheh hamedan	48°41'E	35°12'N	16	1644.00	332.22
19	Yousef abad	51°24'E	35°45'N	15	1460.00	336.93

2-3-Rainfall erosivity indices

In this research four famous indices based on kinetic energy and rainfall intensity such as EI_{30} (Weischmeier and Smith, 1978), AI_m (Lal, 1976), KE>1(Hudson, 1971) and P/√t ‹Onchev) 1985) are calculated 19 recording rain gauge by having rainfall intensity data with the interval of 10m in statistical periods. It is worth to mention that due to the lack of one minute rainfall intensity statistics to calculate the maximum intensity of 7.5m in Lal index, the maximum intensity of 10m was used as the basis. The details and the method of calculation of the above indices are presented in the followings.

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

Where EI_{30} is rainfall erosivity index, E is the total storm kinetic energy (MJ ha^{-1}) and I_{30} is the maximum 30 min rainfall intensity (mmh^{-1}). 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 (Hudson, 1995).

$AI_m= (A) (I_m)$ (2)

Where AI_m is Lal's index, A is the amount rainfall in storm (Cm) and Im is the maximum 7.5 min rainfall intensity (Cmh^{-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.

$$R = \frac{P}{\sqrt{t}} \quad (3)$$

Where R is universal index (Onchev's index), P 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, average annual rainfall (P), maximum daily rainfall (P_{max24}), maximum monthly rainfall (P_{maxm}), standard deviation of monthly rainfall (P_{stdm}) and standard deviation of annual rainfall (P_{stdy}) were calculated for 121 rain gauge stations with the statistical period of 20 to 25 years and 19 recording rainfall stations. The list of the indices and properties are indicated in table (2).

2-4- The estimation of EI_{30}, KE>1, AIm and P/√t in pluviometer stations

In this research 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 (P_{max24}), maximum monthly raionfall (P_{maxm}), monthly rainfall standard deviation (P_{stdm}) and annual rainfall standard deviation (P_{stdy}) were analyzed using multiple linear regressions..

Table 2- The value of EI_{30}, KE>1, AI_m and P/√t indices of pluviograph stations

No	station	latitude	longitude	EI_{30} ($MJ.mm.ha^{-1}.h^{-1}.y^{-1}$)	KE_{30} ($MJ.mm.ha^{-1}.h^{-1}.y^{-1}$)	AI_m (Cm^2h^{-1})	P/√t ($mm/h^{1/2}$)
1	Arak	34°6' N	49°46'E	81.35	0.00	9.40	0.00
2	Isfahan	32°37'N	51°40'E	35.37	0.00	4.16	0.14
3	Northern Aban	35°43'N	51°28'E	102.47	422.04	117.47	5.44
4	Abali	35°46'N	51°59'E	267.82	55.52	30.17	2.58
5	Tehran Pars	35°45'N	51°53'E	113.60	90.90	122.20	8.10
6	Tehran-Mehrabad	35°41'N	51°19'E	35.51	1.31	4.43	0.09
7	Dushan Tape	35°42'N	51°20'E	43.66	3.49	4.05	0.56
8	Karaj Dam	35°57'N	51°6'E	156.00	144.75	192.17	9.13
9	Latian Dam	35°48'N	51°38'E	119.90	209.12	139.26	6.47
10	Semnan	35°33'N	53°23'E	16.74	0.00	1.89	0.00
11	Shahrud	36°25'N	54°57'	38.00	0.00	3.74	0.22
12	Ghazvin	36°15'N	50°00'E	76.61	0.00	8.70	0.29
13	Kashan	33°59'N	51°27'E	14.56	0.00	1.71	0.00
14	Kakh	35°47'N	51°37'E	102.91	0.00	12.61	0.16
15	Kolakchal	35°51'N	51°27'E	176.90	100.03	219.77	9.53
16	Tasfiyekhane kan	35°44'N	51°18'E	99.90	129.10	118.93	5.96
17	Hamedan	34°51'N	48°32'E	35.89	0.00	3.87	0.16
18	Hamedan-Noje	35°12'N	48°41'E	19.31	1.83	1.85	0.18
19	Yousefabad	35°45'N	51°24'E	110.24	64.03	137.98	5.72

2-5- Interpolation methods

In this research to convert point data to regional data and providing rainfall erosivity map precison and of different methods of interpolation such as Inverse Distance Weighted with different powers, Spline, Kriging, Co-Kriging and Fuzzy Kriging methods are being analyzed. In this research in Fuzzy Kriging method FYZZYEK software is used (Bartels, 2000). In this method in two stages fuzzy numbers are entered into calculations. In the first stage input fuzzy values crate fuzzy experimental Variogram. Then, experts interpret the experimental Variogram and fit the best defined theory Variogram based on it. In the second stage, fuzzy input values are used in the final stage of Kriging. So, the final result of Kriging is also fuzzy.

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 Bias Error (MBE), Mean Absolute Error (MAE), Root Mean Squared Error (RMSE).

The calculation methods of these criterions are as the followings:

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|Z^*(x_i) - Z(x_i)\right| \qquad (4)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(Z^*(x_i) - Z(x_i)\right) \qquad (5)$$

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

Where,

MAE: Mean Absolute Error

MBE: Mean Bias Error

RMSE: Root Mean Squared Error

$Z^*(X_i)$: The estimated values

$Z(X_i)$: The observed values

n:The number of observed variables

3- RESULTS AND DISCUSSION

In table 2 the values of EI_{30}, KE>1, AI_m $P/\sqrt{t}$ indices are shown in 19 recording rain gauge stations. The index value of KE>1 in Arak, Isfahan, Shahrud, Ghazvin, Kashan and Kakh in the statistical period investigation was zero. This shows that in the above mentioned stations during the statistical period, there was not rainfall with the intensity of 25mmh^{-1}.That value of Hudson index and $P/\sqrt{t}$ were zero in some stations during statistical period of this research. The results of this research show that value of Hudson index and $P/\sqrt{t}$ 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 four indices EI_{30}, KE>1, AI_m $P/\sqrt{t}$ in pluviograph stations are investigated during the statistical period and are shown in table 3.

Table 3- Descriptive statistics of EI_{30}, KE>1, AI_m and $P/\sqrt{t}$ in pluviograph stations

index	mean	standard deviation	CV%	min	max	range	skewness	kurtosis
EI_{30} (MJ.mm.ha^{-1}.h^{-1}.y^{-1})	86.54	64.93	75	14.56	267.82	253.26	1.24	1.98
KE (MJ.mm.ha^{-1}.h^{-1}.y^{-1})	64.32	107.00	167	0.00	42.04	42.04	6.05	1.01
AI_m (mm^2/h)	59.70	74.58	125	1.71	219.77	218.06	-6.11	1.01
$P/\sqrt{t}$ (mm/h$^{1/2}$)	2.88	3.56	127	0.00	9.53	9.53	0.78	-1.08

Table 4- Descriptive statistics of the indices and available rainfall properties in pluviometer stations

Readily available rainfall	mean	standard deviation	CV%	min	max	range	skewness	kurtosis
Fournier index (mm)	28.43	14.13	49.70	13.97	59.85	45.88	1.04	-0.41
Modified Fournier index (mm)	46.75	18.91	40.44	19.02	81.05	62.03	-0.07	-0.99
Pδ index (mm)	8143.72	6151.43	75.53	331.11	19928.09	19596.98	0.59	-0.53
Annual rainfall (mm)	332.01	123.94	37.33	133.05	559.27	426.22	-0.20	-0.64
Standard Deviation of monthly rainfall	35.97	17.46	48.54	14.38	77.31	62.93	0.87	0.30
Standard Deviation of annual rainfall	474.46	1524.48	30.21	34.65	6759.21	6724.56	4.33	18.84
Maximum daily rainfall (mm)	36.22	15.66	43.24	20.30	78.83	57.53	1.74	2.93
Maximum monthly rainfall (mm)	92.55	36.43	39.36	42.89	159.89	117.00	0.41	-0.66

Table 5- Correlation between indices based rainfall intensity and available indices of rainfall in pluviograph stations

variable	F	MF	P	P.δ	P_{maxm}	P_{max24}	P_{stdm}	P_{stdy}	H
EI_{30}	0.55 *	0.80 **	0.84 **	0.80 **	0.74 **	0.42	0.38	-0.43	0.75 **
KE>1	0.49 *	57.0 *	44.0	49.0 **	59.0 **	71.0 **	47.0 *	-10.0	01.0
AI_m	62.0 **	67.0 **	64.0 **	67.0 **	67.0 **	55.0 *	41.0	-16.0	30.0
$P/\sqrt{t}$	59.0 **	66.0 **	64.0 **	65.0 **	65.0	52.0 *	40.0	-15.0	32.0

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

After evaluating regression models based on coefficient of determination and standard error, four regression models are selected for the estimation of EI_{30}, KE>1, AI_m and $P/\sqrt{t}$ indices. The details of the selected regression models are explained in the followings.

$$Ln(EI_{30}) = -14.9 + 2.55 Ln(MF) + 1.28(H) - 0.0135(P_{max\,m}) \qquad R^2 = 0.93 \qquad (7)$$

Where,

EI_{30}: Rainfall erosivity index (MJ.mm.ha^{-1}.h^{-1}.y^{-1})

MF: The modified Fournier erosivity index (mm)

H: Elevation (m)

P_{maxm}: The maximum monthly rainfall (mm)

$$KE = -112.15 + 4.87(P_{\max 24}) \qquad R^2 = 0.59 \qquad (8)$$

Where:
KE: Hudson index ($MJ.ha^{-1}.mm^{-1}.y^{-1}$)
P_{max24}: The maximum daily rainfall (mm)

$$AI_m = -68.18 + 1.38(P_{\max m}) \qquad R^2 = 0.46 \qquad (9)$$

Where:
AI_m: Rainfall erosivity index (Cm^2h^{-1})
P_{maxm}: The maximum monthly rainfall (mm)

$$P/\sqrt{t} = -2.94 + 0.10 \times MF \qquad R^2 = 0.43 \qquad (10)$$

Where,
MF: The modified Fournier index (mm)
P/√t: Onchev index ($mm/h^{1/2}$)

Table 6- The values of EI_{30}, KE>1, AI_m and P/√t in sediment gauge stations

station	EI_{30} ($MJ.mm.ha^{-1}.h^{-1}.y^{-1}$)	KE>1 ($MJ.mm.ha^{-1}.h^{-1}.y^{-1}$)	AI_m (Cm^2/h)	P/√t ($mm/h^{1/2}$)
Abegarm	52.104	15.23	16.53	40.59
Ghorveh	45.102	73.24	05.57	20.61
Dehsomeh	50.141	47.68	37.85	83.77
Sira	50.141	47.68	37.85	83.77
Sulghan	27.144	80.100	62.98	32.81
Rudak	22.235	90.131	34.147	70.104
Sarabhende	88.145	13.89	31.75	68.70
Yalfan	51.102	40.43	54.52	13.57
Sulan	16.93	80.37	02.50	78.54
Salehabad	07.95	42.37	22.52	92.54
Bahadorbeik	50.94	29.37	09.52	65.53
Khamigan	00.125	00.18	14.59	41.71
Zahteran	00.115	00.27	89.64	59.71

Table 7- The correlation between EI_{30}, KE>1, AI_m , P/√t and specific sediment yield in sediment gauge stations

variable	EI_{30}	KE>1	AI_m	P/√t
specific Sediment yield (T/sq.km)	0.84**	0.74**	0.84**	0.81**

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

In table 7 correlation between EI_{30}, KE>1, AI_m and P/√t indices 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 Namak lake basin.

According to the above table EI_{30}, AI_m with the correlation coefficient of 0.84 (R) have the highest correlation with specific sediment yield. In contrast, KE>1 with the correlation coefficient of 0.74 has the least 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 AI_m 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 Namak lake basin 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 AI_m and EI_{30} indices with correlation of 0.84 ($P \leq 0.01$). 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 Namak lake basin.

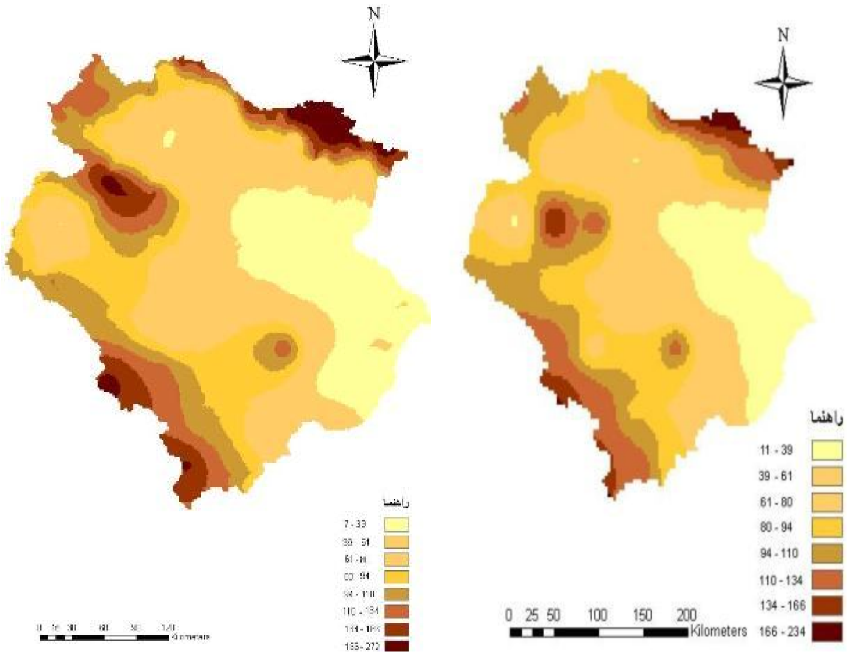
Table 8- The evaluation results of different interpolation methods

Interpolation method			MBE	MAE	RMSE	R^2	Rank
Fuzzy Kriging	Fuzzy Kriging		1.02	10.49	16.59	0.88	1
Co-kriging	Cokriging		0.96	25.15	36.32	0.67	2
Ordinary Kriging	Ordinary Kriging		1.03	27.11	39.65	0.64	3
Spline	Completely Regularized Spline		1.58	28.21	41.84	0.60	4
	Spline with Tension		1.61	29.30	43.20	0.57	5
	Thin Plate Spline		3.38	36.01	68.80	0.35	9
inverse distance weighted	IDW1	power 1	1.91	30.91	44.24	0.55	8
	IDW2	power 2	1.53	30.47	44.44	0.55	6
	IDW3	power 3	1.23	30.86	45.37	0.54	7

As it was not possible to have access to rainfall intensity record in all the stations in Namak lake basin and of 140 stations used in the current research, only 19 stations were equipped with rainfall intensity record. Therefore, the values of indices based on kinetic energy in stations without rainfall intensity records are estimated by regression equations that are always with a little error percent. So, the values of EI_{30} in121 rain gauge stations were considered as fuzzy numbers and EI_{30} values were calculated in recording rain gauge stations as precise numbers.

By FYZZYEK software (Bartels, 2000), the fuzzy experimental variogram was created. After precise interpretation of experimental variogram, the best theoretical variogram that was the combination of exponential and linear model was fitted and rainfall erosivity map was provided by fuzzy numbers. It is worth to mention that due to the time consuming nature of accuracy criterion such as Mean Absolute Error in fuzzy Kriging method and considering the high correlation between EI_{30} index and specific sediment yield, in this research the comparison of fuzzy Kriging accuracy with the ordinary interpolation methods was done only for EI_{30} index.

Fitted model on semivariogram of experimental in Co-Kriging and Ordinary Kriging was exponential that range is varied from 206 Km in ordinary Kriging method to 122 Km in Co-Kriging. Sill values in Ordinary Kriging and Co-Kriging method are equivalent with 0.58 and 3284.6 $(MJ.mm.ha^{-1}.h^{-1}.y^{-1})^2$. A nugget effect value is varied from 0.22 in ordinary Kriging to 1375.10 in Co-Kriging method. In Co-Kriging method, used as maximum daily rainfall an auxiliary variable.Fitted model in Fuzzy Kriging method was the combination of linear and exponential model.



a. Co-Kriging **b. Fuzzy Kriging**

Fig 2- Rainfall erosivity map

According to table 8, fuzzy Kriging method had the least mean absolute error (10.49) and the highest correlation between the estimated data and observed data (R=0.80) and Co-kriging and kriging methods with the mean absolute error are 25.15 and 27.11 in the second and third rank. 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. Figure (2) shows the erosivity map of EI_{30} in Namak lake basin by Co-Kriging method (having the highest accuracy amount between common interpolation methods) and fuzzy Kriging method. As it can be seen in this figure the least amount of EI_{30} are respectively 10.99 in the north western 7km of Namak Lake and the highest amount of EI_{30} as 233.73 are located in the north of Namak Lake. Figure (3) shows the area distribution diagram of the basin in different classes of EI_{30} index by Fuzzy Kriging method. In fuzzy Kriging method 46% of the basin area has less amounts of average limit and only 1% of the basin area is with the rain erosivity index of more than 167 $MJ.mm.ha^{-1}.h^{-1}.y^{-1}$). In the fuzzy method the greatest areas of Namak Lake Basin (20%) is with class 80-93.

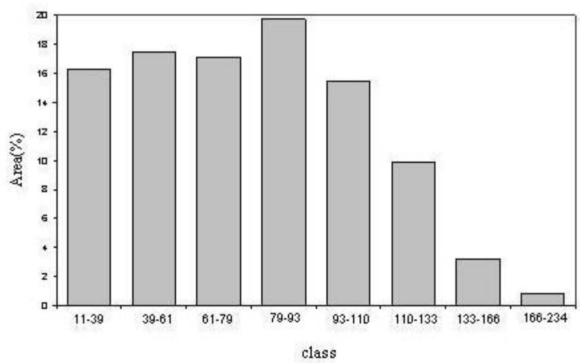


Fig 3- Namak lake basin's area distribution based on several class of rainfall erosivity index

4- Conclusions

That value of Hudson index and P/√t were zero in some stations during statistical period of this research. 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 Namak lake basin. Also, in areas in which rainfall intensity records are not available, using annual average rainfall and modified Fournier index can be good estimation of EI_{30} index. In interpolation discussion, the results of the research indicated that using fuzzy numbers in Kriging method increases accuracy and decreases mean absolute error as 15% in comparison with other geostatistics methods such as Co-Kriging and it causes that the error of rainfall erosivity index estimation decrease considerably in the areas without rainfall intensity records.

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