The determination of the best rain erosivity index for Namak lake basin and evaluation of Spatial Variations

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Abstract: In this research to investigate the displacement of rain erosive factor in Namak Lake Basin, Lal, EI30, Hudson and Onchev are calculated from 16 recording rainfall stations and 3 stations in the proximity of Namak lake basin with the statistics period of 16 to 26 years. Then, among Lal, Ei30, Hudson and Onchev a dependent variable and other indices and rainfall available properties such as Fournier index, modified Fournier index, average 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 EI30, Lal, Hudson and Onchev indices in the stations not equipped with rain intensity statistics. In the next sate, by the given regression equations, the indices were estimated in rain gauge stations. To select the best index, EI30, Lal, Hudson and Onchev indices point data were converted to regional data by a suitable Interpolation method and the average of the given indices were extracted in upstream basins of 13 stations for sediment gauge. Then the correlation relationship was made between the average EI30, Lal, Hudson and Onchev indices with the especial sediment yield of the sub basins. The results show that EI30, Lal indices with the correlation coefficient of 0.84 have the highest correlation amount with the specific sediment yield and this correlation is significant at 1% level. To provide the final rain erosivity map by EI30 index, ordinary kriging interpolation method, co-krigining, Inverse Distance Weighted with different powers, Spline and fuzzy kriging are analyzed. In fuzzy kriging the estimated EI30 values in recording rain stations were used as precise numbers. The results indicated that fuzzy kriging method reduced Mean Absolute error as 15% and it was selected as a good interpolation method to provide rain erosive map in Namak lake basin.

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1. Introduction

Water erosion not only causes soil loss as a natural wealth, but also it causes many problems. Overflow of dam's reservoir, channels, water pollution and mortification environmental phenomenon and ecological changes are a small part of human being problems. Considering the problems, 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 fact, rain erosive index shows the effect of climate on soil loss of water erosion (Hakim Khani, 1384).

Rain erosive, kinetic energy or the power of erosive factors (such as rain and runoff of it) is for the transfer of soil particles (laL, Elliot, 1994). Rain erosive term was proposed by Wischmeier and smith in 1958 to consider the effect of climate on raw erosion (Wischmeier, Smith, 1978). Rain erosion can be determined by two methods of direct measurement and using indices (Lal, Elliot, 1994 and 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, 1987, Lal, 1976, Hudson, 1971 and 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 rain erosive indices are divided into two indices based on kinetics energy and rainfall intensity and indices based on rainfall available statistics (Hakimkhani 1384). 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 EI30 (Wischmeier, Smith, 1978), Aim (Lal, 1976), KE>1 (Hudson, 1971) and (Onchev, 1985). One of the drawbacks of the indices based on kinetics energy and rain 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, 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 EI30 index. The most famous indices of this group are Fournier index and modified Fournier index. 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. In most of the countries regional or country erosive maps are provided but the studies carried out in Iran are very diverse and most of them are just in the form student's thesis. These studies are not very accurate due to the little number of weather stations and not considering interpolation methods. To convert point data to regional data and providing rain erosive map different interpolation methods are applied. There are different methods for data interpolation including Spline (price et.al, 2000, Hutchinson, 1998a, 1998b, Jeffery et.al 2001), weighted moving average (Naoum, Tsanis, 2003 and Price et al, 2000), Regression methods (Naoum, Tsanis, 2003) and other geo-statistics methods (Goovarets, 1999, 2000, Atkinson and LIoyd, 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 geo-statistics.

In geo-statistics 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 (Deutsch, 2002). 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.

This kriging method in which fuzzy data is used is called fuzzy kriging. Fuzzy kriging for the first time was proposed by Bardossy, et al in 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. Also, the identification of a good index for rain erosive and good zoning of this index based on the existing information in Namak Lake basin help the experts to provide access to good strategies to avoid more erosion and soil loss and estimated precisely the erosion in its sub basins and in this way the future studies and investigations are provide.

2. Material and Methods

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 48°(8 to)́52 eastern longitude and 33 to 36 northern latitude. Its minimum height is 800m and maximum height is 4375m. The area of mountain in this basin is 42979 sq km and the total area is 92553 Sq.km.

Average annual rainfall in this region is decreasing from about 700 mm in western and northern highland to less than 100mm in eastern desert and Namak Lake. The average annual temperature is varied from less than 5 in highland regions to more than 17.5 °C around Namak lake. The dominant climate of the region in modified De Martounne system is dry climate covering 44.8 % of the basin area and it is including two super dry climate with the area of 14.2% and arid climate with the area of 30.6%. This area has dedicated 42% of semi-arid climate, 78% Mediterranean and 5.45 semi-humid to humid regions. (Feiz Nia, 1381).

To consider climate changes in EI30 index and achieving a good estimation, we require at least 20 years rainfall intensity statistics and as the statistics were not available in the stations, in this research some stations with the statistical period of more than 15 years were selected. The sum of synoptic, climatology, Evaporimeter, 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). As it was not possible to have access to all rainfall intensity statistics all over Namak lake basin stations, rainfall intensity statistics with the interval of 10 m of 19 recording rain gauge of which 12 belong to weather organization and the remaining is for energy ministry are used to estimated the indices based on rain kinetics energy. Due to the limited number of recording rain gauge stations the statistics of Semnan, Shahrud and Isfahan in the proximity of Namak Lake were used. The geographical dispersion of recording rain gauge of Namak lake basin is shown in figure 1.

Of sediment gauge stations in Namak Lake, 13 stations with good statistics were used. Considering the lack of good statistics and the possible elimination of a great number of stations, statistics base was accepted. Having at least 17 years statistics data, good geographical dispersion and not locating in the downstream of dams are the criterions for the selection of sediment gauge stations.

In this research four famous indices based on kinetic energy and rainfall intensity such as EI30 (Weischmeier, Smith, 1978), Aim (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.

Table 1- Properties and geographical axes of constant rainfall stations in Namak lake basin

Row	Station	Geographical longitude (minute and second)	Geographical latitude (minute and second)	Statistical period (year)	Height (m)	Annual rainfall average (mm)
1	Arak	49°46’	34°6’	26	1708.00	345.69
2	Isfahan	51°40’	32°37’	15	1590.00	124.44
3	North aban	51°28’	35°43’	20	1250.00	388.40
4	Ab-Ali	51°59’	35°46’	23	2450.00	525.30
5	Tehran Pars	51°53’	35°45’	15	1500.00	378.00
6	Tehran Mehrabad	51°19’	35°41’	26	1190.80	224.57
7	Dushan Tape	51°20’	35°42’	16	1209.20	263.27
8	Karaj damp	51°6’	35°57’	20	1588.00	395.29
8	Latiyan damp	51°38’	35°48’	15	1600.00	410.00
10	Semnan	53°23’	35°33’	21	1130.80	145.39
11	Shahrood	54°57’	36°25’	24	1345.30	177.32
12	Gazvin	50°00’	36°15’	20	1278.30	323.81
13	Kashan	51°27’	33°59’	20	982.30	133.05
14	Saadabd house	51°37’	35°47’	15	1548.20	416.60
15	Kolak chal	51°27’	35°51’	18	2250.00	559.27
16	Kan purify home	51°18’	35°44’	22	1320.00	467.13
17	Hamedan airport	48°32’	34°51’	17	1749.00	324.37
18	Nozheh hamedan	48°41’	35°12’	16	1644.00	332.22
19	Yousef abad-Up	51°24’	35°45’	15	1460.00	336.93

EI30= (E) (I30) (1)

Where E: Kinetics energy of a rainfall and I30 is the maximum rainfall intensity of 30 m in a rainfall. This index is calculated for all rainfall during 1 year and the related average as EI30 is obtained for that year. To determined EI30 of annual average for a statistical period, EI30 of statistical years are added and average with each other. KE of kinetic energy is a rainfall event calculated according to EI30 method with the difference that kinetic energy of a rainfall is calculated for time interval with the intensity of more than 1 inch per hour and kinetic energy for time interval of less than 1inch per hour (25mm per hour) is removed.

AIm= (A) (Im) (2)

Aim index was proposed by Lal in 1976. A is the rainfall amount of rain in cm and Im is the maximum rainfall intensity of 10 m rain in cm/h. It is worth to mention that due to the lack of statistics, 1 m rainfall intensity to calculate the maximum 7.5 m intensity in Lal index, the maximum 10m intensity was used as the basis.

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

Where p is the amount of rainfall equal or more than 9.5mL with the raining intensity of equal or more th an 0.18mL /m and t is the rainfall duration with the intensity of equal or more than 0.18mL/m. Also, rainfall available indices such as Fournier index (F), Modified Fournier index (MF), Ciccacci, 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 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).

Table 2- Values in recording rain gauge stations EI_{30}, KE>1, AI_m P/√t

No	station	longitude (degree and minute)	latitude (degree and minute)	EI_{30} ($MJ..mm.ha^{-1}.h^{-1}.y^{-1}$)	KE_{30} ($MJ..mm.ha^{-1}.h^{-1}.y^{-1}$)	AI_m (mm^2/h)	P/√t ($mm/h^{1/2}$)
1	Arak	49°46'	34°6'	81.35	0.00	4.9	0.00
2	Isfahan	51°40'	32°37'	35.37	0.00	16.4	14.0
3	Northern Aban	51°28'	35°43'	102.47	04.422	47.117	44.5
4	Abali	51°59'	35°46'	267.82	52.55	17.30	58.2
5	Tehran Pars	51°53'	35°45'	113.60	9.90	2.122	1.8
6	Tehran-Mehrabad	51°19'	35°41'	35.51	31.1	43.4	09.0
7	Dushan Tape	51°20'	35°42'	43.66	49.3	05.4	56.0
8	Karaj Dam	51°6'	35°57'	156.00	75.144	17.192	13.9
9	Latian Dam	51°38'	35°48'	119.90	12.209	26.139	47.6
10	Semnan	53°23'	35°33'	16.74	00.00	89.1	0.00
11	Shahrud	54°57'	36°25'	38.00	0.00	74.3	22.0
12	Ghazvin	50°00'	36°15'	76.61	0.00	7.8	29.0
13	Kashan	51°27'	33°59'	14.56	0.00	71.1	0.00
14	Kakh	51°37'	35°47'	102.91	0.00	61.12	16.0
15	Kolakchal	51°27'	35°51'	176.90	03.100	77.219	53.9
16	Tasfiekhane kon	51°18'	35°44'	99.90	1.129	93.118	96.5
17	Hamedan-Forudgah	48°32'	34°51'	35.89	0.00	87.3	16.0
18	Hamedan-Noje	48°41'	35°12'	91.31	83.1	85.1	18.0
19	Yousefabad bala	51°24'	35°45'	110.24	0.364	98.137	72.5

In this research to estimate indices EI30،KE>1 ، AIm وP/ √t in rain gauge on relationship between indicesregressi, EI30،KE>1 ، AIm وP/ √t and rainfal availbale properties and indices were investigated by double and multi regression like averge annual rainfall, maximum monthly rainfall, maximum daily rainfall, monthly and annual rainfall standard deviation, Fournier index and Modified Fournier index.

In this research to convert point data to regional data and providing rain erosivity map precison and of different methods of interpolation such as Inverse Distance Weighted with different powers, Spline, Kriging, co-kriging and kriging fuzzy 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 (triangular 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 (Accuracy)

MBE: including Mean Bias Error (Deviation)

RMSE: Root Mean Squared Error.

Z*(Xi): The estimated values of x variable in i point.

Z(Xi): The observed values of x variable in i point.

n: The number of observed variables.

in this research the comparison is based on the main criteria of Mean Absolute Error and if we cannot help to justify it, other criterions such as Mean Bias Error, Root Mean Squared Error and coefficient of determination between observed values are used.

After the estimation of the indices based on kinetic energy and rainfall intensity in other stations, interpolation method is used to convert point data to regional data. After converting point data to regional data moderated values of EI30, KE>1, AIm P/ √t indices in each of upstream basins of sediment gauge were extracted in ARC GIS software, then the correlation between EI30, KE>1, AIm Onchev indices and specific sediment yield of some of the sub-basins of Namak lake basin were investigated. Here the best index having the highest correlation with suspended sediment production in comparison with the other indices is introduced as the rain erosive index.

3. Results and discussion

In table 2 the values of EI30, KE>1, AIm P/ √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 25mm per hour. Also, the index value of P/ √t in Arak, Semnan and Kashan was zero and this indicates that in these stations during the statistical period there wasn’t any rainfall more than 9.5mm with the rainfall intensity of equal or more than 10.8 mm per hour. The descriptive statistics of four indices EI30, KE>1, AIm P/ √t in recording rain gauge stations are investigated during the statistical period and are shown in table 3.

The descriptive statistics of indices and properties of rainfall available data in recording rain gauge stations are shown in table 4.

Table (5) show the correlation coefficient between EI30, KE>1, AIm P/ √t and other rainfall available properties in recording rain gauge stations.

After evaluating regression models based on coefficient of determination and standard error, four regression models are selected for the estimation of EI30, KE>1, AIm P/ √t indices. The details of the selected regression models are explained in the followings.

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

Where,

EI30: Rain erosivity index (MJ.ha-1.mm-1.y-1).

MF: The modified Fournier erosivity index (mm).

H: Height.

Pmaxm: 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).

Pmax24: The maximum daily rainfall(mm).

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

Where:

AIm: Rain erosivity index (m.sq/h).

Pmaxm: The maximum monthly rainfall (mm).

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

Where,

MF: The modified Fournier index (mm).

P/ √ t: Onchev index (mm/second square of hour).

Table 6 shows the average values of EI30, KE>1, AIm P/ √ t in each of upstream basins of sediment gauge stations. According to the table, Rudak station located in the north of Namak Lake basin has the highest amount of EI30, KE>1, AIm P/ √ t indices. Sulan, Khamigan, Sulan and Bahadoric have the least amount of EI30, KE>1, AIm P/ √ t indices, respectively.

In table 7, correlation coefficients between EI30, KE>1, AIm P/ √ t indices with the specific sediment yield of upstream basins of sediment gauge stations are presented. According to this table, correlation coefficient 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 and significant 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 rain erosion and between the slots creating droplets direct impact is the most important factor of sediments creation in Namak lake basin.

According to the above table EI30, AIm with the correlation coefficient of 0.84(R) have the highest correlation with specific sediment yield between other indices and this correlation is significant at 1% level. 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 25mm per hour are deleted and they are not in the calculations, while to calculate EI30, AIm index, there is not such a condition and kinetic energy of all rainfall is considered 7.5 or 30 m. 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 1 inch per hour. 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). According to table 8, correlation coefficient of EI30, AIm indices with specific sediment yield is equal to 0.84 and it is significant at 1% level. As EI30 index is the most common indices used around the world and most of the researchers in different parts of the world made the rain erosivity map according to this index. So, in this research EI30 index is the basis of rain erosivity map in Namak lake basin.

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 EI30 in121 rain gauge stations were considered as fuzzy numbers and EI30 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 rain 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 EI30 index and specific sediment yield, in this research the comparison of fuzzy kriging accuracy with the ordinary interpolation methods was done only for EI30 index.

The given fit model on experimental quasi-changes in co-kriging and ordinary kriging is of exponential type and its effect radius is varied from206 km in ordinary kriging to 122km in co-kriging method. The threshold values in ordinary kriging and co-kriging are respectively, 0.58 and 3284.6 (MJ.ha-1.mm-1.y-1). The values of section effect are varied from 0.22 in ordinary kriging to 1375.10 in co-kriging. In co-kriging method the maximum 24h rainfall is used as additional variable. The fit model in fuzzy kriging was a combination of linear and exponential model (table 8). 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 EI30 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 EI30 are respectively 10.99 in the north western 7km of Namak Lake and the highest amount of EI30 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 EI30 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.ha-1.mm-1.y-1).

In the fuzzy method the greatest areas of Namak Lake Basin (20%) is with class 80-93.

Table 3- Descriptive statistics of the indices based on rainfall intensity in Namak Lake basin

variable / record	average	standard deviation	changes ratio	min	max	range	skeness	elongation
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	422.04	422.04	6.05 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 recording rain gauge stations

variable / **record**	average	standard deviation	changes ratio	min	max	range	skeness	elongation
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
Average 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 coefficient between indices based rainfall intensity and available indices of rainfall in recording gauge stations

independent variable / dependent 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
it is significant at 1%**									
it is significant at 5%*									

Table 6- The average values of EI_{30}, KE>1, AI_m and $P/\sqrt{t}$ in each of the upstream basins of 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 (mm^2/h)	$P/\sqrt{t}$ (mm/h)
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 coefficients of $EI_{30,}$ KE>1, AI_m and $P/\sqrt{t}$ and specific sediment yield in each of the upstream basins of sediment gauge stations

variable	EI_{30}	KE>1	AI_m	$P/\sqrt{t}$
specific Sediment yield (T/sq.km)	**0.84	**0.74	**0.84	**0.81
it is significant at 1%**				
it is significant at 5%*				

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
Cokriging	Cokriging		0.96	25.15	36.32	0.67	2
Ordinary kriging	Ordinary Kriging		1.03	27.11	39.65	0.64	3
	Completely Regularized Spline		1.58	28.21	41.84	0.60	4
Spline	Spline with Tension		1.61	29.30	43.20	0.57	5
	Thin Plate Spline		3.38	36.01	68.80	0.35	9
	IDW1	power 1	1.91	30.91	44.24	0.55	8
inverse distance weighted	IDW2	power 2	1.53	30.47	44.44	0.55	6
	IDW3	power 3	1.23	30.86	45.37	0.54	7

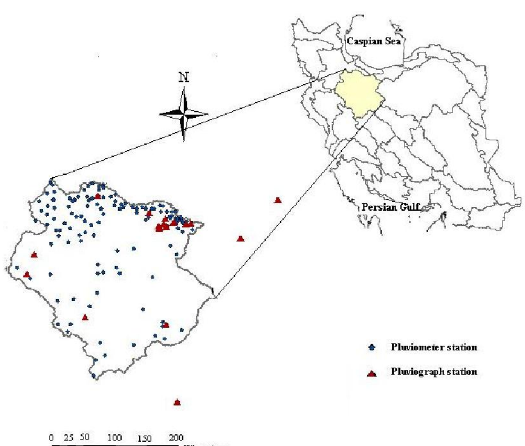
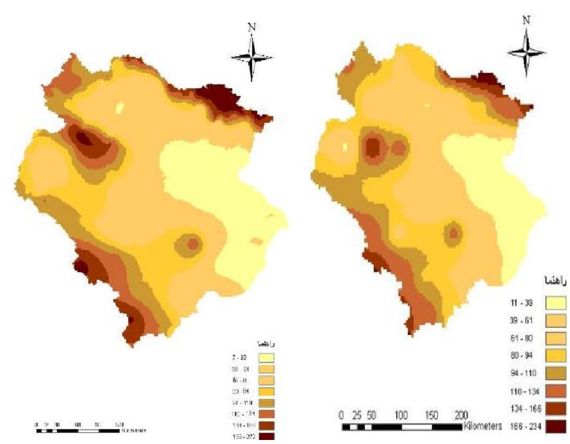


Fig 1- Study area and location map the pluviograph and pluviometer stations in Namak lake basin in Iran



a. Co-Kriging b. Fuzzy Kriging

Fig 2- Rainfall erosivity map by using Co-Kriging and Fuzzy Kriging method

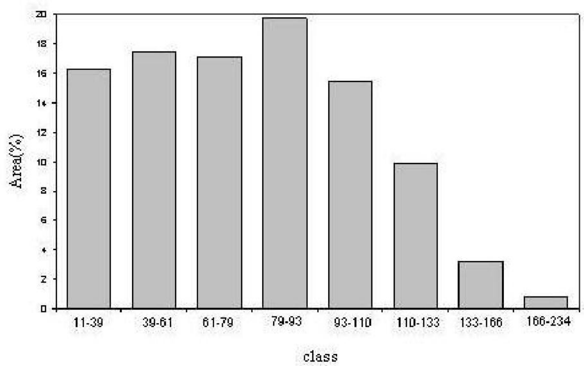


Fig 3- Namak lake basin's area distribution based on several class of rainfall erosive index by using Fuzzy Kriging

4. Conclusions

The results of this research show that Hudson index value and P/ √ t in some of the stations are investigated in record period and they are equal to zero. 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 10.8mm per hour. Considering the high correlation of AIm and EI30 with the specific sediment yield, we can conclude that these two indices are good indices to show the rain erosive 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 EI30 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 rain erosive index estimation decrease considerably in the areas without rainfall intensity records. Also a good method for interpolation (including fuzzy and non-fuzzy) for the estimation of a variable is depending upon the type of variable, density and dispersion of data and regional factors effective on that variable and the selected method in one area cannot be generalized to other regions. So it is recommended that in future researches in areas without having access to rain gauge stations or some basins such as Namak lake in which most of the stations are located in the northern and western regions and data are not equipped with a good geographical dispersion, additional fuzzy points are used and its accuracy is compared with the results of this research.

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