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Assessment of the Rainfall Erodibility Factor uing Different Statistical Methods

Hassan Fathizade[a], Ali Khenamani[b], Mohammad Ali Hakimzadeh Ardakani[c*]

[a]Ph.D. Student, Yazd University, Yazd, Iran
[b]Faculty Member of Yazd University, Yazd, Iran
[c]Associate Professor, Department of Natural Engineering, Yazd University, Yazd, Iran

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Abstract

The aim of this research is to evaluate the rain erosion index in Iran by using the rainfall records from 150 stations over the period of 25-year (2010-1986), using geo-statistical methods. To calculate the rainfall erodibility, factor, and using Fournier index equation, the R factors for all stations were received. The rainfall erosivity factor map was depicted to show the spatial correlation between rainfall erosivity statistics, depicting of variogram become used that the linear to sill variogram with the value of 0.80 confirmed the quality correlation the various facts and was used for the interpolation. Also, to evaluate the amount of rainfall erosivity indexes four extraordinary interpolation methods (IDW) had been used: (GPI), (RBF) local, (LPI), and kriging. Moreover, to choose the satisfactory approach of interpolation, correlation of Geo-statistical techniques with the observational data has been estimated. Kriging simple method with R2 = 0.74 has been chosen as the satisfactory technique. Based on the result of kriging simple and DEM maps of Iran, the area of 8.98-27.19 has the best stage (22.5) and is as much as to 4777 m. The lowest level is allocated to regain 2.12.49, which covers approximately 4.2% of the entire area of Iran. The evaluation confirms the immoderate indices of erosivity for the northern strip and the west provinces of country due to the heavy monthly rainfall.

***Keywords**:* GIS, Interpolation, Kriging, R factor, Variogram.

[*]*Corresponding autho*r. Tel: +98-9103349428
Email address: hakimzadeh15@gmail.com.

1. Introduction

Soil erosion is considered as one of the most critical environmental behaviors because of the growing population of the world as well as the essential results of land use exchange and weather exchange (Lal et al., 1998; Gitas et al., 2009; Yang et al., 2003, Eslami, 2017). In ordinary conditions, the rate of erosion is the function of the amount of rainfall erosivity and soil erodibility (Wischmeier and Smith, 1978; Fathizad et al., 2017; Hakimzadeh and Vahdati, 2018). Rainfall erosivity index in global erosion equation is used as a quantitative indicator of the rain power on soil erosion. This index is a mixture of rainfall kinetic strength and rainfall intensity. In fact, an annual rainfall erosivity index is the sum of all index values of all erosion of showers for the duration of 360 days. Erosion of showers is the function of the intensity, period, mass and speed of the raindrops.

Therefore, it is necessary to determine the rainfall erosivity, and analyzing the distribution of raindrop length (Wischmeier, 1971; Arekhi, 2010). Rain may be quantified through severe erosive measures that the degree of relationships among particle period distribution and kinetic energy is generated with the useful resource of a specific event (Angulo-Mart'ınz et al., 2009). The quantity of rainfall erosion has an instantaneous dating with rainfall and pinnacle. For this reason, in the past, tried to assemble a regional precipitation map the usage a regression dated among altitude and rainfall, and a distinctive regression relationship for rainfall and the rate of rainfall erosion (Angulo-Mart'ınéz et al., 2009). Because of the huge amendment of rainfall in time and space on one hand and absence of pluviometry stations to record daily rainfall on the other hand, the necessity of explaining estimating models of rainfall in time and area is inevitable. Figuring out the appropriate method of interpolation inside the region and giving an explanation of the methods of its spatial and close by distribution is necessary to estimate the spatial distribution of rainfall.

Many researchers have compared and evaluated specific interpolation methods that discovered the importance of this problem in decreasing the error that is the result of the selection process.

Goovaerts (2000) interpolating rainfall and annual regional temperature of and 5000 Km of Portugal, using geo-statistical methods in Hebi Province in China, ordinary kriging method with second degree compared to the ordinary kriging with 0 and primary degree had a higher performance, moreover the fitted Gaussian variogram was higher in performance than the round and exponential variogram.

Onori et al (2006), estimated the erosion and sedimentation in Sicily watershed in northern Italy. Moreover, the rainfall erosivity of this model, using kriging method was changed into interpolated.

Iran has an immoderate climatic variety. From the north to the south, we progressively face special weather zones. Iran is taken into consideration as a dry and semi-arid weather quarter, because of climatic conditions, the vegetation cover has moderate coverage and excessive erosion capacity. Identification of rainfall and its seasonal and spatial distribution, in addition to determine the index of rainfall erosion, are the vicinity to begin for identifying regions with excessive erosion capacity for erosional management prevention making plans, which has not been determined yet in Iran (Arekhi, 2010). The purpose of this studies is to advantage the rainfall erosivity component the usage of 150 datasheets from synoptic stations in Iran with the resource of using awesome geo-statistical methods.

2. Materials and Methods

2.1 Geographical Location of Iran

Iran because of the geographic area of fifteen degrees latitude with variations that exist between the southern and northern factor, additionally, the ups and downs of folds which are visible on its surface have different climates. No matter to these factors, the mixture of air masses which can be derived from different land and collide with each other on Iran plateau, is one of the important factors determining the weather in Iran. Proximity to the Gulf of Oman and the Persian Gulf on the one hand and have an impact on of the Mediterranean Sea alternatively and finally, the existence of the deserts of Arabia and Africa and the wonderful Plains of Siberia in northeastern, deeply affect the kind of air masses that attain Iran. Figure 1 shows the map of Iran and location of 150 used stations.

2.2 Methods

Rainfall erosivity factor (R) for a reason rainfall chart and specific statistics of the shower (intensity of rainfall) rarely are in the weather stations, frequently monthly and annual rainfall is used for estimating R factor (Ferro et al., 1991; Renard and Freimund, 1994).

To calculate the rainfall erosivity factor, the index stations and then the studied region have been determined, monthly and annual rainfall of these stations. Then, the usage of the following equation, (Renard and Freimund, 1994):

$$F = \frac{\sum_{i=1}^{12} pi^{2}}{\sum_{i=1}^{12} p} \tag{1}$$

In equation (1), pi is the rainfall mean (mm) in month I, and p is the mean of annual rainfall (mm). In the present study, by using equation (1), Fournier index for each and all stations were calculated. Then, to compensate lack of detailed data of shower areas (rainfall intensity), Fournier index (Eq1) was placed, in the relations (2) and (3) proposed by Renard and Freimund (1994) and amount of the factor of rainfall erosivity indices were estimated for the indicators stations.

$$R - factor = \frac{(0.07397 \times F^{1.847})}{17.2} \quad \text{If } F < 55 \text{ mm} \tag{2}$$

$$R - factor = \frac{(95.77 - 6.081 \times F + 0.4770 \times F^{2})}{17.2} \quad \text{If } F \geq 55 \text{ mm} \tag{3}$$

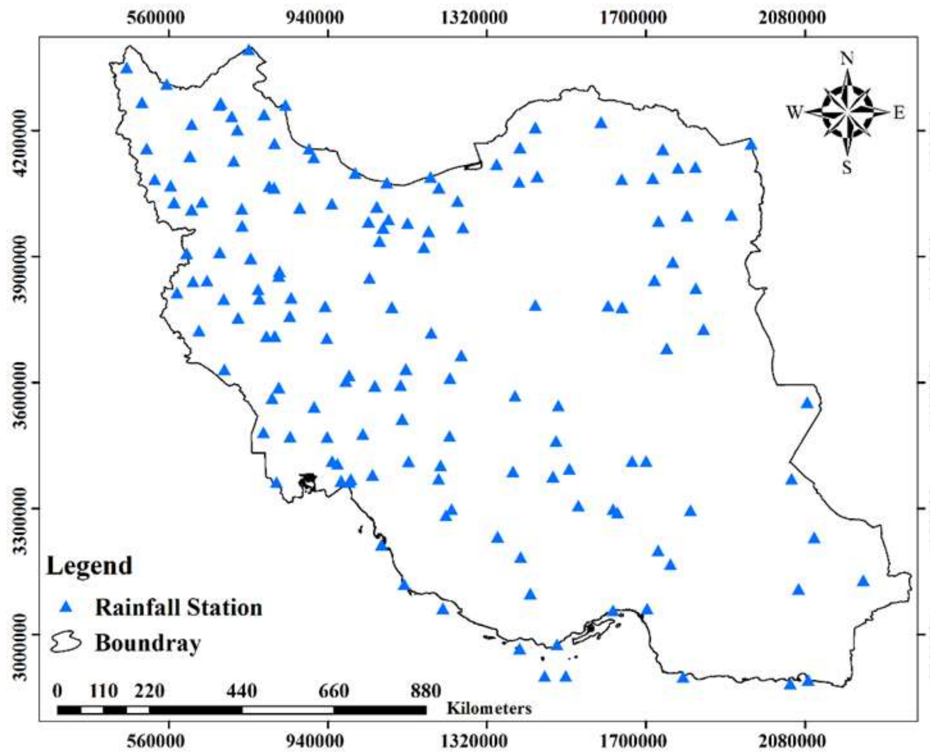


Figure 1. Stations used in the studied area

2.3 Geo-Statistical Analysis

Geo-statistics, to be simply defined is in fact, an interpolation method that the criteria used for interpolation or estimation are the minimization of the variance estimation (Hohn, 1998). Interpolation is the estimation, of the unknown continuous variable based on the known samples in the region (Lu and Wong, 2008).

Geo-statistical estimation is one of the most accurate method for estimation, because it analyzes many factors such as the distance between points, anisotropy and spatial variability. Nevertheless, this method has a high volume of calculations, which causes an increase in the calculation time in large operations (Hirsche, 1998; Fathizad et al., 2018).

Geo-statistical analysis investigates the variable phenomena in space and time and analyzes the samples collected from different locations to produce a steady level (Johnston, 2000: Johnston et al., 2001). The geo-statistical analysis describe the spatial coherence and collect statistical and definitive tools and modeling of these changes. The basic assumption of spatial-statistical analysis is that close observation requires greater statistical correlation than far away observation. It should be noted that access to accurate and efficient results through these analyzes developed when the data were normally distributed as it is possible to be fixed and their mean and variances do not vary in space (Bohling et al., 1991).

2.4 Variogram

Variogram is one of the most important concepts in the field of geo-statistics and the definitions and concepts of the geo-statistics are explained. Variogram is used to determine the spatial correlation of a variable in the sampling intervals and extraction of the necessary parameters at the interpolation step (Shabani et al., 2011). Variogram is considered as the first step in modeling the spatial structure in kriging. The main purpose to establish the Semi-variogram is to identify the variability of variables in relation to the spatial distance. Variogram is calculated by the following equation (Webster and Oliver, 2000):

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(x_i) - z(x_{i+h})]^2 \quad (4)$$

Where: γ(h): is the value of the Semi-variogram for the two points located with the distance of h from each together.

n: number of the two points located at a distance of h from each together.

$z(x_i)$: observed value of the variable at point x.

$z(x_{i+h})$: observed value of the variable located with distance h from x.

In curve Variogram with increasing distance of (h) the value of γ (h) increases that this situation continues until a certain distance from which its amount remains fixed. In this study in order to investigate the erosivity index, inverse distance weights (IDW), Global polynomial interpolation (GPI), Radial basis function (RBF), Local polynomial interpolation (LPI) and Kriging methods are used.

2.5 Evaluation Criteria and Selecting the Best Model

Given that many researchers (Zhang et al., 2011; Li and Shao, 2010; Qiu et al., 2010; Spadavecchia and Williams, 2009) have used the parameters R2, MAE and RMSE to analyze interpolation methods, this research has used these parameters. The methods for calculating the MAE and RMSE factors are shown below.

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

In equation (5), Z *: is the estimated data; Z: the measured value of the mentioned variable; n: number of data; MAE: mean absolute error.

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

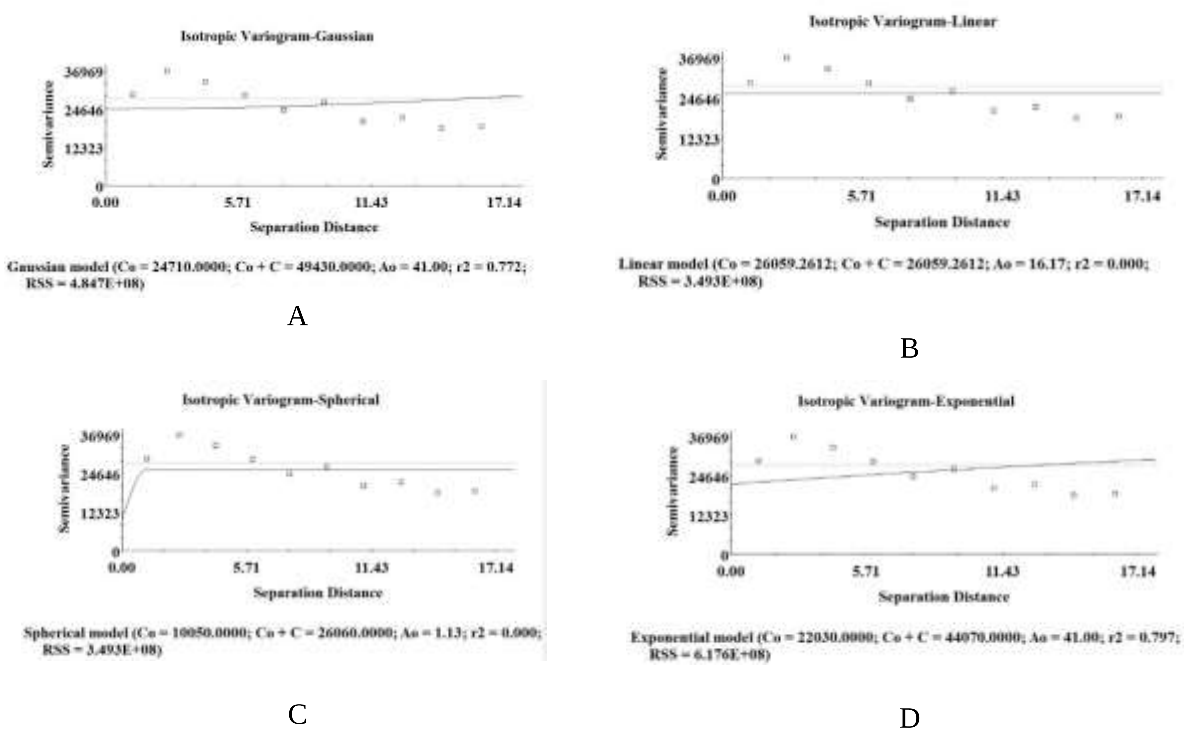
In equation (6), Z (xi): is the observed value of the variable x at point i.; Z * (xi): the estimated value of the variable x at point i.; n: number of data; RMSE: root mean squared error of the estimation.

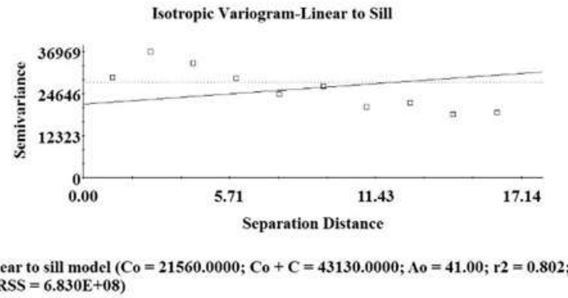
2.6 Validation

Cross-Validation (CV) method is an elaborate and valid method for prediction accuracy analysis. This method is mainly used for random sets or multidisciplinary (k-fold) subsets of the test and training set. The method is known as a simple sampling method, which is a simple approach to validation. In the k-fold validation method, the data sets are split into k sections. We repeat the modeling process for k, and at each time k-1, the data section is used for the learning process, and a part of the data not involved in the training process is used for the testing and validation process of the predictive model. In the end, the calculated prediction error in each k phase is interrupted. The advantage of using randomized subsets of data in this method is to eliminate the effect of the distribution of data for the modeling process. The variance of the results of the mediocre is very small for a very large amount (Asrardel, 2015). In this research, cross-validation was used for validation.

3. Results and Discussions

To display the spatial correlation among the rainfall erosivity factor data the variogram was depicted at GS+ software. The results of the depicting the variogram are seen in Table 1. Variogram was used to fit the data that shows the spatial correlation of the data more favorably than the other variograms. For this, the ratio of the Nugget effect and the sill of variogram were used (Co +C) (Habashi et al., 2007). If the ratio of the Nugget effect on the sill of variogram is less than 0.25 there is a strong spatial correlation among the data. If this ratio is among 0.25 to 0.75 the spatial correlation is average and if it is more than 0.75 percent spatial correlation among the data is low or there is no correlation (Khodakarami et al., 2011). Therefore, this ratio was used to select the best variogram. According to the parameters obtained for fitting variogram, linear to sill variogram with the amount of 0.50 has modeled the correlation among the data and was used for interpolation. Different types of variograms used to fit the data in this study are shown in Figure 2.





E

Figure 2. Variogram fitted to the data of erosivity index using: A- Gaussian variogram B: Linear variogram, C: Spherical variogram, D: Exponential variogram, E: linear sill

Table 1. Parameters of the Nugget effect and sill of obtained variogram for the fitted variogram of Factor R

Model	Nugget) mm^2(Co	Sill Co+C) mm^2(	Proportion Co/Co+C	Range Parameter Ao (km)	R^2
Linear	26059	26059	0.00	16	0.00
Linear to sill	21560	43130	0.50	41	0.80
Gaussian	24710	49430	0.50	41	0.77
Spherical	10050	26060	0.61	1.1	0.00
Exponential	22030	44070	0.50	41	0.79

Comparison of the methods showed that IDW3, RBF and Simple Kriging have lowest error rate, and the highest correlation with the observed data (with R2 = 0.59, R2 = 0.68 and R2 = 0.74 respectively). For better comparison, diagram of measured and predicted values were derived for each method and the mentioned method is presented in Figure 3, it shows that Kriging Simple method has the highest correlation with the observed data (R2 = 0.74). The results of the model evaluation are presented in Table 2.

Table 2. Results from evaluation of IDW2, RBF and Simple Kriging methods

Parameter / Method	R^2	RMSE	MAPE	MaxAPE	MAE	MaxAE
RBF	0.686	157.08	1029.8	7175.97	64.13	1136.14
GPI[1]	0.233	169.91	1425.08	10805.42	78.36	1100.13
GPI[2]	0.291	165.42	1798.31	16786.41	79.02	1098.97
GPI[3]	0.198	163.96	1704.1	14140.53	78.28	1096.53
IDW[1]	0.504	159.74	1217.24	9686.1	67.29	1136.12
IDW[2]	0.616	157.03	1047.24	7106.44	63.76	1152.43
IDW[3]	0.594	156.05	926.11	7991.98	61.65	1160.43
LPI[1]	0.518	1111.91	1064.84	21954.78	177.29	12706.2
LPI[2]	0.56	1080.19	1843.51	124506.59	193.44	10864.05
LPI[3]	0.224	2576.01	1260.97	9621	273.54	30211.63

Kriging Ordinary	0.563	1380.21	1247.63	50577.79	192.66	16376.17
Kriging Simple	0.74	160.44	629.05	2848.02	60.48	1135.96
Kriging Universal	0.567	163.3	2226.05	20284.01	80.82	1073.42
Empirical Bayesian Kriging	0.469	158.07	1037.89	9463.35	64.75	1132.92

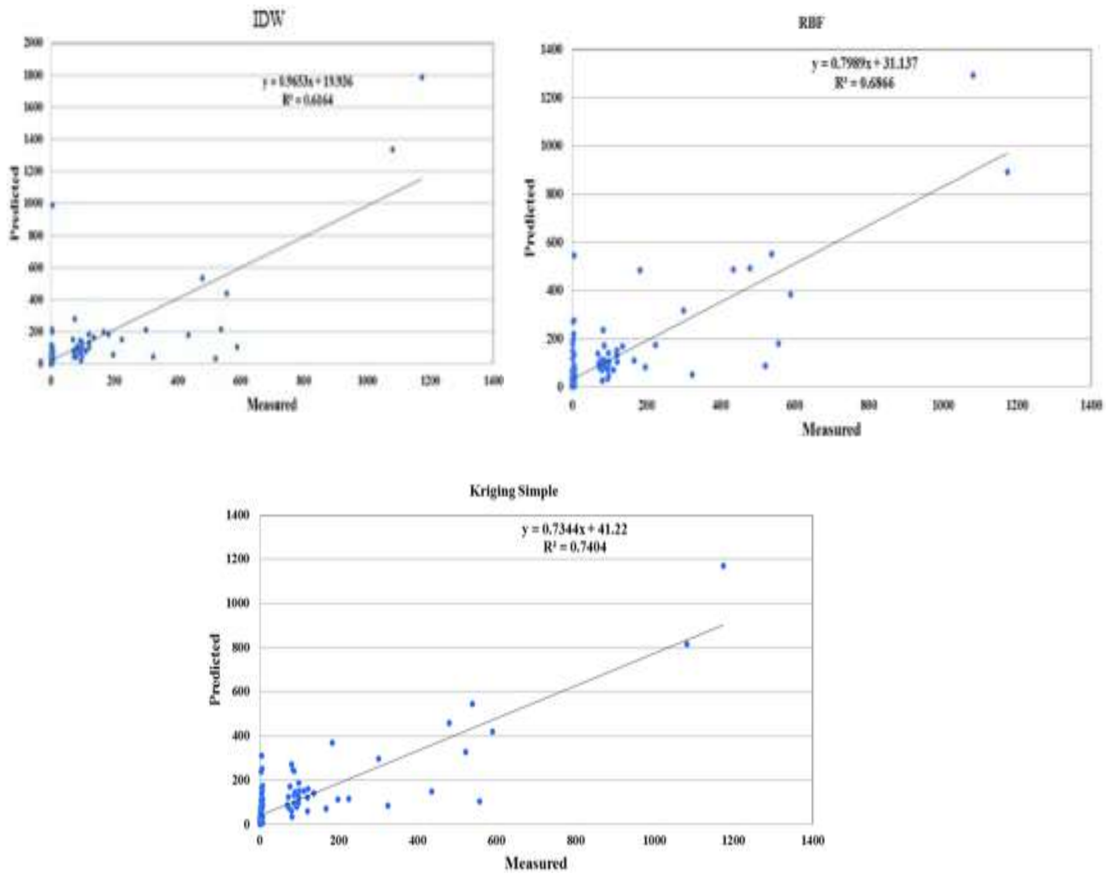
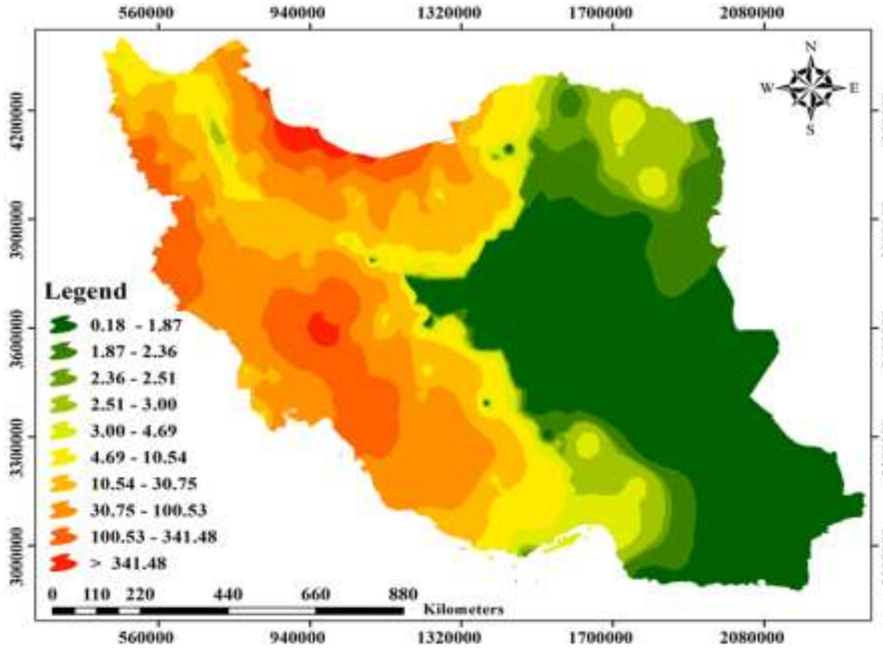


Figure 3. Characteristics of the measured and predicted values of various statistical methods (MJ mm ha-1h-1y-1), respectively: IDW2, RBF and Kriging Simple

Figure 4 shows the mapping pattern of the erosion index for the interpolation of the IDW2, RBF, and Kriging Simple methods. Due to the large number of stations in the area and how they are properly distributed, a complete zonal map of the area is generated.



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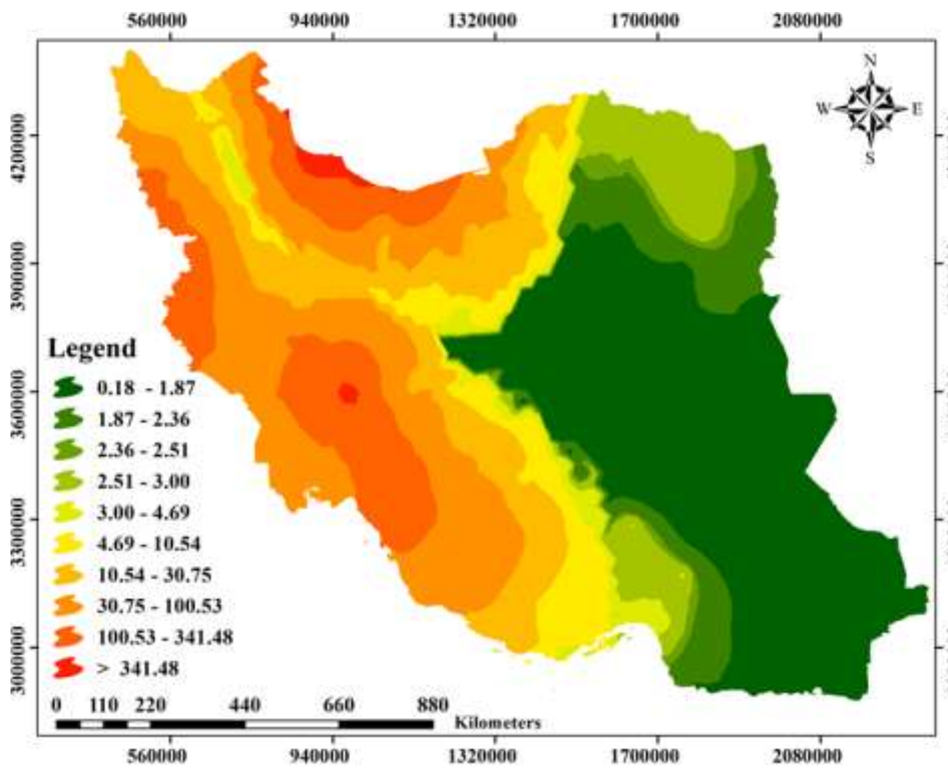
0.18 - 1.87
1.87 - 2.36
2.36 - 2.51
2.51 - 3.00
3.00 - 4.69
4.69 - 10.54
10.54 - 30.75
30.75 - 100.53
100.53 - 341.48
> 341.48
0 110 220 440 660 880
Kilometers

A(IDW)



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4.69 - 10.54
10.54 - 30.75
30.75 - 100.53
100.53 - 341.48
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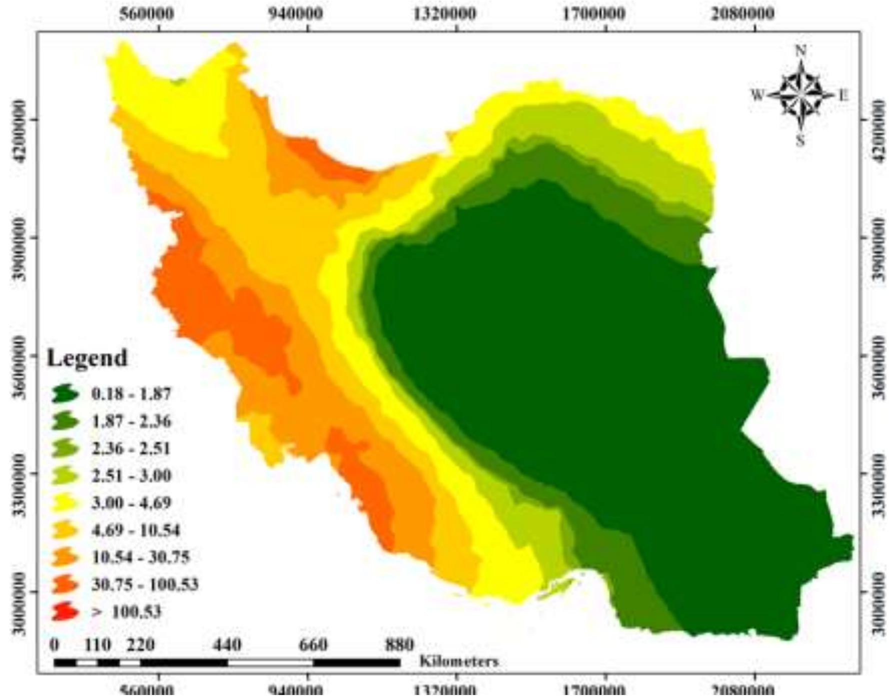
0 110 220 440 660 880
Kilometers

B (RBF**)**



C (Kriging Simple**)**

Figure 4. Erosivity index map of Iran using various statistical methods (MJ mm ha-1h-1y-1)

Figure 5 shows the area (in%) of each erosivity index zones and Figure 6 shows the correlation between measured and estimated values of the Kriging Simple method, which has the highest accuracy compared to other statistical methods.

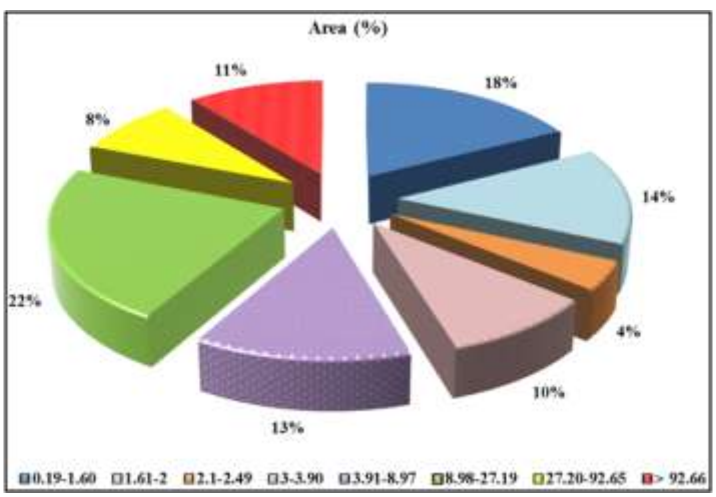


Figure 5. Histogram of each erosive index zones by Kriging Simple method (%)

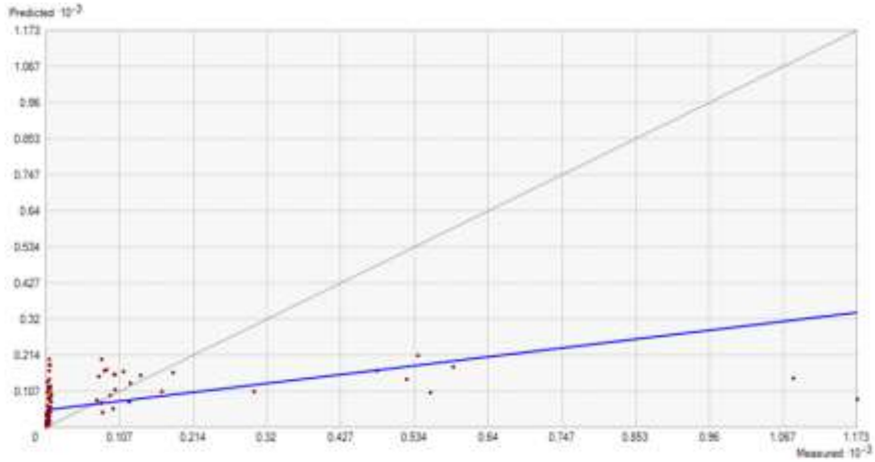


Figure 6. Validation Chart of Kriging Simple Method Using Cross-Validation

A DEM map was used to study the changes in the rainfall erosion factor at different altitude (Figure 7). For this, the zonal statistic as Table option was used in the ArcGIS software environment (Gradient method). The results are presented in Table 3.

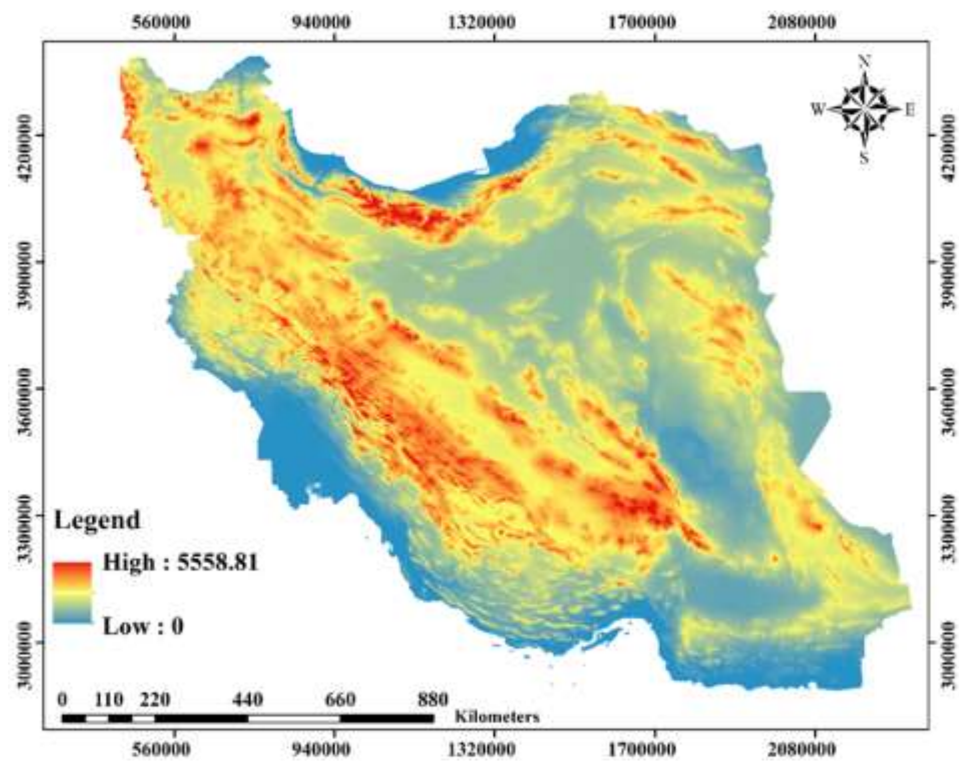


Figure 7. Digital Elevation Model (DEM) map of Iran (in meters)

Table 3. Values of zones of rainfall erosivity index at different altitudes

Classes \ Parameter	Area (ha)	Area (%)	Minimum Elevation	Maximum Elevation	Range	Mean	Std
0.19-1.60	28848008	17.5	123	4442	4319	1079	546
1.61-2	23153621	14.0	19	4312	4293	1191	570
2.1-2.49	6961102	4.2	0	3771	3771	1253	648
3-3.90	15628251	9.5	0	4015	4015	1291	645
3.91-8.97	21663956	13.1	0	5559	5559	1310	716
8.98-27.19	37019243	22.5	0	4777	4777	1559	643
27.20-92.65	13761709	8.3	0	4371	4371	1552	822
> 92.66	17783610	10.8	0	3730	3730	789	655

Based on the results of Fig. 5 and Table 3, the zone 8.98-27.19 includes the highest level (22.5) and up to 4777. The lowest level is allocated to zone 2.12.49, which covers about 4.2% of the total area of Iran.

4. Conclusion

Using GIS for data interpolation in spatial analysis is very important, because most of the maps used in GIS operations are produced by interpolation. Producing smooth and continuous models is possible through the interpolation of spatial and temporal distribution of data.

In this study, 14 interpolation methods of IDW, GPI, RBF, LPI and Kriging were evaluated to assess the country's rainfall erosivity indices. Variograms used in this study clearly showed that depicting variogram in addition to proving the spatial correlation among the rainfall erosivity data can model spatial correlation in different directions. The results showed that using Simple Kriging has the highest correlation with the observed data (R2=0.74). Also, using the Nugget effect on the sill of variogram was found that linear sill variogram with a value of 0.80, had the best correlation among data used for interpolation. After linear sill variogram, exponential and Gaussian variograms had the correlation of 0.79 and 0.77 respectively. The strong correlation among the observed and predicted data indicates good performance of the Simple Kriging method in this study. Meusburger et al. (2012) for data validation, used the relation of calculated and predicted data with the value of R2=0.69.

The distribution of rainfall erosivity factor by Simple Kriging method showed that northern and western parts of the country have the highest rainfall erosivity index. Northern parts of the country are not affected by the Mediterranean climate and in this area monthly rainfall exceeds 250 mm per month and 2000 mm per which largely increases rainfall erosivity index. The lowest index of erosivity is related to the central and eastern parts of Iran, which have an annual rainfall of about 60 mm and about nine months of the year are dry.

Iran's climate is greatly influenced by the Alborz and Zagros Mountains. Alborz Mountains and its northern slope, absorbs plenty of rain of the northern strip of Iran; besides, it prevents northern flows from reaching central parts. Zagros Mountains located on northwest-southeast, absorbs Mediterranean rainfall and does not allow rain to fall into central Iran. As a result, a wide range of the central Iran has less than 100 mm annual rainfall. Other factors which cause rainfall reduction in this region are: it's distance from moisture sources and is located at the high-pressure strip of the middle latitude.

In general, it can be concluded that areas near the Caspian Sea with high amount of rainfall, increases the rain erosivity in these areas. It should be noted that the above map is only indicative of the potential for erosion caused by rain erosivity and in addition to the above factors, many factors, including ways of using lands; vegetation, topography and erosion of soil and rock are involved in actuality of water erosivity in the region. So in the areas with high rate of erosivity more attention must be given to protect and improve the resistance factors against erosion including vegetation. The results of the analysis of both temporal and spatial patterns of rainfall erosivity index and maps of Iran can be used in cases to assist in planning, provision and implementation of appropriate soil conservation plans, help the researcher through raising awareness of erosion (Shamshad et al., 2008; Onori et al, 2006; Hudson, 1995) and their use in erosion estimation models (Wischmeier and Smith,1978).

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