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Application of geostastical methods for determining annual precipitation in Karoon and Dez basins

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Abstract

Prediction of annual average precipitation over a regin is one of important issues in watersherd management and natural resources planning. Geostatistics is one of the useful methods for precipitation prediction which varies based on type of the variable. This study was conducted in Karoon and Dez Basins located in southwertern of Iran. The data set including 20 years of annual precipitation of stations were used. At first normality and homogeneity of data are examined. Then variographic analysis using three techniques including kriging, co-krigining and Weighted Moving Average (WMA) were applied for predicting annual precipitation. Finally compaction of the results using statistical techniques showed that kinging method has the highest accuracy and provides more accentuate results.

Keywords: Annual precipitation; Interpolation; Geostatistics; Kiriging; Co- kiriging; WMA; Dez and Karoon Basins; Iran

1. Introduction

Prediction of average precipitation over a region is one of the important parameters in natural resources planning and management. There are different methods for regional prediction of precipitation such as Theissen, arithmetic average and Isohyet map approaches. These methods are easy to use but do not consider correlation and location of data which may lead to low accuracy of the results. Application of geostatistics techniques in hydrological sciences is a useful approach to avoid such errors and increase of calculation accuracy as well. In classic statistics samples taken from a population are lack of spatial properties. Therefore the calculated values of a parameter in a homogeneous sample do not include any information of the same parameter in another sample with a defined distance.

Geostatistics consider the value as well as location of the sample. Then it is possible to analyze value and location of the samples together. To achieve this purpose it is necessary to relate spatial properties (distance, direction) of different samples using mathematical formula called spatial structure.

Obviously geostatistical methods use various variables and then produce different results. In many cases a method which is selected to reach the prediction process but it is vital to find out the most appropriate interpolation technique for precipitation prediction. The first application of geostatistics was happened in mine exploitation and extended to other branches of earth science. Amini (2002) applied kriging and co-kriging techniques for predicting Cl- concentration of soil in Roudash, Isfahan which showed that kinging method provides more accurate and low cost results.

Azimzadeh et al. (2005) used kriging technique to estimate the area of desert pavement and threshold velocity of wind erosion in Mehriz, Yazd. The results indicated that common kinging is a precise and relevant method to produce the map of the effective

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factors of wind erosion including Reg area and iso-velocity threshold maps. Mahdavi et al. (2004) studied the capability of geostatistical techniques for estimating spaial distribution of annual rainfall in arid and semi-arid regions of south eastern Iran which showed TPSS method using elevation as a variable is the most relevant method of rainfall estimation while kinging and WMA methods having second power placed in next orders. Campling et al. (2001) estimated regional average precipitation in southern Spain using Theissen and geostatistical methods and concluded that the results obtained by kriging has the highest correlation with the data. Prodhorome and Reed (1999) used geostatistical techniques for estimating extreme rainfall in mountainous regions of Scotland that showed kriging and modified residual kriging due to simplicity are more applicable methods. But modified residual method has more precise results than other approaches.

Campling et al (2007) were used kriging method to estimate spatial distribution of rainfall as well as to optimize the number and location of rain gauges in Spain. Drogue et al. (2002) were used geostatistical techniques for estimating and quantifying monthly and annual rainfall in France that showed efficiency of the method.

Rousso et al. (2005) evaluated rainfall in urban areas which showed that kriging method is a good technique for this purpose. Diodato (2005) evaluated the influence of topography on spatial variability of precipitation over small watersheds of complex terrain in mountainous regions of Italy. The results showed that common kriging method has the highest error while multivariate regression produced the lowest error. Diodato and Ceuarelli (2005) were studied spatial variation of monthly and annual precipitation in southern Italy which showed that weighted moving average has the highest error while linear regression and common co-kriging methods produce the lowest errors. Johanson and Chen (2003) studied the influence of wind and topography on precipitation distribution in Sweden that showed high efficiency of these methods for predicting spatial distribution of precipitation.

In the current study, kriging, co-kriging and Weighted Moving Average with the power of 2, 3 and 5 were applied for estimating annual precipitation in southwestern of Iran.

2. Materials and Methods

2.1. Study area

The study region includes Dez and Karoon basins in Central Zagros Mountains. The geographical coordinates of the region are 48° 10′-52° 38′ E and 30° 20′-35° 5′ N. The total area is 47080 km^2 in uplands and foothills and 21934 km^2 in plains. Temperature varation in the region is high due to elevation. The minimum temperature in Shahreh Kord station is -32°C while it reaches to higher than 42° C in Ahwaz station. The annual pan evaporation varies between 1500-3400 mm. The climate of study area is mostly semi-arid and the annual precipitation ranges from 148.4 mm in Khoramshahr station up to 1477 mm in Chelgerd station. Figure 1 shows the distribution of gauging stations in the study area. After normality and homogeneity analysis, records of 104 stations with 20 year duration were used.

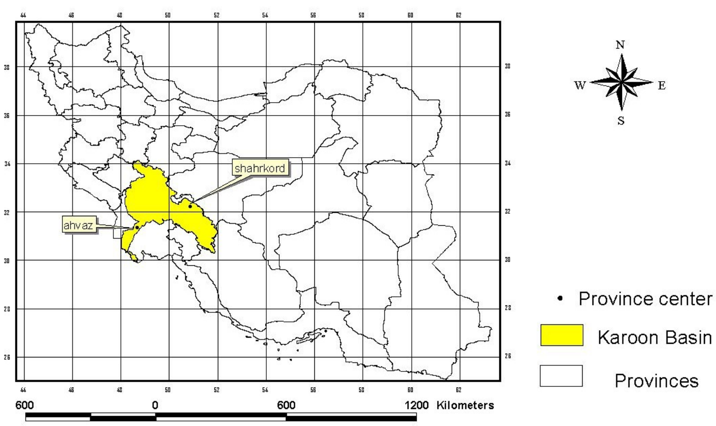

Fig. 1. Location of the study area in Iran map

2.2. Geostatistics

Geostatistical prediction includes two stages which is first identification and modeling of spatial structure. At this stage continuity, homogeneity and spatial structure of a given variable is studied using variogram. Second stage is geostatistical estimation using kriging technique which depends on the properties of the fitted variogram which affects all stages of the process.

2.3. Variogram analysis

Variogram method is a suitable technique for estimating spatial variability of a variable. Calculation of variogram graph is one of essential stages in geostatistics which is defined as follow:

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} \left[Z(xi) - Z(xi+h) \right]^2 \qquad (1)$$

Where:
γ(h): value of variogram for pair points with distance h
n(h): Number of pair points with distance h
Z(xi): observed value of variable x
Z(xi+h): Observed value of the variable with distance h from x

For variogram plotting it is necessary to compute y (h) for different values of h and then to plot the values for different distances of h. In another word variogram is the variance of different points with distance h. The obtained variograph of measured samples is called experimental variogram which is a vector value that is a dependent of distance and direction.

The properties variogram include threshold (sill=C0). The threshold is the maximum value of variogram which is spatial variance of the variable. The lowest value of variogram includes partial effect which shows variance of errors of measurements. The effective distance demonstrates the distance. That variogram has the highest value. Instead of variance, covariance shows the similarity of variables. Since arithmetic summation of similarity and dissimilarity is constant then it is possible to replace it with the average difference of points of distance h. The relation between variogram and co-variogram is defined as:

$$y(h)+c(h)= \sigma^2 \qquad (2)$$

Where:
σ^2=threshold
y (h): variogram value
c (h): co-variance value

2.4. Theory of common kriging

Kriging is a prediction method that considers values of a variable in unsampled points as a linear composition of the values of surrounding points. Considering the values of variable Z in n measured points as follow:
Z= (z(x,), Z (x2),….Z (xn))
Estimation of Z in point X0 using kriging estimation is defined as:

$$Z^*(x_0) = \sum_{i=1}^{n} \lambda_i z(x_i) \qquad (3)$$

The most important part of kriging is statistical weights assigned to λ_i .
To avoid bias of estimation, the weighted should be determined in a way that summation is equal to one $(\sum_{i=1}^{n} \lambda_i = 1)$ and the variance of estimates should be minimized as:

$$Var\ [z^*(x.)=E[(z^*(x.)-z(x.))^2]=Min \qquad (4)$$

2.5. Co-kriging theory

Co-kriging is a developed kriging which considers secondary variables. Given Z, as a primary variable measured in n_1 points and Z_2 as secondary variable measured in n_2 points of D space as follow:
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Where s and v are the location of samples in D=(s,r).
In such condition, Co-kriging estimation is defined as:

$$Z_1(s.) = \sum_{a1=1}^{n1} \lambda_{a1} z_1(s_{a1}) + \sum_{\beta 1=1}^{n2} \lambda_{\beta 2} Z_2(V_{\beta 1}) \qquad (5)$$

In this equation is estimation of variable z_1 in point s_0, $\lambda_{\alpha 1}$ and $\lambda_{\beta 1}$ statistical weights of primary and secondary variables. To avoid bias of the estimation, the following equations should be established.

$$\sum_{a_1=1}^{n_1} \lambda_{a_1} = 1 \qquad (6)$$

$$\sum_{\beta_2=1}^{n_2} \lambda_{\beta_1} = 0 \qquad (7)$$

For optimum estimation based on the mentioned limitations, Lagrange coefficients should be used those results in linear set with (n1 + n2 + 2) equations.

2.6. Weighted Moving Average (WMA)

In WMA technique, the value of weighting factor (λ_i) is estimated based on the following equation.
Where:

$$\lambda i = \frac{Di^{-\alpha}}{\sum_{i=1}^{n} D_i^{-\alpha}} \qquad (8)$$

D:the distance between observed and estimated points
α :equation order
n: number of observed points:
three mentioned methods were validated using the following criteria :

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(z^*(xi) - Qz(xi))^2} \qquad (9)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|z^*(xi) - z(xi)\right| \qquad (10)$$

It should be mentioned that the results of three described methods were obtained using GS^+ software.

3. Results

Since the first step for geostatistical application for a set of data is variogram analysis, then the results of variogram analysis in the study area were calculated (Table 1). Then kriging, co-kriging and WMA methods were applied (Table 2).

It is necessary to keep in mind that normality test was examined and logarithm of the data were used to avoid skewness. Figure (2) shows isohyet map of the study area.

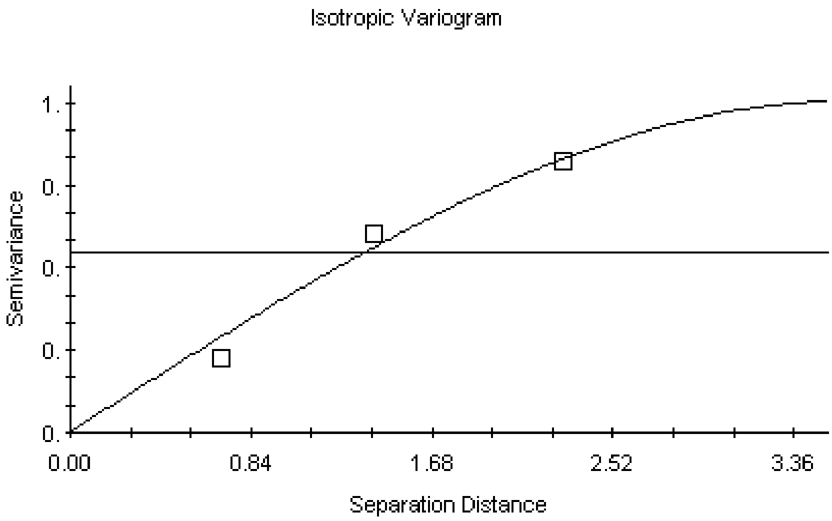

Fig. 2. Variogeram

Table 1. The properties of suitable variogram model of the variables

C_o/C_o+C	R_o	Sill	Nugget	Model	Variable
0.98	3.55	11010	5150	Spherical	Precipitation
1	3.37	2112000	1000	Gaussian	Elevation
1	0.7	29420	10	Gaussian	Correlation of elevation and precipitation

Table 2. The results of estimation of different geostatistical techniques

MAE	RMSE	Method of estimation
66.5	85.9	Kriging
98.2	147.3	Co-kriging
96	128.6	WMA-2
106.5	143	WMA-3
118.7	159.8	WMA-5

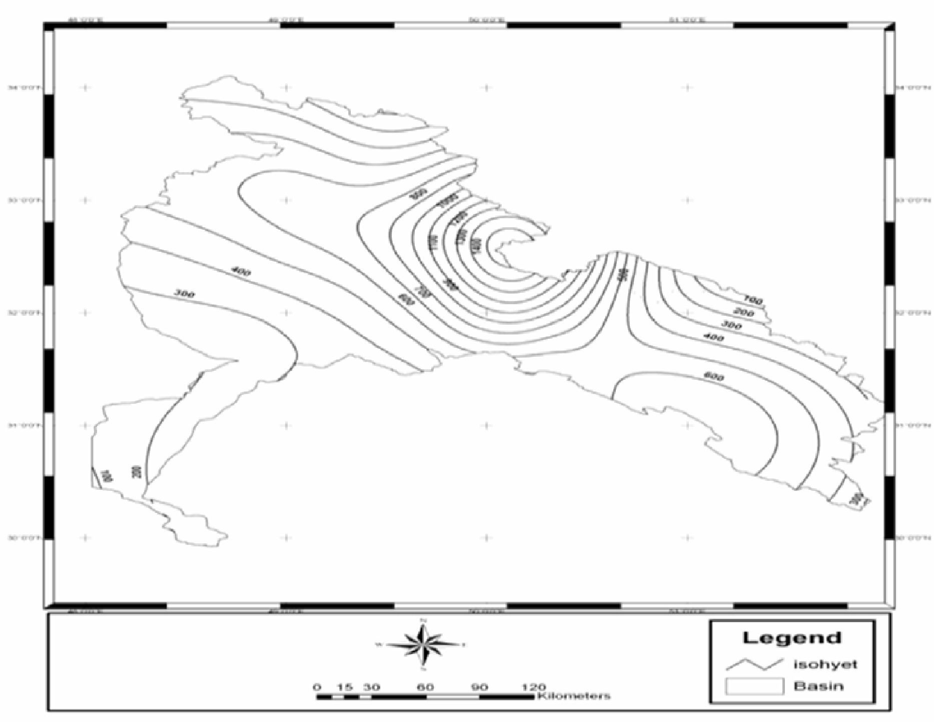

Fig. 3. Isohyet map of the study area

4. Conclusion

As seen in the variogram results (Table 1) the most appropriate models fitted to precipitation, elevation and elevation-precipitation variables are spherical and Gaussian models respectively. However the results of current study showed weak spatial structure of data but the most appropriate results based on the statistical comparisons showed high capability of kriging technique. The results also confirm the research conducted by Mahdavi et al. (2004) in arid and semi arid regions of southeastern of Iran, Diodata in southern of Italy (2005) and Russo (2005) in central Italy.

Since there was a weak correlation between elevation and precipitation in the study area then application of elevation data did not increased the precision of estimates while in case of high correlation between elevation and precipitation, considering elevation data would increase the precision of estimated results.

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