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ORIGINAL ARTICLE

Application of Geostatistics for Evaluation of Spatial variability of Precipitation concentration Index (PCI) in Ghazvin Province, Iran

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ABSTRACT
Variability of rainfall in space and time is one of the more obvious features of arid and semiarid climates. The temporal variability of precipitation that consists of long-term trends and changes, including changes in intra-annual rainfall in different months of the year are. Intra-annual Changes in rainfall is determined as Precipitation Concentration Index (PCI). The purpose of this paper focuses on PCI and its map preparation. Geostatistical (Kriging and co-kriging) was studied and best characterized. Based on the best way to map spatial interpolation of PCI is provided. Point information of studied variables in 74 meteorological stations of Ghazvin province, calculated. Point information is converted to regional to prepare of spatial variations map of PCI. Results indicate that Cokriging have lowest error and highest accuracy for interpolation of PCI. According to map of spatial variations in PCI, the highest amount of PCI in North, South and South East of study area is seen to include a plain areas. Precipitation concentration index ranged from 15 to 20 indicating the seasonality of rainfall and limited rainfall in certain months.
Key words: *Interpolation, Kriging, Precipitation Concentration Index*

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INTRODUCTION

Understanding of temporal and spatial characteristics of rainfall is essential to water resources planning and management. Such information is important in agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modeling, water resource assessments, climate change impacts and other environmental assessments [1]. Many studies on the temporal and spatial characteristics of rainfall were carried out [2, 3, 4, 5, 6].
No individual method can reveal the different statistical properties of precipitation variability, and each method has its own strength and weakness. One of these methods is precipitation concentration index. Intra-annual Changes in rainfall is determined as precipitation concentration index which was proposed by Oliver in 1982 [7, 8, 3, 9, 10]. This index gives the advantage of getting information on the long-term variability of the precipitations within a region and the yearly, monthly and seasonal regime [3, 9, 10]. The Precipitation Concentration Index (PCI) is a powerful indicator of the temporal distribution of precipitation, traditionally applied at annual scales; as the value increases, the more concentrated the precipitation [10]. De luis et al. (2011), the mean values of annual, seasonal and wet and dry periods of PCI in the conterminous Spain and for two normal periods (1946–1975 and 1976–2005) were studied.
The objective of this study was to showing the intra-annual and seasonal precipitation characteristics of Ghazvin Province, Iran. Another objective was to identify possible changes in the spatial distribution of PCI.

DATA AND METHODS

Ghazvin province, Iran, located in the central basin has an area of 15,821 square kilometers. Ghazvin between '45 ° 48 to '51 ° 50 'east longitude and '24 ° 35 '48 ° 36 north latitude, located up the mountain and plain is divided into two areas. It is located in the northern mountainous region. Climate of Ghazvin province contains 1 - cold weather mountainous northern province encompasses the southwestern highlands. 2 - Temperate climate in hilly slopes 3 - Relatively arid to semi-arid climate of central zones 4 -

Humid tropical weather in parts of the province. Average rainfall in Ghazvin province is about 330 mm per year.
For the present study were used monthly precipitation values recorded at 74 Ghazvin Province meteorological stations between foundation date and 2013.
The study approach is summarised as follows: Database construction and quality control of the rainfall data were first performed by checking for outliers and temporal homogeneity (using double mass analysis), investigation of the spatial distribution patterns of Precipitation Concentration Index using Geostatistical interpolation method throughout Ghazvin Province was carried out.
To assess variation of precipitation amount, Precipitation Concentration Index (PCI) was calculated, which was proposed by Oliver in 1982 [7, 8, 3, 9, 10].The following equations of PCI [10] were used to calculate the yearly variation:

$$PCI = \frac{\sum_{i=1}^{12} p_i^2}{(\sum_{i=1}^{12} p_i)^2}$$

Where pi is the precipitation of the *i*th month. The values index ranges from 8.3 to 100. For PCI values below 10, there is uniform monthly precipitation distribution over the year variabilityin precipitation amounts. Values from 11 to 15 denote a moderate seasonality in precipitation distribution, and PCI values from 16 to 20 denote a seasonal distribution. Values above 20 correspond to climates with substantial monthly variability in precipitation amounts. In this study to examine the spatial variation of PCI, first pci index was used in rainfall stations. In the next step using geostatistical interpolation methods (kriging and cokriging), this index interpolated in all of the stations. Finally, by evaluation of different interpolation methods, iso PCI map of Ghazvin province was prepared.

kriging

Kriging has since found its way into the earth sciences and other disciplines. It is an improvement over inverse distance weighting because prediction estimates tend to be less bias and because predictions are accompanied by prediction standard errors (quantification of the uncertainty in the predicted value) [11]. Kriging is a branch of geostatistical techniques that provides the best linear unbiased estimation of the variable of interest at an unobserved location from observations of the random field at nearby locations. In Kriging methods, the random variable Z is decomposed into a trend (m) and a residual (ε), where Z(x) = m(x) + ε (x) [12]. The Kriging estimator is given by a linear combination of the surrounding observations [13]).

Ordinary Kriging

Ordinary kriging is a common type of Kriging in practice. In the OK, the trend is considered as unknown and constant. OK estimates the unknown precipitation depth at the unsampled location as a linear combination of neighboring observations. The optimal weights are obtained through solving a series of linear functions known as the Ordinary Kriging System [13, 12), kriging techniques have added some constraints to the matrices, to minimize the error, and these techniques are unbiasedness estimations. Generally, these factors would describe some external limit (restriction) on the input data, which cannot simply be observed in the measured values [14].As discussed above, if the sum of all weighting coefficient is 1, kriging expression can be written as:

$$\gamma(Z_1-Z_1)\xi\lambda_1 + \gamma(Z_1-Z_2)\xi\lambda_2 + \gamma(Z_1-Z_v)\xi\lambda_v + \mu = \gamma(Z_1-Z)$$
$$\gamma(Z_2-Z_1)\xi\lambda_1 + \gamma(Z_2-Z_2)\xi\,\lambda_2 + \gamma(Z_2-Z_v)\xi\lambda_v + \mu = \gamma(Z_2-Z)$$

$$\gamma(Z_v-Z_1)\xi\lambda_1 + \gamma(Zv-Z2)\xi\,\lambda_2 + \square + \gamma(Zv-Zv)\xi\lambda_v + \mu = \gamma(Z_v-Z)$$
$$\lambda_{1\text{-}} + \lambda_2 + \square + \lambda_v + 0 = 1$$

If such a system of linear equations is shown as kriging matrices it can be written as [14]:

$$\begin{bmatrix} \gamma(Z_1-Z_1) & \gamma(Z_1-Z_2) & \dots & \gamma(Z_1-Z_n) & 1 \\ \gamma(Z_2-Z_1) & \gamma(Z_2-Z_2) & \dots & \gamma(Z_2-Z_n) & 1 \\ & & & & 1 \\ \gamma(Z_n-Z_1) & \gamma(Z_n-Z_2) & \dots & \gamma(Z_n-Z_n) & 1 \\ 1 & 1 & \dots & 1 & 0 \end{bmatrix} \times \begin{bmatrix} \lambda_1 \\ \lambda_2 \\ \\ \lambda_n \\ m \end{bmatrix} = \begin{bmatrix} \gamma(Z_1-Z) \\ \gamma(Z_2-Z) \\ \\ \gamma(Z_n-Z) \\ 1 \end{bmatrix}$$

The number of weighting coefficients and control points can be very large, but contemporary computers can successfully solve numerically demanding tasks. The estimation can be performed simply by calculating the influence of all control points weighted [14]:

$$Z = \lambda_1 \cdot Z_1 + \lambda_2 \cdot Z_2 + \dots + \lambda_n \cdot Z_n$$

Spatial correlation can be quantified with semivariograms. Kriging relates the semivariogram, half the expected squared difference between paired data values z(x) and z(x + h) to the distance lag h, by which locations are separated [15].

$$\mathbf{y}\ (\mathbf{h}) = \frac{1}{2}\ \mathrm{E}\left[\mathrm{z}\ (\mathbf{x}) - \mathrm{z}\ (\mathbf{x}+\mathbf{h})\right]^2$$

For discrete sampling sites the function is written in the form:

$$\gamma(\mathbf{h}) = \frac{1}{2N(h)} \Sigma_{i=1}^{N(h)} \left[\mathbf{z}(\mathbf{x_i}) - \mathbf{z}(\mathbf{x_i}+\mathbf{h})\right]^2$$

Where z (xi) is the value of the variable Z at location of xi, h is the lag, and N (h) is the number of pairs of sample points separated by h. In theoretical view point there are no differences between Cokriging and Kriging methods, in Cokriging method can accomplish estimating process by considering secondary variable which have sufficient data from that and according to cross correlation among main and secondary variables.

Four types of semivariogram models (Circular, Spherical, Exponential, and Gaussian,) were tested for PCI for the selection of the best one. Predictive performances of the fitted models were checked on the basis of cross validation tests. In this method in every stage, one observing point is omitted and with rest of observing point, that point will estimated. For estimating carefulness and slip MAE, RMSE and determination factor criteria are used that consist of:

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

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

MAE average of absolute value that introduce carefulness of method and amount of slip average, Isaks and Serivastara (1989) suggested that MAE can be used to compare carefulness of methods as a criterion that includes both method carefulness and deflexion. RMSE is square of MAE that whatever these criteria are close to zero indicates less difference among estimated amounts and observed amounts. Index interpolation and replacement plan preparation in Arc GIS software was accomplished.

RESULTS AND DISCUSSIONS

Descriptive statistics PCI index in Ghazvin province meteorological stations are presented in Table 1. PCI index has a lower coefficient of variation and skewness with respect to 1.1, data for this indicator are approximately normally distributed.

Table 1: Descriptive statistics of PCI of the meteorological station of Ghazvin

Vaiable	Mean	Standard deviation	Coefficient of variations	Minimum	Maximum	Skewness	Kurtosis
PCI	17.23	1.25	7.2	14.1	22.2	1.1	3.4

The results of different interpolation methods to precipitation concentration index are presented in Table 2. Cokriging interpolation method has better results in interpolation. In order to use geostatistical methods must be used to fit experimental variogram model theory, and then according to the model fitted interpolation to be done. Models included: circular, spherical, exponential and Gaussian is. In cokriging the auxiliary variable interpolation is used due to the high correlation coefficient of average annual rainfall , with precipitation concentration index (-0.608) was used as an auxiliary.

Table 2: Results of the evaluation of interpolation methods in precipitation concentration index

Interpolation method	MAE	RMSE	R^2
Cokriging	0.703	1.033	0.32
Ordinary kriging	0.786	1.142	0.17

The modified model fitted the experimental shots in a circular kriging and cokriging exponential type (Table 3). The impact radius of kriging was 191 kilometers and in cokriging was 73 km. $(\frac{C_0}{C_0+C})$ or the percentage measurement error in kriging 79% and 52% cokrigings, the error is relatively large (Table 3). These numbers represent the low and medium spatial correlation.

Table 3: Characteristics of precipitation concentration index model fitted the data

method	Fitted model	Impact radius(m)	Sill	Nugget effect	Measurement error (%)
Kriging	Circular	191220	0.35	1.394	79
Cokriging	Exponential	73364	0.77	0.892	52

According to Table 2, for mapping precipitation concentration index, the cokriging interpolation method with average annual rainfall of auxiliary variables used. Figure 1 shows the spatial distribution of Ghazvin gives Precipitation Concentration Index. According to the map, the highest amounts of precipitation concentration index (PCI) North-South and South-East region, which includes areas of study are plain and warm and is drier. Lowest in the North East and South West Ghazvin PCI index values are due to more rainfall and the climate is cooler and more rainfall.

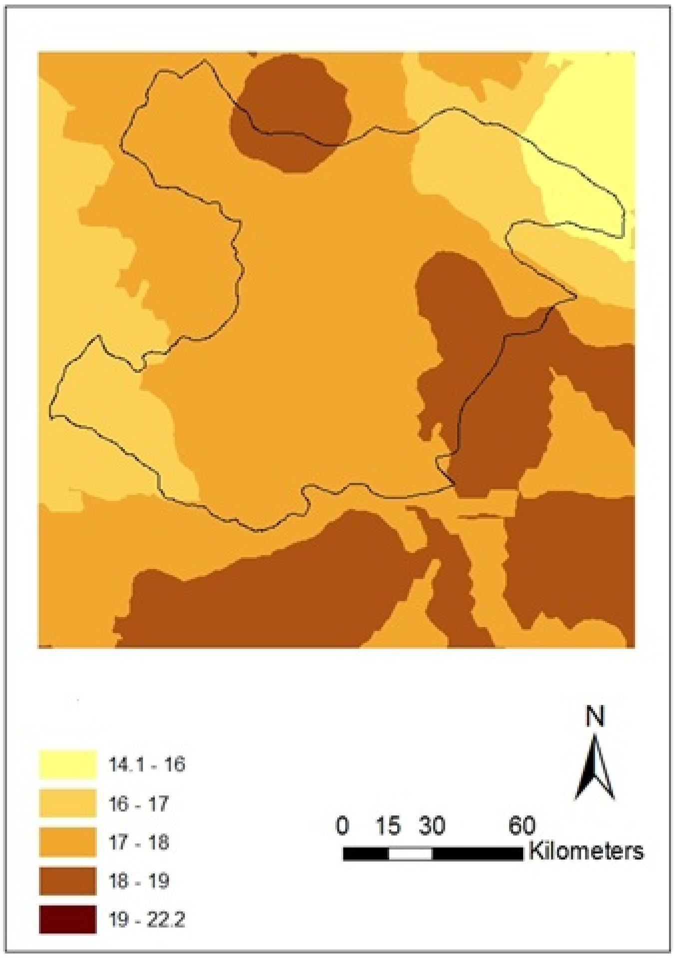

Figure 1 - Map of Ghazvin precipitation concentration index interpolation method cokriging

CONCLUSIONS

The geostatistical interpolation method used in this study cokriging has higher accuracy than other method of interpolation. The results of this study confirm the method of interpolation is appropriate. Use of auxiliary variables in cokriging in our country where lack of information and the limiting factor in the accuracy and quality of sample density interpolation is the most important and effective acts of environmental variables. In this method, the average annual rainfall variable was used as an auxiliary variable. Rainfall data are available easily and with high accuracy and the access to the auxiliary variables can be used effectively. The results with Taj Ali Pour et al(2009), Shesh Angosht et al(2005), Nourzadeh Haddad (2013) and Goovaerts (1999) is consistent. The researchers also examined various interpolation methods, cokriging interpolation suitable for their recognition. Ray et al (2012) to illustrate and explain the spatial variations in precipitation concentration index, kriging interpolation method was used. Evaluation studies show that interpolation methods vary depending on the characteristics of the study area, the density of measurement points and their arrangement, they cannot provide accurate results in a different area, easy to other district generalized. Therefore, it is necessary for each region and for each variable, separate studies were conducted to a suitable technique for the study area and the parameter can be obtained. Results of precipitation concentration index and its spatial distribution indicate that rainfall in Ghazvin province is seasonal and is limited to a few specific months. Precipitation concentration index ranged from 15 to 20.

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