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# A Geo-statistical Approach to the Change Procedure Study of Under-Ground Water Table in a GIS Framework, Case Study: Razan-Ghahavand Plain, Hamedan Province, Iran

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**Abstract**
Qualitative and quantitative parameters of underground water resources could be studied by taking discrete samples at different locations in study area. In this way, for change procedure study of mentioned parameters and to gain a deeper understanding of the phenomena, a continues surface need to be generated. The main purpose of Geo-Statistical analysis is creating or interpolating a continuous surface from discrete sample points; in the other hand, Geo-statistical Analyst, derives a surface using values from the measured sampling points to predict values for each location in the landscape. The ultimate goal is to produce a surface of predicted target values.

In Geo-Statistics, there are two main categories for interpolation: deterministic and geostatistical. The first category, based on the similarity and distance from measured points (Inverse Distance Weighting, Global Polynomial Interpolation, and Local Polynomial Interpolation) or the degree of smoothing (Radial Basis Functions); and second category employs some statistical properties of observed samples (Kriging and Co-Kriging).

This paper utilizes Geo-statistics for the estimation of underground water table at location of interest where measured values are not available. In this regard, by employing Kriging, IDW and RBF procedures, underground water table contours have been created. For best estimator selection, results have been validated by some statistical indices such as Mean Absolute Error (MAE), Mean Absolute Relative Error (MARE), Root Mean Square Error (RMSE), Mean Biased Error (MBE) and Coefficient of Correlation. Absolute relative error variation curve for the number of sample points used for examination of efficiency and accuracy of each Geo-Statistical estimators.

Eventually, Kriging method has been selected as the best method to estimate the underground water table of Razan-Ghahavand plain. In order to Kriging estimations, direction of underground flow, which is the major relevant issue to Hydro-Geologic studies, has been gained.

**Key words:** *Geo-Statistics, Underground water table, Statistical Indices, GIS.*

## 1-Introduction

A thorough knowledge of underground water resource situations could be lead to great important factors in development and management of such resources. Exploring the current situation and qualitative-quantitative mapping of target value in study area is one of the main steps in the water resources studies. In this regard, extracting and recording data related to evident resource periodically and regularly and the preparation of database plays the main role on analyzing and evaluating existent situation and some future predictions. So with having access to recorded data base from the set of bench marks and the use of Geo-statistics procedures, one can draw variation curves of target value in the limit of study area. It is remarkable to note that whatever the rate of contour value changes become attentive, the studies of further stages also grow more attentive.

Geo-statistical experts, regarding the needs, provide different procedures for generating the continuous surface from target values which each procedure has its own strengths and weaknesses. In this study under ground flow direction which is an important factor in relation to hydraulic connection of aquifers will be drawn with the use of Geo-statistical procedure in Razan-Ghahvand plain. The base information of mentioned spatial characteristic has been gained from exploration and piezometer wells in the area of interest. The stages of this study will be explained completely further.

## 2- Background of Research

Groundwater depth and drawdown monitoring is an essential step in characterizing groundwater systems which could be mentioned as the basic studies on hydro-geological studies. Mentioned spatial characteristics and some similar values are regionalized variables which have studied by so many researchers. Baalousha H. (2010) assesses the groundwater quality network using vulnerability mapping and geostatistics, his technical study is on Heretaunga Plains, New Zealand. In mentioned study, his methodology combines hydrogeology, as represented by vulnerability mapping that employs the DRASTIC approach, with geostatistics as represented by spatial variance. The results of both factors were combined, by GIS application and employing its tools, the result was a classified map that identified optimal sampling points [1]. Luc Feyen and Jef Caers study about "Multiple-point geostatistics". Most applications of geostatistics in hydrogeology have employed variogram-based techniques. Their study indicate that multiple-point geostatistics is potentially a very powerful tool to characterize subsurface heterogeneity for hydro-geological applications in a wide variety of complex geological settings [2]. Yun-Bin Lin et al studied on the first time analyzes a completely heterotopic dataset. Three methods of treating data with various associated uncertainty were conducted to relocate the dataset without destroying the spatial structure of the original dataset. Finally the results of their study show that the porous media compressions contribute 12% of the variation of the groundwater levels, over a distance of influence of 9 km, the hydro-geological heterogeneity of the sediments within the aquifer contributes 37%, over a distance of influence of 12 km and the cyclic loading of deviatoric stress contributes 51% over a distance of influence of 36 km. Winfried Schroder (2006) studied on "GIS, geostatistics, metadata banking, and tree-based models for data analysis and mapping in environmental monitoring and epidemiology". He has presented some applications of geographic information systems (GIS), geostatistics, metadata banking, and Classification and Regression Trees (CART). His studies cover these tools for mapping statistically estimated hot spots of vectors and pathogens and recommended the Geographic Information Systems for such these applications [3]. On 2008, Giuseppe Raspa et al, employs means of multivariate geostatistics for Geotechnical characterization of the upper Pleistocene–Holocene alluvial deposits. Technical study of mentioned paper is Roma (Italy) and they attempt to evaluate the spatial variability of geotechnical parameters in the upper Pleistocene–Holocene alluvial deposits of Roma by means of multivariate geostatistics. Dataset of this research have been gathered from 719 samples of 283 boreholes. In mentioned paper, relationships between the geotechnical parameters have been carried out. F. Bellotti et al (2010), studied on Geostatistics and multivariate analysis as a tool to characterize volcaniclastic deposits. Mentioned research has employs the dataset from Nevado de Toluca volcano, Mexico and they compare some statistical parameters and the way of their change with distance from the source [4]. On 2010, Donato Sollitto et al studied on Assessing heavy metal contamination in soils by multivariate geostatistics. They apply their methodology on Zagreb region (Northwest Croatia) by an extended dataset which have been gathered from all around the study area. By the co-regionalization analysis they show that some metals were characterized by both short-range and long-range variability [5]. E. Poizot et al (2006) studied on the application of geostatistics in defining the characteristic distance for grain size trend analysis. In mentioned research, they apply Geostatistics to improve the determination of a characteristic distance known as Dcr for Sediment trend analysis [6]. S.A.H.A. van Beurden and H.Th. Riezebos, Utrecht (1988) apply geostatistics in erosion hazard mapping. In their study, in order to improve the reliability of the input data for an erosion model, Kriging method has been applied instead of the conventional choropleth mapping [7]. Juan Guillermo Cobo et al (2010) for assessment of soil spatial variability at landscape level apply Integration of mid-infrared spectroscopy and geostatistics. In this study, Mid-infrared spectroscopy (MIRS) and geostatistics were integrated for evaluating soil Spatial structures of three land settlement schemes in Zimbabwe (i.e. communal area, old resettlement and new resettlement; on loamy-sand, sandy-loam and clay soils, respectively) [8].

### 3-The Location of study area

Study area of Razan-Ghahavand is located in Hamedan province with the area of 3083 square kilometer. Razan-Ghahavand plain has covered 72 percent of the study area which is about 2205 square kilometers. This study area is located between longitudes of 48˚ 45΄ to 49˚ 26΄ eastern hemisphere and latitudes of 34˚ 42΄ to 35˚ 37΄ northern hemispheres.  Map no.1 shows the location of the study area and Razan-Ghahavand plain.

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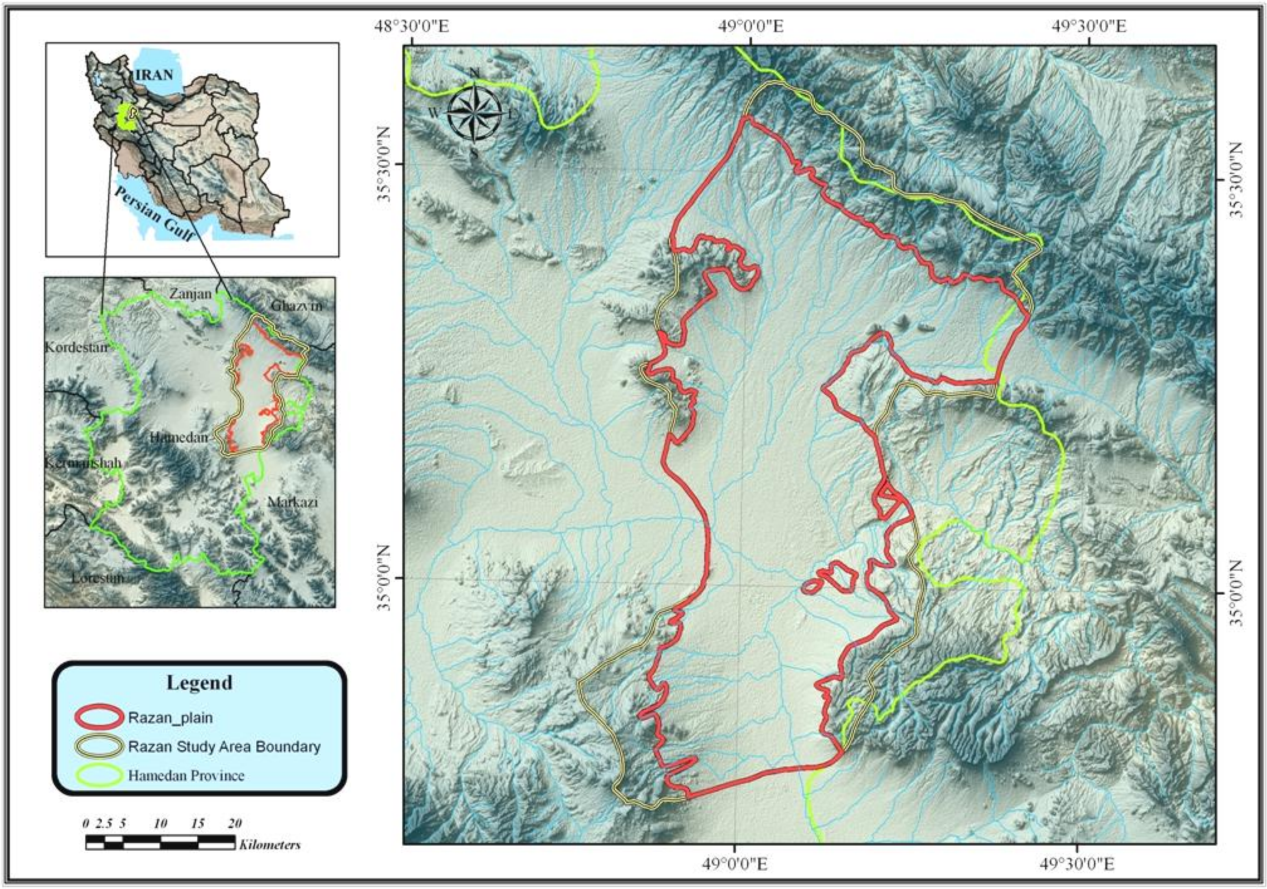


**Map No. 1: The Location of Study Area**

## 4-Methodology

Stages of this research concludes of collecting data, providing geo-database in GIS environment, using of Geo-Statistical procedures, comparing of the results of each noted procedure and selecting better estimator model. Figure no. 1 shows these stages in order.

## 5-Introduction of Geo-Statistics

In general, Geo-statistical procedure, based on Regionalized Variable theorem. Regionalized Variable refers to every environmental feature distributed in two or three dimensional space. The changes of this set of variables from one point to another are clear and their continuity is obvious. The features such as the depth of underground water, texture of soil and/or the amount of different elements in soil are examples of the regionalized variables. The major difference between classic statistics and Geostatistics is the effect and dependency of each statistical society member on others. In the other hand, that it is assumed that the samples collected form society are not depend on each other in classic statistics, therefore the existence of one sample does not give any information about the other samples located in certain distance. So regionalized variable theorem is based on the different environmental features which has regionalized dependency in the way that the amount of one environmental variable in close distance are similar and with distance increase this similarity

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decreases. Regionalized dependency between samples can be shown through a mathematical model entitled variogram. Variogram also known as variance of increment and that is a useful tool in determining the spatial behavior of a property distribution [9, 10 and 11]. Equation No. 1 defines the Variogram $\gamma(h)$:

$$\gamma(h)=\frac{1}{2}E\{[Z(x+h)-Z(x)]^2\}=\frac{1}{2N}\left(\sum_{i=1}^{N}[Z(x+h)-Z(x)]^2\right) \tag{1}$$

In which $Z(x)$ is observed value at a specified (x) location, h presents the distance from observed point and N shows the number of points.

### 5-1-Kriging procedure

Incorporating continuity in the estimation of property distribution was recognized by Krige [10, 11 and 17] as applied to gold mine in South Africa. This procedure is also known as Best Linear Unbiased Estimator (BLUE). Kriging method has based on statistical models and its estimations based on the logic of weighted moving average. Equation no.2 shows the method of estimation in Kriging procedure.

$$\hat{z}(x)=\sum_{i=1}^{n}\lambda_i.z(x_i) \tag{2}$$

In which $\hat{z}(x)$ is the estimated parameter, $\lambda_i$ is the weight of $i^{th}$ observation and finally, $z(x_i)$ is the $i^{th}$ observation point [10,12, 14 and 15].

### 5-2-The procedure of Inverse Distance Weighing or IDW

In general, things that are closer together tend to be more alike than things that are farther apart and it could call the fundamental of spatial characteristics. In this procedure, the target value of each observation point has the main effect on its neighborhood and this effect decreases when the locations get farther away. In other words, in this procedure, the amount of regional characteristic has been calculated with its neighbor observations in a weighted average manner. It should be considered that inverse of distance from one known sampling point to an unknown location have been applied as the weight measured point effect on unmeasured location. Equation No. (3) Describes the concept of IDW method.

$$\hat{z}(x_i)=\frac{1}{n}\sum_{i=1}^{n}z(x_i) \tag{3}$$

In that $\hat{z}(x)$ is the estimated characteristics and $z(x_i)$ is known characteristic [13, 16 and 17].

### 5-3-The procedure of Radial Basis Functions or RBF

RBFs are conceptually similar to fitting a rubber membrane through the measured sample values while minimizing the total curvature of the surface. In general speaking, RBFs are exact interpolators that create smooth surfaces. They produce

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good results for gently varying surfaces. Because predictions are exact, RBFs can be locally sensitive to outliers. RBFs are procedure which contains 5 kinds of radial functions as explained through following. There is not a great difference between the results of each radial functions. The selection of the radial basis function could be done by cross validation of results of estimations, in the same way with IDW and Kriging methods. It could mentioned that cross validation is used to determine "how good" the model is. It is worth to note that Root Mean Squared Prediction Error (RMSPE) could describe the accuracy of prediction and more accuracy in prediction could lead to more efficiency and workability of estimations. In this method, with taking distance from known points, the estimated amount will change. The equations no.4 to no.8 introduces these functions in order: TPS[1], MQ, IMQ, CRS, and SWT. The CRS function is used in this research. The procedures and the functions of RBF are a form of Artificial Neural Networks (ANN). [17].

$$\hat{z}(r) = (\sigma.r)^2.\ln(\sigma.r) \quad (4)$$

$$\hat{z}(r) = (r^2 + \sigma^2)^{0.5} \quad (5)$$

$$\hat{z}(r) = (r^2 + \sigma^2)^{-0.5} \quad (6)$$

$$\hat{z}(r) = -\sum_{n=1}^{\infty} \frac{(-1)^n . r^{2n}}{n!n} = \ln(\frac{\sigma.r}{2})^2 + E_1(\frac{\sigma.r}{2})^2 + C_E \quad (7)$$

$$\hat{z}(r) = \ln(\frac{\sigma.r}{2}) + K_0(\sigma.r)^2 + C_E \quad (8)$$

In these equations $\sigma$ is Tension Parameter, $E_1$ is Exponential Integral Function, $C_E$ is Euler Constant, and $K_0$ is Modified Bessel Function.

## 6-Establishing and Validating Geo-Statistical Model

Validation dataset have been selected from main dataset, randomly. The number of validation sample points is about 20% of the number of main dataset sample points. In a Geographic Information Systems framework and employing appropriate tools, Random selection has been done and random samples could be gained. After random selection stage, Kriging, IDW, and RBF have to be validated. The results of mentioned methods are shown in the figure no.2. One of the criteria in examining of the validity of the attained results from Geo-Statistical methods is the Coefficient of correlation (r). Whatever its absolute value gets closer to 1, the better adaptation between the observed values and predicted ones exist. It would be considered that just by employing the Coefficient of correlation (r), one can not declare anything about the efficiency and the accuracy of the method; therefore other parameters and statistics will be used for examining the selected method. In this regard, as it mentioned before the criteria of Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Relative Error (MARE) and Mean Bias Error (MBE) have been used to complete evaluations. The equations number (9) to (13) shows these parameters in order. The amount of mentioned statistical indices, in both training and testing (validating) stages Geo-Statistics methods are shown in Table no. 1.

[1]Thin-Plate Spline

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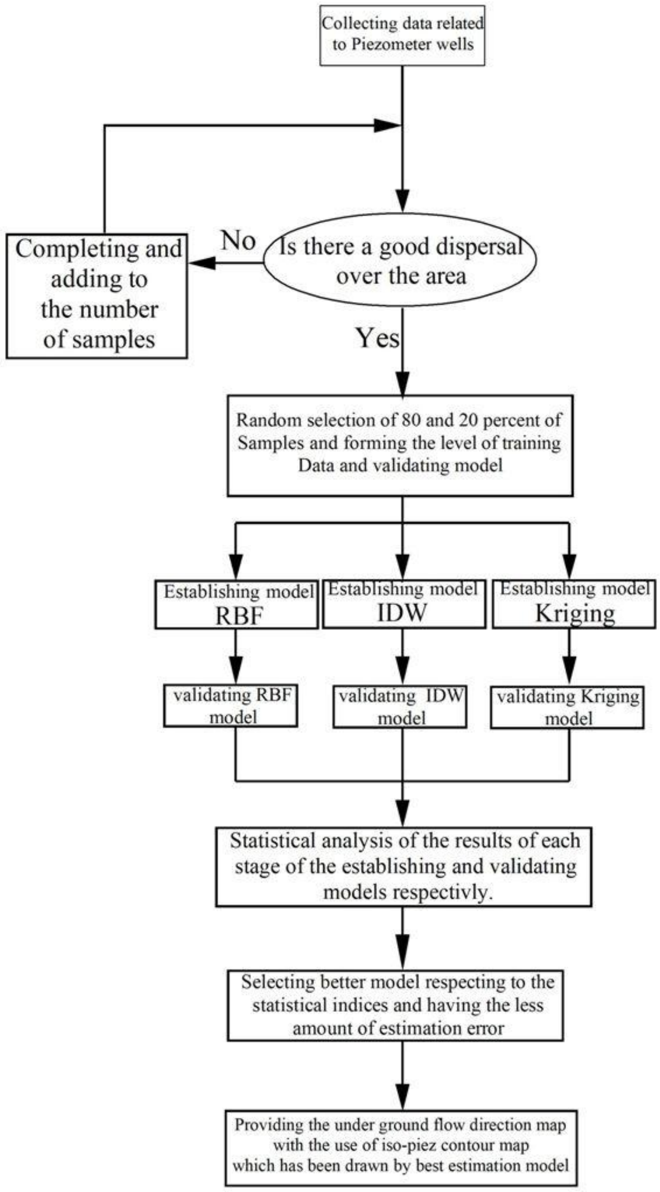


**Figure no.1: research procedure**

$$r = \frac{\sum_{i=1}^{n}(p_i - \bar{p})(O_i - \bar{O})}{\sqrt{\sum_{i=1}^{n}(p_i - \bar{p})^2 (O_i - \bar{O})^2}} \quad (9)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2} \quad (10)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|O_i - P_i| \quad (11)$$

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$$MARE = \frac{1}{n}\sum_{i=1}^{n}\frac{|O_i - P_i|}{O_i} \qquad (12)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(O_i - P_i) \qquad (13)$$

In these equations, $O_i$ is the observed amount, $P_i$ is the predicted amount and *n* is the number of observations. The above introduced features are the whole statistical indices which do not provide any information about the procedure of error distribution; therefore for evaluating the capacity of the methods, a statistical feature needed which specifies how errors distribute in the estimations. In this regard, Absolute relative error variation curves for the number of sample points used for examination of efficiency and accuracy of each Geo-Statistical estimators. (Figure No. 9 and 10 for training and testing (validation) stages, respectively).

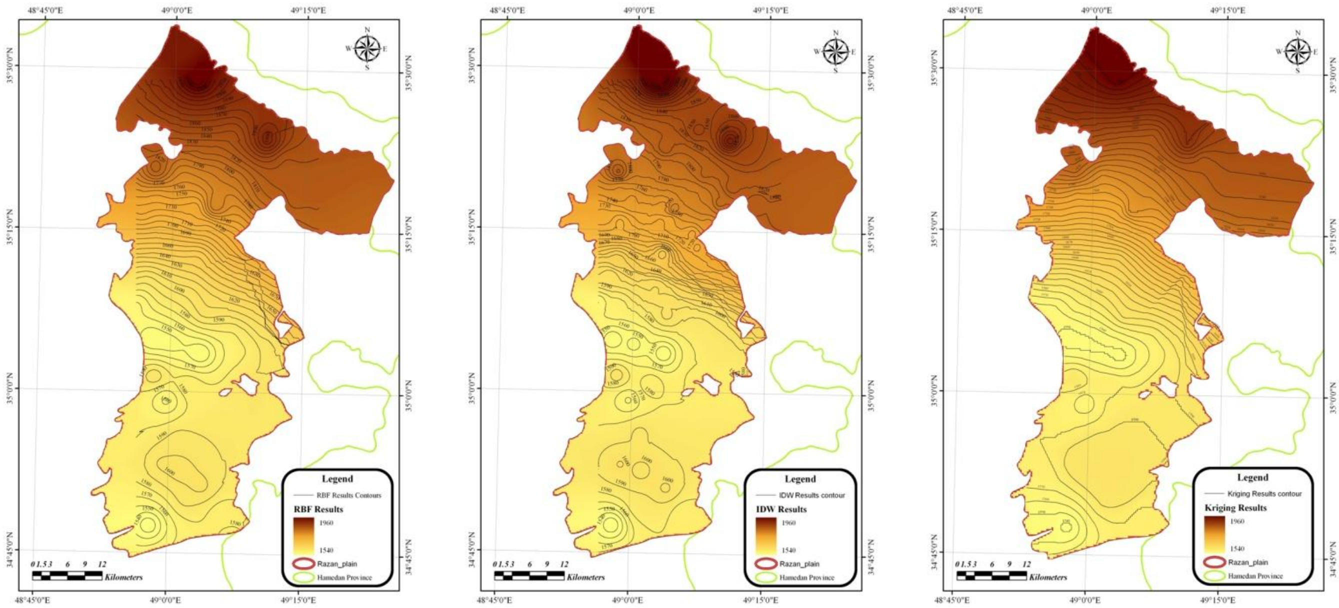


**Figure no. 2: Comparison of Underground water table curves, the result of RBF, IDW and Kriging methods (from left to right, respectively)**

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**Table no. 1: Comparison of different Geo-Statistics procedures with the use of statistical indices**

| Test Stage | Training Stage | Statistical Index | |
|---|---|---|---|
| *0.9828* | *0.9462* | *R2* | Kriging |
| *12.65* | *17.3* | *MAE* | |
| *0.0072* | *0.01* | *MARE* | |
| *17.92* | *26.51* | *RMSE* | |
| *4.79* | *2.49* | *MBE* | |
| *0.9617* | *0.9321* | *R2* | IDW |
| *19.91* | *20.37* | *MAE* | |
| *0.011* | *0.011* | *MARE* | |
| *28.91* | *31.63* | *RMSE* | |
| *14.77* | *3.39* | *MBE* | |
| *0.9797* | *0.9437* | *R2* | RBF |
| *13.31* | *17.28* | *MAE* | |
| *0.0076* | *0.01* | *MARE* | |
| *20* | *27.51* | *RMSE* | |
| *8.71* | *2.11* | *MBE* | |

Figures number 3 to 8 present a comparison between the observed values and predicted amounts in two stages of establishing and validating of each method. As it is obvious in these figures, Kriging procedure always has provided better results. The earlier proof to this issue is table no. 1.

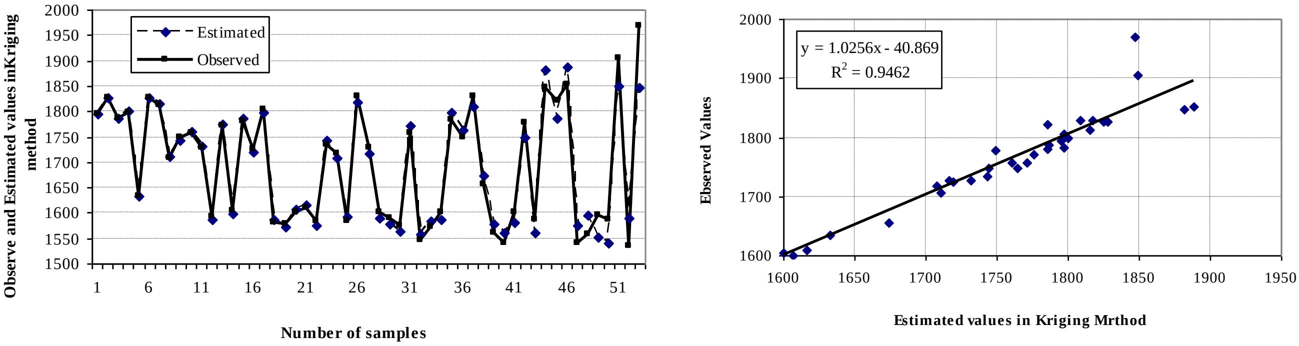


**Figure no. 3: A comparison between the observed and the predicted values in establishing stage of Kriging method**

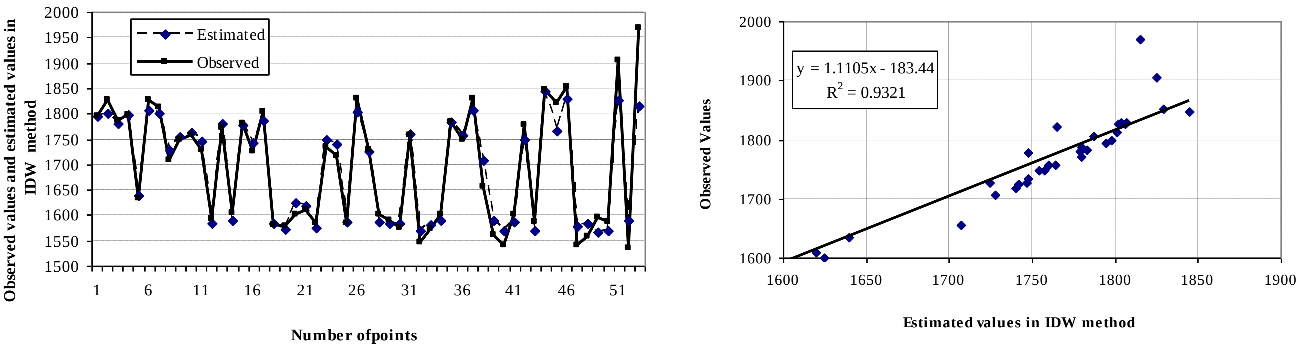


**Figure no. 4: A comparison between the observed and predicted amount in the stage of establishing of IDW method**

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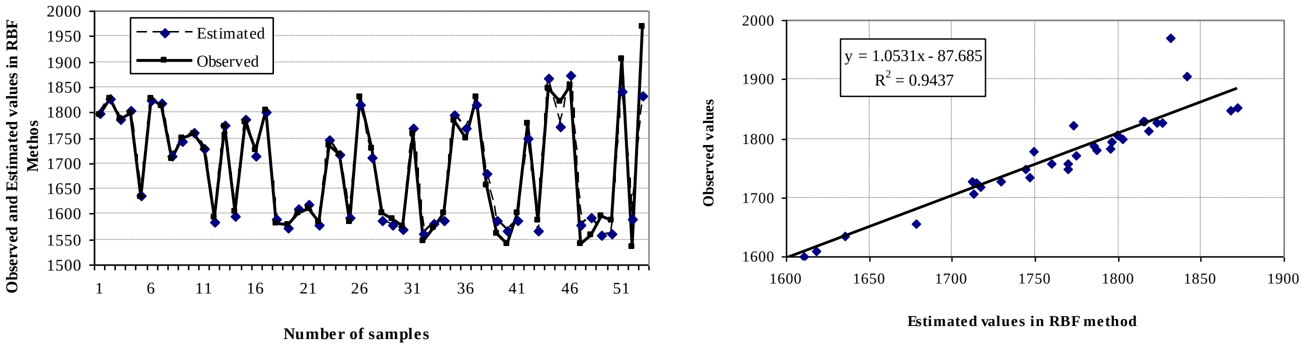


**Figure no. 5: A Comparison between the observed and predicted values in the establishing stage of RBF method**

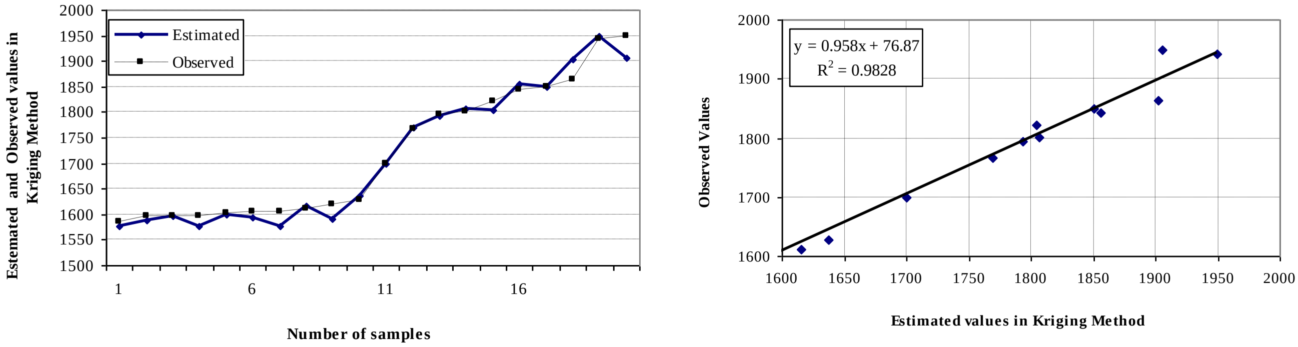


**Figure no. 6: Comparison of observed and predicted values in validating stage of Kriging method**

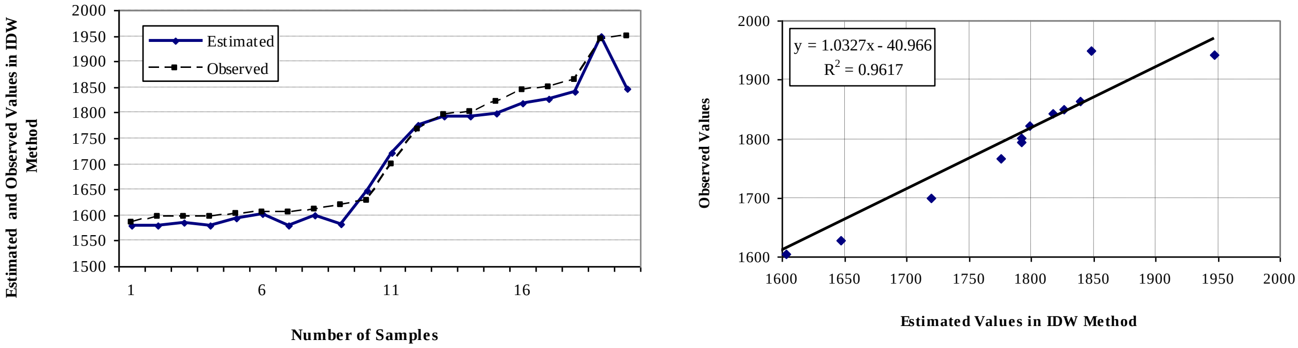


**Figure no.7: Comparison of observed and predicted values in the validating stage of IDW method**

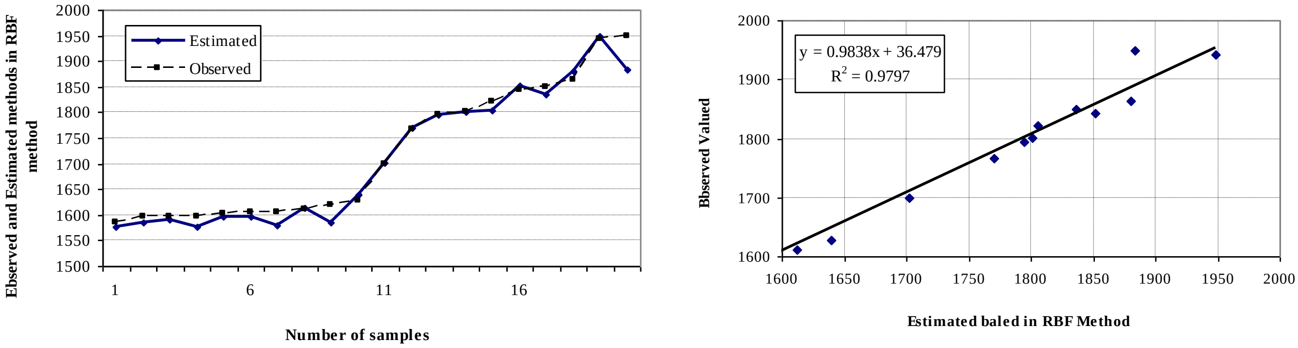


**Figure no.8: Comparison of observed and predicted values in the stage of validating RBF method**

## 6-1-The selection of accurate Geo-Statistical method

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In this research, for prediction accuracy assessment, not only Absolute relative error variation curve for the number of sample points is used, but also statistical parameters (table no.1), and comparison between the observed and predicted values (figure number 3 to 8) have been employed. In figure No. 9 and 10, it easily could be concluded that for specific percent of sample points, how much the mean absolute relative error is. Also, from mentioned graphs the state of distribution of mentioned error, could be gained in each stage of Geo-Statistical analysis.

For instance, it is possible to declare that "mean absolute relative error" of about 80 percent of predictions in establishing stage for all assessed methods (Kriging, RBf and IDW) is less than 1.5%. 70 percent of the predictions in Kriging and RBF establishing stage have relative error less than 1 percent, and this error in IDW approach is about 1.2%. It worth to say that mean absolute relative error of all Kriging predictions in the validation stage, has less relative error than 2.5%, mentioned error in IDW and RBF method is about 5.2% and 3.4%, respectively.

By considering these conclusions about mean absolute relative error and also results of statistical analysis, Kriging method has selected as the best and accurate prediction approach in order to RBF and IDW predictions. Eventually, Mentioned BLU Estimator (Best Linear Unbiased Estimator) is selected for underground water table estimation in unmeasured locations. It should be mentioned that, in Kriging method, Spherical Variogram used for creating Geo-Statistical model for predictions. In this research, the equation of spherical Variogram has presented in equation No. 14.

$$\gamma(h)=\begin{cases}\omega\left[\dfrac{3}{2}\left(\dfrac{h}{a}\right)-\dfrac{1}{2}\left(\dfrac{h}{a}\right)^{3}\right] & (h\le a)\\ \omega & (h>a)\end{cases} \qquad (14)$$

In this equation, $h$ describes distance from each known point and $\omega$ and $a$ are constant values.

**6-2-Providing underground flow direction vector map by applying the concepts of Kriging method as selected Geo-Statistical prediction method**

In this part, by having the concepts of Kriging method and employing the selected variography (spherical Variogram), underground flow direction has been generated. The general direction of underground flow is from the north towards the south of the plain and from the central part of study area, underground flow leaves the plain. Figure No. 11 shows the direction of the underground flow in the Razan-Ghahavand plain.

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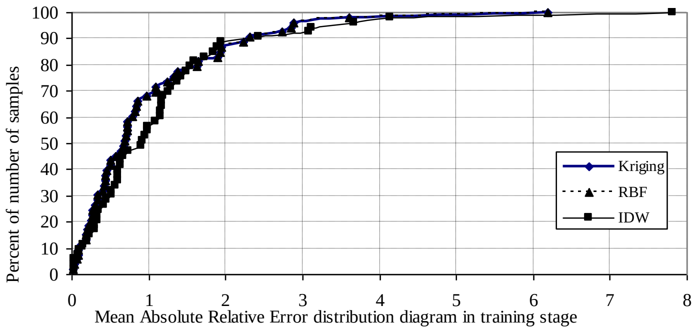


**Figure No.9: Absolute relative error variation curve for the number of sample points in the establishing stage**

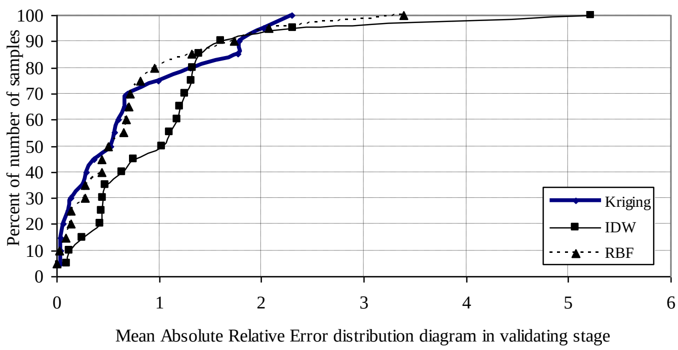


**Figure No. 10: Absolute relative error variation curve for the number of sample points in the testing (validating) stage**

## 7-Conclusion

This paper presented an application of the Geo-Statistical technique to study the spatial variation of underground water table in Razan-Ghahavand plain. It is concluded that geostatistical technique is useful to study the spatial variation of the mentioned spatial regionalized character in the area of interest.

With the use of Geo-Statistic procedures and statistical analysis of results, it is tried to find out the best estimator of underground water table in area of interest. The best estimator is Kriging model respecting part no.6.

Respecting to Mean Absolute Error (MAE), the amount of absolute error, has extracted for each Geo-Statistical method (Table No. 1). With regard to table No.1, Kriging method has the best estimate which has the least absolute estimation error.

The amount of Mean Biased Error (MBE) and respecting equation No. 13, one can see this point that if MBE is negative there might be an overestimated prediction, and if it is positive, the estimation is underestimating. In the other hand, MBE is negative when the elevation of observed underground water is less than the predicted one, so there might a misunderstanding about true situation of underground water table; this misunderstanding could be lead to mismanagement of underground water resource. So, positive MBE is more reliable and it is acceptable for estimating the volume of extractable water from aquifer.

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Change procedure determination of quantitative and qualitative parameters could counted as the input data for further studies of water resources; so selecting the best estimator method and its careful estimation has a direct influence on the carefulness of further stages.

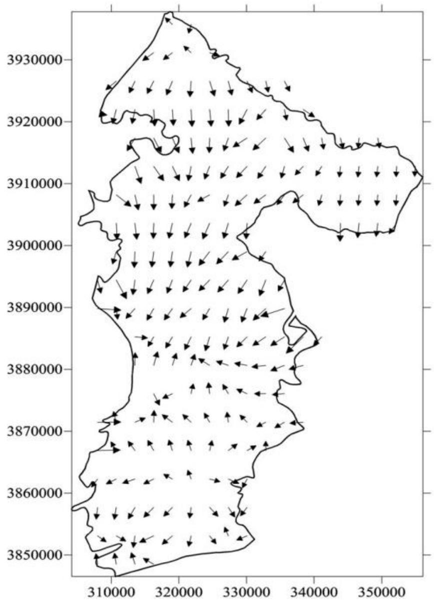


**Figure No. 11: Direction of the underground flow in the studied plain**

## 8-Suggestions

1. Optimization of constant coefficients such as tension parameter in RBF procedure and power in IDW procedure, for better estimations has recommended. (Application of statistical indices in validation of predictions is undeniable).

2. The comparison of the results of Geo-Statistics and the procedures of Hutchinson (more information about Hutchinson method prepared in reference No. [17]) method in providing the Iso-maps and cross validation of each method by Mean Absolute Relative Error distribution assessment graph.

3. Sensitivity Analysis (SA) of underground water table to location changes in the area of interest.

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