

Geostatistical analysis of groundwater levels in the south Al Jabal Al Akhdar area using GIS

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Abstract. The geostatistical analysis of the groundwater levels from 95 water wells in south Al Jabal Al Akhdar area north east Libya was conducted according to GIS methodology. Water level data firstly was explored for normality using exploratory spatial data analysis (ESDA) tools, as the transformation was required to drive the data into normality. Spatial interpolation also was carried out using geostatistics ordinary kriging model through out modeling semivariogram and covariance. Afterward the surface was generated for water level map, which shows the groundwater is at a deeper level in the northern parts of the study area. However, it gradually becomes shallow in the south. Mapping potentiometric surface was conducted from digital elevation model (DEM) and groundwater level raster, where it shows high values in the northern parts of the study area, this high values decreases to the southern parts of the area. Furthermore, four water divides were defined from the potentiometric surface.

Keywords: geostatistical analysis, groundwater levels, ordinary kriging

1 Introduction

The study area, as shown in Figure 1, is located on the southern slope of Al Jabal Al Akhdar area, which represents a mountain range along the northern coast of north-eastern Libya, located approximately 31° N, and 23° E, with areal extent about 20,000 km², extending from Wadi Al Bab in the west to Tamimi in the east, and from Taknis and Sidi Al Humree in the north to the Balat areas in the south. On other hand, the boundary of the study area represents the southern wadies catchments.

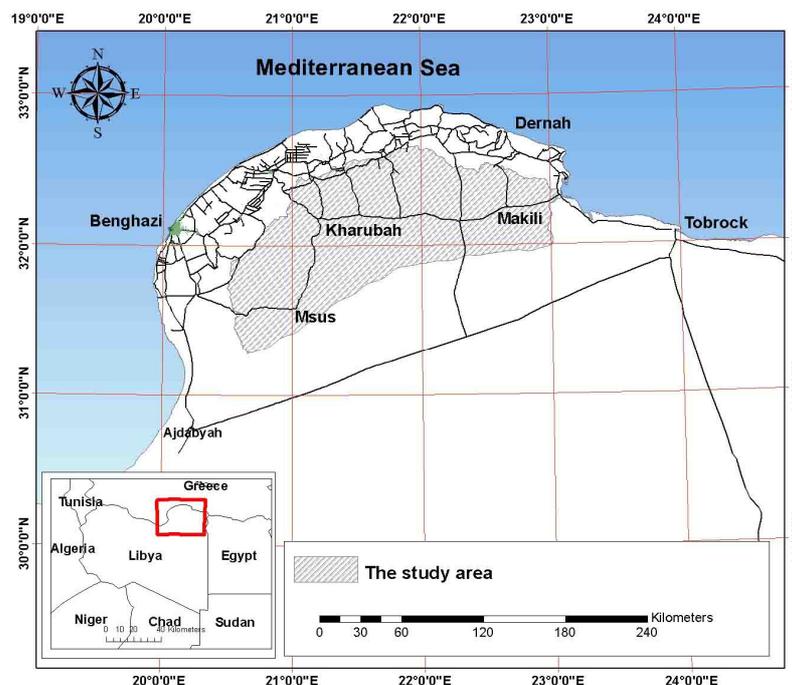


Fig. 1. Location map of the study area.

2 Objectives

The overall general goal of this paper is to study the pattern of a spatial distribution of groundwater levels in south Al Jabal Al Akhdar area using contemporary techniques that are inherent in the Science of Geographic Information Systems (GIS).

3 Methodology

The applied GIS methodology for the spatial analysis of the groundwater levels is as illustrated in Figure 2, and involved the following steps:

- Exploratory spatial data analysis (ESDA) using ArcGIS software for the water level to study the following:
 - Data distribution.
 - Global and local outliers.
 - Trend analysis.
- Spatial interpolation for water level data using ArcGIS software, while ordinary kriging is applied by involving the following procedures:
 - Semivariogram and covariance modelling.
 - Model validation using cross validation.
 - Surfaces generation of the groundwater level data.

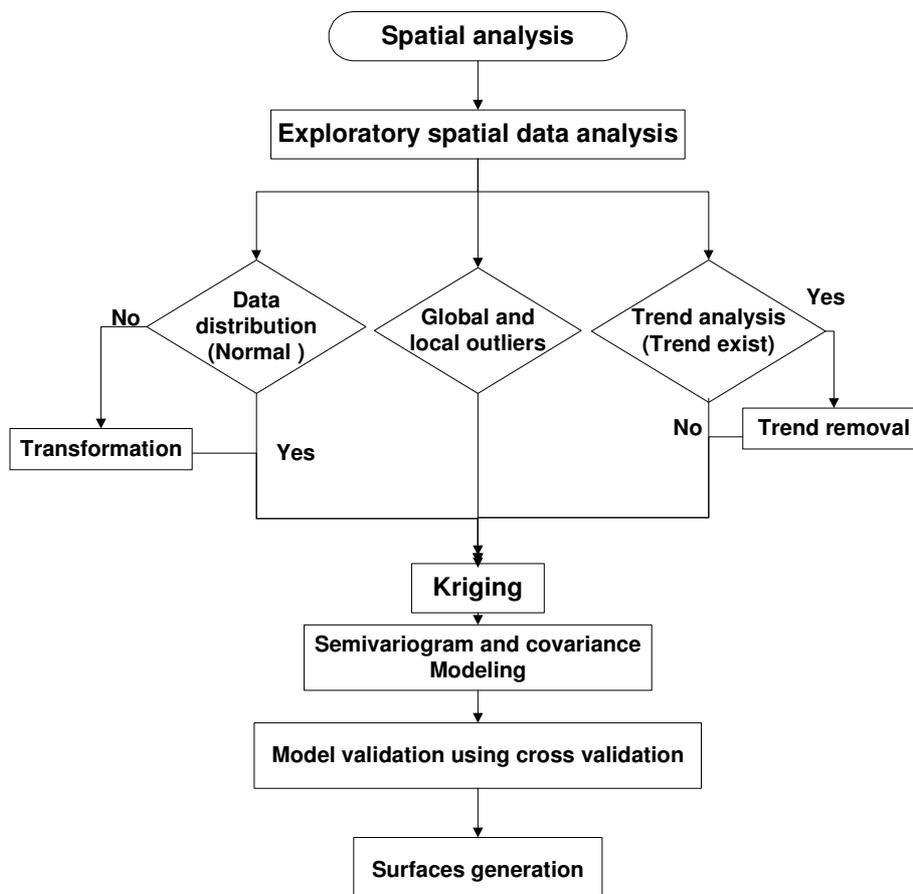


Fig. 2. Flow chart of the geostatistical analysis steps

4 Groundwater level and Potentiometric level

Groundwater level represents the theoretical surface which is approximated by the elevation of water surfaces in the wells which penetrate only a short distance into the saturated zone. If ground-water flow is horizontal, then water levels in the wells will correspond very closely to the water table. The presence of the wells, nevertheless, will distort slightly the flow pattern and hence the water levels in the wells. The most common definitions of the water table state that it is the surface separating the capillary fringe from the zone of saturation, or that it is the surface defined by the water levels in wells which tap an unconfined saturated material. A more exact definition states that the water level is the surface in unconfined material along which the hydrostatic pressure is equal to the atmospheric pressure [3].

Potentiometric level is an imaginary level representing the total head of groundwater and defined by the level to which water will rise in a well [2]. Mathematically, the potentiometric level is the result of subtraction of the water level from ground elevation.

5 Geostatistical analysis Analysis

GIS is designed to support a range of different kinds of analysis of geographic information: techniques to examine and explore data from a geographic perspective, to develop and test models, and to present data in ways that lead to greater insight and understanding [7]. A linkage between GIS and spatial data analysis is considered to be an important aspect in the development of GIS into a research tool to explore and analyze spatial relationships [1].

5.1 Exploratory spatial data analysis

Exploratory spatial data analysis (ESDA) as an extension of EDA to detect spatial properties of data. Need additional techniques to those found in EDA for:

- Detecting spatial patterns in data.
- Formulating hypotheses based on the geography of the data.
- Assessing spatial models.

ESDA is used to examine the data in different ways, and give a deeper understanding of the investigated phenomena to make better decisions on the issues related to the data. There are certain useful tasks those can be performed on the data in most explorations [4].

5.1.1 Distribution of the groundwater levels data

There are some methods of spatial modelling that are working better if the experimental distribution of available data is close to normal one, therefore it is necessary to check for normality before performing any spatial modelling. Transformations are necessary to drive the data to normal distribution in case of non-normality, where several transformations including Box-Cox also known as power transformations, arcsine, and logarithmic one, can be used to make the data more normally distributed [5]. The groundwater levels data are plotted in the histogram as illustrated in Figure3, where groundwater level data is not normally distributed, as it's also obvious from the statistic in Table 1, where the mean value is larger than the median value. Therefore they were transformed to be approximately close to the normal distributed by log transformation as in Figure 4 and Table 2.

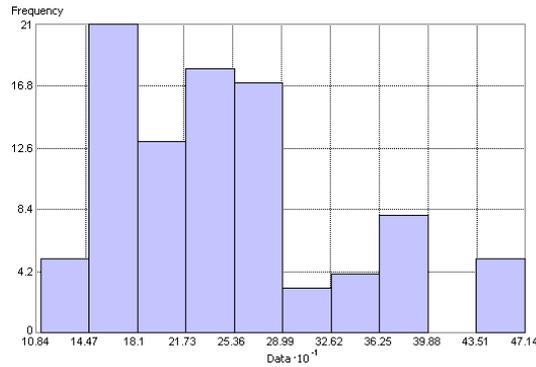


Fig. 3. The histogram for groundwater level data before transformation.

Table 1. Statistic of groundwater levels data before transformation.

Min	112
Max	471.3
Mean	247.98
Median	241.63
Standard deviation	84.241
Skewness	0.82226
Kurtosis	3.1768

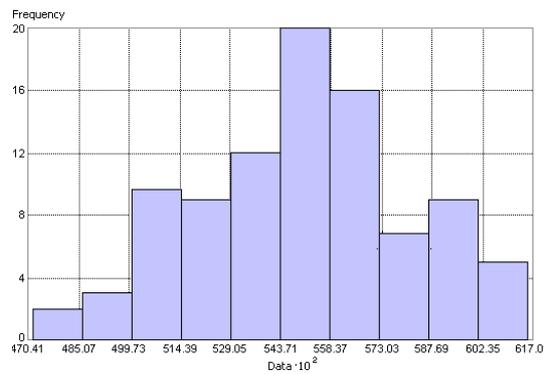


Fig. 4 The histogram for groundwater level after log transformation.

Table 2. Statistic of groundwater levels data after log transformation.

Min	4.7185
Max	6.1555
Mean	5.4589
Median	5.4872
Standard deviation	0.33054
Skewness	0.11288
Kurtosis	2.4638

5.1.2 Global trends

Trend is a surface that may be made up of two main components: a fixed global trend and random short-range variation. The global trend is sometimes referred to as the fixed mean structure. Somewhat different approach to ESDA for continuous data represented as a point set with z-values is to examine whether any simple trends are present [5]. During the field measurements of the groundwater levels, most of the low water level data in the southern parts of the study area, while the high values tend to be in the north. This spatial trend can be further analyzed using a three-dimensional perspective using ArcGIS geostatistical analyst trend analysis tool (Figure 5). The green line shows the data values decreased from the west to the east of the study area, while the blue line also decreased from the north to the south.

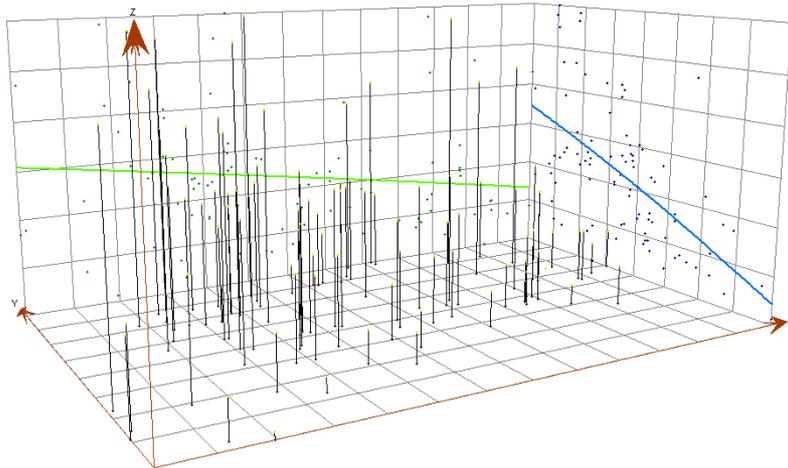


Fig. 5. Trend Analysis for the groundwater level data.

5.1.3 Identifying global and local outliers

A global outlier is a measured sample point that has a very high or a very low value relative to all of the values in a dataset. For example, if 99 out of 100 points have value between 300 and 400, but the 100th point has a value of 750, the 100th point may be a global outlier. Local outlier is a measured sample point that has a value that is within the normal range for the entire dataset, but, when compared to the surrounding points, it is unusually high or low [5]. Both global and local outlier were remarked as illustrated in Figure 6. That figure shows a semivariogram cloud developed by ArcGIS software geostatistical analyst for the groundwater level data in south Al Jabal Al Akhdar area, and through out office and field check of the data these outliers represent a real abnormalities in the groundwater levels data, and can be interpreted as the effect of the topography in the study area.

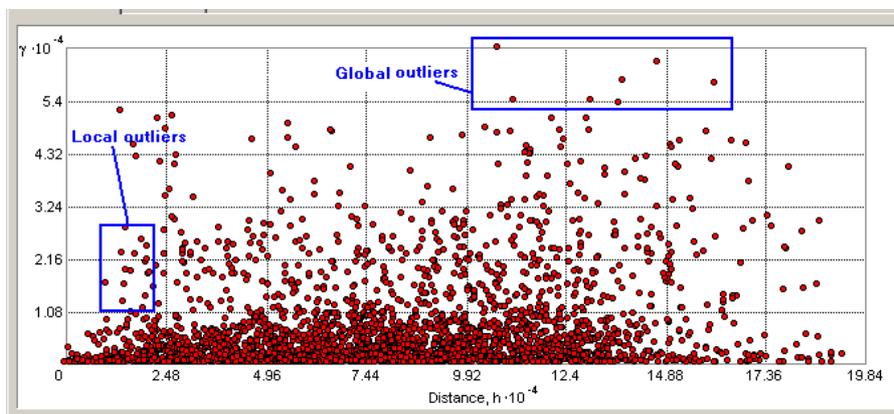


Fig. 6. Semivariogram cloud shows the global and local outlier for the groundwater level data in south Al Jabal Al Akhdar area.

6 Spatial interpolation

6.1 Modeling semivariogram and covariance

Kriging is divided into two distinct tasks: quantifying the spatial structure of the data and producing a prediction. Quantifying the structure, known as variography, is where the fit of a spatial-dependence model to the data. Making a prediction for an unknown value for a specific location, kriging will use the fitted model from variography, the spatial data configuration, and the values of the measured sample points around the prediction location. Variography is the process of estimating the theoretical semivariogram. It begins with exploratory data analysis, then computing the empirical semivariogram, binning, fitting a semivariogram model, and using diagnostics to assess the fitted model. The semivariogram and covariance function quantify the assumption that things nearby tend to be more similar than things that are farther apart. They both measure the strength of statistical correlation as a function of distance[5].

The detrending of the data using was carried out the const order of trend that means a zero-order (constant), afterward modeling semivariogram and covariance was carried out as illustrated in Figures 7 and 8, and the best-fitted semivariogram model parameters are in Table 3.

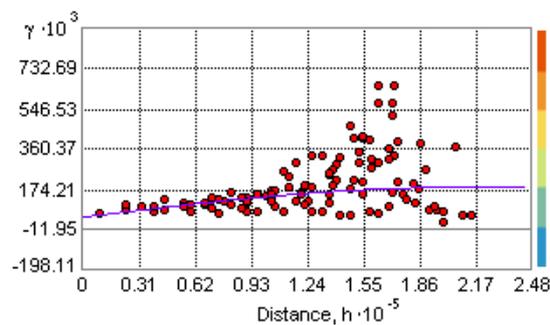


Fig. 7. Semivariogram model for the groundwater level data.

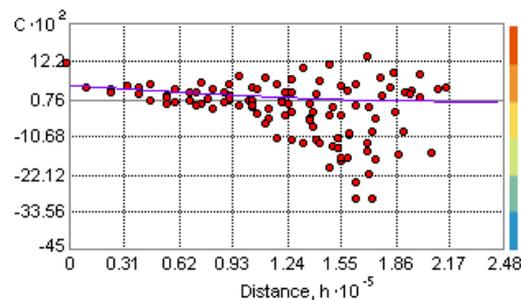


Fig. 8. Covariance model for the groundwater level data.

Table 3. Best-fitted semivariogram model parameters of groundwater level data.

Model	Spherical
Partial sill	0.057687
Nugget	0.050406
Lag size	16324
Number of lags	15
Angle direction	76.9
Angle tolerance	45
Bandwidth(lags)	10

Validation should be carried out before producing the final surface, where it helps in making an informed decision as to which model provides the best predictions should have. The most popular methods for verifying predictions are cross validation and validation provided in ArcGIS Geostatistical Analyst. In this research only the cross validation was used for model validation [6].

Cross validation of the modeled semivariogram and covariance was plotted as illustrated in Figure 9, where the calculated statistics as in Table 4, which serve as diagnostics that indicate whether the model and/or its associated parameter values are reasonable.

If the mean prediction error is near zero, predictions are centred on the measurement values. The closer the predictions are to their true values the smaller the root-mean-square prediction errors. The average root-mean-square prediction errors are computed as the square root of the average of the squared difference between observed and predicted values. For a model that provides accurate predictions, the root-mean-squared prediction error should be as small as possible. The average standard error and the mean standardized prediction error should be as small as possible. Also the root-mean-squared standardized prediction error should be close to one [6].

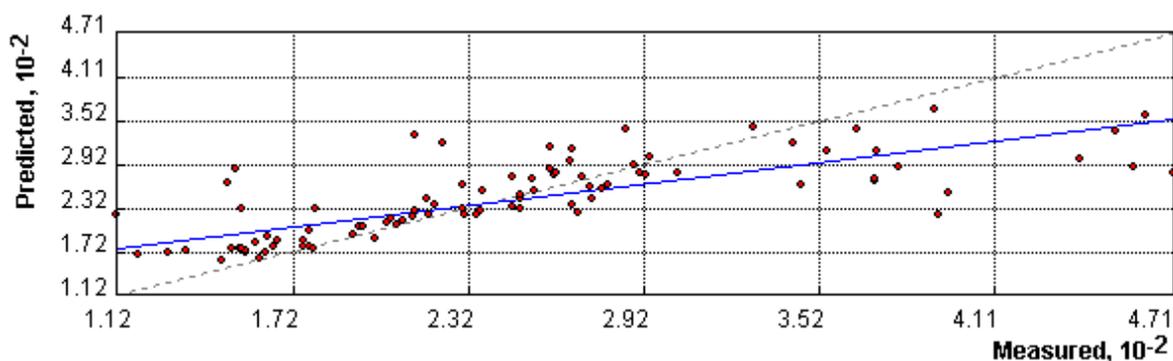


Fig. 9. Cross validation of the modeled semivariogram and covariance for the groundwater level data.

Table 3. Calculated statistics of the cross validation.

Mean:	-1.362
Root-Mean-Square:	57.19
Average Standard Error:	67.34
Mean Standardized:	-0.007288
Root-Mean-Square Standardized:	0.8164

7 Surface generation

After model validation the surface was generated to produce the water level map as in Figure 10, where it shows the spatial variations in the groundwater level in the study area in which the groundwater is at a deeper position in the northern parts of the study area, and decreasing gradually to the south.

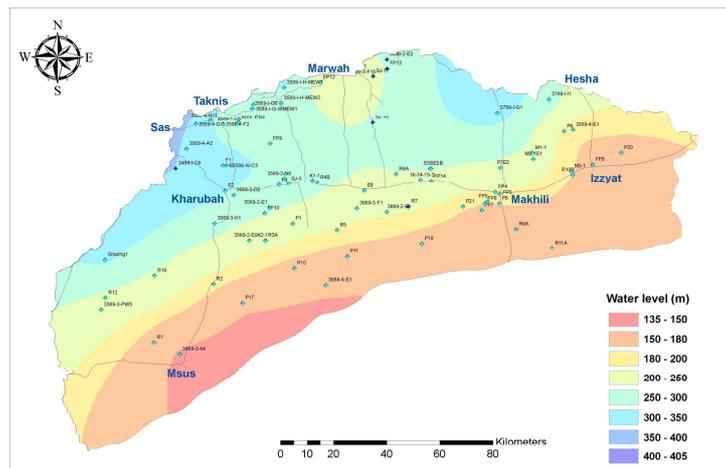


Fig. 10. Groundwater level map (Ordinary kriging)

8 Mapping potentiometric surface

The potentiometric surface is the result of the subtraction of the water level raster from digital elevation model (DEM), which carried out using ArcGIS spatial analyst raster calculator to produce potentiometric map for the groundwater as in Figure 11, where the map shows high values in the northern parts of the study area, this high values decreases to the southern direction.

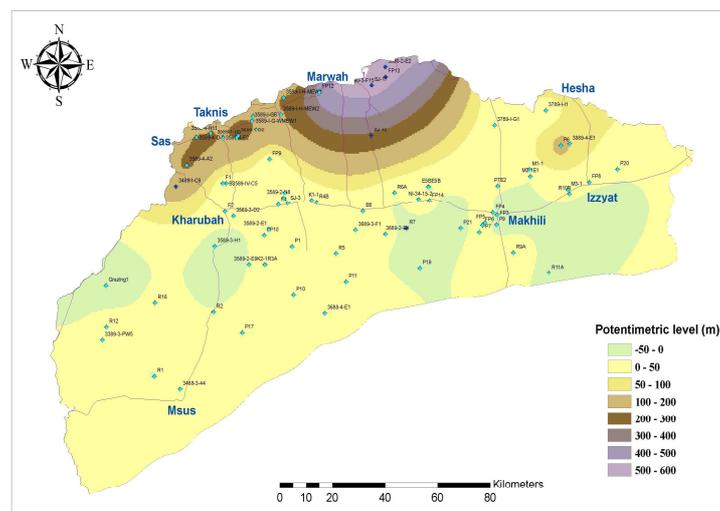


Fig. 11. Potentiometric map.

Potentiometric contour map in Figure 12 shows three flow directions; north-south, southeast, and southwest, where the contour lines of potentiometric level characterized by steep slope in the middle of the northern parts of the study area where the upper cretaceous aquifer exist, which can interpreted as the aquifer characterized by high transmissivities resulting in high hydraulic gradient. Southern parts of the study area where the tertiary aquifer exist characterized by gentle slope of potentiometric level contour lines, where the aquifer characterized by low transmissivities.

Four water divides were defined, where three of them in the west direction of the study area and the other in the east ward. The direction of ground water flow and water divides is generally controlled by geological formations, and structures that are dominant in the study area, in addition to the karst processes associated with carbonate rocks those forming the geological formations in south Al Jabal Al Akhdar area.

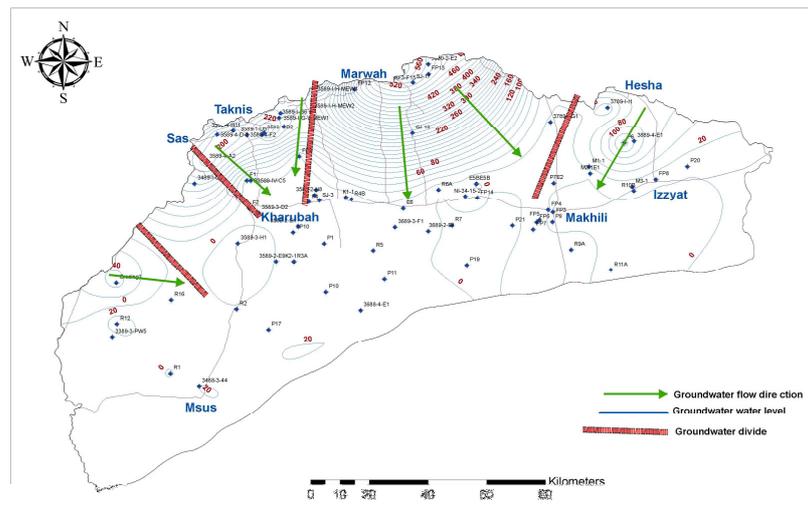


Fig. 12. Potentiometric contour map.

9 Conclusions

Spatial analysis of the groundwater level was carried out according to GIS methodology and the result can be concluded here:

- The result of the exploratory spatial data analysis (ESDA) for the groundwater level data of 94 water wells leads to the following:
 - Data distribution was not normally, therefore log transformation was applied to drive data into the normality.
 - Global and local outliers were found, and through out the filed and office check, where the outliers represent real abnormalities in the groundwater level values.
 - Trend analysis shows a major trend in the groundwater level data, where the data values decreases from north to south direction.
- The spatial interpolation for the groundwater level data was carried out using ordinary kriging according to followed methodology procedures, which can be described here:
 - Modeled semivariogram and covariance used spherical model shows a best fitted model in north east direction, where the model shows a progressive decrease of the spatial autocorrelation until some distance beyond which autocorrelation is zero.
 - Model validation was carried out using cross validation calculated statistics, which were used to verify the best chosen model.
 - Surface generation was done to produce the water level map that shows the spatial variation in the groundwater level in the study area in which the groundwater is at a deeper position in the northern parts of the study area, decreasing gradually to the south.
- Mapping potentiometric surface was done by subtracting the generated surface of groundwater level from the ground elevation from (DEM) data, leading to the following result:
 - High values of potentiometric surface in the northern parts of the study area, the high values decreases to the southern direction.
 - Contour map potentiometric surface shows three flow directions; north-south, southeast, and southwest, where the contour lines of potentiometric level characterized by steep slope in the middle of the northern parts of the study area where the upper cretaceous aquifer exist, which is interpreted as the aquifer characterized by high transmissivities resulting in high hydraulic gradient. While the southern parts of the study area where the tertiary aquifer exist characterized by gentle slope of potentiometric level contour lines, where the aquifer characterized by low transmissivities.

- Four water divides were defined, where three of them in the west direction of the study area, and the other is located towards the east direction.
- The direction of ground water flow and water divides is generally controlled by geological structures that are dominant in the study area, in addition to karst processes associated with carbonate rocks those forming the geological formations in south Al Jabal Al Akhdar area.

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