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# Spatial Analysis of groundwater hydrochemistry in central part of Cyrenaica

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Abstract

Hydrochemical data gathered from 86 water wells in the in central part of Cyrenaica area including major cations and anions, as well as pH, total dissolved solids (TDS) were explored with spatial data analysis (ESDA) .Further more spatial analysis and interpolation for all the hydrochemical data was carried out using geostatistics simple and universal kriging resulting in the high concentration of both cations and anions as one moves toward the southern parts of the study area.

## 1 Introduction

The study area as shown in figure (1) is located on central part of Cyrenaica known as 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 aerial extent about 20,000 km² .

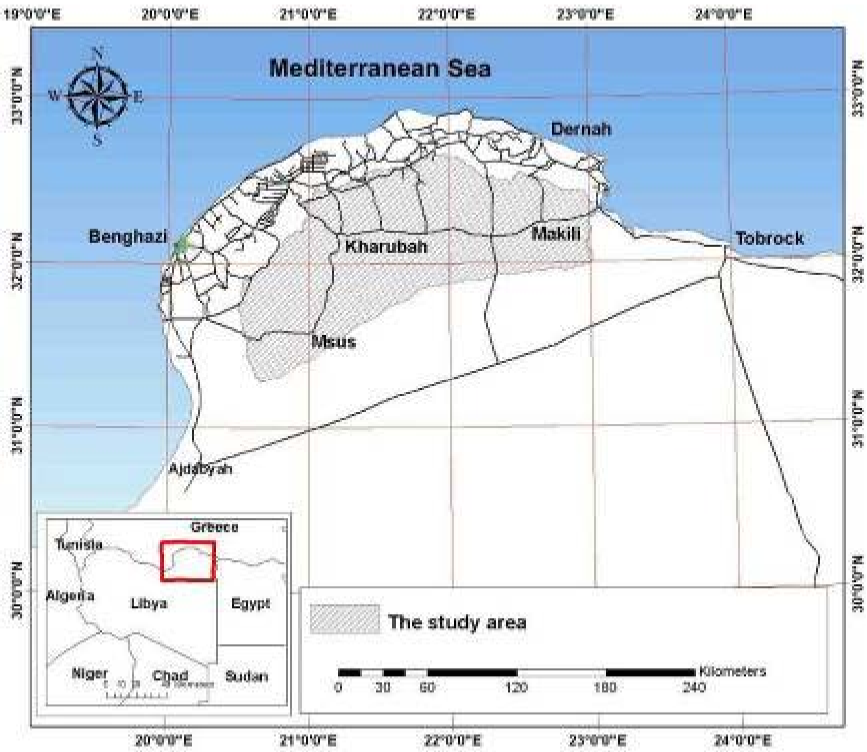


**Fig. 1:** Location of the study area

## 2 Spatial Analysis

Spatial Analysis is the process of examining the locations, attributes, and relationships of features in spatial data through overlay and other analytical techniques in order to address a question or gain useful knowledge (Wade and Sommer, 2006). 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 (Anselin, 1992).

### Exploratory spatial data analysis

Haining and Wise (1997) defined 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, and 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 those involving; distribution of the data, global and local outliers, and global trends (Jay et al, 2003).

### Spatial interpolation

The estimation of the surface values at unsampled points based on known surface values of surrounding points .Interpolation can be used to estimate elevation, rainfall, temperature, chemical dispersion or other spatially based phenomena (Wade and Sommer, 2006).There are two main groupings of interpolation techniques: deterministic and geostatistical. Deterministic interpolation techniques create surfaces from measured points, based on either the extent of similarity (e.g., Inverse Distance Weighted (IDW)) or the degree of smoothing (e.g., radial basis functions). Geostatistical interpolation techniques (e.g., kriging) utilize the statistical properties of the measured points. The geostatistical techniques quantify the spatial autocorrelation among measured points and account for the spatial configuration of the sample points around the prediction location (Jay et al, 2003).This research uses only the geostatistics interpolation technique. Geostatistics is a set of models and tools developed for statistical analysis of continuous data. Many methods are associated with geostatistics, but they are all in the kriging family; ordinary, simple, universal, probability, indicator, and disjunctive kriging along with their counterparts in cokriging.

## 3 Objectives

The overall general goal of this paper is to run spatial analysis for groundwater hydro chemical data gathered from water wells in the south Al Jabal Al Akhdar area using contemporary techniques inherent in the Science of Geographic Information Systems (GIS).

## 4 Methodology

The applied GIS methodology for the spatial analysis of the hydrochemistry data is as illustrated in figure (2), and involved the following:

1. Exploratory spatial data analysis (ESDA) using ArcGIS 9.2 software for the hydrochemical data to study the following:
    - Data distribution.
    - Global and local outliers.
    - Trend analysis.
2. Spatial interpolation for hydrochemical data using ArcGIS 9.2 software, while simple and universal kriging were applied by involving the following procedures:

- Semivariogram and covariance.
- Model validation using cross validation.
- Surfaces generation of the hydrochemical data.

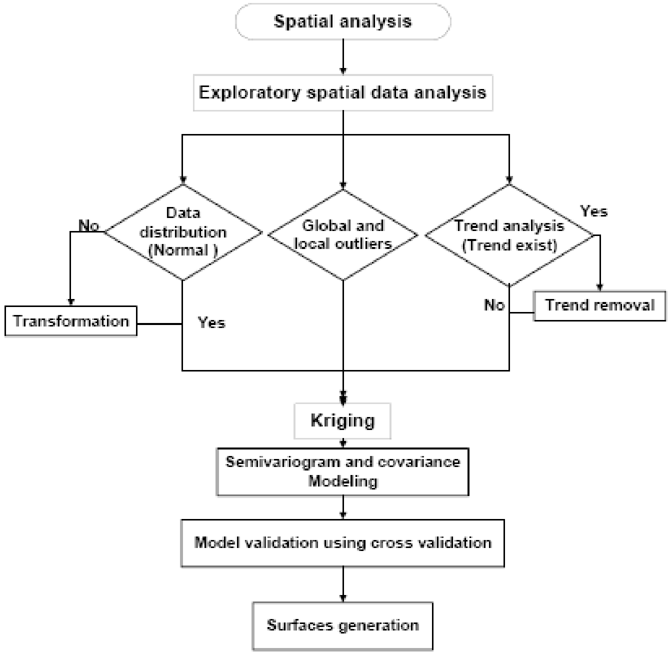


**Fig.** 2: Flow chart of the spatial analysis stages

## 5 Exploratory spatial data analysis of the hydrochemical data

The hydrochemical data of 86 water wells have been explored using ArcGIS geostatistical analyst exploratory spatial data analysis tool, and Golden software Grapher as in the following:

### 5.1 Simple statistics and distribution of the hydrochemical data

The statistics of the hydrochemical data are summarized in (Table 1), where they show the data is not normally distributed, in which the mean value is larger than the median value, therefore were subjected to transformation to drive them into the normality as in (Table 2), where the log transformation was applied to the data.

**Table (1) statistic of hydrochemical data before transformation**

| Variable | Min | Max | Mean | Median | Standard deviation | Skew-ness | Kurtosis |
|---|---|---|---|---|---|---|---|
| TDS | 291 | 14370 | 2282.2 | 1273.5 | 2621 | 2.3907 | 9.2157 |
| $Ca^{2+}$ | 35 | 995 | 230.22 | 148 | 229.51 | 1.9706 | 6.0752 |
| $Na^{+}$ | 23 | 2318 | 389.47 | 225.5 | 480.28 | 2.2598 | 8.0942 |
| $Mg^{2+}$ | 10 | 535 | 102.85 | 67.75 | 102.13 | 2.2648 | 8.6068 |
| $K^{+}$ | 1 | 50 | 8.7547 | 6.4 | 8.7547 | 2.4633 | 11.193 |
| $HCO_3^{-}$ | 26 | 351 | 217.81 | 219.85 | 62.782 | -0.51845 | 3.7616 |
| $SO_4^{2-}$ | 5 | 3000 | 550.57 | 325 | 690.76 | 1.8898 | 5.696 |
| Cl | 43 | 4750 | 749.83 | 399 | 951.19 | 2.364 | 8.6473 |

**Table (2) statistic of hydrochemical data after log transformation**

| Variable | Min | Max | Mean | Median | Standard deviation | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| TDS | 5.6733 | 9.5729 | 7.2642 | 7.1495 | 0.94423 | 0.37328 | 2.5194 |
| $Ca^{2+}$ | 3.5553 | 6.9027 | 5.0829 | 4.9972 | 0.80819 | 0.52778 | 2.6857 |
| $Na^{+}$ | 3.1355 | 7.7485 | 5.3597 | 5.4183 | 1.1254 | 0.0789 | 2.4014 |
| $Mg^{2+}$ | 2.3026 | 6.2823 | 4.261 | 4.2158 | 0.86134 | 0.13573 | 2.7129 |
| $K^{+}$ | 0 | 3.912 | 1.8244 | 1.8562 | 0.8697 | -0.28076 | 2.8878 |
| $HCO_3^{-}$ | 3.2581 | 5.8608 | 5.3235 | 5.3929 | 0.39972 | -2.4762 | 11.722 |
| $SO_4^{2-}$ | 1.6094 | 8.0064 | 5.3968 | 5.7838 | 1.6347 | -0.62036 | 2.481 |
| Cl | 3.7612 | 8.46559 | 6.006 | 5.989 | 1.124 | 0.11464 | 2.4808 |

## 5.2 Global and local trends of the hydrochemical data

During the trend analysis of the hydrochemical data, a remarkable main trend found, where all the hydrochemical data values increases in the south direction, with exception of bicarbonate that shows little increases in west direction without north-south trend. TDS was used here for the presentation of the trend in the hydrochemical data as illustrated in the (Figure 3), where it represents the sum of cations and anions.

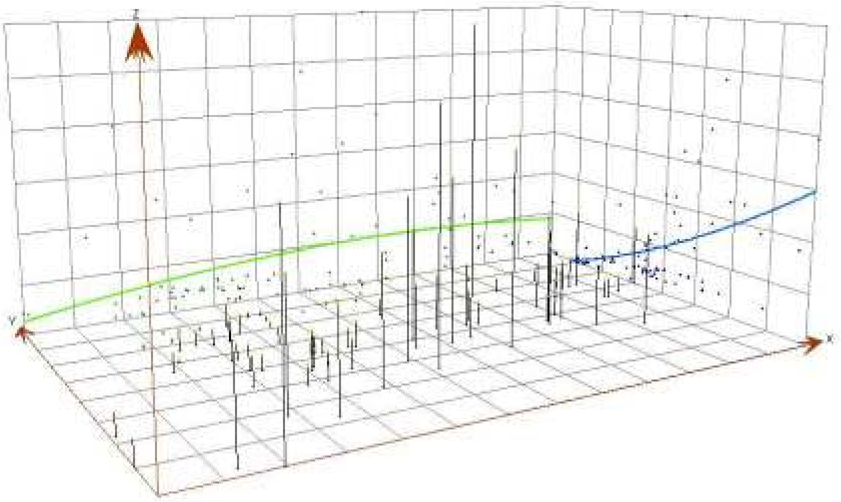

**Fig. 3:** Trend analysis for the hydrochemical data

## 5.3 Identifying global and local outliers

Both global and local outlier were remarked in the hydrochemical data, and through out office and field check of the data these outliers represents a real abnormalities in the hydrochemical data in the study area, and can be interpreted as the effect of the different litholgical characteristics in the study area.

# 6 Spatial interpolation of hydrochemical data

The spatial interpolation of hydrochemical data was carried out using ArcGIS geostatistical analyst, where simple and universal kriging were applied during the interpolations according to the following:

## 6.1 Modeling semivariogram and covariance

The detrending of the data was carried out using the const order of trend that means a zero-order (constant) ,afterward modeling semivariogram and covariance for all of the hydrochemical data was carried out with exception of bicarbonate that show no good spatial autocorrelation during the semivariogram modeling even with application of different kriging models.The semivariogram and covariance models are illustrated in (Figures 4, 5, and 5.6), also the best fitted semivariogram and co-variance models parameters are as in (Table 3).Cross validation of semivariogram and covariance models were done, where the calculated statistics are as in (Table 4).

**Table (3) Best-fitted semivariogram models parameters of the hydrochemical data.**

| Vari-able | kriging | Model | Partial sill | Nugget | Lag size | Num-ber of lags | Angle direc-tion | Angle tolerance | Band-width (lags) |
|---|---|---|---|---|---|---|---|---|---|
| TDS | Universal | Spherical | **0.4149** | **0.18304** | **11347** | **15** | **80.1** | **59.0** | **12.9** |
| $Ca^{2+}$ | Simple | Spherical | **0.4130** | **0.09797** | **11247** | **16** | **63.1** | **55** | **11.5** |
| $Na^{+}$ | Universal | Spherical | **1.3353** | **0.01156** | **11523** | **17** | **84.2** | **61** | **11.2** |
| $Mg^{2+}$ | Simple | Spherical | **0.6097** | **0.13696** | **5825.7** | **24** | **61.8** | **67.5** | **18.6** |
| $K^{+}$ | Simple | Spherical | **0.5733** | **0.17426** | **10768** | **13** | **76.9** | **88** | **10.8** |
| $SO_4^{2-}$ | Simple | Spherical | **2.0413** | **0.33272** | **8997.5** | **18** | **76.2** | **53.6** | **15** |
| Cl | Universal | Spherical | **0.8215** | **0.25662** | **12243** | **16** | **73.6** | **57.7** | **11.4** |

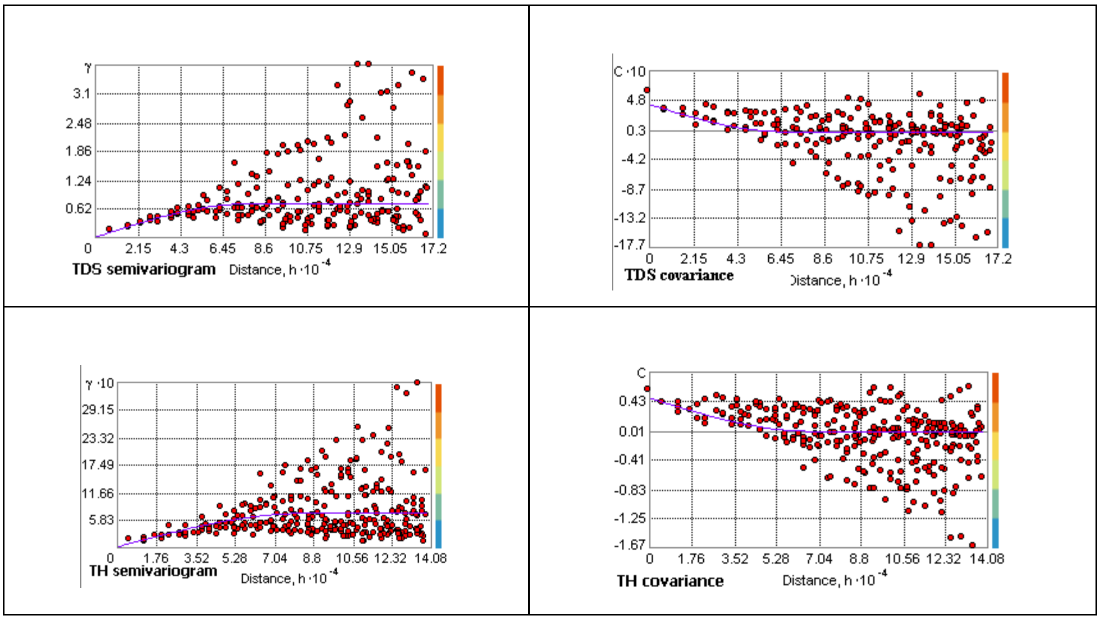


**Fig. 4: Semivariogram and covariance models for the TH and TDS**

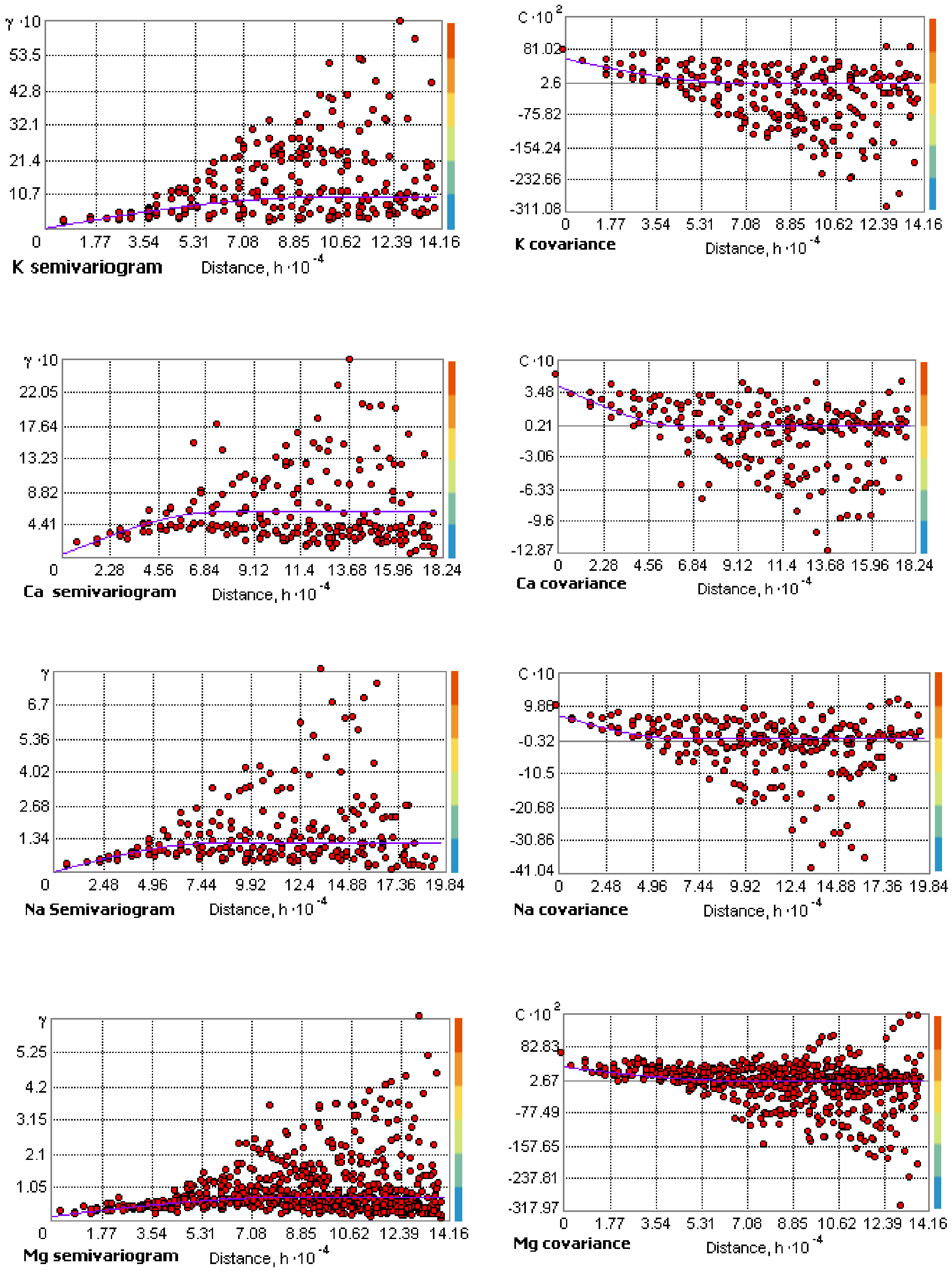


**Fig. 4:** Semivariogram and covariance models for the cations

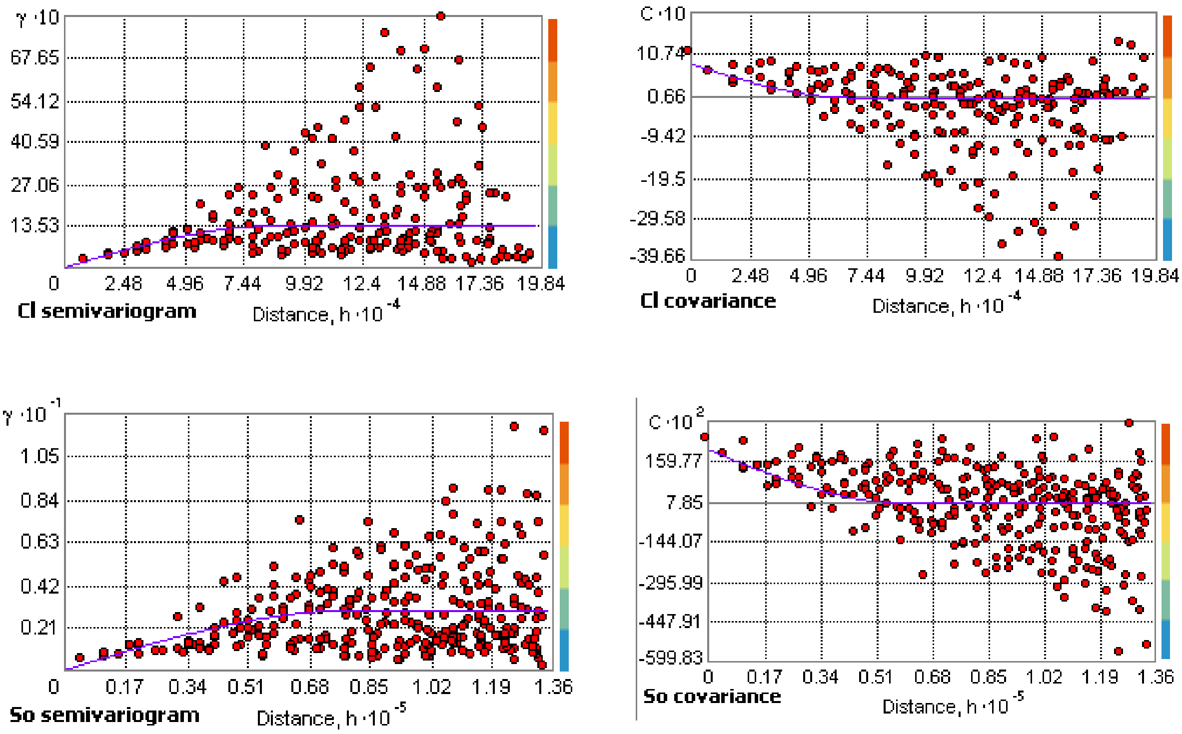


**Fig. 6: Semivariogram and covariance models for the anions**

**Table (4) Cross validation calculated statistics for the hydrochemical data.**

| Variable | Mean | Root-Mean-Square | Average Standard Error | Mean Standardized | Root-Mean-Square Standardized |
|---|---|---|---|---|---|
| TDS | -100.6 | 1505 | 1598 | -0.01312 | 0.829 |
| $Ca^{2+}$ | -4.741 | 109.3 | 142.3 | 0.08144 | 0.7376 |
| $Na^{+}$ | -6.586 | 260.2 | 457.6 | -0.00844 | 0.6982 |
| $Mg^{2+}$ | -4.043 | 73.53 | 68.74 | -0.02339 | 1.065 |
| $K^{+}$ | 0.07925 | 5.966 | 6.719 | 0.05942 | 0.8221 |
| $SO_4^{2-}$ | 85.52 | 553.7 | 1101 | -0.03993 | 0.9205 |
| Cl | -15.3 | 516.3 | 887.1 | -0.01426 | 0.994 |

### 5.2.4.3 Surface generation and spatial distribution of the hydrochemical data

**Total dissolved solids (TDS)**

The generated surface illustrated in (Figure 7) shows the spatial distribution of TDS, in which a general increase towards the main flow direction from north to the south. An anomalous area of higher TDS values is located in the southern central part of the study area. The source of higher TDS values can be interpreted as the affect of the geological formations in the southern parts of the study area, those characterized by marine carbonate rocks intercalated with shallow marine deposits of lagoons and sabkha like gypsum, and anhydrite, therefore the aquifers water is affected by these formations. The generated surface of the TDS was classified according to (Bouwer, 1978) as illustrated in (Figure 8).

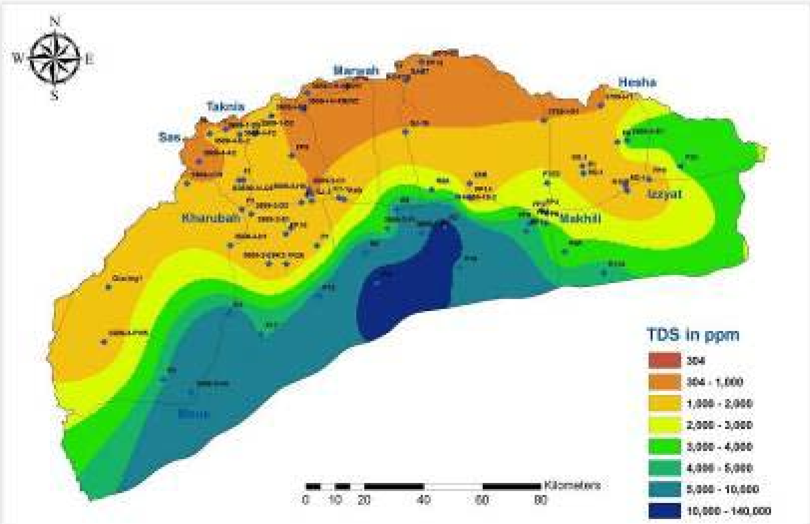


**Fig. 7:** Spatial distribution **(TDS)**

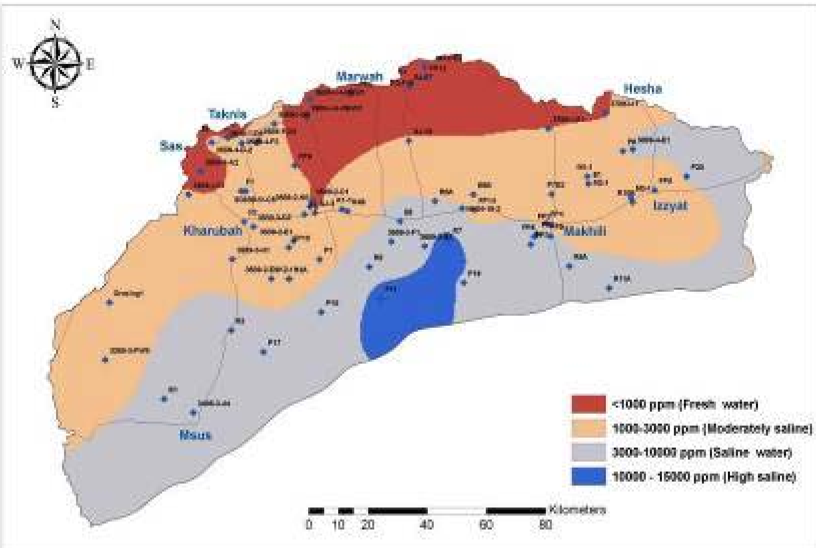


**Fig. 8: Classified Total dissolved solids according to (Bouwer,1978)**

**Total hardness (TH)**

The generated surface illustrated in (Figure 9) shows the spatial distribution of total hardness, in which a general increase towards the main flow direction from north to the south as previously re-marked with TDS. In addition to an anomalous area of higher total hardness values is located in the southern central part of the study area. The source of higher total hardness values can be interpreted as the high calcium magnesium content in the geological formations of the study area

The generated surface of the total hardness was classified according to (Bouwer,1978) as illustrated in (Figure 10), where the hard water is only exist in small area in the north part of the study area and the very hard water is the dominant in the whole south Al Jabal al Akhdar area.

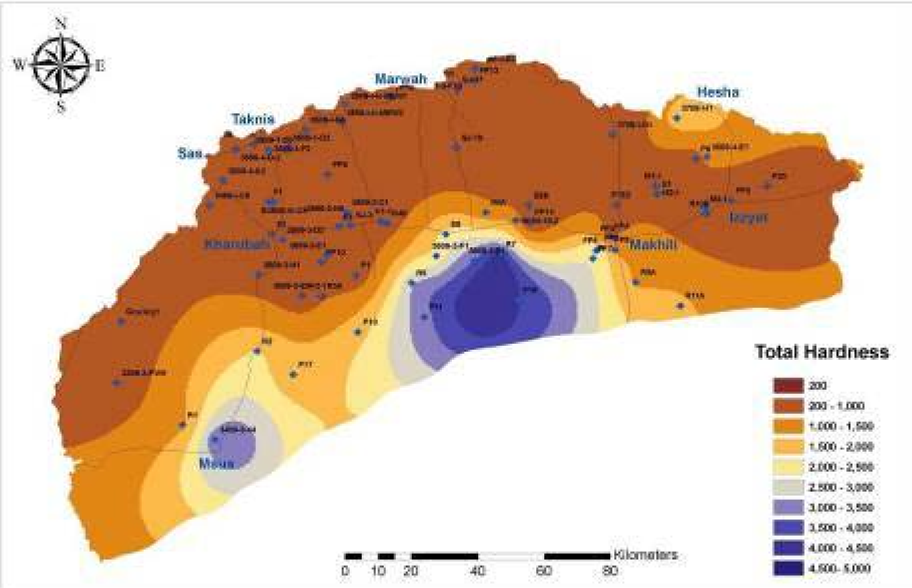


**Fig. 9:** Spatial distribution of total hardness

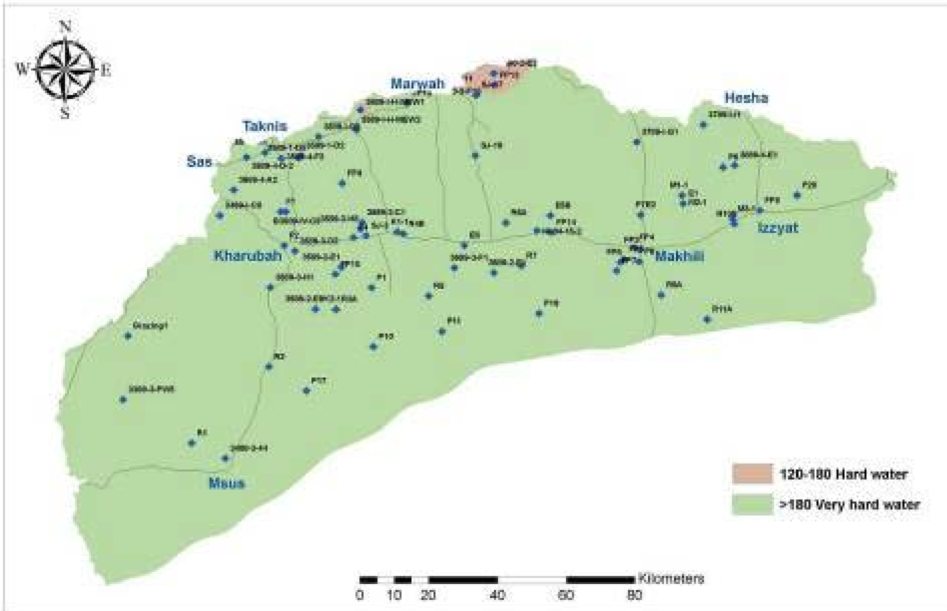


**Fig. 9:** Classified total hardness according to (Bouwer,1978)

## Cations

The generated surfaces of cations are illustrated in (Figure 11), where the spatial distribution of magnesium, sodium calcium, and potassium, in which a general increase towards the main flow direction from north to the south area remarkable. Also two anomalous areas of higher cations values are located in the southern central part, and south western part of the study area. These higher values of cations can be interpreted as the affect of the geological formations the aquifers water.

## Anions

The spatial distribution of the anions is same as the cations as can be seen from the generated surfaces of anions in (Figure 12), those show the spatial distribution of chloride, and sulfate.

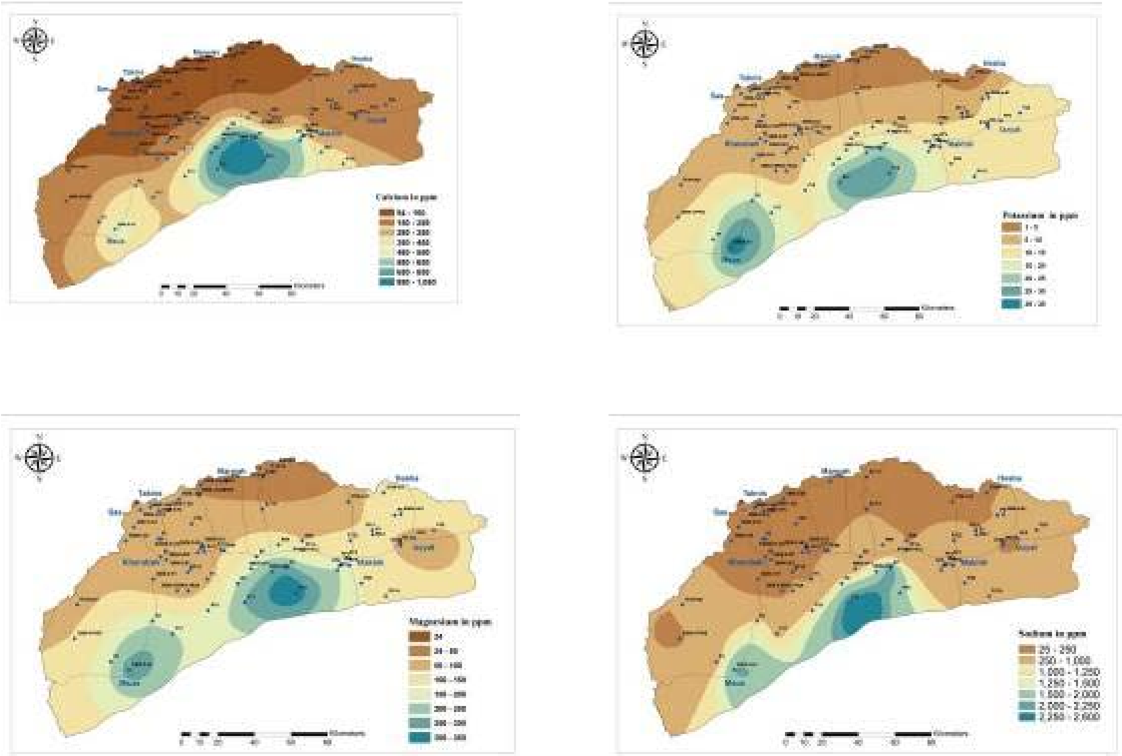

**Fig. 11:** Spatial distribution of the cations

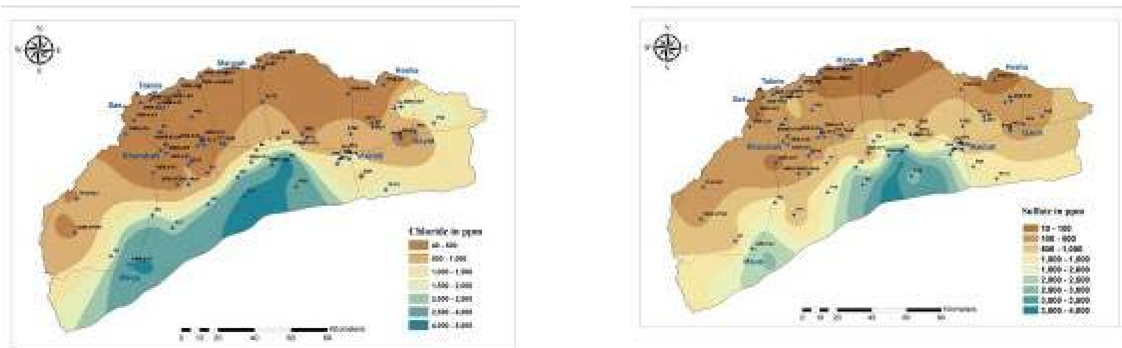

**Fig. 12:** Spatial distribution of the anions

# 4 Conclusion

1-The spatial interpolation for the hydrochemical data was carried out using simple kriging, and universal according to followed methodology procedures, which can be described here:

- Molded semivariogram and covariance used spherical model shows a best fitted model in the north east search direction for all the hydrochemical data, 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.
- Surfaces generation was carried out to produce maps for the hydrochemical data that shows the spatial variations which can be concluded here:

2-The spatial distribution of TDS, cations, and anions shows a general increase towards the main flow direction from the north to south. An anomalous area of higher values is located in the southern central part of the study area. The source of higher values can be interpreted as the affect of the geological formations in the southern parts of the study area, those characterized by marine carbonate rocks intercalated with shallow marine deposits of lagoons and sabkha like gypsum, and anhydrite, therefore the aquifers water is affected by these formations.

# References

Anselin, Luc. Spatial Data Analysis with GIS. (1992). National Center for Geographic Information and Analysis University of California-USA.

Available online: URL http://www.ncgia.ucsb.edu/Publications/Tech_Reports/92/92-10.PDF

Bouwer, (1978).Groundwater Hydrology. -490 p., Tokyou (McGraw-Hill Ltd).

Haining, Robert and Wise, Stephen (1997) Exploratory Spatial Data Analysis, NCGIA Core Curriculum in GIScience, Available online http://www.ncgia.ucsb.edu/giscc/units/u128/u128.html

Kevin, J. Jay, M. Ver, H. Konstantin Krivoruchko. And Neil Lucas.(2003).Using ArcGIS® Geostatistical Analyst. -308 p- ESRI (Enivironmental System Research Institute)-USA.

Wade Tasha. Sommer Shelly. (2001).A to Z GIS. -268 p.ESRI (Enivironmental System Research Institute)-USA.