

## Research Article

# Distribution Maps of TDS Concentration using GIS at Assiut, Egypt

**El-Dakar MA<sup>1\*</sup>, Sefelnasr A<sup>2</sup> and Senosy MM<sup>2</sup>**<sup>1</sup>Egyptian Environmental Affairs Agency, Assiut RBO, Egypt<sup>2</sup>Geology Department, Faculty of Science, Assiut University, Egypt**\*Corresponding author:** Marco A. El-Dakar, Egyptian Environmental Affairs Agency, Assiut RBO, Egypt**Received:** June 24, 2016; **Accepted:** September 15, 2016; **Published:** September 21, 2016**Abstract**

The scarcity of water is one of the main issues in Egypt. In particular, the extreme climate in the form of less frequent rainfall affects the groundwater availability. Moreover, groundwater has been depleted by the increase in population. In this research, the spatial distribution of groundwater salinity has been developed, and the prediction of groundwater Total Dissolved Solid (TDS) has been made by using geostatistical analysis in Geographic Information System (GIS) software. The study area is the western flood plain from the River Nile in Assiut governorate located in the Upper Egypt. Ordinary kriging method was applied to map the spatial distribution of the ground water chemistry for period 22 month (2009-2010). In predicting the Total Dissolved Solid (TDS) concentration of groundwater distribution maps show increasing toward the western part of the Nile valley closed to western plateau. The lowest value of the Total Dissolved Solid (TDS) concentrations of wells was in the areas close to the River Nile, where the TDS concentration was low than 200ppm around the year 2009 except in January, October, November and December, while the highest value of TDS concentrations was in the area closed to Western Plateau in December 2009 and January 2010 (1000ppm).

**Keywords:** Groundwater quality; GIS; Geostatistics; Ordinary kriging; Semivariogram; Spatial distribution; TDS concentration

**Introduction**

In order to discuss the role that groundwater may play in the management of regional water resources, the both surface water and groundwater are present in relatively significant quantities in a region. Actually, surface water and groundwater are not necessarily independent water resources. Base flow in streams is nothing more than groundwater emerging at ground surface. In this way, rivers and lakes, in direct, continuous hydraulic contact with adjacent or underlying aquifers serve as boundaries to the flow domain in the latter. By controlling groundwater levels in the vicinity of a spring, its discharge is controlled, or even stopped completely. The above considerations apply not only to water quantity, but also to water quality defined, for example by some chemical species or microorganisms carried with the water. Polluted surface water may easily reach and pollute groundwater and vice versa [1].

Both surface water and groundwater are susceptible to man-made pollution, which usually requires costly remediation and treatment operations for its removal. In certain formations, pollutants may travel large distances in an aquifer without being attenuated. As for mineral contents in general the groundwater is more liable to picking up minerals in solution, although the range of concentrations encountered is very large. The removal of such minerals is usually very expensive. When groundwater does get polluted, the restoration of quality and the removal of pollutants is a very slow, hence, lengthy and sometimes practically impossible. This is due to the very slow movement of groundwater, especially in layers of very fine material, imbedded in formations of higher permeability and to adsorption and ion exchange phenomena on the surface of the solid matrix. These

phenomena are especially significant when fine grained materials are present in an aquifer [1].

The assessment of spatial correlation in hydro chemical variables is an important tool in the analysis of groundwater chemistry especially in arid and semiarid zones. In geostatistical methods, kriging technique is quite popular. The technique is applicable to cases such as determining groundwater level, estimation of hydro chemical distribution of soil properties, and other estimations [2] have compared various variogram models, i.e., spherical, exponential, and Gaussian semivariogram models to fit the experimental semivariogram in identifying the spatial analysis of groundwater levels in small part of Rajasthan area, India. The results indicate that the kriged groundwater levels satisfactorily matched the observed groundwater levels. The role of Geographic Information System (GIS) software's in analyzing spatial distribution of groundwater has been investigated by many authors such as [3,4]. Studied groundwater potential zonation for basaltic watersheds [5]. Investigated disasters and risk reduction in groundwater [6]. Applied the probabilistic based frequency ratio in groundwater potential [7,8]. Applied an integrated geostatistic and GIS technique in groundwater [9]. Estimated groundwater vulnerability to pollution and [6] Studied prediction of groundwater potential zones.

The objectives of the present research are to investigate the application of various spatial models and data transformation to interpret the spatial distribution of the groundwater Total Dissolved Solid (TDS) at the western flood plain from the River Nile in Assiut governorate located in the Upper Egypt. In this study, kriging techniques in the framework of GIS software (ArcGIS Geostatistical Analyst) are used.

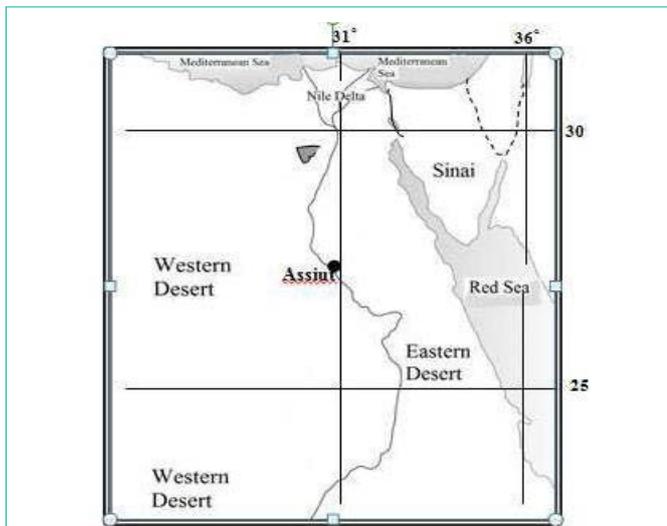


Figure 1: Location of Assiut Governorate.

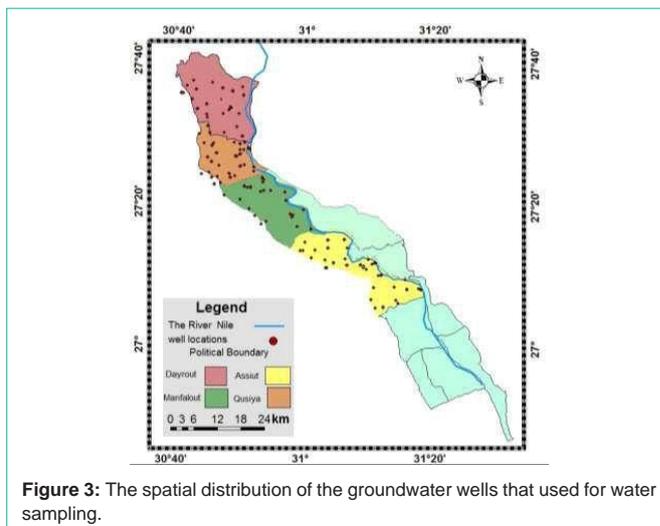


Figure 3: The spatial distribution of the groundwater wells that used for water sampling.

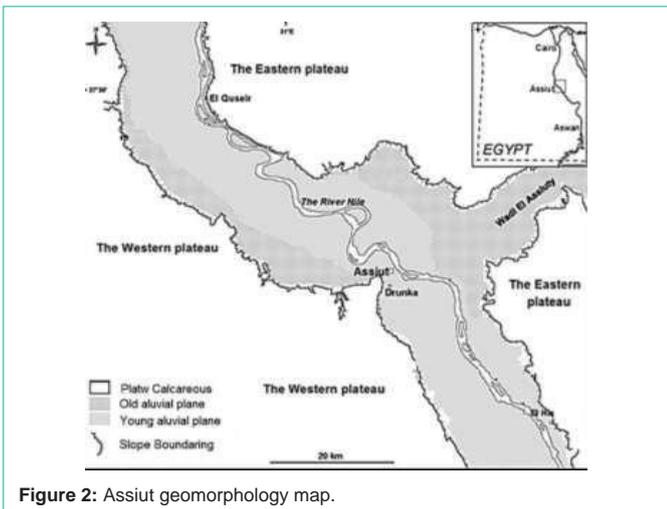


Figure 2: Assiut geomorphology map.

**Description of the study area and data collection**

Assiut governorate is located on the River Nile at about 375 kilometers south of Cairo. It occupies a stretch of low land about 25926 square kilometers located between latitudes 27°8' and 27°40' North and longitudes 30°40' and 31°18' East (Figure 1). It is bordered from the east by the River Nile then a limestone Eocene plateau known locally as El-Gabal El-Sharki and from the west by another Eocene plateau known as El-Gabal El-Gharbi.

The area under investigation as a part of Middle Egypt is characterized by semiarid to arid climatic conditions. It represents the central part of Upper Egypt and lies within the arid belt of North Africa. Its climate is hot, dry and almost rainless in summer, being mild with low rate of rainfall in winter.

All wells are utilized as the source of drinking water, in addition to agricultural and domestic uses. There are two types of water resources in Assiut governorate. These two resources are the Groundwater represented to the Quaternary aquifer and surface water represented to the River Nile with its irrigation system. The main irrigation canals have large length, width and depth. These canals are generally

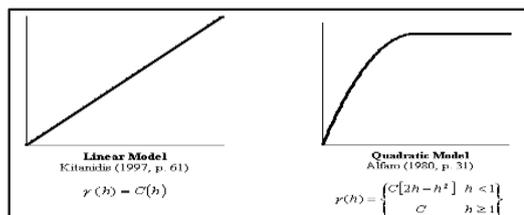


Figure 4: The linear and quadratic variogram models.

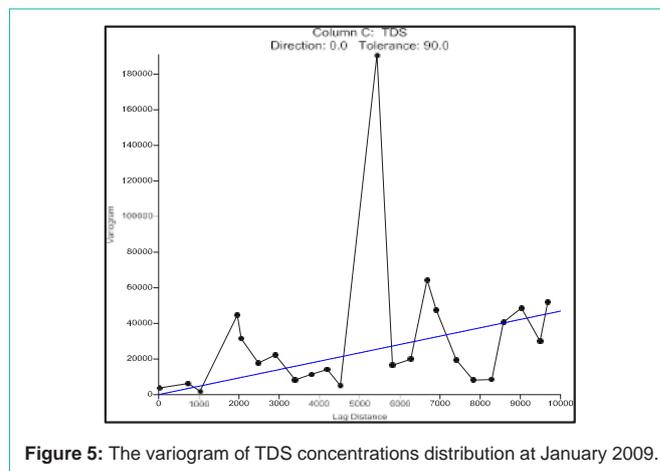


Figure 5: The variogram of TDS concentrations distribution at January 2009.

recharged directly from the River Nile at the upstream sides of the barrage which are constructed through the river course. Three main irrigation canals traverse the study area; Ibrahimia Canal, El Sohagia Canal and East Nag Hammadi Canal. The precipitation is very low with 1.65mm as the monthly average and temperature varies from 14 to 39°C from winter to summer. Geologically, the study area lies between the Eocene limestone plateau from the west and the Recent Nile deposits from the east. It essentially a plain topography devoid of outcrops in most cases. The plain is covered by different Quaternary deposits (e.g. gravels, sands, silts, and clay). The elevation of the limestone plateau ranges from 80 to 180 m, whereas the elevation of the floor of the studied area varies from 35 to 90 m above sea level (Figure 2).

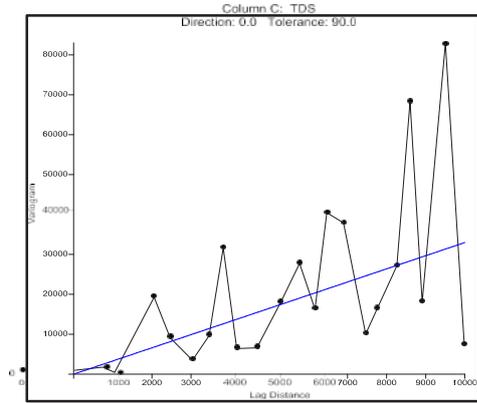


Figure 6: The variogram of TDS concentrations distribution at May 2009.

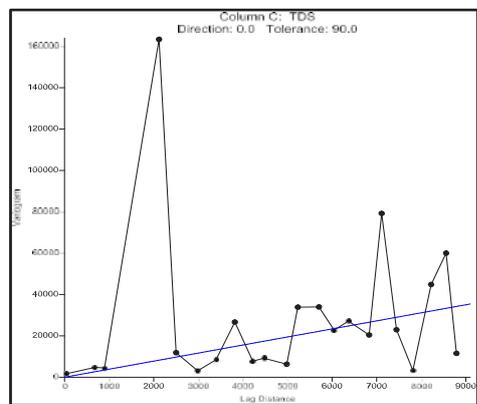


Figure 7: The variogram of TDS concentrations distribution at August 2009.

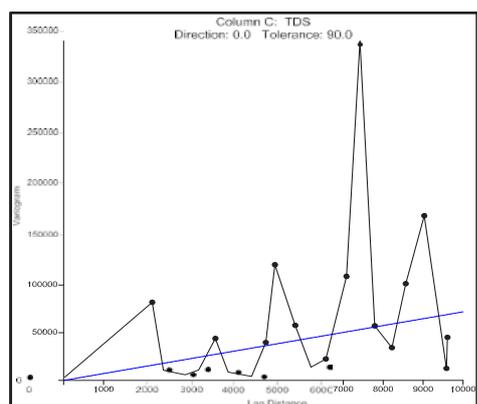


Figure 8: The variogram of TDS concentrations distribution at December 2009.

In the River Nile and canal, the Total Dissolved Solid (TDS) concentration record 180ppm while it reaches to 300ppm in the Quaternary Aquifer. The difference in the concentrations of TDS may be due to many reasons such as; (1) the exchange occur between surface water and groundwater outcome (surface water ground water interaction) which leads to reduce (TDS) concentration of wells near to surface water, by moving away from the surface water the concentrations will increase, (2) the population growth and activities

led to high withdrawal amount of water from Quaternary Aquifer and this leads to increase the (TDS) concentration in the wells, (3) the rainfall have an important impact on the (TDS) concentration that means increase amount of rainfall lead to reduce the (TDS) concentration, (4) the lateral flux of water effects on the (TDS) concentrations, although all studies confirm that the Western Plateau is uncertified limestone but in the actual there are many wells in the Western Plateau which gives sincerity to probability of impact of lateral flux of water phenomenon on the (TDS) concentration. So, it was important to study the occurrence and distribution of (TDS) concentration in the Quaternary Aquifer.

### Materials and Methods

Water samples were collected at selected wells to improve the understanding of the occurrence and distribution of concentrations of Total Dissolved Solid (TDS) of the Quaternary Aquifer at the area under interest. 1612 water samples were collected from 282 wells during the period from January to December 2009 (in Assiut city) except April 2009 (low recorded data) and the period from January to November 2010 (in Dirout, Qusiya, Manfalout and Assiut city).

The water samples were collected after a minimum purge time of one minute at each well, of course taking into account the predefined

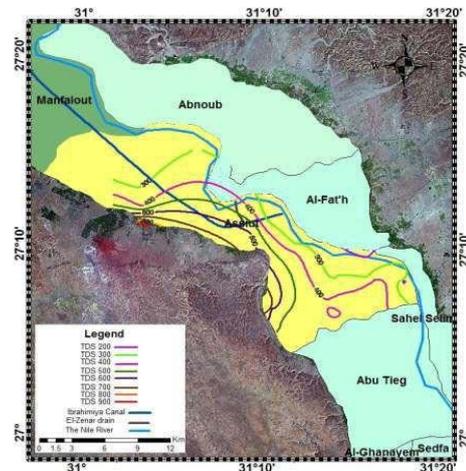


Figure 9: The TDS concentrations distribution in January 2009.

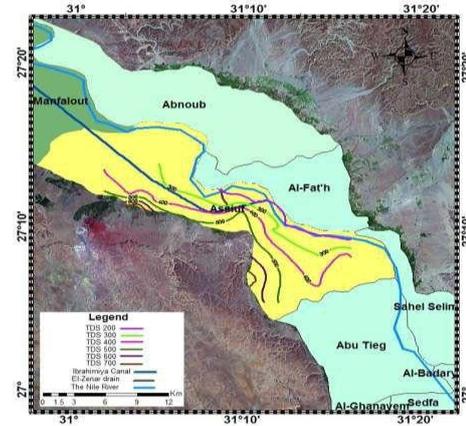


Figure 10: The TDS concentrations distribution in February 2009.

sampling standard methodology and precautions. The sampling was conducted on monthly basis; consequently, eleven sampling data datasets were obtained per year during the sampling period. The sampling database was improved and supported by the available data at the holding drinking water company for the same sampling period (Figure 3). It shows the spatial distribution of the wells from which the water samples were taken.

**The geostatistics and interpolation**

**Interpolation:** It is a method of constructing new data points within the range of a discrete set of known data points. Interpolation is a procedure used to predict the values of cells at locations that lack sampled points. It is based on the principle of spatial autocorrelation or spatial dependence, which measures degree of relationship/dependence between near and distant objects [10].

**Geostatistics:** It is a class of statistics used to analyze and predict the values associated with spatial or spatio-temporal phenomena. Geostatistics provides a means of exploring spatial data and generating continuous surfaces from selected sampled data points [11]. Geostatistics is intimately related to interpolation methods, but extends far beyond simple interpolation problems. Geostatistical techniques rely on statistical models that are based on random function (or random variable) theory to model the uncertainty associated with spatial estimation and simulation [12].

A number of simpler interpolation methods/algorithms, such

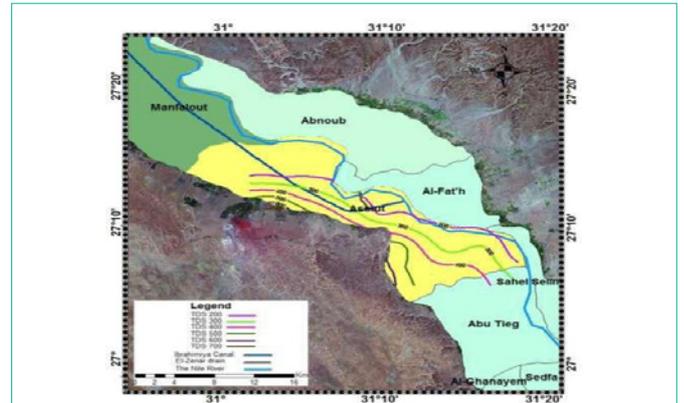


Figure 13: The TDS concentrations distribution in June 2009.

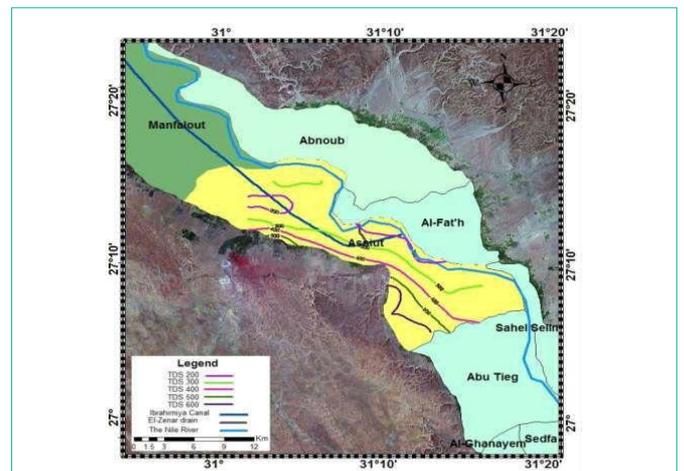


Figure 14: The TDS concentrations distribution in July 2009.

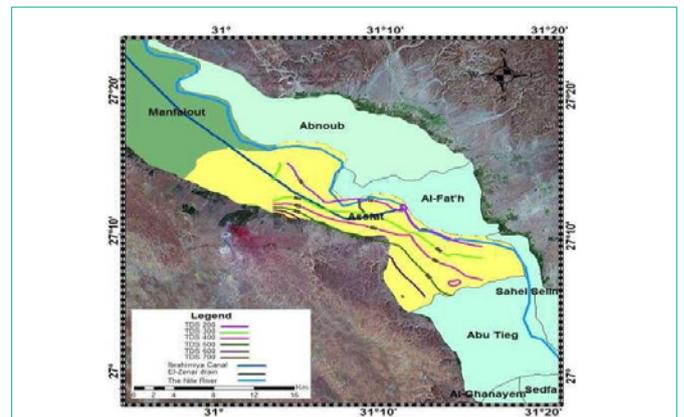


Figure 15: The TDS concentrations distribution in August 2009.

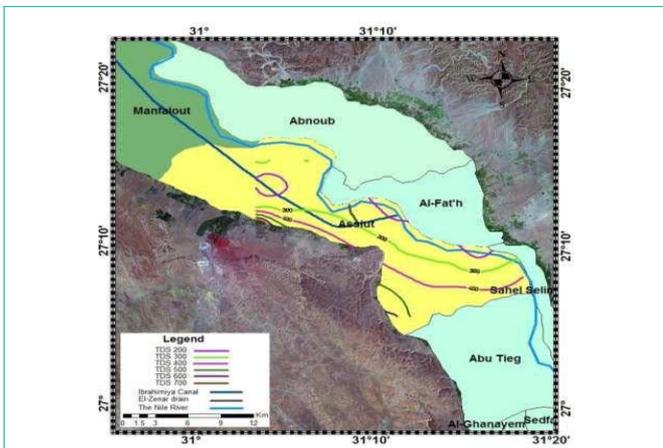


Figure 11: The TDS concentrations distribution in March 2009.

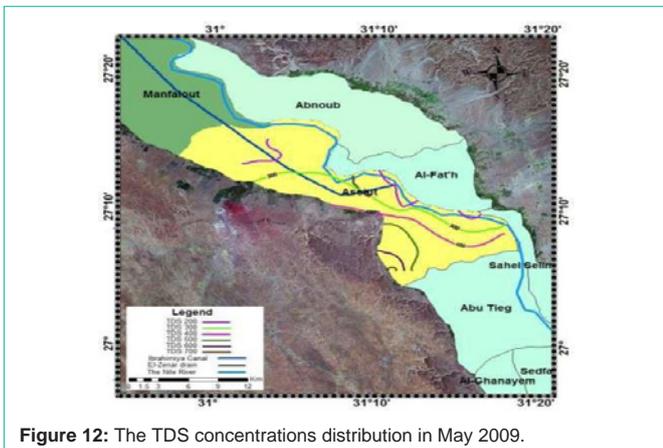


Figure 12: The TDS concentrations distribution in May 2009.

as inverse distance weighting, bilinear interpolation and nearest-neighbor interpolation were already well known before geostatistics [12]. Geostatistics goes beyond the interpolation problem by considering the studied phenomenon at unknown locations as a set of correlated random variables.

In geostatistical models, sampled data is interpreted as the result of a random process. The fact that these models incorporate uncertainty in their conceptualization doesn't mean that the phenomenon - the

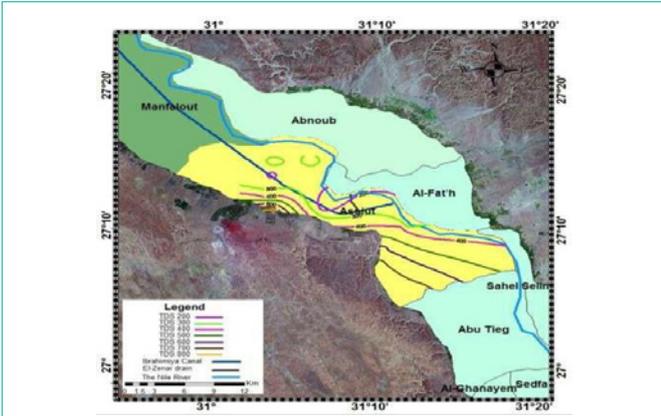


Figure 16: The TDS concentrations distribution in September 2009.

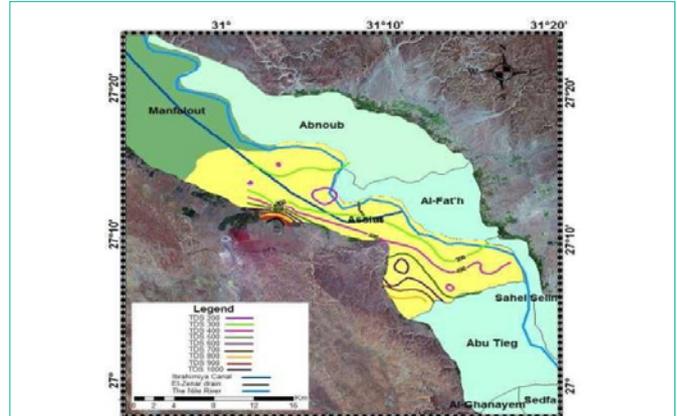


Figure 19: The TDS concentrations distribution in December 2009.

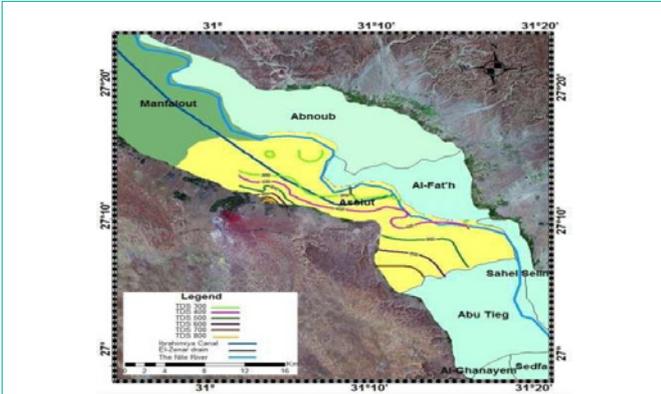


Figure 17: The TDS concentrations distribution in October 2009.

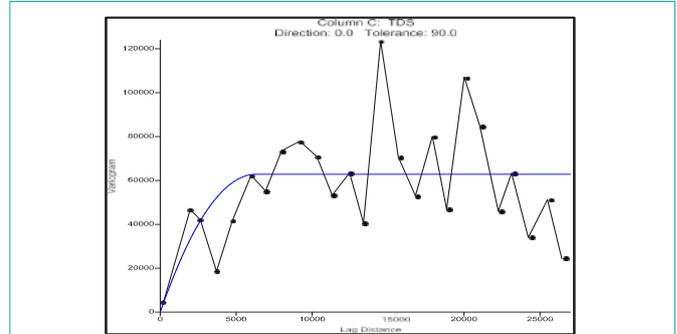


Figure 20: The Variogram of TDS concentrations distribution at January 2010.

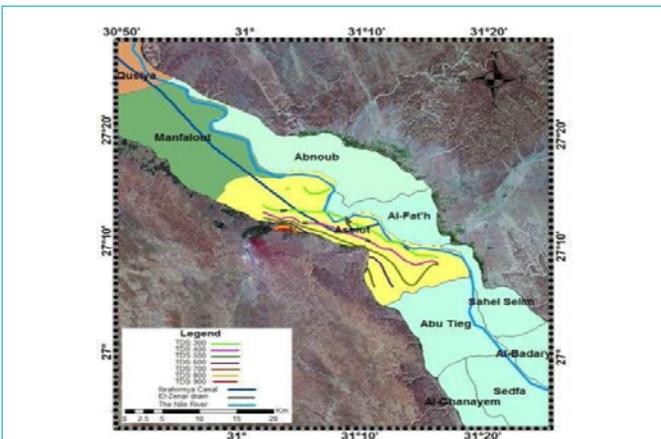


Figure 18: The TDS concentrations distribution in November.

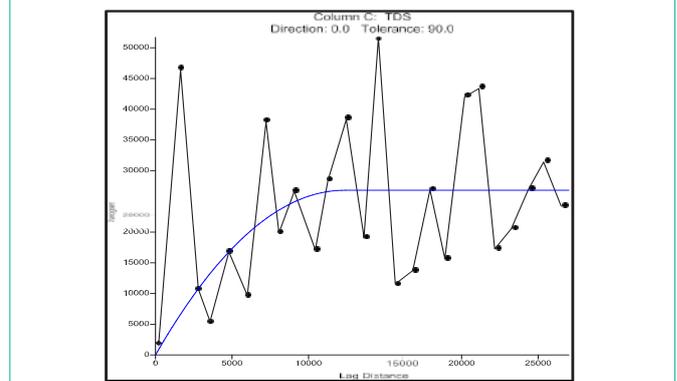


Figure 21: The Variogram of TDS concentrations distribution at June 2010.

forest, the aquifer, the mineral deposit - has resulted from a random process, but rather it allows one to build a methodological basis for the spatial inference of quantities in unobserved locations, and to quantify the uncertainty associated with the estimator.

A value from location  $\chi_1$  (generic denomination of a set of geographic coordinates) is interpreted as a realization  $z(\chi_1)$  of the random variable  $Z(\chi_1)$ . In the space A, where the set of samples is dispersed, there are N realizations of the random variables  $Z(\chi_1), Z(\chi_2), \dots, Z(\chi_i)$ , correlated between themselves.

The set of random variables constitutes a random function of which only one realization is known  $z(\chi_i)$  - the set of observed data. With only one realization of each random variable it's theoretically impossible to determine any statistical parameter of the individual variables or the function.

The proposed solution in the geostatistical formalism consists in assuming various degrees of stationarity in the random function, in order to make possible the inference of some statistic values.

For instance, if one assumes, based on the homogeneity of samples in area A where the variable is distributed, the hypothesis that the first moment is stationary (i.e. all random variables have the

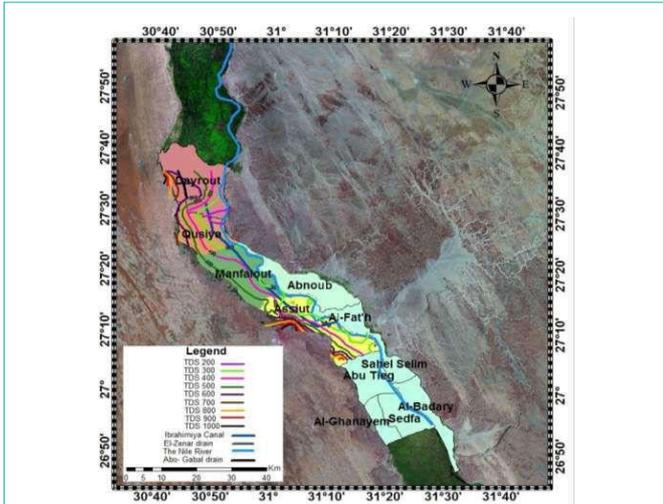


Figure 22: The TDS concentrations distribution in January 2010.

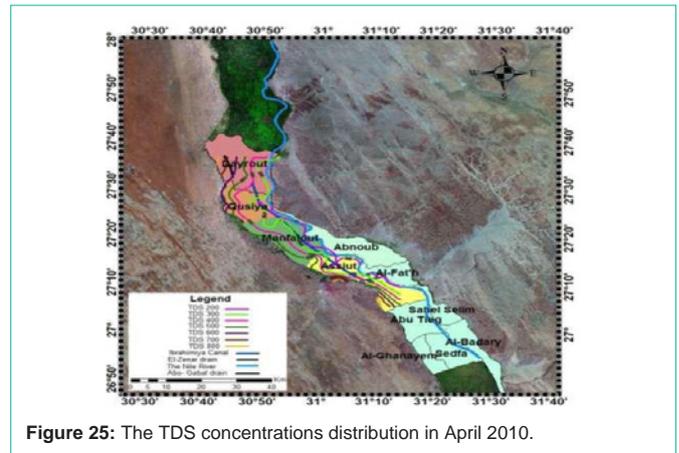


Figure 25: The TDS concentrations distribution in April 2010.

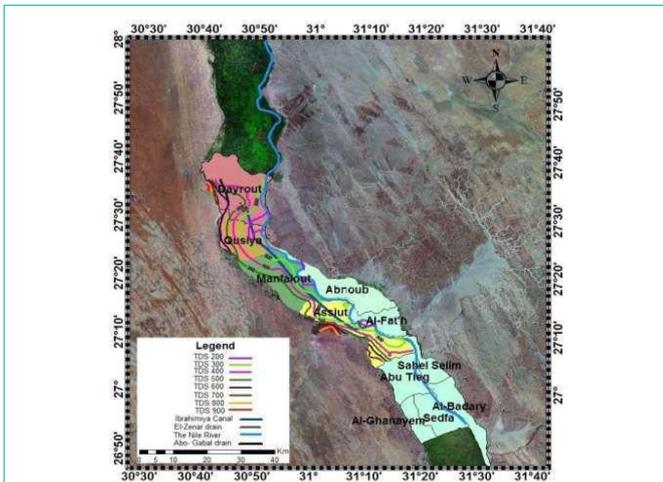


Figure 23: The TDS concentrations distribution in February 2010.

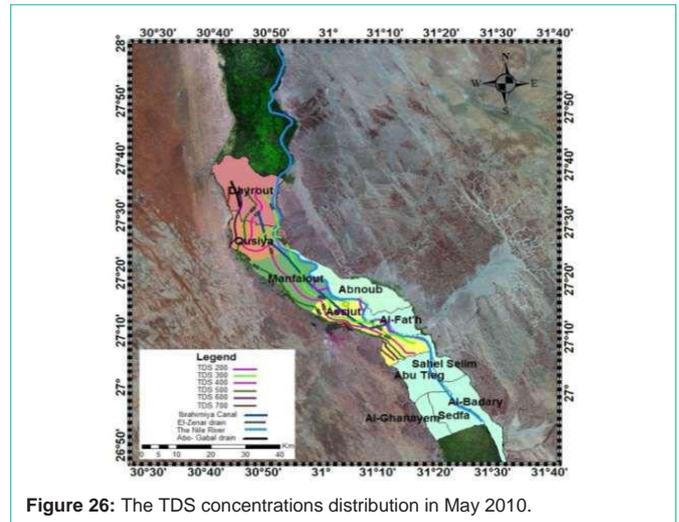


Figure 26: The TDS concentrations distribution in May 2010.

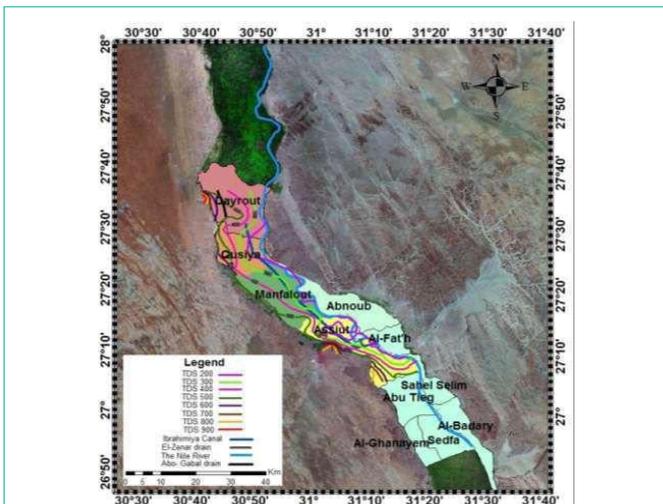


Figure 24: The TDS concentrations distribution in March 2010.

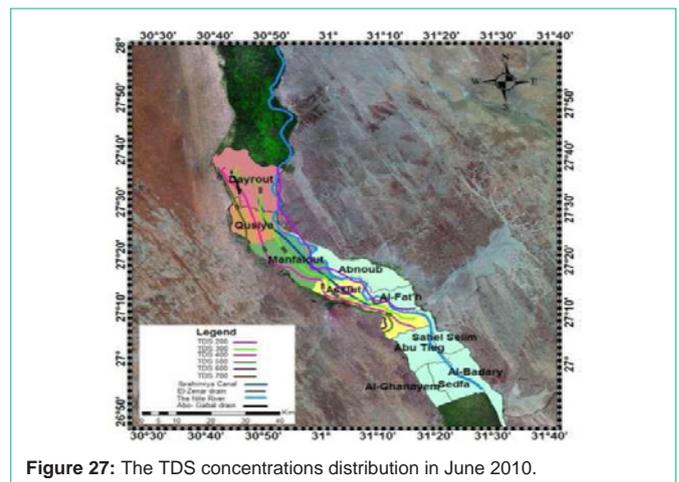


Figure 27: The TDS concentrations distribution in June 2010.

same mean), then one is assuming that the mean can be estimated by the arithmetic mean of sampled values. Judging such a hypothesis as

appropriate is equivalent to considering the sample values sufficiently homogeneous to validate that representation.

By applying a single spatial model on an entire domain, one makes the assumption that Z is a stationary process. It means that the same statistical properties are applicable on the entire domain. Several geostatistical methods provide ways of relaxing this stationary assumption.

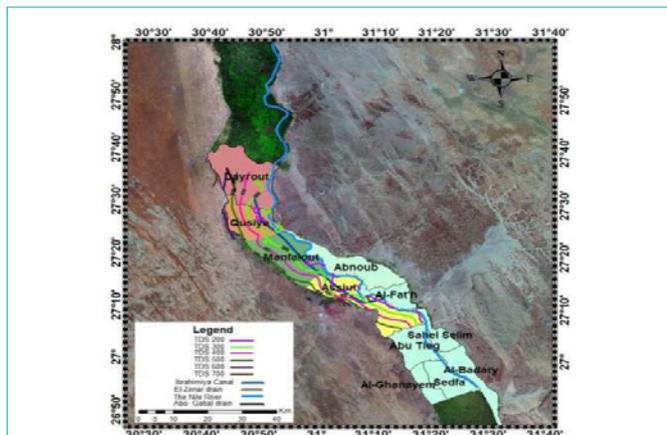


Figure 28: The TDS concentrations distribution in July 2010.

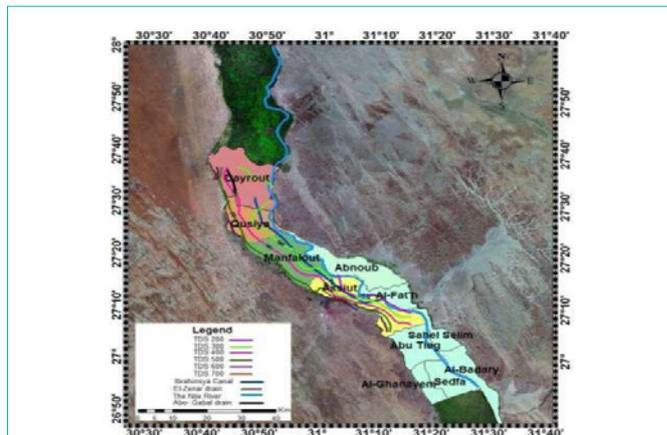


Figure 29: The TDS concentrations distribution in August 2010.

The hypothesis of stationary related to the second moment is defined in the following way: the correlation between two random variables solely depends on the spatial distance between them, and is independent of their location:

$$\gamma(Z(\chi_1), Z(\chi_2)) = \gamma(Z(\chi_1), Z(\chi_i + h))^2 = \gamma(h)$$

Where,  $h = (\chi_1, \chi_2) = (\chi_i, \chi_i + h)$

This hypothesis allows measure the variogram based on the N samples:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (Z(\chi_i) - Z(\chi_i + h))^2$$

**The variogram:** Surfer includes an extensive variogram modelling subsystem. This capability was added to Surfer as an integrated data analysis tool. The primary purpose of the variogram modelling subsystem is to assist you in selecting an appropriate variogram model when gridding with the kriging algorithm. There are several types of variogram model, this study was analyzed the data by two models (linear and Quadratic). The reason for using these models is the fixed equations of these models are match with the distribution of Total Dissolved Solid concentration points (Figure 4) (Surfer tutorial).

### Results and Discussion

The spatial distribution of the chemical elements can give a good picture on the relationship between the surface water and the groundwater within the area under interest.

#### The distribution of Total Dissolved Solid (TDS) concentration in 2009

The amount of water flow of the main surface water such as the River Nile and the Ibrahimia canal was variable monthly during 2009 (Table 1), where it reaches to the minimum values in winter due to the winter embankment then it increase gradually to reach maximum values in summer months.

To assume the distribution and spatial variability of the Total Dissolved Solids within the area under interest, the values were handled by sophisticated geostatistical methods so as to apply the spatial distribution. The distribution of the Total Dissolved Solid (TDS) concentration of wells at year 2009 is located in Assiut city only (due to available data) except April 2009 due to low sampling records in this month. (Figures 5-8) show the variograms of TDS

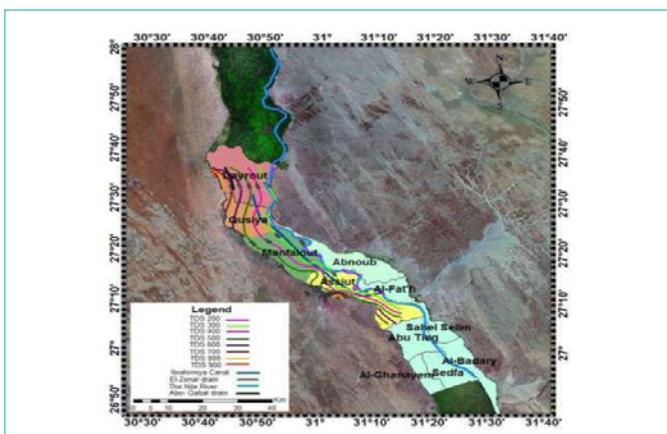


Figure 30: The TDS concentrations distribution in September 2010.

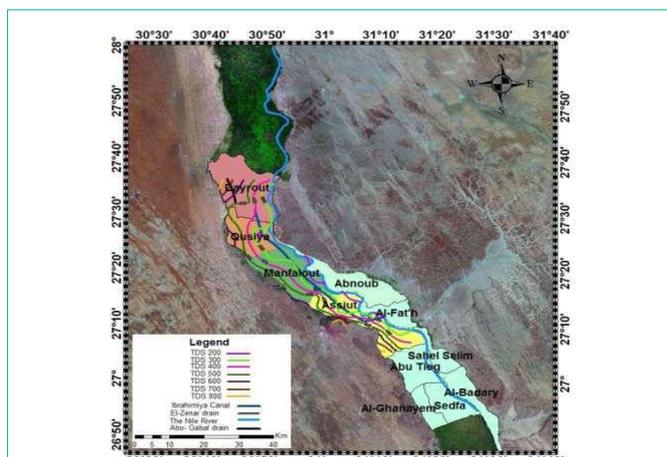


Figure 31: The TDS concentrations distribution in October 2010.

distribution during year 2009 represented by January, May, August and December.

Using of surfer program show that the variogram of TDS distribution of the January 2009 is linear with zero direction (90 tolerance and 1.6 slope) (Figure 5). The anisotropy is 3.1 ratios and 70 angles.

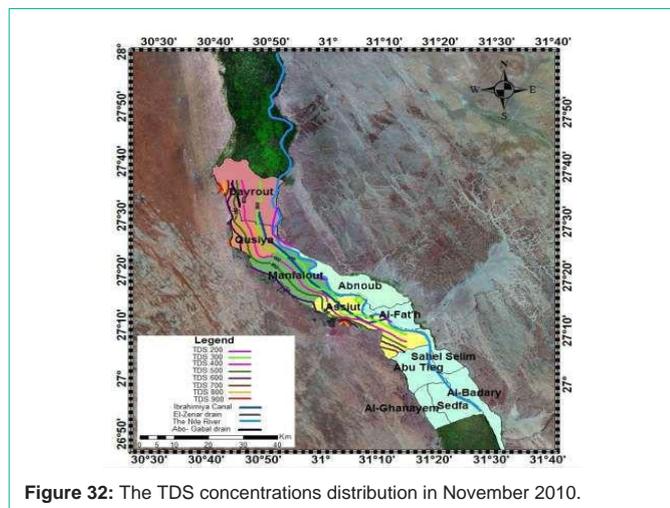


Figure 32: The TDS concentrations distribution in November 2010.

Table 1: The Water flow (Q) of main surface water during 2009 in Assiut city.

Month	The River Nile (Mm <sup>3</sup> )	Ibrahimia canal (Mm <sup>3</sup> )
January	2124.06	297.6
February	2335.399	774.2
March	3197.948	952.6
April	3558.064	903.9
May	4199.009	921.9
June	4928.016	1090.7
July	5032.644	1160.8
August	4422.653	1135.6
September	2960.974	834.3
October	2869.559	764.8
November	2401.686	703.1
December	1866.772	555.1

The variogram of TDS distribution of the May 2009 by using of surfer program is linear with zero direction (90 tolerances and 3.0 slopes) (Figure 6). The anisotropy is 1.1 ratios and 85 angles.

The variogram of TDS distribution of the August 2009 by using of surfer program is linear with zero direction (90 tolerances and 3.0 slopes) (Figure 7). The anisotropy is 1.3 ratios and 85 angles.

The variogram of TDS distribution of the December 2009 by using of surfer program is linear with zero direction (90 tolerances and 6.0 slopes) (Figure 8). The anisotropy is 1.2 ratios and 85 angles.

The Total Dissolved Solid (TDS) concentrations of wells are changing in areas and monthly during 2009. In the areas close to the River Nile, the TDS concentration range from 0.00ppm to 200ppm except in January, October, November and December reaches to 300ppm. At the south part of valley, the TDS concentrations increase gradually from 200ppm at the area closed of the River Nile to reach 800ppm during December at western part of the valley. In the middle of valley where the Ibrahimia canal presents, the majority of TDS concentrations were 300ppm and 400ppm while it reach to 500ppm in January and February. By reaching to Western Plateau, the TDS concentrations ranging between 700ppm to 900ppm, the minimum value is 600ppm in July and records the maximum value (1000ppm)

Table 2: The Water flow (Q) of main surface water during 2010 in Assiut.

Month	The River Nile (Mm <sup>3</sup> )	Ibrahimia canal (Mm <sup>3</sup> )
January	1858.204	324.88
February	2238.282	677.6
March	2815.58	847.1
April	2950.622	805.4
May	3804.126	868.5
June	4765.755	1043.3
July	4856.73	1114.3
August	4380.476	1132.5
September	2902.207	845.3
October	2936.411	794.5
November	2478.635	713.6
December	1770.498	552.7

in December (Figures 9-19).

**The distribution of Total Dissolved Solid (TDS) concentration in 2010**

The amount of water flow of the main surface water such as the River Nile and the Ibrahimia canal was variable monthly during 2010 (Table 2), where it reaches to the minimum values in winter due to the winter embankment then it increase gradually to reach maximum values in summer months.

The distribution of the Total Dissolved Solid (TDS) concentration of wells at year 2010 is located in four centers (Dirout, Qusiya, Manfalout and Assiut city). (Figures 20 & 21) show the variograms of TDS distribution during year 2010 represented by January and June.

Using of surfer program show that the variogram of TDS distribution of the January 2010 is Quadratic with zero direction, 90 tolerances, 62800 scales and 14500 lengths (Figure 20). The anisotropy is 2.5 ratios and 115 angles.

The variogram of TDS distribution of the June 2010 by using of surfer program is Quadratic with zero direction, 90 tolerances, 26800 scales and 17900 lengths (Figure 21). The anisotropy is 1.45 ratios and 90 angles.

In the majority months, The Total Dissolved Solid (TDS) concentrations of wells rang between 200ppm to 300ppm in the areas close to the River Nile. The TDS concentrations increase gradually to reach the maximum value in the western part of the valley close to western plateau, it record 1000ppm at Assiut and Dirout in January while it record 700ppm in January, September and November at Qusiya and in January at Manfalout (Figures 22-32).

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