Journal of Al Azhar University-Gaza *(Natural Sciences)*, 2018, 20 (2) : 49-62

Evaluating Spatial Variability of Groundwater Electrical Conductivity via Geostatistical Methods

Ali Hassan Abuzaid

Department of Mathematics, Faculty of Science, Al Azhar University – Gaza, Palestine.

Email: a.abuzaid@alazhar.edu.ps

Received 4/10/2018 *Accepted* 14/11/2018

Abstract:

This paper aims to evaluate and map the groundwater quality in the Gaza Strip by the means of geostatistical procedures including variograms, Kriging and maps interpolation. Electrical Conductivity (EC) of water is an easy measure of water quality. It measures the ability to conduct an electric current due to the breakdown of salts or other chemicals into negatively and positively charged ions. The purer the water the lower the conductivity.

There are more than 4000 wells within the Gaza Strip, only 109 wells are operated by municipalities. The results of analysis reveal a critical situation of water quality, where there are only 23 (21.1%) of the wells are below the safe limit, while the other 86 (78.9 %) of the wells exceed the safe limits. Spatial maps interpolation show that the west region of Gaza governorate tends to get impermissible values of EC. Furthermore, due to lack of sample from wells in the south east of Gaza strip, high values of prediction errors have been obtained.

الملخص:

يهدف هذا البحث لتقييم جودة المياه الجوفية في قطاع غزة باستخدام اجراءات الإحصاء الجغرافي والتي تشمل رسم التغير (Variogram)، و طرق الاحصاء الجيولوجي لاستكمال القيم (Kriging)، وتوليد الخرائط المكانية (Maps interpolation) .

يعتبر التوصيل الكهربائي للمياه مقياساً سهلاً لجودة المياه. حيث يقيس القدرة على سريان التيار الكهربائي بسبب تحلل الأملاح أو المواد الكيميائية الأخرى إلى أيونات سالبة وموجبة الشحنة، فكلما كان الماء أكثر نقاءً كلما قلت الموصلية.

يوجد في قطاع غزة أكثر من 4000 بئراً للمياه، منها 109 آبار يتم تشغيلها من خلال البلديات. تعكس نتائج التحليل وضعاً حرجاً لجودة المياه الجوفية في قطاع غزة حيث أن هناك 23 بئراً فقط وبما نسبته 21.1% كانت مؤشراتها أقل من الحد الآمن، بينما يوجد 86 بئراً وبما نسبته 78.9% تجاوزت مؤشراتها هذا الحد. أظهرت الاستقراءات المكانية للخرائط أن المنطقة الغربية لمحافظة غزة تميل إلى الحصول على قيم غير مسموح بها للتوصيل الكهربائي.، علاوة على أن محدودية عدد العينات من الآبار في منطقة الجنوب الشرقي لقطاع غزة أدت للحصول على قيم عالية لأخطاء للتنبؤ.

Keywords: Coordinates; cross-validation; modeling; prediction.

1. INTRODUCTION

Gaza Strip is a narrow slide of land located at the south east Mediterranean Sea coast at longitudes $34^\circ 20'$ East and $31^\circ 25'$ North with total area of 365 km^2. It is considered as one of the most densely populated areas in the world, 5239 inhabitants per km^2 with estimated growth rate 3.21 (PCBS, 2017). Gaza Strip is divided into five administrative governorates, namely, Northern Gaza, Gaza, Deir el-Balah, Khan Younis and Rafah with 25 municipalities. (PCBS, 2015).

Water quality is a vital factor controlling health status in both humans and animals (WHO, 2011). Abu Mayla and Abu Amr (2010) concluded that, the deterioration of chemical and microbiological qualities of drinking water in Gaza Strip may result in adverse human health impacts. Gaza Strip is considered as one of the scarcest renewable water resources areas, (PWA, 2014). The groundwater aquifer is the main source of water in the Gaza Strip, where there is no permanent surface water. Furthermore, low rainfall and over pumping have contributed negatively to the quantity and quality of water, (PHG, 2002).

The total water supplied for domestic use in Gaza Strip was about 88.466 mcm in 2014, where, 96 % (84.9 mcm) of that water is supplied from groundwater through 247 water wells. While the remaining 4 % (3.54 mcm) is supplied from Mekorot (PWA, 2014). Shomar, et al (2010) and Abbas, et al (2013) concluded that no groundwater in Gaza Strip meets all WHO drinking water standards and some actions to improve the groundwater conditions are necessary to safeguard the population.

Ghabayen, et al (2006) mentioned that the main sources affected the quality of water in Gaza including: sea water intrusion or upcoming and disposal of domestic and industrial wastes into the aquifer, mobilization of deep brines and soil/water interaction in the unsaturated zone due to recharge and return flows.

Few studies considered the problem of water quality in the Gaza Strip depending on different chemical factors and various traditional statistical methods. Abu Mayla and Abu Amr (2010) used summary statistics to evaluate the chemical and microbiological qualities of the drinking water based on the concentration of total dissolved solids (TDS), chloride (Cl-) and nitrate (NO3-) in drinking water wells, and contamination of total and fecal coliforms in water wells and distribution networks.

Abbas, et al (2013) analyzed major ions and trace elements to check if the water quality is improving compared to previous studies based on summary statistics and using the piper plot. Yassin, et al (2006) assessed the contamination level of total and fecal coliforms in water wells and distribution networks, and their association with human health in Gaza Governorate based on summary statistics.

Shomar, et al (2010) was the first to use (GIS) tool to construct thematic maps for groundwater quality in the Gaza Strip, without further statistical modeling.

Since the standard statistics may miss important trends in the data, then the spatial methods create better estimates of differences among treatments or sites where it uses the underlying spatial variations (Scheiner & Gurevitch 2001). There are several authors used the geostatistical methods to assess ground water quality, such as (Agoubi, et al.,2013, Liu, et al, 2011, Nas and Berktay 2010, Sha'Ato, et al, 2010).

This paper considers the assessment of groundwater quality in the Gaza Strip based on the analysis of the spatial variability of electricity conductivity via geostatistical methods. The rest of paper is organized as follows: Section 2 reviews the electric conductivity as one of the main measures of water quality, Section 3 presents the essential geo-statistics procedures. Description and analysis of data is discussed in Section 4.

2. THE ELECTRIC CONDUCTIVITY

The quality of water is assessed by a wide range of measurable characteristics, which can be categorized into physical, microbiological, chemical and radiological (NHMRC, 2011). The Electric Conductivity (EC) is one of these measures.

EC estimates the amount of total dissolved salts (TDS) in a volume of water. It is the inverse of resistivity of an electrical current, which is measured by the unit of invers of ohms (mho) or Siemen (abbreviated “S”). It measures the ease with which electrical current can pass through water.

According to (Moore, et al 2008) EC has some advantages where it can be measured with high resolution in the field, and it can be recorded with a data logger electronically. Furthermore, EC can be considered as an indicator of hydrologic process (interpret the changing sources of run off on both diurnal/storm event and seasonal time scales).

The electrical conductivity of the water depends on water temperature; the higher the temperature, the higher the electrical conductivity would be. The electrical conductivity of water increases by 2-3% for an increase of 1 degree Celsius of water temperature. Many EC meters nowadays automatically standardize the readings to 25^{o}C.

World Health Organization (WHO) (2011) has set the standard for quality of drinking water to be (less than) 1400 (µS/cm). In this paper the values of EC is considered as the measure of the groundwater quality in the Gaza Strip.

3. GEOSTATISTICAL METODS

Geo-statistics is a branch of statistics which describes the spatial continuity of natural phenomena (Isaaks and Srivastava, 1989). It collects theories and numerical techniques which deal with the characterization of spatial attributes, by employing primarily random models similar to the way of characterizing temporal data in time series analysis (Olea, 1999). The basic component of geo-statistics are variogram analysis, Kriging and maps interpolation, as explained in the following subsections, respectively.

3.1 Variogram

Variogram is a classical way in geo-statistics to measure spatial correlation, or simply the variation between successive points. It presents the mean variance found in comparisons of samples of increasing lag distance, in other words, the variogram is a function that relates semivariance of data points to the distance that separates them. The variogram γ is obtained as follows

$$h(\vec{\gamma}) = \frac{1}{2}E\left[\left[Z(\vec{x}+\vec{h}) - Z(\vec{x})\right]^2\right] = \frac{1}{2}Var\left[\left[Z(\vec{x}+\vec{h}) - Z(\vec{x})\right]^2\right],$$

where $Z(\vec{x})$ and $Z(\vec{x}+\vec{h})$ are random variables, $\vec{x}$ and $\vec{x}+\vec{h}$ are the spatial positions separated by a vector $\vec{h}$. The $h(\vec{\gamma})$ depends only on the separation vector $\vec{h}$ but not the location $\vec{x}$.

There will be little difference in the variance (γ) at any distance comparison if the data are randomly distributed. However, the existence of certain distributional pattern leads to the expectation of increasing that variance at the comparisons of closed autocorrelated samples. Some important models are linear, spherical, exponential, wave, and Gaussian models (Chiles and Delfiner, 1999).

It is worth to mention that, some authors use the term semivariogram, while others use the term variogram, recently Bachmaier and Backes (2011) remarked that the term semivariogram should be avoided.

3.2 Kringing

Kriging is a tool of spatial prediction to estimate unknown local values of variables that are distributed in a space of dimension. It attempts to model the variability in the data as a function through the variogram (Isah, 2009).

In Kriging estimation each observation is given a weight according to the direction and distance between that point and the point to be estimated. These weights are assigned using either; the inverse of the number of values, inverse of the square of the distances, or the inverse of the distance, where an optimal set of weights are obtained based on the information from the variogram, which minimize the Kriging variance or the square root of the Kriging error (Vieira, et al., 1982)

The most reliable estimation method is Ordinary Kriging (OK), while there are some other types of Kriging estimation, such as Simple Kriging (SK), Universal Kriging (UK), Block Kriging (BK), Co-Kriging (CK) and Disjunctive Kriging (DK). For further information see (Lichtenstern, 2013).

The validation of the proposed Kriging model is assessed based on cross-validation methodology by leaving out 10% of the available data as test data and considering the rest 90% as training data. Furthermore, the validation is measured by the root mean squared prediction errors (RMSE) and the root mean squared standardized prediction errors (RMSSE) as given by

$$RMSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\hat{z}_{-i}(s_i)-z(s_i)\right)^2},\ \text{and}\ RMSSE=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\left[\hat{z}_{-i}(s_i)-z(s_i)\right]/\sigma_{-i}\right)^2},$$

where $\hat{z}_{-i}(s_i)$ and σ_{-i} are the best linear drop-one prediction based on all observations $z(s_i)$ for $i\neq j$ and its corresponding drop-one prediction standard deviation, respectively. The best model is the model with the smallest value of RMSE, while RMSSE should be close to 1, if it is less than 1.

3.3 Maps Interpolation

Spatial interpolation is the process of predicting unknown points based on a set of points with known values. There are many interpolation methods, where the most widely used interpolation methods are Inverse Distance Weighting (IDW) and Triangulated Irregular Networks (TIN). For further information see (Chang, 2006)

4. DATA AND ANALYSIS

4.1 Description

The number of wells in Gaza strip is estimated to be about 4000 wells, only 109 wells are operated by the municipalities, where the measurements of its characteristics are obtained periodically. Data is obtained from the Ministry of Planning in Gaza, Palestine, for a total of 109 wells which are operated by municipalities and distributed on spatial $77585.36 < X < 106475.1$ and $78491.00 < Y < 107217.9$.

Summary statistics for the EC in 2013 according to the five governorates are given in Table 1. Results show that for 109 wells the EC ranges between 729 µS/cm and 32300 µS/cm with mean 3899.08 µS/cm and standard deviation 3976.87 µS/cm. Figure 1 presents the sample locations in the Gaza Strip for the EC data, where the sizes of bubbles are proportionally correlated to the values of EC.

Table 1: Summary statistics for EC in ground water in the Gaza Strip, (*n*=109)

		EC (µS/cm)				
Governorate	**No.**	**Mean**	**S.d.**	**Min.**	**Max.**	**Median**
North	29	1842.00	1641.88	729.00	8070.00	1379.00
Gaza	35	5335.03	5852.14	989.00	32300.00	3180.00
Deir el-Balah	16	4505.00	1794.77	2070.00	8460.00	4255.00
Khan Younis	19	4298.42	3287.53	935.00	15000.00	3740.00
Rafah	10	3110.60	1304.65	825.00	4830.00	3430.00
Total	**109**	**3899.08**	**3976.88**	**729.00**	**32300.00**	**2960.00**

Consistently with summary statistics in Table 1, the sizes of bubbles in Figure 1 reveals that the EC of the samples collected from the wells in the Gaza governorate has the highest values, while the minimum values of EC are obtained from wells in the North governorate.

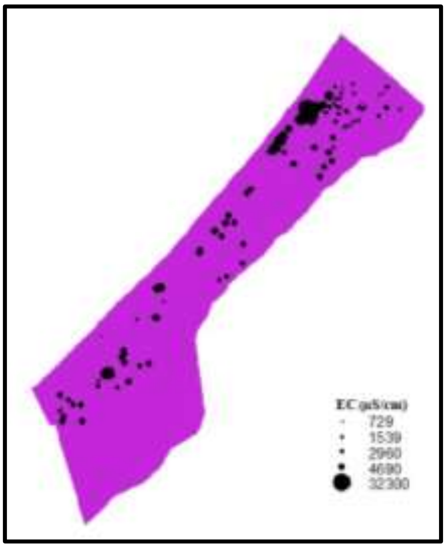


Figure 1: The sample locations in Gaza Strip for the EC data, (*n*=109).

Furthermore, the distribution of the wells according to their location and quality assessment based on EC is given in Table 2, where The EC values of the majority of samples are higher than permissible limit (1400 μS/cm). As per the classification on conductivity values, there are only 23 (21.1%) of the wells are below the safe limit, while the 86 (78.9 %) of the wells exceed the safe limit which reveals a critical situation. There is a significant association between the governorates and quality of water where the value of Chi-square test is 23.607 at 4 degrees of freedom with p-value =0.000, where the EC of the majority of ground water samples in Gaza, Deir el-Balah, Khan Younis and Rafah exceed the safe limit, while 51.7% of the obtained EC of groundwater samples in the North governorate are less than the safe limit.

Table 2: Cross tabulation of the water quality indicators and governorates.

Governorate	Permissible	Not permissible	Total
North	15 (51.7%)	14 (48.3%)	29
Gaza	5 (14.3%)	30 (85.7%)	35
Deir el-Balah	0 (0.0%)	16 (100.0%)	16
Khan Younis	2 (10.5%)	17 (89.5%)	19
Rafah	1 (10.0%)	9 (90.0%)	10
Total	**23 (21.1%)**	**86 (78.9%)**	**109**

The value of Shapiro-Wilk test of normality for EC is 0.64195 with p-value = 0.00, which reveals non-normal distribution. Since the geostatistical procedures require the normality of the investigated variable, the value of Shapiro-Wilk test of normality of logarithmic transformation of EC is 0.994 with p-value = 0.829 which reveals the normality of the transformed EC.

4.2 Modeling and Prediction

There are different models of variogram can be used for prediction purpose. Table 3 gives a set of available variogram models associated with the indicators of the validation of these models to predict unknown values of the EC in the Gaza Strip. After applying different ordinary kriging models on the estimated valid variograms to the empirical variograms. Cross validation methodology is applied and then the RMSE and RMSSE are obtained.

Table 3: Cross-validation results of log (EC) modeling

Model	Mean	RMSE	RMSSE
Nugget	7.9779	0.6726	1.1613
Exponential	7.9511	0.5056	0.9466
Spherical	7.9606	0.5202	0.9579
Gaussian	7.9705	0.5197	0.9422
Exponential class/stable	7.9544	0.5117	0.9211
Matern	7.9523	0.5054	0.9558
Matern, M. Stein's	7.9547	0.4902	0.9274

Circular	7.9606	0.5001	0.9233
Linear	7.9574	0.5335	0.9711
Bessel	7.9771	0.4970	0.9128
Penta spherical	7.9686	0.4870	0.9002
Wave	7.9570	0.4353	0.9972

Results in Table 3 suggest that the wave variogram model which has the smallest value of RMSE (0.4353) and with value of RMSSE (0.9972) which is the nearest to 1 among all compared variogram models. Thus, the wave variogram model (with mean 7.9570, nugget 0.2205, partial sill 0.5251 and range 4371.454) fitted to the empirical variogram is the best for modeling the spatial structures of the log-transformed EC data in the Gaza Strip.

Figure 2 shows the fitted theoretical wave parametric variogram model to the empirical model of the log (EC) in the Gaza Strip.

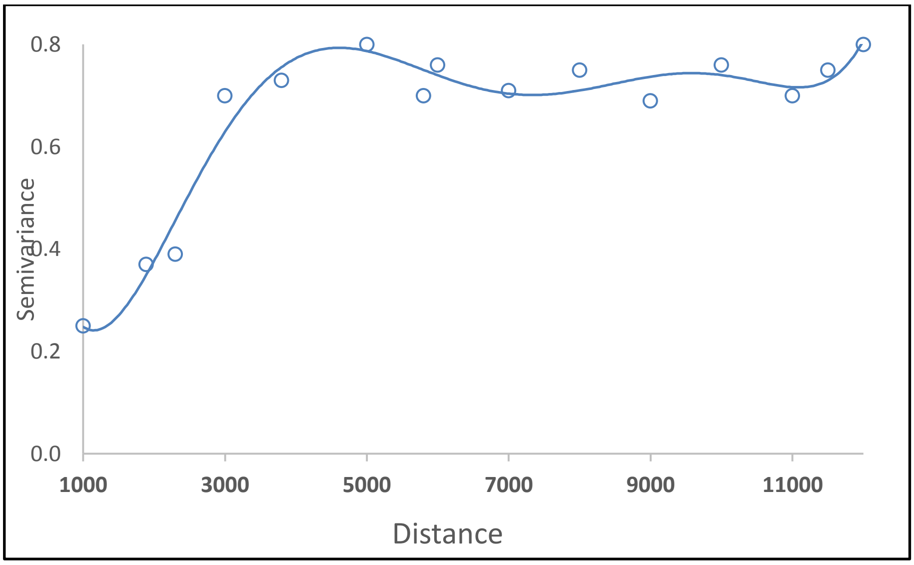
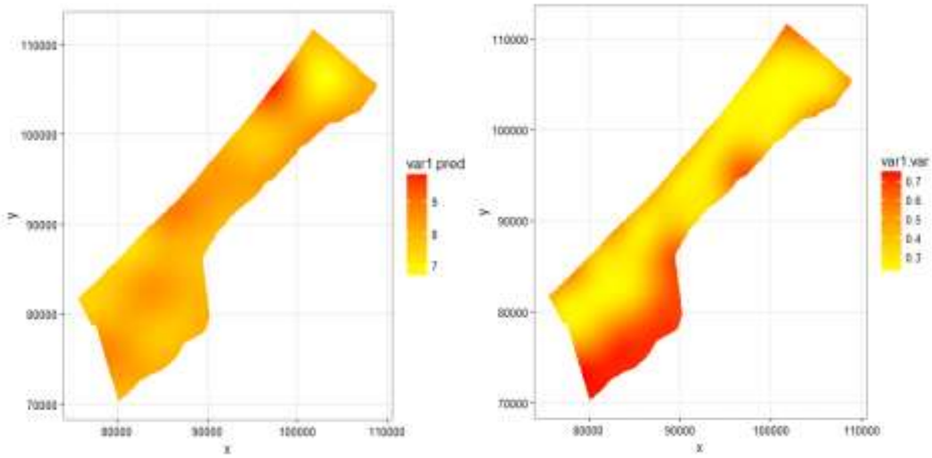


Figure 2: The wave parametric variogram for the log(EC) in the Gaza Strip.

Once the best model is selected, then interpolation spatial distribution maps of these parameters are generated. Figure 3 (a) shows the ordinary kriging prediction of EC distributed spatially into nine levels from very low (white areas) to moderate values of EC (grey areas), to high values of EC (black areas) on the map. The coast of Gaza governorate is very highly risked of getting not permissible values of EC, followed by the Khan Younis coast. On the other hand, the lowest values of EC are predicted to be located in North governorate. On the other side Figure 3 (b) presents the kriging prediction error variances map. The darkness of shadow inversely correlated to number of wells presented in Figure 1, where the variances of errors are the highest in east south borders of the Gaza Strip.



(a) Predicted levels (b) Predicted errors

Figure 3: (a) Predicted levels, (b) Predicted errors of EC based on ordinary kriging interpolation with a wave variogram.

The modeling and prediction of spatial EC data have been conducted by using a set of libraries in R statistical software including *sp, gstat. ggplot2, rgdal, and maptools*.

5. CONCLUSIONS

Due to the infeasibility of collecting sample of water from all the locations in the study areas; the importance of geostatistical analysis is raised. The quality of groundwater in the Gaza Strip has been evaluated and mapped based on set of geostatistical procedures including varigoram, ordinary kriging and the spatial distribution maps of the EC of 109 samples from groundwater. Cross-validation method was used to assess the prediction performances by twelve different variogram models.

Further researches based on the coordinates of sample elements in different disciplines are acknowledged, especially after the conduction of the National Palestinian Population, Housing and Establishment Censes, 2017 based on tablets, which provide the coordinates of sampling units.

REFERENCES

Abbas, M., Barbieri, M., Battistel, M., Brattini, G., Garone, A. and Parisse, B. (2013). Water Quality in the Gaza Strip: The Present Scenario. *Journal of Water Resource and Protection*, **5**, 54-63.

Abu Mayla, Y. S. and Abu Amr, S. S. (2010). Chemical and microbiological quality of drinking water in Gaza Strip, Palestine, *Science Vision*, **10** (3), 80-88.

Agoubi, B., Kharroubi, A., and Abida, H. (2013). Hydrochemistry of groundwater and its assessment for irrigation purpose in coastal Jeffara Aquifer, southeastern Tunisia. *Arabian Journal of Geosciences*, **6** (4), 1163–1172.

Bachmaier, M. and Backes, M. (2011). Variogram or Semivariogram? Variance or Semivariance? Allan Variance or Introducing a New Term?. *Mathematical Geosciences*, **43**, 735–740

Chiles, J. P., Delfiner, P. (1999). *Geostatistics: Modeling Spatial Uncertainty*. John Wiley & Sons, New York.

Chang, K. (2006). *Introduction to Geographic Information Systems*. 3rd Edition. McGraw Hill.

Ghabayen, G., McKee, M. S. and Kemblowski, M. (2006). Ionic and Isotopic Ratios for Identification of Salinity Sources and Missing Data in the Gaza Aquifer. *Journal of Hydrology*, **318** (1-4), 360-373.

Isaaks, E. H. and Srivastava, R. M. (1989). *An Introduction to Applied Geostatistics*, Oxford University Press.

Isah A. (2009). Spatio-Temporal Modeling of Nonstationary Processes, *Journal of Science, Education and Technology*, **2** (1), 372-377.

Lichtenstern, A. (2013). *Kriging Methods in Spatial Statistics*, Master Thesis, Technical University of Munich, Germany.

Liu, W.C., Yu, H.L., and Chung, C.E. (2011). Assessment of water quality in a subtropical Alpine Lake using multivariate statistical techniques and geostatistical mapping: a case study. *International Journal of Environmental Research and Public Health*, **8** (4), 1126–1140.

Moore, R. D., Richards, G. and Story, A. (2008). Electrical Conductivity as an Indicator of Water Chemistry and Hydrologic Process. *Streamline Watershed Management Bulletin*, **11**(2), 25-29

Nas, B., and Berktay, A. (2010). Groundwater quality mapping in urban groundwater using GIS. *Environmental Monitoring and Assessment*, **160** (1–4), 215–227.

NHMRC, NRMMC (2011). Australian Drinking Water Guidelines, Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra.

Olea, R. A. (1999). *Geostatistics for Engineers and Earth Scientists*, Kluwer Academic Publishers.

Palestinian Central Bureau of Statistics (2015). *Local Communities Survey, 2015: Main Findings*. Ramallah, Palestine.

Palestinian Central Bureau of Statistics (2017). *Palestine in Numbers, 2016*. Ramallah, Palestine.

Palestinian Hydrology Group for Water and Environmental Resources Development (PHG) (2002). *Quality use of home reverse osmosis filters of some areas in Gaza Strip*, Gaza, Palestine.

Palestinian Water Authority (2014). *Gaza Water Resources Status Report 2013/2014*. Gaza, Palestine.

Scheiner, S. M. and Gurevitch, J. (2001). Design and Analysis of Ecological Experiments, 2nd Ed. Oxford University Press.

Sha'Ato, R., Akaahan, T. J., and Oluma, H.O.A. (2010). Physico-chemical and bacteriological quality of water from shallow wells in two rural communities in Benue State, Nigeria. *Pakistan Journal of Analytical and Environmental Chemistry*. **11**(1), 73-78.

Shomar, B., Abu Fakher, S. and Yahya, A. (2010). Assessment of Groundwater Quality in the Gaza Strip, Palestine Using GIS Mapping. *Journal of Water Resource and Protection*, **2**, 93-104.

Vieira, R. J., Hartfield, L.J., Nielsen, D. R. and Biggar, W. J. (1982). Geostatistical Theory and Application to Variability of some Agronomical Properties. *Hilgardia*. **51**(3), 1-75.

World Health Organization (WHO) (2011). Guidelines for Drinking Water Quality, 4th ed., World Health Organization Recommendations, Geneva, 1-4.

Yassin, M. M., Abu Amr, S. S. and Al-Najar, H. M. (2006). Assessment of microbiological water quality and its relation to human health in Gaza Governorate, Gaza Strip, *Public Health*, 120 (12), 1177-1187