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Effect of GIS Interpolation Techniques on the Accuracy of the Spatial Representation of Groundwater Monitoring Data in Gaza Strip

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ABSTRACT

Spatial representation of groundwater water data is usually produced using Geographical Information System (GIS) as a tool for groundwater management. This study aimed at investigating the effect of the GIS interpolation techniques on the accuracy of the spatial representation of such data. In this research, groundwater data (chloride concentration and water level) were collected from many wells along the Gaza Strip (GS). The data were then processed by GIS using three different interpolation techniques (e.g., Inverse Distance Weighting (IDW), Kriging, Spline). Statistical analysis using regression and residual analyses were applied for each interpolation technique to select the best fitted model. Then, cross-validation of the best fitted model was performed using two independent sets of data. Results showed that Kriging method produced the most accurate interpolating model for chloride concentration and for groundwater level prediction compared to IDW and Spline. It was therefore concluded that the Kriging method should be used in producing the surface maps for GS conditions to represent the two investigated parameters.

Key words: GIS interpolation, spatial distribution, groundwater quality, geostatistical analysis, cross validation

INTRODUCTION

Groundwater reservoir is the sole source of fresh water in GS. Unfortunately, it suffers from a yearly deficit of 30-40 MCM/y due to over abstraction of water and low rainfall intensities (200-400 mm year^{-1}) (CMWU, 2008). The deficit is increasing with time due to the rapid population growth (Nassar *et al.*, 2009) and the decreasing rainfall infiltration rates resulting from the rapid urbanization activities (Khalaf *et al.*, 2006). Moreover, it is exposed to pollution from many sources such as wastewaters, solid wastes, sea water intrusion and excessive use of fertilizers (Alslaibi *et al.*, 2011; Hilles and Al-Najar, 2011; Al-Safady and Al-Najar, 2011). These facts indicate the crucial importance of managing and monitoring this vital resource.

As many professionals indicated, groundwater quality mapping over extensive areas is the first step in water resources planning (Todd, 1980). In response to the facts mentioned above, the Palestinian Water Authority (PWA) in GS established a GIS unit in 1997. This unit is responsible for producing groundwater quality mapping for the purpose of managing and monitoring the GS coastal aquifer (PWA, 2000). GIS applications that are of particular importance to groundwater industry are: mapping, monitoring, modelling and maintenance (Shamsi, 2005). Unfortunately, the produced surface maps for the groundwater parameters in GS aquifer proved to give inaccurate representation compared to field inspections. One of the suspected reasons including insufficient data and wrong sampling norms is the inaccuracy of the interpolation method used in producing such maps (PWA, 2000). In groundwater, due to aspects of time and cost, data monitoring is conducted at a limited number of sites (i.e., municipal wells, agricultural wells and observation wells) (Kholghi and Hosseini, 2008). Consequently, an interpolation method has to be used to estimate surface values at those locations where no samples or measurements are taken (Hartkamp *et al*., 1999).

The effect of interpolation methods on the accuracy of the GIS mapping was also recognized by Mehrjardi *et al*. (2008). They compared the efficiency of three interpolation techniques (i.e., IDW, Kriging and Cokriging) for predicting some groundwater quality indices. The results showed that cokriging performed better than the other methods. Coulibaly and Becker (2007) performed a study to interpolate the spatial distribution of annual rainfall using IDW, ordinary Kriging (OK), universal Kriging and Cokriging. The best results were achieved by ordinary Kriging. Sun *et al*. (2009) produced surface maps for groundwater level. Results of their work showed that Kriging achieved high prediction accuracy compared to other methods. Ibrakhimov *et al*. (2007) analyzed the temporal dynamics of groundwater table and salinity. The study revealed that Kriging gave the most accurate maps. Shamsudduha (2007) investigated the spatial distribution of groundwater arsenic concentration. The results showed that the OK method performed considerably better than other methods. Salih *et al*. (2002) studied the spatial correlation between radon in groundwater and bedrock uranium. The best spatial correlation between the two elements was produced using IDW interpolator.

This research was therefore carried out to investigate the effect of the different interpolation methods (i.e., Kriging, IDW and Spline) on the accuracy of the spatial representation of groundwater data in GS. Another objective of the research was to recommend the best fitted interpolation method regarding GS groundwater monitoring data. These three methods were specifically selected for evaluation since they are the interpolating methods applied by the PWA GIS unit in GS.

MATERIALS AND METHODS

Study area: The Gaza Strip (GS) is a semi arid area located between longitudes 34° 2" and 34° 25" east and latitudes 31° 16" and 31° 45" north .The GS is bordered by the Mediterranean Sea from the west, Egypt from the south and the occupied Palestinian territories from the east (Fig. 1). It has an area of about 365 km^2 and a recent population of 1.5 million (MOPIC, 1998).

Groundwater monitoring data: The study dataset comprised of two categories: groundwater quality parameter (Chloride (Cl^-) and groundwater level (WL). These dataset were obtained in years from 2000-2007 from PWA and Coastal Municipalities Water Utility (CMWU) data bank's departments as they are both the solely official source of water data in GS. The evaluation only considered the working wells while there were many wells recently closed due to increasing salinity in the water or damaging and faulting of the mechanical parts of these wells.

Measurements of GS groundwater parameters in years 2001, 2003, 2005 and 2007 were considered in the study for reasons of availability and consistency of data. Further, two parameters were selected for the assessment of interpolation effect; namely, chloride (mg L^{-1}) as a testing groundwater quality parameter and groundwater level.

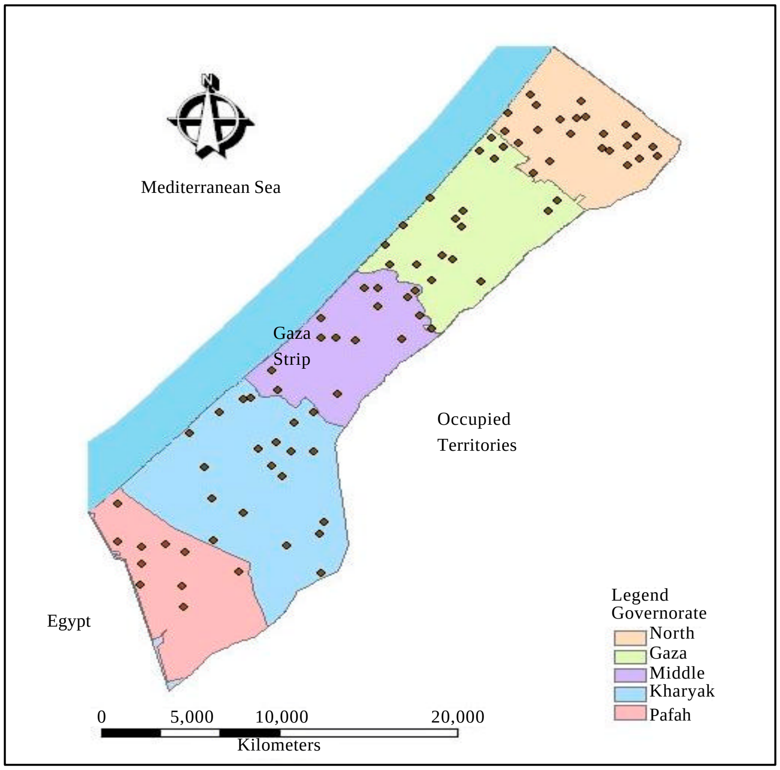

Fig. 1: Geographical distribution of the studied groundwater wells along Gaza Strip

Table 1: Summary of the numbers and distribution of the used groundwater wells

Description/Year	2001	2003	2005	2007
Chloride				
No. of total study wells	71	88	104	129
No. of wells used for calibration	10	15	20	23
No. of wells used for modeling	61	73	84	106
Groundwater level				
No. of total study wells	101	102	105	99
No. of wells used for calibration	9	10	10	10
No. of wells used for modeling	92	92	94	89

Table 1 details the distribution of wells which were considered in this study as these wells were regularly monitored and sampled by official entities in GS. The selection of modeled and calibration wells was based on geospatial representation of the study area.

Methods of data processing and analysis: The dataset of water quality monitoring was imported into ESRI ArcMap software (http://www.esri.com/). The ESRI Geographic Information System (GIS) was used for the construction of the interpolation surfaces of chloride concentration and groundwater level through applying the 'Geostatistical Analyst' extensions of ArcGIS-ArcMap 9.2 software package.

Three interpolation models were used in this study to generate a set of predicted values at known locations along the GS. The three models were:

- Kriging model (Ordinary Kriging type) subjected to semivariogram with smoothing factor under exponential and spherical tuning techniques
- Inverse Distance Weighting (IDW) with optimized power and smoothing factor
- Spline (RBF) with optimized tension power and smoothing factor

The predicted values by each model were generated by systematically removing some of the input data (Calibration data) for Chloride concentration and groundwater level then their values were calculated based on other data (Modeling data). The performance of each prediction model was evaluated by the magnitude and distribution of prediction errors when comparing the predicted values with the calibration data.

The theoretical and mathematical details of the Kriging, IDW and Spline techniques are given in ESRI (2009) (http://www.esri.com/), Lam (1983) and Naoum and Tsanis (2004), respectively.

Model validation and evaluation

Validation and cross-validation: Validation and cross validation were used in this research for models verification. The details of these two techniques are given by Foglia *et al.* (2007).

Evaluation: The choice of the "best fitted" model for each interpolation method and its corresponding parameters was based on the evaluation of the estimated errors. (the residuals, or estimated errors, are the differences between the observed data and fitted model) as it can be briefed as selecting the highest regression correlation coefficient for predicted vs. observed together with the lowest regression coefficient for the residuals for the agreements between the predicted models and the observed data.

RESULTS AND DISCUSSION

Prediction of chloride concentrations: The three interpolation methods, Kriging, IDW and Spline were used to predict the chloride concentration in the groundwater. Water samples were taken from a group of groundwater wells for the years 2001, 2003, 2005 and 2007. Figure 2 a-d gives the interpolation results produced by these three methods compared to the measured chloride concentrations for the above mentioned years, respectively. It was clearly observed from Fig. 2 a-d that each interpolation method consistently gave different predictions of the chloride concentrations. This supports the hypothesis of this study that the selected interpolation method affects the prediction accuracy of the chloride concentrations. To find out the best interpolation method a statistical analysis was performed to determine the prediction errors of each method. Table 2 gives a summary of the statistical analysis for the chloride datasets.

It is interpreted from the statistical analysis presented in Table 2 that the Kriging method produced the best predication model compared to the other two methods as it resulted in the highest correlation values and the smallest residual errors values. For example, the regression correlation coefficient (R^2) produced by Kriging in 2003 was 0.78 compared to 0.66 and 0.63 produced by the IDW and Spline, respectively. Kriging method has also given the lowest residual errors coefficient (R^2) of 0.39 compared to 0.51 and .74 produced by the IDW and Spline, respectively. The Kriging method showed similar superior results over the other two methods for the years 2001, 2005 and 2007 as shown in Table 2.

Prediction of groundwater levels: The three interpolation methods were also used to predict the groundwater level. Figure 3 a-d gives the interpolation results produced by each of the three

Table 2: Summary of statistical analysis for Chloride datasets using the three interpolations methods (Kriging, *IDW, Spline)

	Correlation analysis			Residual analysis		
Year	Kriging	IDW	Spline	Kriging	IDW	Spline
2007						
**R^2	0.26	0.13	0.18	0.36	0.55	0.64
Slope	0.44	0.26	0.26	-0.56	-0.74	-0.74
Intercept	340.30	408.86	398.12	340.30	408.86	398.12
2005						
R^2	0.69	0.68	0.54	0.21	0.37	0.18
Slope	0.72	0.66	0.69	-0.26	-0.34	-0.30
Intercept	159.49	174.17	159.53	159.49	174.17	159.53
2003						
R^2	0.78	0.66	0.63	0.39	0.51	0.74
Slope	0.69	0.61	0.45	-0.30	-0.39	-0.55
Intercept	134.29	135.09	209.61	134.29	135.09	209.61
2001						
R^2	0.75	0.66	0.63	0.15	0.26	0.30
Slope	0.81	0.70	0.66	-0.19	-0.29	-0.34
Intercept	86.17	99.89	121.19	86.17	99.89	121.19

*Inverse distance weighting, **Coefficient of determination

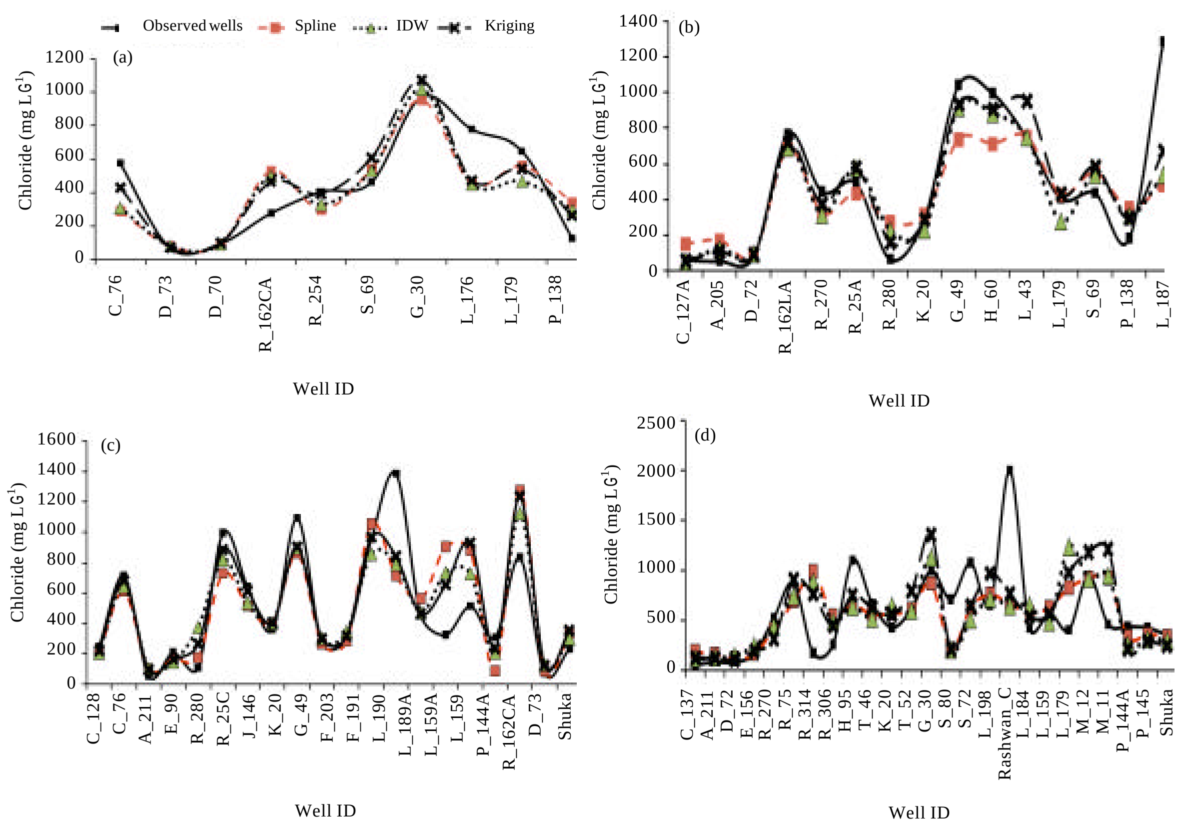

Fig. 2: Predicted vs. observed plots for Chloride dataset in different study years, (a) 2001, (b) 2003, (c) 2005 and (d) 2007

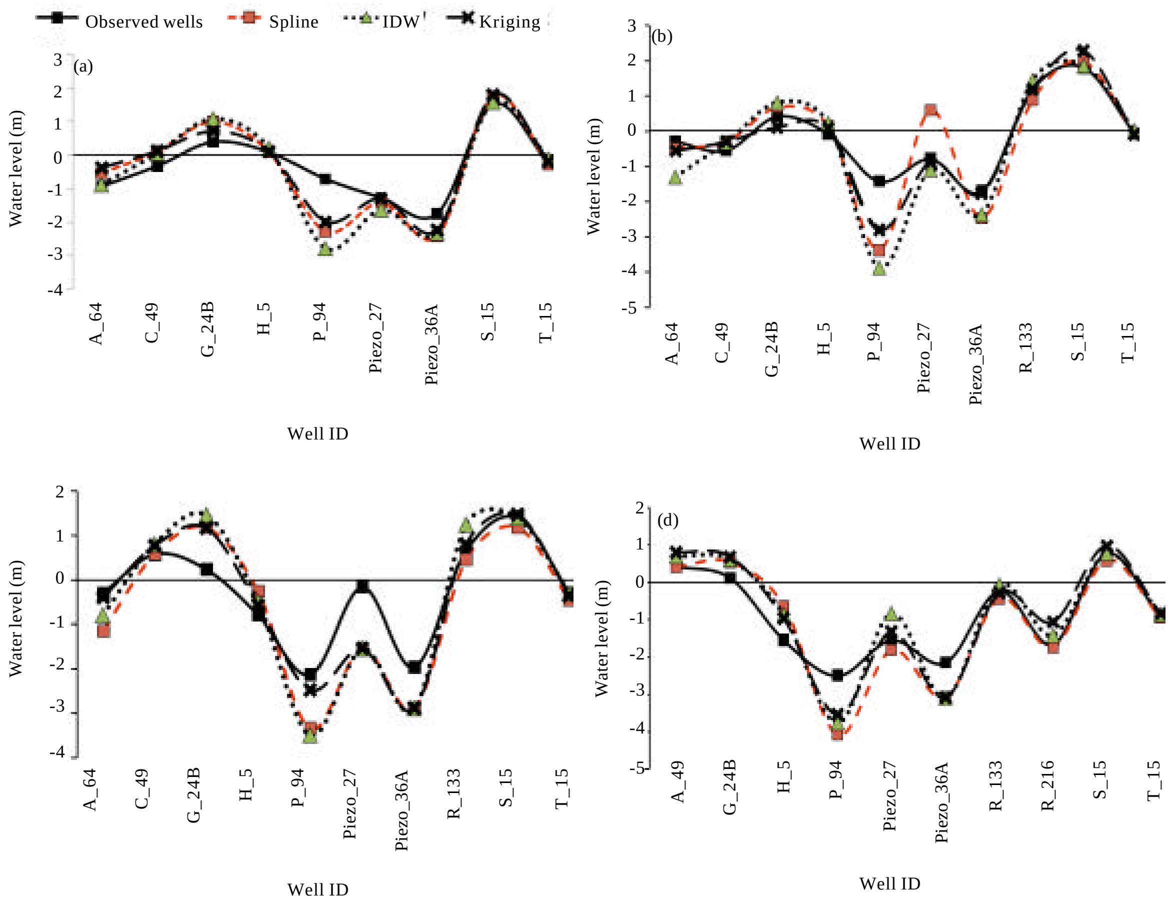

Fig. 3: Predicted vs. observed plots for Water level dataset in different study years, (a) 2001, (b) 2003, (c) 2005 and (d) 2007

methods compared to the measured groundwater water levels all over the study area for the years 2001, 2003, 2005 and 2007, respectively. It is evident from Fig. 3 a-d that each interpolation method consistently produced different values of the water level in the studied water wells. Statistical analysis was performed to determine the prediction errors of each method to decide the relatively best prediction method. Table 3 gives a summary of these statistical analysis results of the water level datasets.

As interpreted from Table 3, the Kriging method produced the best fitting model for the groundwater level prediction as well. The Kriging method gave the highest correlation values and the smallest residual errors values. For example, the regression correlation coefficient (R^2) produced by Kriging in 2003 was 0.91 compared to 0.84 and 0.74 produced by the IDW and Spline, respectively. Kriging method has also given the lowest residual errors coefficient (R^2) of 0.12 compared to 0.35 and 0.29 produced by the IDW and Spline, respectively. The Kriging method showed similar superior results over the other two methods for the years 2001, 2005 and 2007 as shown in Table 3. This finding indicates obvious advantage in using Kriging over Spline and IDW as an interpolator that can be the most applicable model for surface mapping the groundwater level dataset.

Table 3: Summary of statistical analysis for groundwater level using the three interpolations methods (Kriging, *IDW, Spline)

	Correlation analysis			Residual analysis		
Year	Kriging	IDW	Spline	Kriging	IDW	Spline
2007						
**R^2	0.89	0.86	0.85	0.22	0.22	0.29
Slope	1.29	1.27	1.28	0.29	0.27	0.28
Intercept	0.32	0.30	0.07	0.32	0.30	0.07
2005						
R^2	0.85	0.85	0.82	0.19	0.37	0.20
Slope	1.25	1.46	1.30	0.25	0.46	0.30
Intercept	-0.05	-0.05	-0.26	-0.05	-0.05	-0.26
2003						
R^2	0.91	0.84	0.74	0.12	0.35	0.29
Slope	1.25	1.48	1.27	0.27	0.48	0.25
Intercept	-0.08	-0.23	-0.05	-0.05	-0.23	-0.08
2001						
R^2	0.83	0.76	0.81	0.30	0.38	0.33
Slope	1.21	1.34	1.31	-0.32	-0.25	-0.28
Intercept	0.07	-0.05	0.03	-0.19	-0.02	-0.10

*Inverse distance weighting, **Coefficient of determination

Table 4: Results of similar investigations by other researchers

Names of researchers	Best interpolation method
Mehrjardi *et al.* (2008)	Cokriging
Sun *et al.* (2009)	Kriging
Ibrakhimov *et al.* (2007)	Kriging
Shamsudduha (2007)	Ordinary Kriging
Coulibaly and Becker (2007)	Ordinary Kriging
Wu *et al.* (2005)	IDW
Salih *et al.* (2002)	IDW

DISCUSSION

As illustrated above, it was found that the Kriging method is the best GIS interpolation method for predicting the chloride concentration and the groundwater level. Many researchers invistigated the effect of the interpolation methods on ground water quality parameters and rainfall spatial representation. The findings of some of these researchers are given in Table 4. As illlustrated in Table 4, some of the researchers reached similar results to this study while others found different results. Further invistigations are needed to figure out the cause of the variations in the results between the different invistigations. Data (type,quality, size) and specific site characteristics maybe some of the variation causes to be explored.

Surface mapping: For each dataset and after the validation and cross validation processes, surface map generation was conducted using the three interpolation methods for year 2007 to produce the chloride concentration and groundwater level prediction maps that show the spatial variation of these parameters in the study area (GS) as shown in Fig. 4 (a-c) and 5 (a-c). The

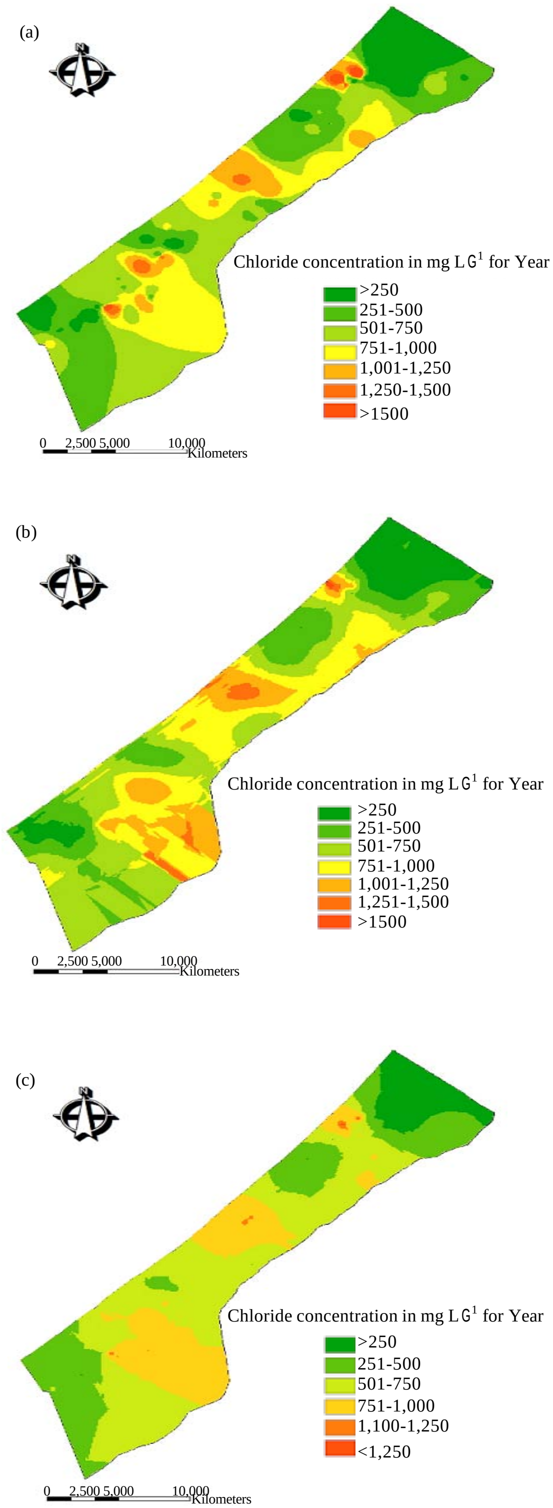

Fig 4: Spatial representation maps of Chloride concentration in GS for year 2007 produced by the three interpolation methods; (a) IDW, (b) Kriging and (c) Spline

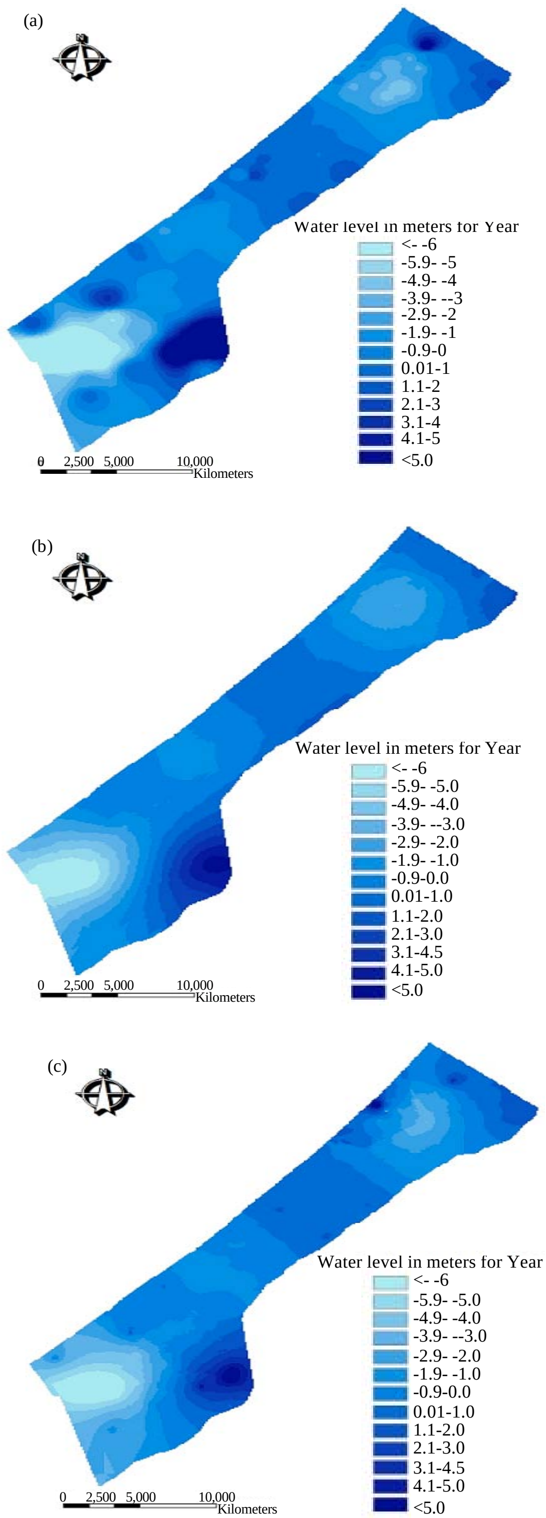

Fig. 5: Spatial representation maps of groundwater level in GS for year 2007 produced by the three interpolation methods; (a) IDW, (b) Kriging and (c) Spline

difference between the produced prediction maps using the different interpolation methods (i.e., Kriging, IDW and Spline) is visually clear which again supports the hypothesis of this study that each method gives different predictions of the studied parameters.

CONCLUSIONS

This study has conducted comprehensive comparative evaluation for three different interpolation methods for generating surface maps of two groundwater parameters in Gaza Strip (i.e., Chloride concentration and water level). The three methods were: Kriging, IDW and Spline. Each method was applied for the chloride concentration and water level data taken from a large number of groundwater wells for the years 2001, 2003, 2005 and 2007. Kriging method produced the best predication model compared to the other two methods as it resulted in the highest correlation values and the smallest residual errors values. These findings indicated the obvious advantage in using Kriging over Spline and IDW as an interpolator for producing chloride concentration and groundwater level surface maps. Accordingly, it is recommended that the Kriging method should be used in producing the surface maps for Gaza Strip conditions to predict and represent the two mentioned parameters. However, for other groundwater quality parameters such as nitrate concentration, similar studies should be done to investigate if Kriging maintains its superiority over the other interpolation methods.

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