# Analysis and Modelling of Groundwater Salinity Dynamics in the Gaza strip

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Recibido: 06/04/2017 | Aceptado: 05/04/2018

## Abstract

The Gaza Strip suffers from an acute problem in the water quality and quantity. Groundwater is used as drinking water, for agricultural uses, and industrial processes. Salinity is increasing in groundwater in the Gaza Strip. Seawater intrusion is the main source of salinity. A chloride ion-selective is used as indicator of salinity for analysis and modelling of salinity of groundwater in the Gaza Strip by 2023. Research depends on three models for prediction of chloride concentration in groundwater: Forecasting, Linear regression and Multiple regression for the year 2023. The result of three models showed water salinity will increase in all areas in the Gaza Strip by the year 2023. Only a small area in the North Governorate will keep less than 250 mg/L of chloride concentration in fresh water, which represents 4.56 % of the total of the Gaza Strip area. The analysis of seawater intrusion within the cross sections is clear along the coastline and outspreads from the Mediterranean Sea to the East part of the Gaza Strip.

Keywords: Groundwater; Salinity; Seawater intrusion; Modelling; GIS.

## Resumen

### *Análisis y modelización de la salinidad del agua subterránea en la Franja de Gaza*

La Franja de Gaza sufre un grave problema relacionado con la calidad y cantidad del agua. El agua subterránea se utiliza como agua potable, para usos agrícolas y para procesos industriales. La salinidad del agua está aumentando en la Franja de Gaza, siendo la intrusión de agua de mar la principal fuente de salinidad. En este trabajo, los iones selectivos de cloruro se utilizan, como indicador de la salinidad, para el análisis y modelización de la salinidad del agua subterránea en la Franja de Gaza para el horizonte 2023. Tres modelos de previsión del aumento de cloruros en las aguas subterráneas son considerados para 2023: el modelo basado en pronóstico, la regresión lineal y la regresión múltiple. El resultado de estos tres modelos muestra que la salinidad del agua aumentará en todas las áreas de la Franja de Gaza para el año 2023. Solo una pequeña zona en la provincia del norte tendrá menos de 250 mg/l de concentración de cloruro en agua dulce, lo que representa 4.56% del total del área de la Franja de Gaza. La intrusión de agua de mar se pone de manifiesto en los cortes transversales a lo largo de la costa, extendiéndose desde el Mar Mediterráneo hasta el este de la Franja de Gaza.

Palabras clave: Aguas Subterráneas; Salinidad; Intrusión de agua de mar; Modelización; SIG.

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e-ISSN 2340-0129

## Résumé

La bande de Gaza souffre d'un problème aigu de la qualité et de la quantité de l'eau. Les eaux souterraines sont utilisées comme eau potable, à des fins agricoles et à des procédés industriels. La salinité des eaux souterraines augmente dans la bande de Gaza. L'intrusion d'eau de mer est la principale source de salinité. Un ion chlorure sélectif est utilisé comme indicateur de salinité pour l'analyse et la modélisation de la salinité des eaux souterraines dans la bande de Gaza pour l'horizon 2023. Trois modèles de prévision sont considérés pour l'augmentation de la concentration des chlorures dans les eaux souterraines pour l'année 2023: Le modèle de prévision, régression linéaire et régression multiple. Le résultat de trois modèles a montré que la salinité de l'eau augmenterait dans toutes les zones de la bande de Gaza d'ici l'an 2023. Une petite superficie dans le gouvernorat du Nord conserverait moins de 250 mg / L de concentration de chlorure dans l'eau douce, ce qui représente 4,56% du total de la bande de Gaza. L'intrusion d'eau' de mer dans les sections transversales est claire le long du littoral et progresse de la mer Méditerranée vers la partie est de la bande de Gaza.

Mots-clés: Eau souterraine; Salinité; Intrusion d'eau de mer; Modélisation; SIG.

## 1. Introduction

The Gaza Strip suffers from an acute problem in the water quality and quantity that will affect the future of the population in the Gaza Strip that was around 1.8 in 2014 in an area of around 365Km². The estimated population in 2023 is of 2.4 million (PCBS, 2014). In Gaza Strip, the water crisis is a function of population growth, an agriculturally intensive, economy, a fragile water ecosystem and a highly inequitable distribution of resources (Kelly and Homer-Dixon, 1995).

Groundwater is considered the main and only water supply source for all kinds of human usages in the Gaza Strip (domestic, agricultural and industrial) and this aquifer can only be fed by rainfall and lateral flow from the east (Hamad *et al.*,2012). Salinity is increasing in many ground water areas in the Gaza Strip, which is the main reason of soil salinity and changes of agriculture systems in the Gaza strip. Seawater intrusion is the main source of sodium chloride in groundwater in the Gaza Strip. Therefore chloride is considered an indicator of salinity (Al-Agha, 1995; Qahman *et al.*, 2006; Baalousha, 2011).

Seawater intrusion is the movement of seawater into fresh water aquifers due to natural processes or human activities. Seawater intrusion is caused by decreases in groundwater levels or by rises in seawater levels (Al-Agha, 1995; Qahman, *et al.*, 2006; Mogheir *et al.*, 2014). In coastal areas, chloride from saltwater aquifers can find its way into freshwater waters. Salinity is an ecological factor of considerable importance, influencing the types of organisms that live in a body of water (Peñalver *et al.*, 2010). As well, salinity influences the kinds of plants that will grow either in a water body, or irrigated by a groundwater. Chlorides are widely distributed in nature as salts of Chloride sodium (NaCl), Chloride potassium (KCl), and chloride calcium ($CaCl_2$) (WHO, 2003). Seawater has a natural chloride of about 19,400 mg/L (ppt) combined with sodium. The salinity level in seawater is fairly constant, at about 35,000 mg/l while brackish has chloride levels of between 500 and 5,000 mg/land may have salinity levels between 1 and 10 ppt. When Chloride concentrations exceed 250 mg/L, it can give detectable salinity taste in water; salinity can be determined from chloride concentration. The following formula is used (WHO, 2003): Salinity (ppt) = 0.0018066 X$Cl^-$ (mg/l can be used to determine the salinity, which chloride ion selective electrode can be converted to a salinity value.

There is no health-based guideline value in the WHO organization to be proposed for chloride in drinking-water. Water Salinity can have significant impacts on Agricultural production, public health, Terrestrial biodiversity, and Soil erosion. The accumulation of salts (often sodium chloride) occurs from water irrigation in soil and water to levels that impact on human.

Increasing of population number and urban expansion has raised concern about water use and potential for degradation of water Quality in the Gaza Strip. Urbanization in the Gaza Strip is increasing dramatically and is placing more stress on the agricultural areas, causing soil erosion, and affecting water quality and quantity, because of the natural growth of the population (Abuelaish, 2018) and will affect food security (Abuelaish and Camacho Olmedo, 2016).

The population growth rate in the Gaza Strip in 2013 was 3.44% and the population is expected to grow to over 2.4 million by 2023 (PCBS, 2013). The demand for drinking water will place additional stress on water land cover and other environmental themes.

The water currently pumped from the coastal aquifer in the Gaza Strip is divided into 92.8 million cubic meter (mcm) for urban and domestic use and 86 mcm for agricultural use, average water consumption per person is 70 to 90 liters a day, most residents buy their drinking water from door-to-door salespeople (btselem, 2014), who sell water that has been treated by own Water Desalination Plants.

Qahman (2006) shows an increase in the groundwater salinity of the Gaza Strip within two cross sections, one in the north of the Gaza Strip and the other in the south. Both cross sections ran from the Mediterranean Sea to the eastern inland part of the Gaza Strip. His study uses historical data from 1969 to 2003 to make estimates for the year 2020. It offers no details about the spatial distribution of salinity or the salinity trends. Seyam and Moghier (2011) showed the influence of the input variables on chloride concentration in the Gaza Strip using the ANN model. It proved that chloride concentration in groundwater is reduced by decreasing abstraction, average abstraction rate and life time. It is also reduced by decreasing the recharge rate and aquifer thickness. Al halaq and Abu elaish (2012) demonstrated and assessed the vulnerability of groundwater to contamination in the Khanyounis Governorate using the DRASTIC model, and then identified the groundwater zones most vulnerable to contamination in the aquifer in the study area.

The aim of our research is to analyze, simulate and model the salinity in the groundwater of the Gaza Strip for the year 2023 within a context of urban expansion, through temporal mapping between 1972 to 2013, i.e., to show those planning the future of the Gaza Strip the real dangers regarding future water supply. This is why we decided to research this issue to provide detailed information on the trends of seawater intrusion flow through six cross sections and present three simple models that have not been applied in the study area.

## 2. Study Area

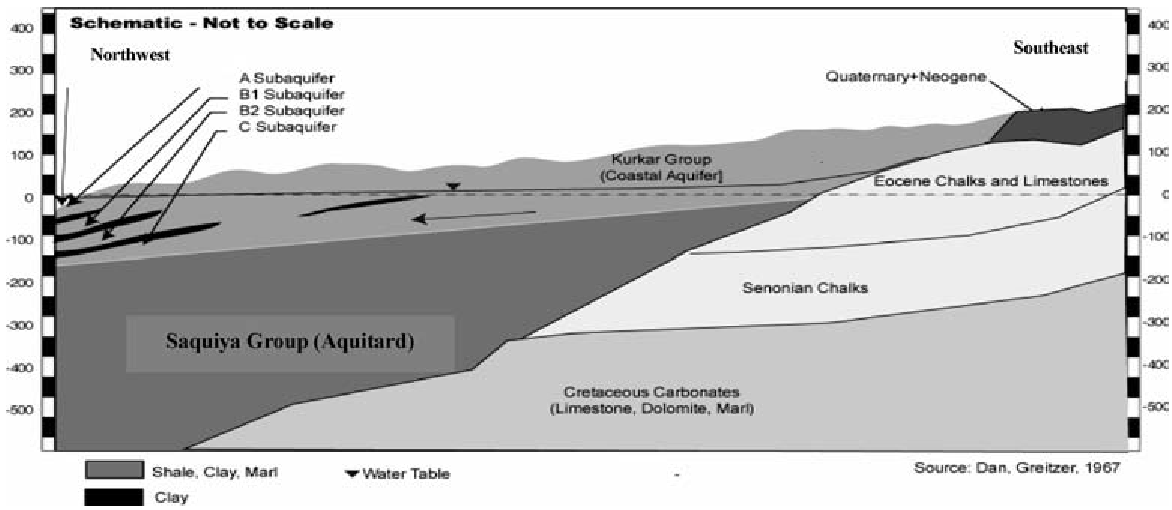
The Gaza Strip is a narrow area that occupies the southern region of the Palestinian coast on the Mediterranean Sea, and gained its name from the largest city of Gaza. The Gaza Strip extends to 365 square kilometers, and a length of 41 kilometers, and varies in width between 6.5 and 12.5 kilometers. It is bound from the north and east by Israel; the Mediterranean Sea is to the west as shown in Figure 1, while bordered by Egypt to the south-west (Abuelaish and Camacho Olmedo, 2016).

DOI: http://dx.doi.org/10.30827/cuadgeo.v57i2.5914


The Gaza Strip has a temperate climate, with mild winters and dry, hot summers subject to drought. Average rainfall is of about 300 mm. The terrain is flat or rolling, with dunes near the coast. The highest point is 105 m above sea level. There are no permanent water bodies in the Gaza Strip (MOAg, 2013).

Figure 1. Location of the Gaza Strip


Figure 2. The hydrogeological cross-section of the aquifer in the Gaza Strip (Dan and Greitzer, 1967, cited in PWA/USAID 2000); vertical scale in meters.




The coastal aquifer of the Gaza strip extends 41 km along the Mediterranean Sea, which is a part of the Gaza Strip Pleistocene coastal aquifer. Its average thickness ranges from 60 m in the eastern margins to about 200 m in the west along the coastline to a few meters (Vengosh *et al*., 1999; Zaineldeen, 2014). The aquifer is mainly composed of gravel, calcareous sandstone, clay and un-

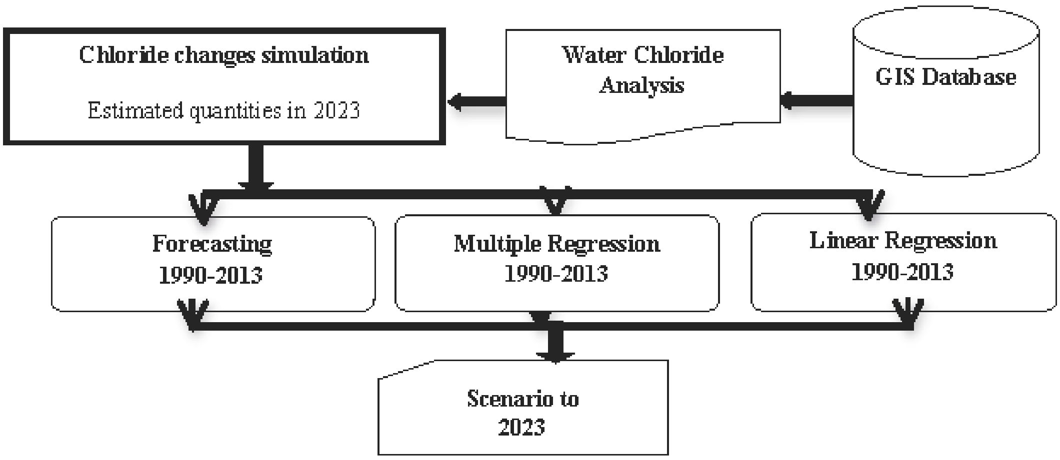

e-ISSN 2340-0129

consolidated sands (sand dunes). Near the coast, coastal clays extend about 2-4 km inland, and divide the aquifer sequence into three sub aquifers (A, B, and C). Towards the east, the clay pinch out and the aquifer is largely unconfined as shown in Figure 2 (PWA, 2001; Al halaq *et al*., 2012; Zaineldeen, 2014).

## 3. Methodology

The methodology based on the aims to analyze chloride concentration and the future scenario by 2023 in the aspect of raising of chloride in the ground water of Gaza Strip, urban expansion and the high population rate which will lead to increase the water abstraction from the groundwater wells. Scenarios are used depending on the historical data of wells. One past trend scenario was evaluated using the input parameters within three models: the Forecasting, Linear, and Multiple linear regression models as shown in Figure 3.

Figure 3. Methodology flow chart of water chloride analysis




### *3.1. GIS Database*

The available data of agriculture and municipals wells are collected from the Palestinian Water Authority and Ministry of Agriculture as series time data for the years 1972 to 2015, and all data are converted from Microsoft excel to Shapefiles using ArcGIS 10.3 that have coordinates for all wells. The chloride ions are selected only for analysis and simulation. The number of wells varies according to the year but normally increases with early years. It was a number of 486 wells in 2013. It was filtered to 180 wells depending on the all selected years from 1990 to 2013 as series time data for modelling and scenario by the year 2023 using three models. The selected year 2015 is used for validity of models. The urban GIS database was used to analyze the effect of urban expansion on water salinity for year 1993, 2003 and 2013.

### *3.2. Interpolation*

There are many methods of interpolation algorithms of data to create surface maps. Inverse Distance weighted (or Inverse Distance Weighted), denoted IDW (Tolosana-Delgado *et al*., 2011), is a method for interpolation of irregularly-spaced data. It is one of the most popular methods adopted by geoscientists and geographers (Lu *et al*., 2008; Mather *et al*., 2011).

 e-ISSN 2340-0129

Interpolation of all points is based on the IDW method or estimation of the unknown cells in the space using the ArcGIS10.3 software. The formulation of IDW method is used as follows. The value u at a given point X interpolated from a set of known samples ui=u(Xi) for i=0,1,…,N. the IDW Equation (1)

$$u(\mathbf{x}) = \begin{cases} \dfrac{\sum_{i=1}^{N} w_i(\mathbf{x}) u_i}{\sum_{i=1}^{N} w_i(\mathbf{x})}, & \text{if } d(\mathbf{x}, \mathbf{x}_i) \neq 0 \text{ for all } i, \\ u_i, & \text{if } d(\mathbf{x}, \mathbf{x}_i) = 0 \text{ for some } i, \end{cases} \quad (1)$$

Where $w_i(X)=1/d(X,X_i)^p$, $w_i(X)$ is a simple IDW weighting function, as defined by Shepard (1968), $d(X,X_i)$ is the distance function from unknown points $X$ to known point $X_i$ with positive power parameter $p$, and $N$ is the number of known points included in the calculation.

### *3.3. Water chloride analysis*

The analysis of water chloride concentration depends on classification of data using the main ArcGis10.3 software based on the following concepts:

- Classification of the chloride concentration to six classes, taking into consideration the salinity above 250 mg\L of the WHO parameter and the maximum value of chloride concentration.
- Analysis of chloride concentration transition from class to others during the time series to show the changes clearly.

The cross sections are produced by the «Stack Profile» tool in the ArcGIS 10.3 software for the selected layers from1972, 1982, 1993, 2003, 2013 and 2023 that are estimated by three models. It creates a table and optional graph denoting the profile of line features over one or more multi-patch, raster, TIN, or terrain (ArcGIS 10.3 help, 2016).

### *3.4. Water chloride changes modeling*

The research depends on three models for prediction of chloride concentration for the year 2023: Forecasting, linear regression, and multiple regression. The three models process the chloride concentration as dependent variable. Forecasting and linear regression are determined on the time series (years) only as independent variables, but multiple regression is determined by time series, population, water level, the precipitation and the Pumping from groundwater (production). The RMSE is used to assess goodness-of-fit in models depending on the results of the three models and the real data for the year 2015.

#### 3.4.1. Forecasting

Forecasting is the process of making predictions of the future based on past and present data and analysis of trends. Forecasting estimates values at certain specific future times Forecasting methods can be classified as qualitative or quantitative. This can be developed using a time series method or a causal method.

The forecast time series modeling the study are produced depending on the Forecasting Function which takes the form: The FORECAST(x, known y's, known x's) function returns the predicted value of the dependent variable (represented in the data by known y's) for the specific value 'x' of the independent variable (represented in the data by known x's) by using a best fit (least squares) linear regression to predict y values from x values

The equation (2) for FORECAST is

$$a + bX \qquad (2)$$

Where:

$$\boldsymbol{a = \bar{Y} - b\bar{X}} \qquad (3)$$

and

$$\boldsymbol{b = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sum(X+\bar{X})^2}} \qquad (4)$$

Where $\bar{X}$ and $\bar{Y}$ are the average (known X's) and average (known Y's).

### 3.4.2. Linear regression

Linear regression is used when we want to predict the value of a variable based on the value of another variable. If plots of data versus time suggest a simple linear increase or decrease over time, a linear regression of the water quality variable Y against time T may be fit to the data (Gilbert, 1987).

A linear regression line has an equation (5) of the form:

$$Y = b_0 + b_1 X + c \qquad (5)$$

Where $X$ is the explanatory variable and $Y$ is the dependent variable $b_0$ and $b_1$, are constants, called the model regression coefficients or parameters (i.e. $b_0$ called the intercept or constant coefficient, and $b_1$ called the slope of the least squares regression line), and $c$ is a random disturbance or error in the approximation of Y.

In the study, The IBM SPSS statistics software is used to run the model where the chloride concentration is the dependent variable and the year from 1990-2013 is the independent variable.

### 3.4.3. Multiple Linear regression

Multiple linear regression is the most common form of linear regression analysis. As a predictive analysis, the multiple linear regression is used to explain the relationship between one continuous dependent variable (criterion or endogenous or regress variable) and two or more independent variables (predictor or regressor variables). In the study, the IBM SPSS statistics software is used to run the multiple regression model where the dependent variable is the chloride concentration, and the independent variables are the population, water level, the rainfall in the whole Gaza Strip, and the production of each well in a time series, that is using Stepwise linear regression, method of variables while simultaneously removing those that aren't important. Stepwise regression essentially does multiple regression a number of times, each time removing the weakest correlated variable. At the end you are left with the variables that explain the distribution best.

3.4.4. Root Mean Square Error (RMSE)

The root mean square error (RMSE) is a frequently used measure of the difference between values predicted by a model and the values actually observed from the environment that is being modeled. The RMSE serves to aggregate them into a single measure of predictive power (6):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{model,i})^2}{n}} \quad (6)$$

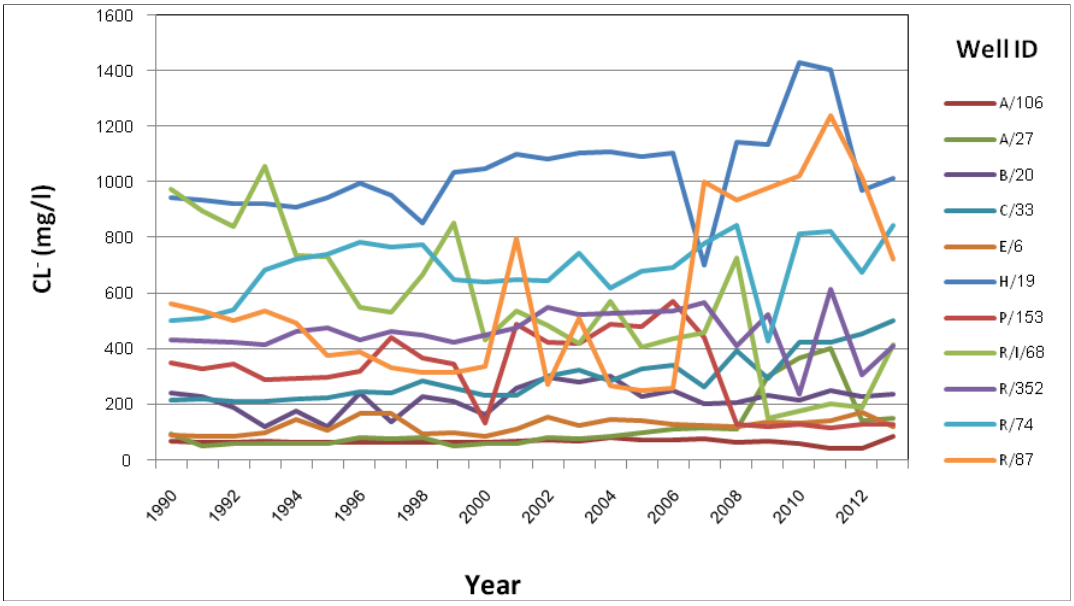
Where $X_{obs}$ is observed values and $X_{model}$ is modeled values at time/place *i*. The RMSE values can be used to distinguish model performance in a calibration period with that of a validation period as well as to compare the individual model performance to that of other predictive models (Fujita *et al*., 2014) otherwise the RMSE is used to assess goodness-of-fit in models.

## 4. The results

### *4.1. Water chloride analysis*

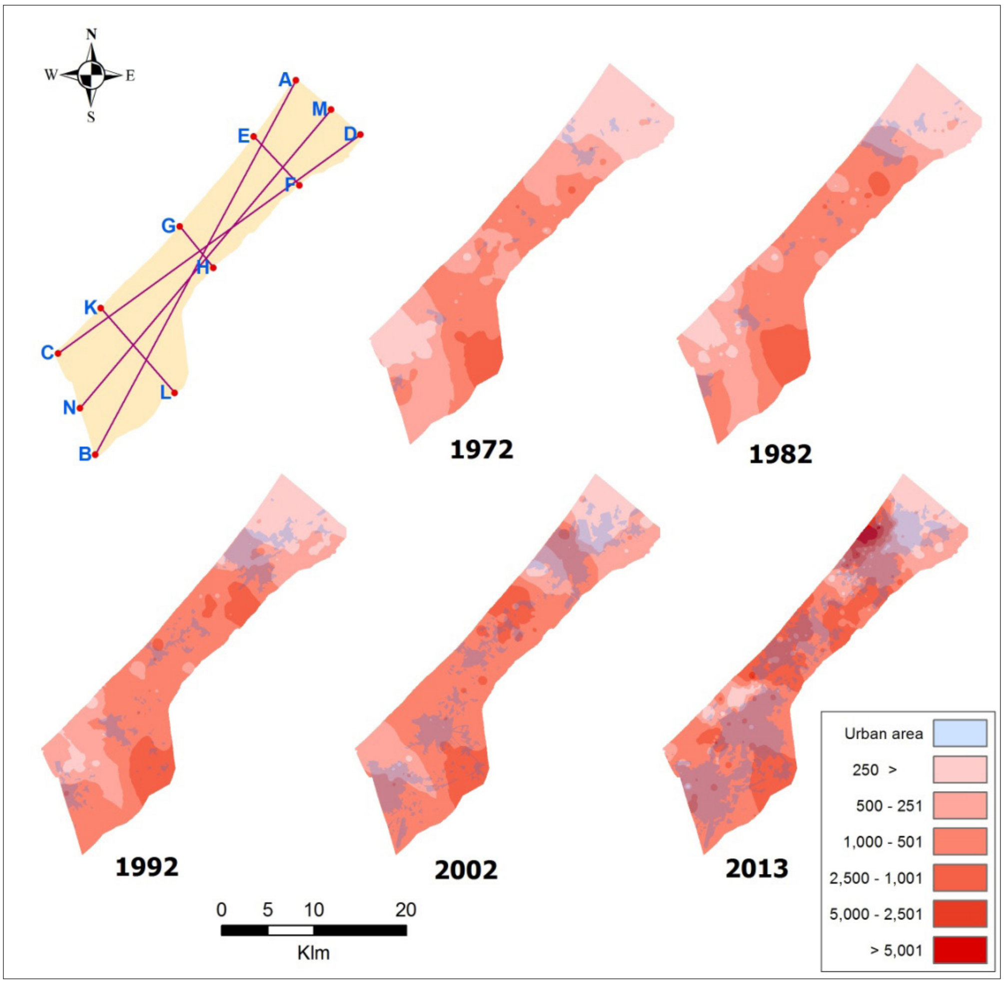
Water analysis depends on the behavior of chloride concentration in the ground water in a time series of each well. Figure 4 shows variation from 1972-2013 for eleven sample wells in different places of the Gaza Strip. Figure 4 shows the chloride concentration trend, which varies from one well to the next for various reasons such as location and topography, water level, water extraction and precipitation among others. Sometimes when the salinity level rises, local people or councils begin digging to find fresh water. This explains the rise in salinity between 1972 and 2013.

Figure 4. Behaviors of chloride concentration in the sample selected wells from 1990 to 2013




The simulation of chloride concentration for the years 1972, 1982, 1993, 2003 and 2013 (Figure 5), clearly shows an increase and demonstrates the positive relationship with the increase in urban areas.

Figure 5. Chloride concentration (mg/L), urban areas and locations of cross sections.

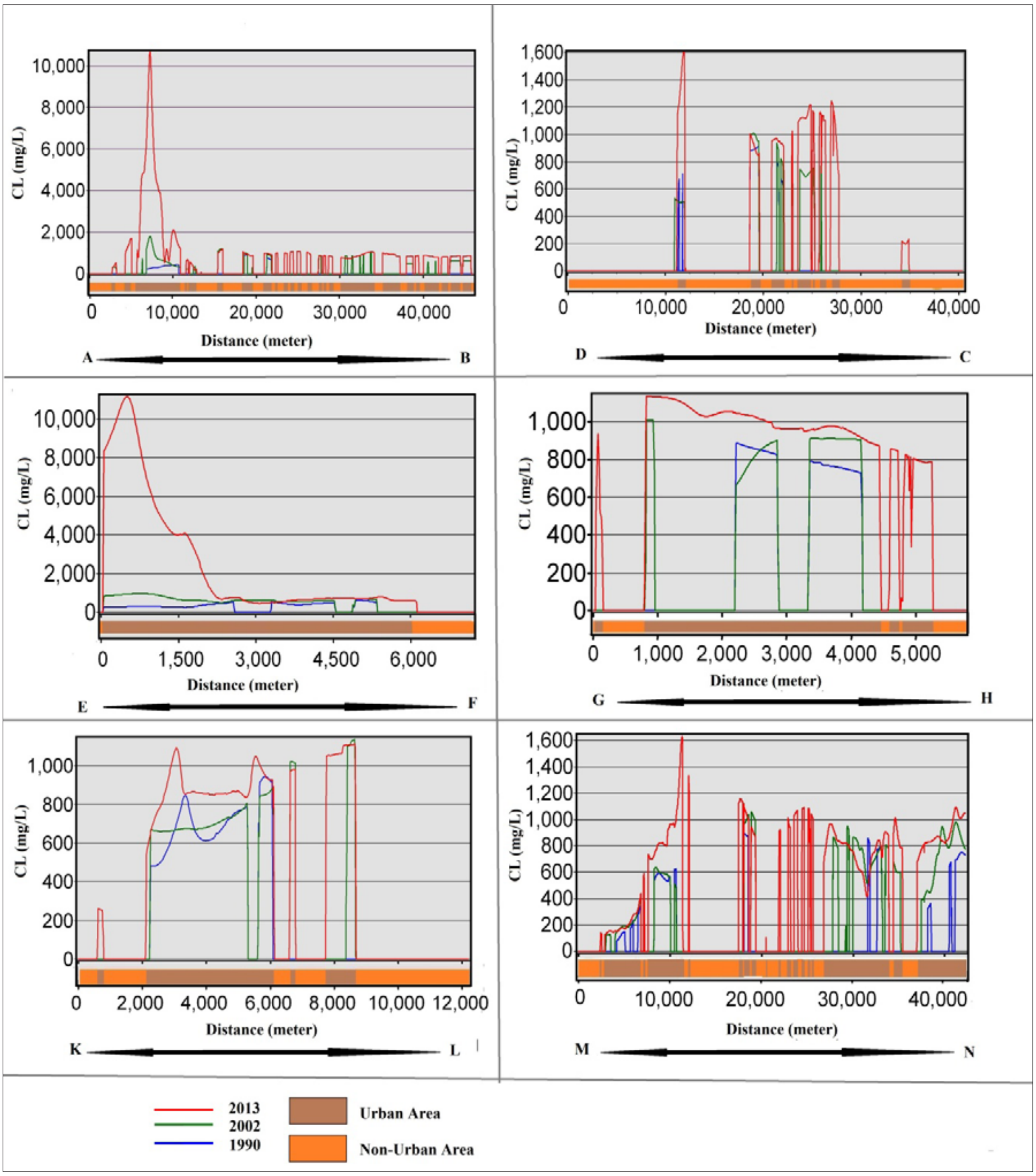



Six chloride profiles (Figure 5) were selected to extract the chloride concentration. Figure 6 illustrates the chloride concentrations in the ground water within elaborated six cross sections for year 1993, 2003 and 2013 that are focused over the urban areas and other non-urban areas equal zero. The chloride concentration of ground water in the whole of the Gaza strip was classified to six classes for the years 1972, 1982, 1993, 2003 and 2013 as shown in Table 1.

Table 1. Chloride concentration in ground water according to classification

| CL- | 1972 (Km²) | 1972 % | 1982 (Km2) | 1982 % | 1993 (Km²) | 1993 % | 2003 (Km²) | 2003 % | 2013 (Km²) | 2013 % |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 – 250 | 97.5 | 27.01 | 77.4 | 21.4 | 57.01 | 15.8 | 38.1 | 10.5 | 40.4 | 11.2 |
| 250 -500 | 118.7 | 32.9 | 85.8 | 23.8 | 84.2 | 23.3 | 76.9 | 21.3 | 45.1 | 12.5 |
| 500 -1000 | 124.6 | 34.4 | 165.7 | 45.9 | 179.1 | 49.6 | 202.5 | 56.1 | 170.9 | 47.3 |
| 1000 -2500 | 20.6 | 5.7 | 32.1 | 8.9 | 40.8 | 11.3 | 43.7 | 12.1 | 97.3 | 27.0 |
| 2500 -5000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4.6 | 1.3 |
| > 5000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.8 | 0.8 |

Figure 6. The selected profiles focused over urban areas: A-B, C-D, E-F, G-H, M-N, and K-L.




## 4.2. Water chloride changes modeling

The results of water chloride changes modeling are shown in Figure 7. Three maps are produced that represent three simulations for the year 2023. There are some differences in the results of the three models that are classified to six classes as shown in Table 2.

Figure 8 presents the chloride concentration profiles, which illustrate increases in chloride levels in water along the cross sections.

Calculation of the RMSE values as predictive power shows that the Linear regression has the highest value at 1668.3, followed by Forecasting (1656.9), and Multiple Linear regression (1631.723).

Figure 7. Simulated chloride concentration for the year 2023 as results of F) Forecasting Model, L) Linear Regression Model, and M) Multiple Linear Regression Model.

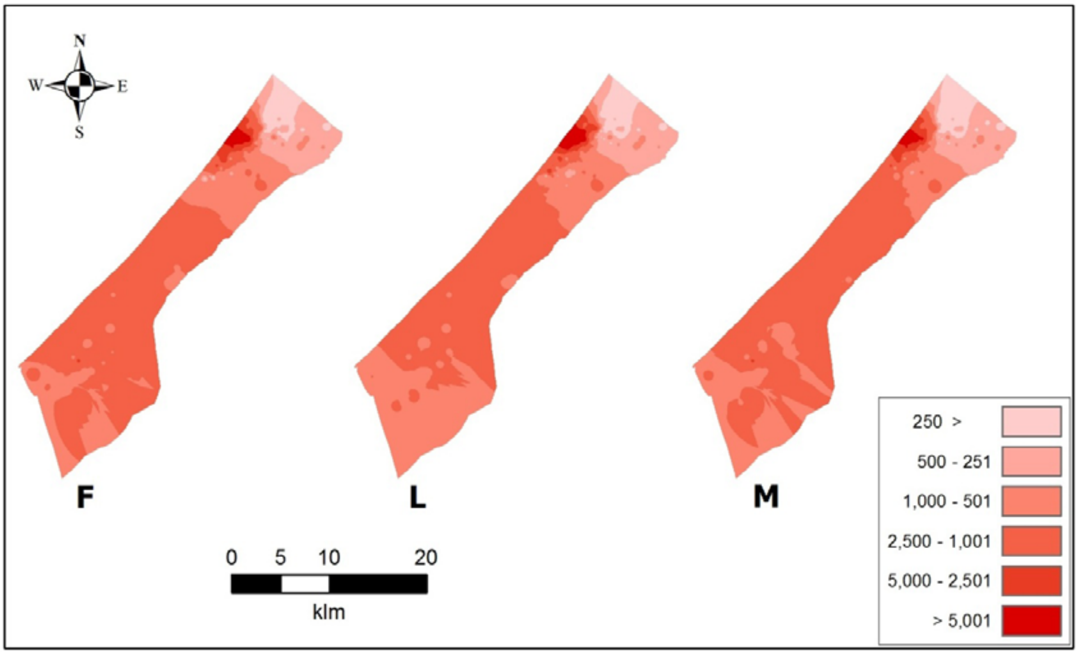
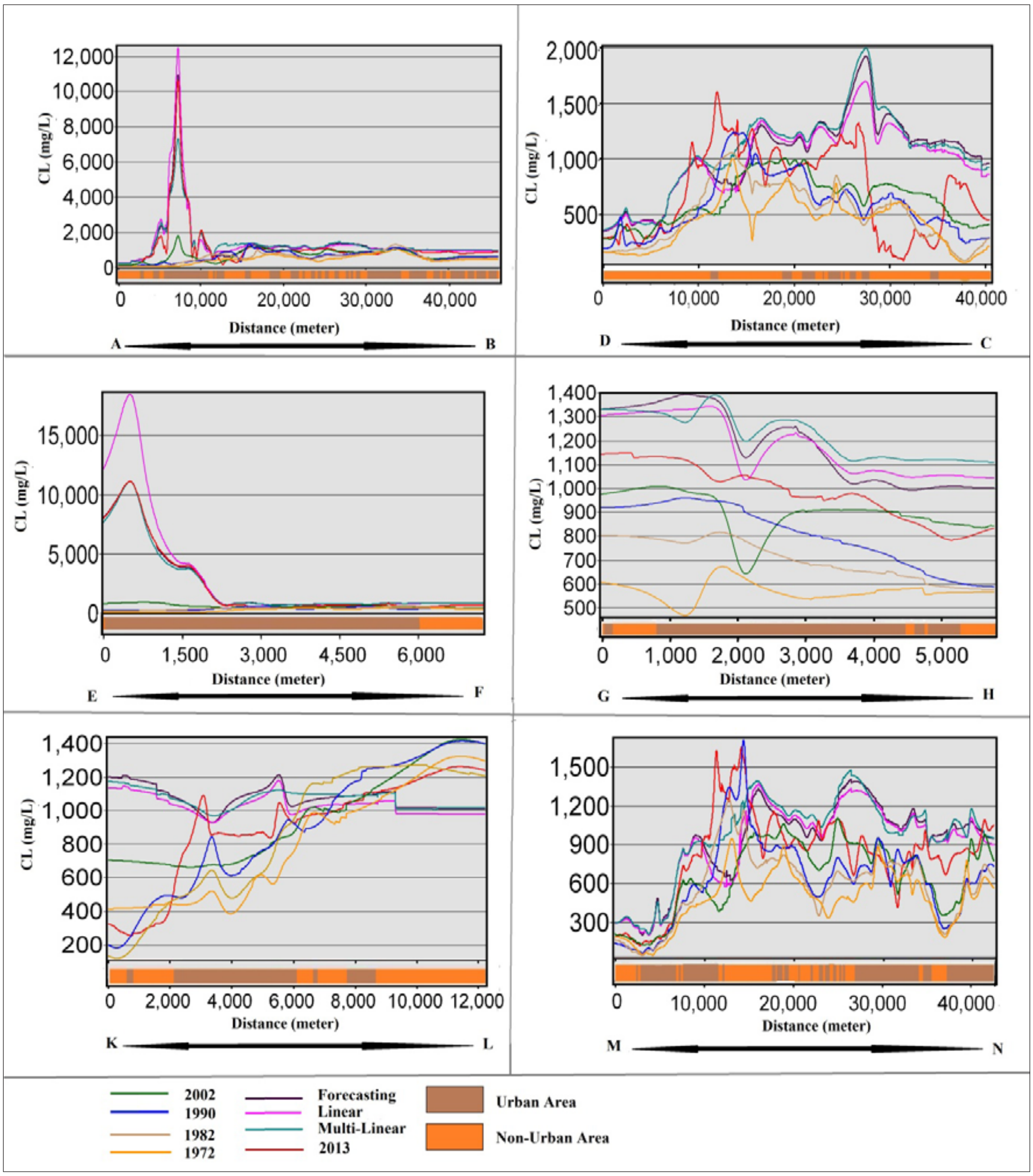



Table 2. Area and percentage of simulated chloride concentration for the year 2023 as results of F) Forecasting Model, L) Linear Regression Model, and M) Multiple Linear Regression Model.

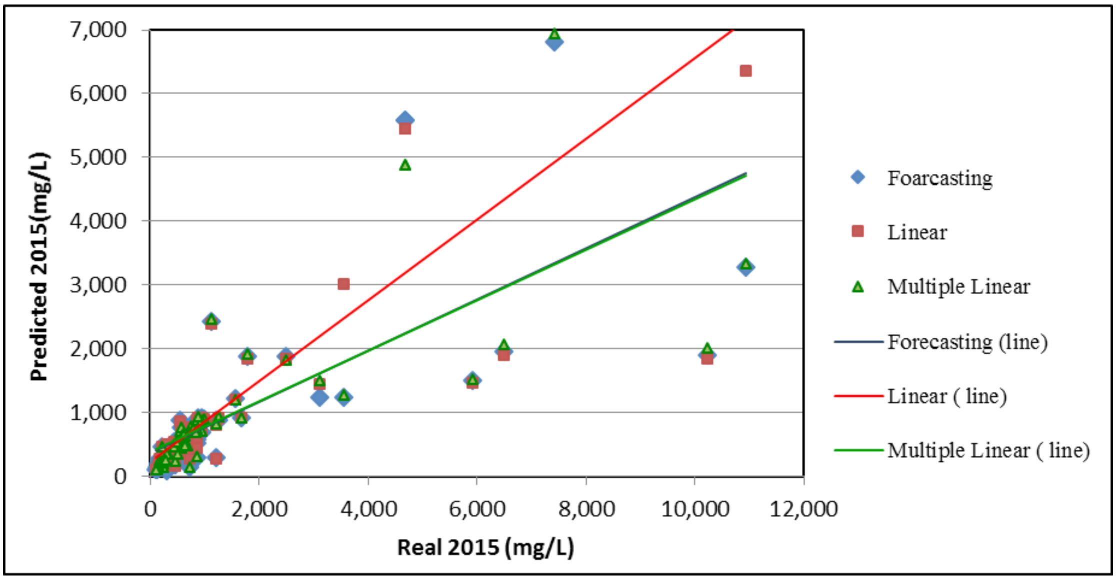
| CL(mg/L) | F (Km²) | F % | L (Km²) | L % | M (Km²) | M % | Average (Km²) | Average % |
|---|---|---|---|---|---|---|---|---|
| 0 – 250 | 15.90 | 4.40 | 15.58 | 4.31 | 17.90 | 4.96 | 16.46 | 4.56 |
| 250 -500 | 36.27 | 10.05 | 36.50 | 10.11 | 34.00 | 9.41 | 35.59 | 9.86 |
| 500 -1000 | 95.09 | 26.33 | 134.02 | 37.11 | 93.66 | 25.94 | 107.59 | 29.80 |
| 1000 -2500 | 205.68 | 56.96 | 166.49 | 46.11 | 207.71 | 57.52 | 193.29 | 53.53 |
| 2500 -5000 | 5.09 | 1.41 | 4.41 | 1.22 | 5.41 | 1.50 | 4.97 | 1.38 |
| > 5000 | 3.07 | 0.85 | 4.11 | 1.14 | 2.41 | 0.67 | 3.20 | 0.89 |

Figure 8. The selected profiles: A-B, C-D, E-F, G-H, M-N, and K-L




Scatter plots in Figure 9 represent the real data for chloride concentration on the *x*-axes and the predicted chloride concentration on the *y*-axes. The scatter diagram points for Forecasting and Multiple Linear are close to a line predictor while the Linear regression is further away from them.

Figure 9. The scatter plot for chloride concentration (mg/L). Real data for 2015 versus predicted data models for 2015 of Forecasting, Linear, and Multiple linear regression.




The data inputs and output for the chloride concentration from 1972-2013 and 2023 represented the severe change in water chloride that is showed clearly in 2008 in the Gaza Strip as shown inFigure10. Chloride expanding is shown in the whole area of the Gaza Strip. The area with chloride concentrations of less than 250 mg/L will become less than 10% for the Gaza Strip by the year 2023.

Figure 10. Increase in the area of chloride concentration from 1972 to 2023.

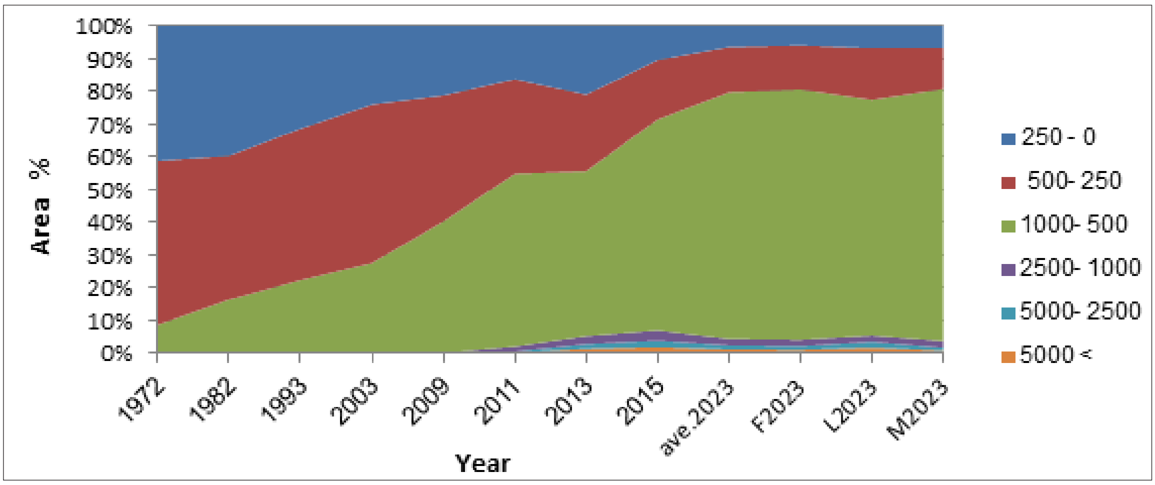



Figure 11, Table 3 and Table 4 show the result of overlaying the three simulated maps Forecasting, Linear and Multi-linear regression, highlighting specifically the simulated increases or stability in chloride concentration in the six classes from 2013, the area and percentage of the classes obtained from this map.

DOI: http://dx.doi.org/10.30827/cuadgeo.v57i2.5914


Figure 11. Overlaying of the three simulated maps for 2023: Forecasting, Linear and Multi-linear regression highlighting specifically the simulated increase or stability in the chloride concentration in the six classes from 2013.

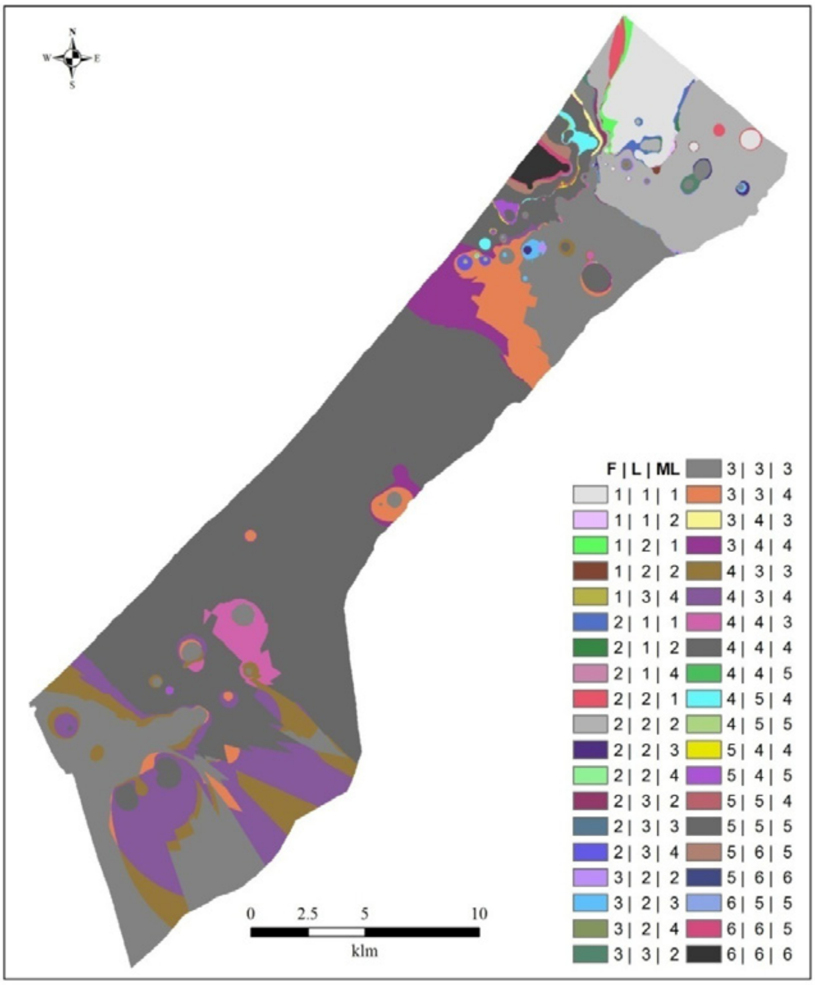



Table 3. Area (km²) and percentage of overlaying of the three simulated maps by three models, specifically the simulated stability in chloride levels and simulated increase in chloride levels from 2013

| Simulation (The base is by year 2013) | Area (Km²) | Percent % |
|---|---|---|
| Stability 3 models | 149.6 | 41.4 |
| Increase in CL by 3 models | 121.1 | 33.5 |
| Increase in CL by Forecasting and Linear | 24.6 | 6.8 |
| Increase in CL by Forecasting and Multi-Linear | 36.6 | 10.1 |
| increase in CL by Linear and Multi-Linear | 28.9 | 8.1 |


e-ISSN 2340-0129

Table 4. Area (km²) and percent of overlaying of the three simulated maps using three models according to the classes of chloride concentration and simulated increasing from 2013

| $CL^-$ | F \|L \|ML | Area (Km²) | Percent % |
|---|---|---|---|
| 0 – 250 | 1 \| 1 \| 1 | 14.359 | 4.0 |
| 250 -500 | 2 \| 2 \| 2 | 32.109 | 8.9 |
| 500 -1000 | 3 \| 3 \| 3 | 68.791 | 19.1 |
| 1000 -2500 | 4 \| 4 \| 4 | 150.083 | 41.6 |
| 2500 -5000 | 5 \| 5 \| 5 | 2.909 | 0.8 |
| > 5000 | 6 \| 6 \| 6 | 2.412 | 0.7 |
| Total area of 3 models at the same spatial distribution | | 270.7 | 75.0 |

Figure 12 demonstrates chloride concentrations in 1993, 2003 and 2013 inside the urban area 2013. Non-urban areas are masked, and the figures are therefore focused on chloride concentrations inside urban areas only. Figure 13 shows that the chloride concentration increases in each governorate in most classes.

Figure 12. The area of classified chloride concentrations by years 1993, 2003 and 2013 within the urban area 2013.

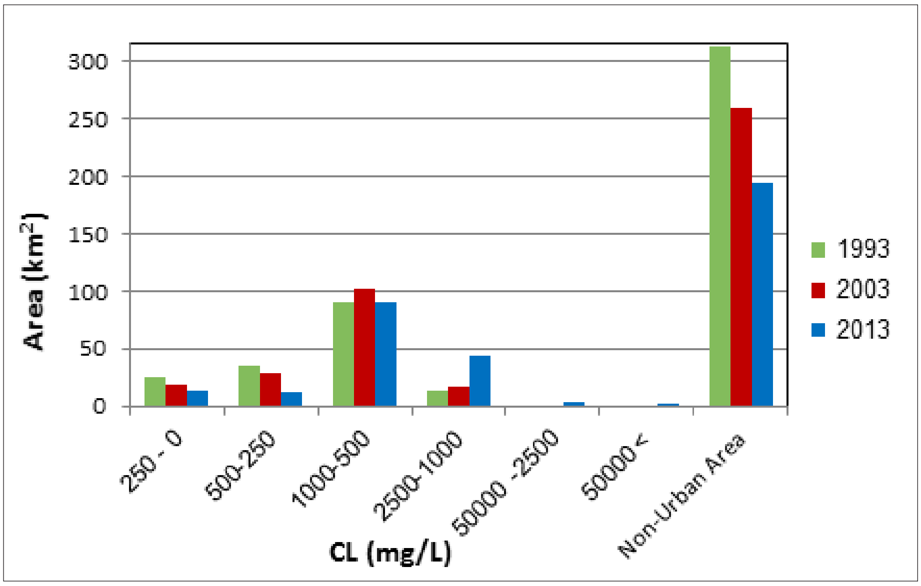
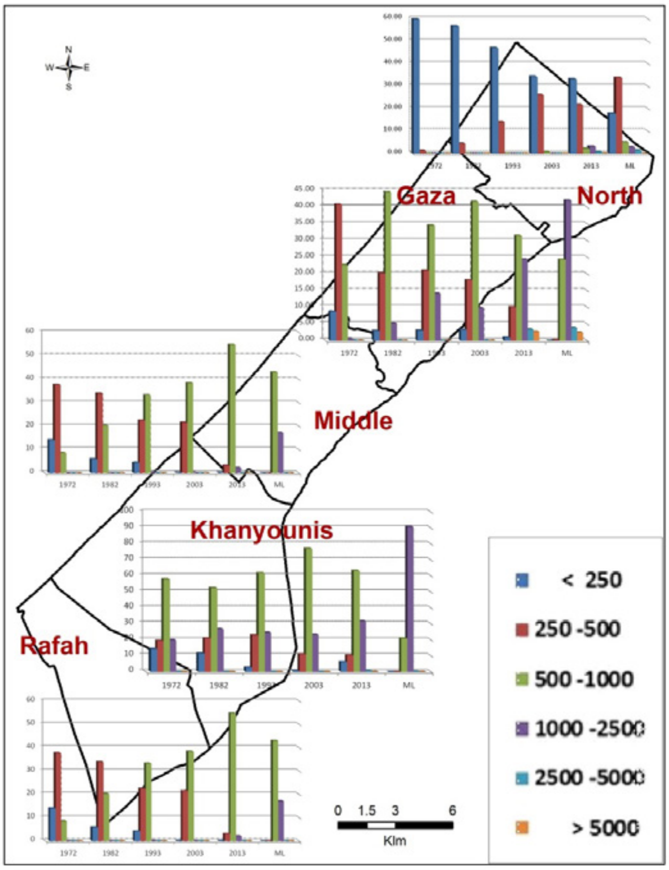


Figure 13. Increase in chloride concentration (mg/L) in each Governorate




## 5. Discussion and conclusion

Groundwater is an important source of fresh water in the Gaza Strip for domestic and irrigation use. Groundwater quality is influenced by geological formation and anthropogenic activities, e.g. changes in land use, urbanization, intensive irrigated agriculture, mining activities, disposal of untreated sewage in river, lack of rational management, etc. (Voudouris, 2009). Groundwater contamination may cause severe threaten on public health due to human activities.

During the analysis of chloride concentration in each well, we found some problems in some years, which changed suddenly due to many reasons, as the discharge rate, the rainfall weight per year; because at a given location the amount of infiltrating water depends on geomorphology, water conductivity of superficial rocks, air temperature, amount, duration and physical state of precipitation, and also vegetation and many other factor (Kovács et. al., 2012), in addition to the error of chloride analysis or readings or registering, and the changing the depth of well to get to brackish water. The urban areas suffered more than others as demonstrated in Figure 12, where the chloride concentrations increased clearly from the early year to the higher concentration rate in the late years. As mentioned before, Figure 6 illustrated the positive relationship with the increasing of urban areas in all cross sections. It was highlighted higher concentrations of chloride concentrations in urban areas in 2013 than in previous years in 1993 and 2002.The visual analysis of cross sections is based on the water data analysis profiles which describe how the chloride is increasing to continue everywhere in the Gaza Strip along the time series from 1972 to 2023.


e-ISSN 2340-0129

Figure 8 shows chloride expansion in the whole of the Gaza strip and the increase from early years to late years for 1972, 1982, 1990, 2002, 2013 and by 2023 in the three models. The trend of expansion from the west to the east due to the seawater intrusion is evident in all cross section as following:

Along the cross-section A-B chloride is above 250 mg/L. After 5,000 meters from point A near the Mediterranean Sea chloride increases to 2,500 mg/L and at a distance of 7,500 meters it reaches 7,500 mg/L in 2013 and 11,500 to 12,500 by the year 2023 which considers the center of the Gaza city. It decreases 1,500 -2000 mg/L at a distance of 10,000 meters at point B. The cross section D-C shows the area from the north at Biet Hanoun town (C) to the south at Rafah city (D). We noticed time series increased in chloride, while Biet Hanoun along time has the best water quality in the Gaza Strip, which will get chloride to reach 1100 mg/L by the year 2023.

The across section drawn from the transect E-F starts from the coast of the city of Gaza with highest population density at point E to get to around 11,000 mg/L at the coastal area. Chloride in the years from 1972 to 1993 was of around 1000mg/L along the cross section, which is an evidence of increase in 2013 and will get more increased by the year 2023.The cross section G-H intersects Alnusairat town at point G and H point at the east of the Gaza Strip. During the time series from 1972 to 2023, the chloride concentration increased with rate 150-200 mg/L per ten years. In the cross section K-L, there is evidence of an increase of chloride concentration at point K in the Almauasi area which is considered an agricultural land and a sensitive area near the Mediterranean Sea. The chloride concentration increases from K to L in the east during the time series from 1972 to 2023.

The cross section M-N intersects the Gaza Strip from the northern border at point M to the southern border at point N. Point M at the Biet Lahia has the best water quality in the Gaza Strip during the time series from 1972 to 2013, but the area that has the chloride concentration below 250 mg/L will be reduced by the year 2023.We noticed from the cross sections E-F, G-H, and K-L clearly, that water salinity moved toward the coastal zone eastwards. Hence, sea water intrusion has an effect on all areas; therefore, this will have an effect on the agricultural systems, and consequently many agricultures types and trees will change to others with salt tolerance to water salinity.

Multiple Linear regression is considered the best model in our study according to the Root Mean Square Error (RMSE), then the Forecasting model and then Linear regression in order of importance. When the stepwise method in Multiple Linear regression is used by SPSS, the wells are affected by all input variables at a different rate; the year has more effectiveness, around 45%, population 35 %, production 10 %, rainfall 10 % and water level 10%.

Figure 11, Table 2 and Table 3 show the probability trend of increases of salinity in most areas within the three used models that are very high, and the stability of three models is 149.6 Km2 (41.4 %), and the increased area of salinity is 121.1 Km2 (33.5 %).

In this study, one scenario of chloride concentration increase as an indicator of salinity by 2023 is presented. There is another scenario to be envisaged that is to create a big desalination plant in the Gaza Strip. The EU has invested EUR 10 million during this phase which, when fully operational, will produce 6,000 $m^3$ of potable water daily. This will provide over 75,000 Palestinians with safe drinking water approximately 35,000 people in Khanyounis and 40,000 people in Rafah, southern Gaza Strip. EU Commissioner Johannes Hahn announced an additional funding of EUR 10 Mil-

 e-ISSN 2340-0129

lion for the second phase of the desalination plant to start in mid-June 2016, which is expected to be completed within 36 months. Then the plant will produce a total of 12,000 $m^3$ of safe drinkable water, each day (IMEMC, 2016). The annually increasing rate of the required water in the Gaza strip is 2,240,437 $m^3$ per year from 2016 to 2023. Hence the desalination plant will reduce the problem of drinking water. If the EU plant worked, it would produce 4,380,000 $m^3$ annually after 36 months.

This paper presents the analysis and modeling of chloride concentration in the ground water of the Gaza Strip using the historical data from 1972 to 2015.Three models are used for the estimation of chloride concentration by the year 2023 depending on the data from 1990 to 2013 based on the one past trend scenario.

The following conclusions were drawn from results and analysis of this research:

- Water salinity will increase in all areas in the Gaza Strip by the year 2023.
- The north governorate will keep only the fresh water that has a chloride concentration of less than 250 mg/L, which represents a percentage of 4.56% of the Gaza Strip area by the year 2023.
- Water salinity will cover the area 95% of the Gaza Strip that have an effect on the agricultural systems and salt tolerance of vegetables and trees to water salinity. In addition to the main reason of soil degradation that will have an effect on the soil capability and productivity
- The trend towards increases in salinity is very high in most areas within the three models such that the salinity level remains stable in 41.4 % of the area, and increases in 33.5 %

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