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Spatial analysis of physico-chemical status of groundwater beneath Assiut governorate, Egypt

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ABSTRACT: The purpose of the current paper has been to assess the groundwater status in the Nile aquifer underneath Assiut governorate, Egypt. The physico-chemical status of groundwater samples from 796 wells have been examined from 2006 to 2013. The physicochemical data include: electric conductivity, pH, anions (HCO_3^-, SO_4^{2-}, Cl^-), cations (Ca^{2+}, Na^+, Mg^{2+}, K^+), Fe, Si, Mn, TDS, Well depth, Water height in each well, and Turbidity. Statistical and spatial analyses of the data were conducted to assess groundwater quality in the different districts belonging to the Assiut governorate using GIS. The results of spatial analysis display that most of groundwater data in the central fringes of the Assiut governorate towards Al-wadi Al-Asuyti in the west and Arab Al-madabegh in the east are high. The results also indicate that most of samples have high salinity hazard and low sodium hazard; so, it can be suitable for irrigation purposes.

KEYWORDS: Groundwater quality, spatial analysis, Geographic Information Systems (GIS).

I.INTRODUCTION

Groundwater is vital source for life as well as its class is governed by the geological properties of the aquifer, different activities, recharge and consumption rate [1; 2].

Almost three quarters of the population in Assiut governorate (73.5%) lives in rural areas and depends mainly on groundwater for drinking and irrigation [3]. Drinking water is generally supplied by groundwater plants, which is preferable than surface water treatment plants due its low cost of construction, and the short time of the construction phases. Whereas, irrigation water can be obtained through wells dug by farmers or authorities in some areas on the fringes of the governorate [4].Unrestrained waste disposal and usage of fertilizers and pesticides in agriculture are the key sources of groundwater pollution [5].

Groundwater quality assessment is considered a complex process because it is related to many variables. It is correlated to the usage of water, thus, different uses need different criteria. These criteria have been established by the World Health Organization (WHO) and competent organizations in each country. By comparing the physical and chemical variables with pre-established standards, the suitability of water can be concluded [6].

The lack of groundwater quality has a detrimental effect on plants, soil and then humans, therefore, it must be treated and protected from contaminants. Since this issue is considered as very serious, it has been investigated using surface geoelectrical methods, chemical analysis, biological analysis, and so on [7 - 10]. It is noted that El-Madabegh and Beni Ghalib areas suffer from groundwater pollution because the wastewater treatment plant of Assiut city in the El-Madabegh region and industrial waste disposal in the Beni Ghalib area [8; 10]. These two regions are small compared to the total area of Assiut Governorate. Thus, it still needs more studies over a wide scale to cover the entire

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governorate. For that reason, the current study tries to conduct a statistical and spatial analysis of the physico-chemical status of groundwater in the Nile aquifer system below Assiut governorate.

II.STUDY AREA

Assiut is one of the most important governorates in Upper Egypt. It is bordered to the north by El-Minia governorate at latitude 27° 37′ N., and to the south by Sohag governorate at latitude 26°47′ N. whereas, it extends in the west-east direction, between longitudes 30° 37′ and 31° 34′ E (Figure 1) [11]. The total area of Assiut Governorate is 25,926 km². The length of the River Nile along Assiut Governorate is about 125 km, and the width of the valley ranges between 16 and 60 km. The area of urban and agricultural parts in Assiut Governorate is about 2674.54 km^2. River Nile divides the study area in the west-east direction into two parts. With regard to the topography of the study area, the eastern and western sides of the calculus plateau tend towards the Nile River [12].

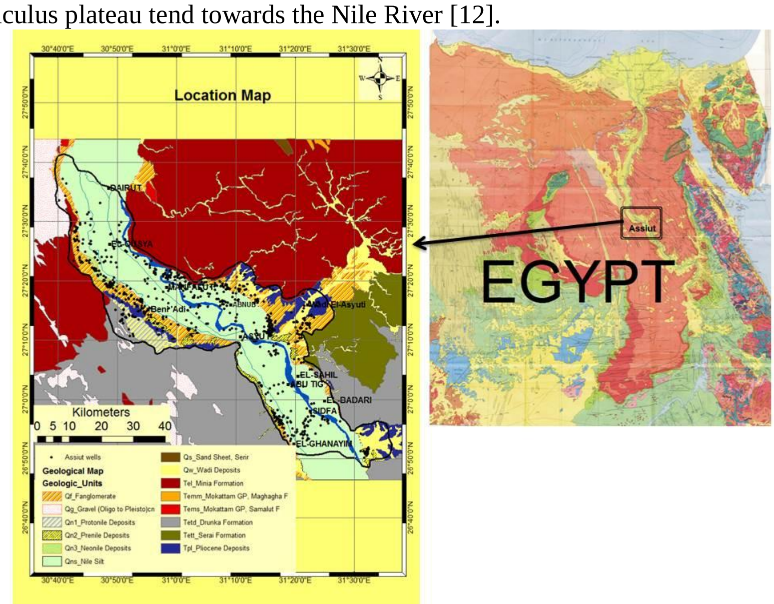

Fig1: Study area

III.METHODOLOGY

The physicochemical data has been obtained from the General Administration of Groundwater in Upper Egypt, El-Minia, Egypt, which belongs to the Ministry of Water Resources and Irrigation (MWRI). Geographic data was obtained from the Department of Geology, Faculty of Science, Assiut University. The different categories of groundwater data include: electric conductivity, pH, anions (HCO_3^-, SO_4^{2-}, Cl^-), cations (Ca^{2+}, Na^+, Mg^{2+}, K^+), Fe, Si, Mn, TDS, Well depth, Water height in each well, and Turbidity. These data were classified into separate groups annually from 2006 to 2013. ArcGIS 9.3 has been used to produce spatial distribution maps for each factor apart.

Seven hundred and ninety six samples have been explored using the Geostatistical Analyst exploratory spatial data analysis tool in ArcGIS 9.3 software; in addition to Microsoft office excel 2007 to detect the statistical properties of data:

Statistical distribution of the groundwater data

Descriptive statistics were used in examining the data distribution to determine whether the data has normality or not. Groundwater data can be described by determining its shape. If the data has a systematic distribution, mean, median, and mode will be equal to each other. Whereas, if the data has a positive skewed distribution, the relationship between mean, median, and mode will be Mean > Median > Mode. On the other hand, if the data is described as negatively skewed, the relationship will be Mean < Median < Mode [13].
The following equations illustrate the statistical relationships used in the current study.

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A) Karl Pearson coefficient of skewness

It can be defined as "a measure of skewness based on the difference between mean and mode/or median" [14]. It can calculated as follows:

$$Sk_{p_1} = \frac{\text{mean} - \text{mode}}{\text{Standard deviation}} \quad (1)$$

Or

$$Sk_{p_2} = \frac{3(\text{mean} - \text{median})}{\text{Standard deviation}} \quad (2)$$

- $-1 \leq Skp \leq 1$.
- $Skp = 0 \rightarrow$ distribution is symmetrical about mean.
- $Skp > 0 \rightarrow$ distribution is skewed to the right.
- $Skp < 0 \rightarrow$ distribution is skewed to the left.

A histogram was used to display frequency distributions of groundwater data graphically. It gives an initial perception of whether data is distributed normally or not.

B) Mean, Median and Mode

The mean ($\bar{X}$) is calculated as the sum of all data values Xi, divided by the sample size n:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad (3)$$

The median is "the central value of the distribution when the data are ranked in order of magnitude". Whereas, the mode is "the most frequently observed value" [14].
If x_1 and x_n are the lowest and biggest observations respectively, the median can be calculated as follows:

$$\text{median } (P_{0.50}) = \frac{X_{(n+1)}}{2} \quad \text{when n is odd} \quad (4)$$

$$\text{median } (P_{0.50}) = \frac{1}{2}\left(X_{\left(\frac{n}{2}\right)} + X_{\left(\frac{n}{2}+1\right)}\right) \quad \text{when n is even} \quad (5)$$

C) Standard deviation

The standard deviation is "a number that measures how far data values are from their mean" [13; 15].
- The population standard deviation:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \quad (6)$$

where x_i = the i^{th} data value,
μ = the true process average,
N = the population size
- The sample standard deviation:

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad (7)$$

where x_i = the i^{th} data value,
x-bar = the sample average,
n = the sample size.
The sample standard deviation has been used in this paper because it is more appropriate to groundwater samples.

Preliminary examination of the data

As an initial attempt to identify areas where the physico-chemical variables are above the standard permissible limits set by the World Health Organization [16] , graphs of the mean of each individual factor were plotted in each region, compared with the standard limits. Although this method is not accurate for assessing groundwater quality, it gives an initial perception of the regions that should be focused on and controlled.
The use of GIS has become necessary for spatial analyses, which depend on physiochemical properties of the Nile aquifer. Consequently, GIS facilitates the monitoring process and helps decision makers to choose and undertake proper procedures to prevent groundwater contamination [17]. GIS was therefore used to provide spatial analysis distribution maps of the groundwater quality parameters.

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Groundwater type & Salinity and alkalinity hazard

Groundwater categorizes many water types based on its chemical analysis. The categorization is done throughout some plot diagrams like piper diagrams [18]. This plot has been used to identify the water type.

Salinity Hazard

Electrical conductivity (EC) is an adequate measure of the salinity hazard. Groundwater is classified into 4 sets based on electric conductivity (EC) (Table 1) [19].

Table 1. Classification of Electrical conductivity (EC)

Class symbol	Classes, micromhos/cm	Salinity hazard
C1	0 – 250	Low
C2	250 – 750	Medium
C3	750 – 2250	High
C4	> 2250	Very High

Sodium (Alkali) Hazard

Sodium concentration is significant in categorizing groundwater because it reacts with soil to decrease its permeability. the percent sodium can be defined as the ratio between ($Na^+ + K^+$) and ($Ca^{2+} + Mg^{2+} + Na^+ + K^+$) [20] as follows:

$$Na\% = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100 \quad (8)$$

Where, Ca^{2+}, Mg^{2+} Na^+ and K^+ are expressed in epm.

Groundwater can be classified based on Na% as follows (Table 2) [21].

Table 2.Classification of groundwater quality based on Na%.

Na%	Groundwater quality Class
0-20	Excellent
20-40	Good
40-60	Permissible
60-80	Doubtful
>80	Unsuitable

Sodium Absorption Ratio (SAR) is another measure of sodium hazard and is recommended by the salinity laboratory of the United States for use instead of Na% (Table 3). It can be calculated as follows: [22].

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (9)$$

Where the concentrations of the constituents are expressed in meq /L.

Table 3.classification groundwater quality based on SAR.

SAR	Groundwater quality Class	Sodium (Alkali) Hazard
up to 10	Excellent	Low
10-18	Good	Medium
18-26	Fair	High
>26	Poor	Very High

Increasing the magnesium content above the permissible limits in irrigation water is a serious indicator because it makes the soil alkaline, which negatively affects crop growth [23; 24]. Magnesium hazard MH can be calculated by Equation (10) [25] as follows:

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100 \quad (10)$$

If MH > 50, groundwater is considered as unsafe to use for irrigation.

USSL Diagram for classifying groundwater for irrigation

This diagram represents the relationship between the electrical conductivity (EC) in micromhos/cm and the sodium adsorption ratio (SAR) (Figure 2) [21]. the US salinity Diagram (USSL) has been plotted in this paper to classify the suitability of groundwater for irrigation.

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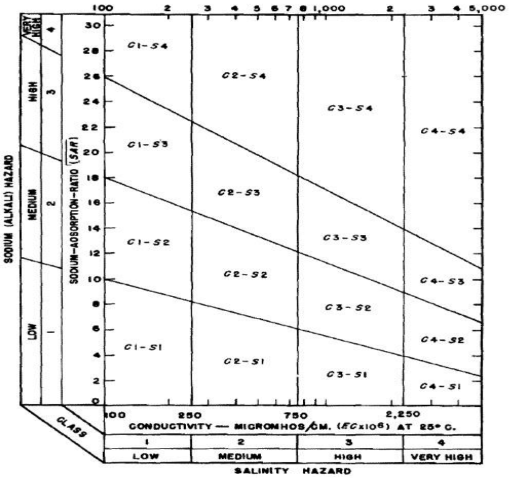

Fig2: Diagram for the classification of irrigation waters

Spatial analysis of groundwater data

Interpolation methods are used in the ArcGIS environment to derive non-measured values between values already measured to create the surfaces representing any phenomenon [26]. These methods are principally established to facilitate estimate the undefined cell value using the lowest number of data. The basic premise on which the interpolation technique was based is that wells close to each other are similar in their characteristics and vice versa. Inverse Distance Weighted (IDW), Spline, and Kriging are the most commonly used methods for applying interpolation principles [27]. Those three methods are involved in ArcGIS 9.3 software under the spatial analyst. Inverse Distance Weighted (IDW) was used to generate the spatial distribution maps of groundwater data. The idea of weight is to give special weight to the point when calculating the mean position. The weights do not depend only on the distance between the points, but on the spatial distribution of these points, which depends on the so-called "autocorrelation" between the points [28; 29].

$$\hat{z}(x_0) = \sum_{i=1}^{n} w_i \cdot z(x_i) \quad (11)$$

Where,

$\hat{z}(x_0)$ = unknown value & $Z(x_i)$ = measured value

w_i = weight of point & n = number of measured values

The value derived in IDW is a weighted average of the measured values used in calculation. The inverse of distance between the unknown value and the measured values has been calculated to get the weights [30; 31]. The total weights for all points are equal to one:

$$\sum_{i=1}^{n} w_i = 1 \quad (12)$$

Where,

w_i = the weight of each i point.

$$w_i = \frac{d_{io}^{-p}}{\sum_{i=1}^{n} d_{io}^{-p}} \quad (13)$$

Where:

w_i = the weight of point i; & p: the power ten of weight.

d_{i0} = The distance between the predicted point x_0 and the other measured near points

the inverse of the distance between calculated point and the closed measured points raises to the power value p . The value of (p) affects the value of the weights of the measured points in the prediction point, so the greater the distance, the less the weight will be increased quickly [32]. Locations with the same distances take the same weights [33]. The power value p can take three values either 0, 1 or 2. These values represent the rate of decrease in the value of weight. If p = 0, there is no decrease and the weight is equal for each location. If p =2, only the close neighbouring points will affect the expectation (Figure 3) [34].

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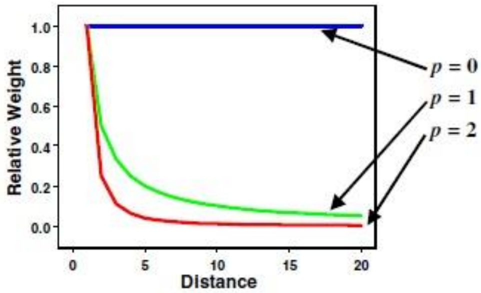

Fig3: Decrease of weight with distance illustration

Based on this principle, the data was processed in ArcGIS 9.3 softwareas will be shown in the hazard maps included in the results and discussions.

IV. RESULTS AND DISCUSSIONS

Statistical analysis of groundwater data

Statistical analyses that was applied by determining Mean, Median, Standard Deviation, Mode, Skewness, Kurtosis, and Pearson's skewness coefficient (PSKC) hves been summarized in Table 4.

Table 4: Summary Descriptive Statistics of all data wells in Assiut Governorate

	Na^+	K^+	Ca^{2+}	Mg^{2+}	Co_3^{2-}	HCO_3^-	So_4^{2-}	Cl^-	Fe	Mn	Si	EC	TDS
Mean	6.59	0.09	3.58	3.83	0.06	3.55	2.47	7.73	0.13	0.07	2.10	2.04	1304.1
Median	4.63	0.06	2.49	2.95	0.00	3.17	1.77	4.15	0.01	0.00	0.30	1.34	857.60
St. Dev.	7.68	0.10	3.99	3.15	0.43	1.62	2.13	10.03	1.13	0.27	2.71	1.95	1247.6
Mode	5.43	0.05	1.20	2.62	0.00	2.32	0.67	2.00	0.01	0.00	0.20	0.81	518.40
Skewness	6.23	6.27	3.85	3.08	10.43	0.83	2.06	3.87	25.60	5.42	1.51	2.65	2.65
Kurtosis	59.73	66.04	24.86	15.08	128.63	0.59	5.49	22.75	695.6	34.2	1.67	8.49	8.49
PSKC	0.76	0.97	0.82	0.83	0.44	0.70	0.98	1.07	0.33	0.82	1.99	1.07	1.07

The results reveal that all data excepting Na^+ achieve the following rule: Mean > Median > Mode. In addition, the Pearson's skewness coefficient of all data has positive skewness on the right side ranging between 0 and 2. Thus, data is not represented by a normal distribution.

The mean was calculated based on the locations of groundwater wells. The arithmetic sum of the various ion values in each well was computed; then, it was divided by the number of wells in each area to get a representative value of each ion separately. For Na^+ and Cl^-, the average concentration is under the threshold values in all regions except in Abu-Teeg and Assiut districts (Figure 4a and Figure 4g). Respecting K^+, the chart has shown a rise in Abu-Teeg also and abnoub districts, but it is within the normal range in the rest of the areas (Figure 4b). With regard to SO_4^{2-}, it has increased in Abu-Teeg district also without any anomalies in the other districts (Figure 4m). For HCO_3^-, it exceeds the threshold value in most regions with the exception of Al-Qussia and Dyrout (Figure 5e). Increased concentrations of iron and manganese have been also observed in all groundwater samples taken from wells. This represents a risk to human, animal and plant health because Fe and Mn have harmful effects. Iron (Fe) and Manganese (Mn) are an essential element for human health, but excess levels can affect nerve functions; also cause staining of sinks / cooking utensils and gives a metallic taste at the lower levels.

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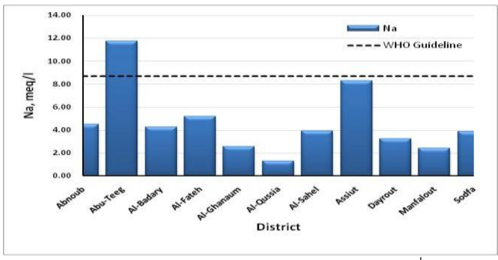


Fig4(a): Avg. concentration of Na^{+}

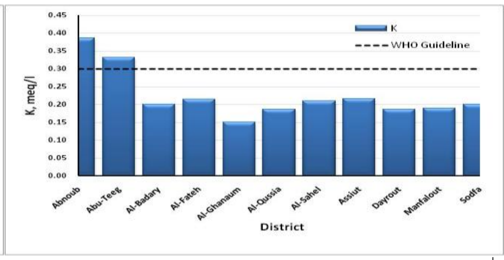


Fig4(b): Avg. concentration of K^{+}

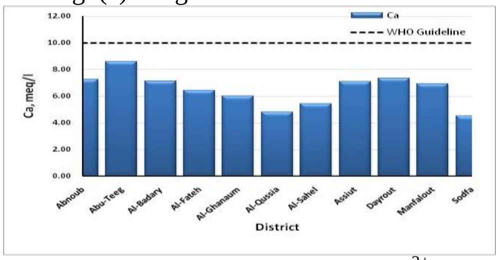


Fig4(c): Avg. concentration of Ca^{2+}

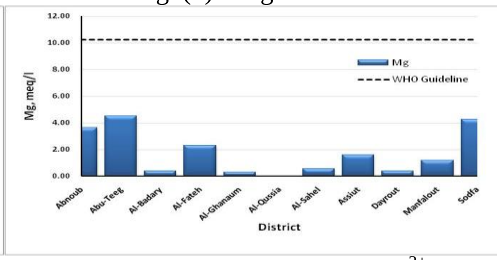
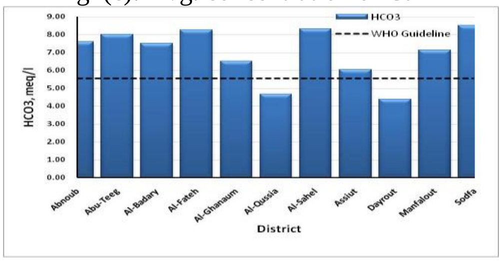


Fig4(d): Avg. concentration of Mg^{2+}



Fig(e): Avg. concentration of HCO_3^{-}

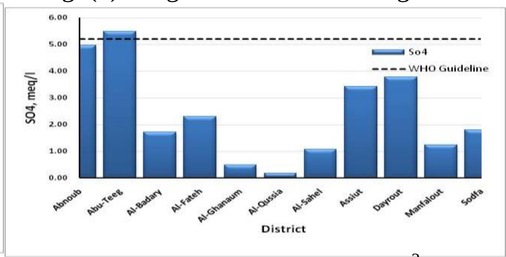


Fig4(f): Avg. concentration of SO_4^{2-}

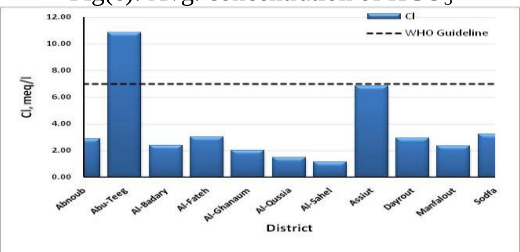


Fig4(g): Avg. concentration of Cl^{-}

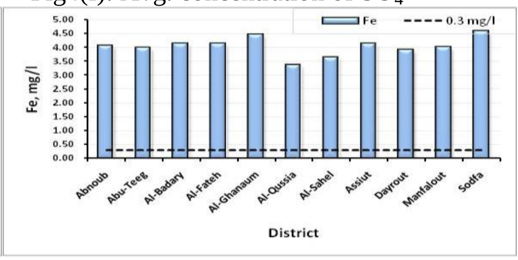


Fig4(h): Avg. concentration of Fe

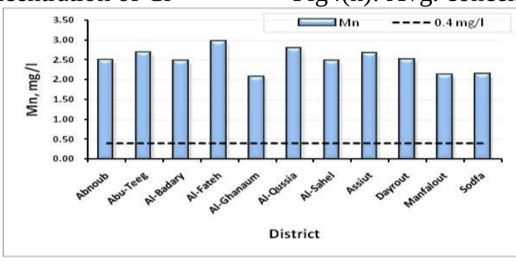


Fig4(i): Avg. concentration of Mn

Fig4: Summary statistical charts of average concentration levels

They are available solid minerals in soils and rock under aerobic conditions and the forms of their solution are very stable but become soluble increasingly under acidic conditions and / or non-aerobic. Thus, the high proportion of iron and manganese in groundwater is attributed to solution of these elements in water from surrounding rocks and soil. This requires setting up treatment stations to remove iron and manganese using three consecutive steps which are aeration, filtration and precipitation.

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Determining groundwater type

The samples from groundwater wells have been plotted on the Piper-trilinear diagram (Figure 5) to conclude hydrochemicalfacies in order to understand water type.

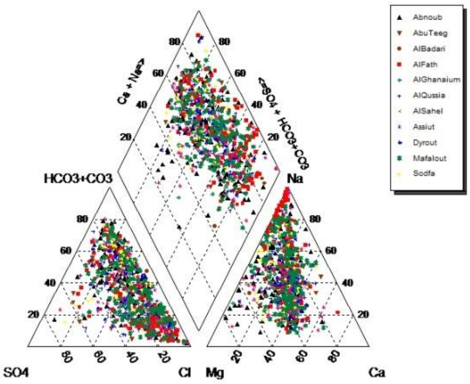

Fig5: Piper diagram of all samples from 2006 to 2013

It is noted that the water type of the most samples is Na-Ca-HCO_3-SO_4facies and Na-Ca-Cl facies as shown in the diamond shape.

Salinity and alkalinity hazard

Sodium adsorption ratio (SAR) and Electrical conductivity (Ec) were used to determine the alkalinity and salinity hazard respectively. These two parameters are utilized together to plot the US salinity diagram (Figure 6 a, b, c, d, e, f, g, and h). According to the US diagram in 2006, 2007, 2008, 2009, 2010 and 2011, the largest part of the groundwater samples are plotted in C3-S1 category, and the rest of the samples are distributed separately in the regions of C2-S1, C3-S2, C4-S1, C4-S2, and C4-S3. This result indicates that groundwater during the period from 2006 to 2011 has high salinity hazard and low sodium hazard; so, it can be suitable for irrigation purposes in most soil kinds with small chance of exchangeable sodium. From the US salinity plotted for 2012 and 2013, most of the samples fall in C3-S1, C3-S2 and C2-S1, this refers to the salinity hazard value of groundwater samples within this period fluctuates between medium to high, while the alkalinity hazard values varying between low and medium. It is noted there are some samples within the period 2012-2013 that are in C4-S3 and C4-S4; almost all of them belong to Al-Fateh district, indicating very high salinity hazard and high alkalinity hazard. This last result may be attributed to the locations of these samples that are in the far east of the study area nearby Wadi-Al-Assiuti where all the surrounding environmental conditions are different.

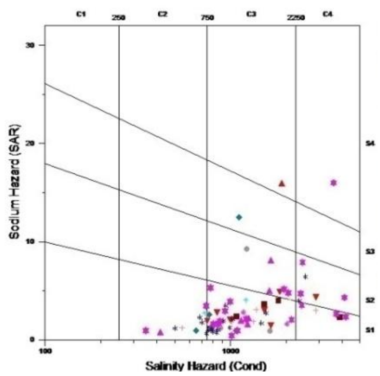

Fig6(a): salinity diagram in 2006

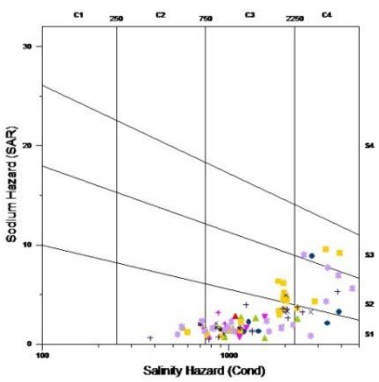

Fig6(b): salinity diagram in 2007

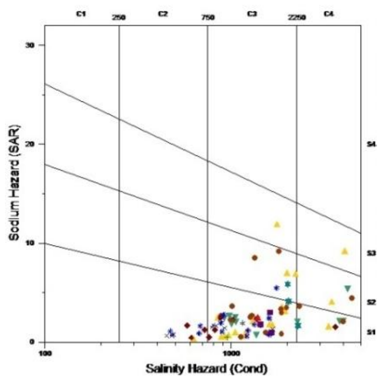

Fig6(c): salinity diagram in 2008

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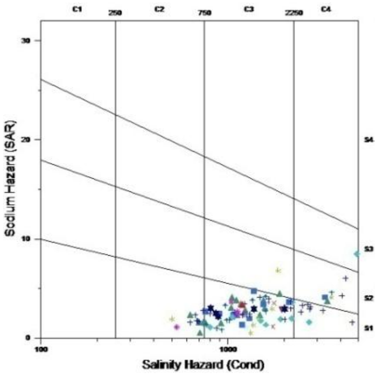

Fig6(d): salinity diagram in 2009

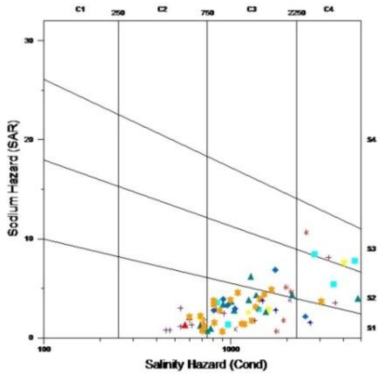

Fig6(e): salinity diagram in 2010

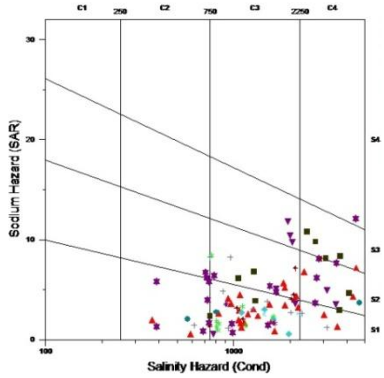

Fig6(f): salinity diagram in 2011

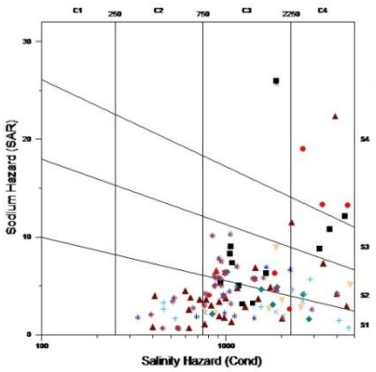

Fig6(g):salinity diagram in 2012

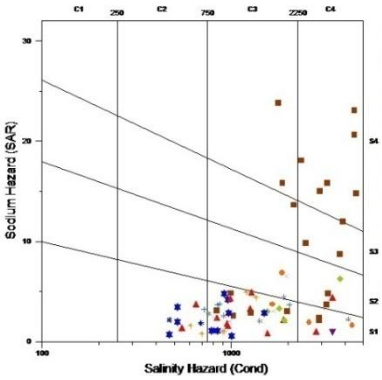

Fig6(h): salinity diagram in 2013

Fig6: US salinity diagram of groundwater during different years

Spatial analysis of groundwater data using ArcGIS software

Spatial distribution maps have been created for EC, TDS, SAR, Na%, Cl, Mg, Fe, and Mn. The spatial distribution map of each factor is representative of its danger, so the maps produced by GIS techniques are called "risk maps" (Figure 7.a, 7.b, 7.c, 7.d, 7.e, 7.f, 7.g, and 7.h). Two maps were generated for salinity hazard based on TDS and EC (Figure 7.a and 7.b). The results show (Figure 7.a) there are areas that have EC more than 2250 micromhos/cm in the middle part of the study area, especially on the eastern and western sides. This means that the salinity hazard of those regions is very high and the groundwater is unsuitable for use without treatment.

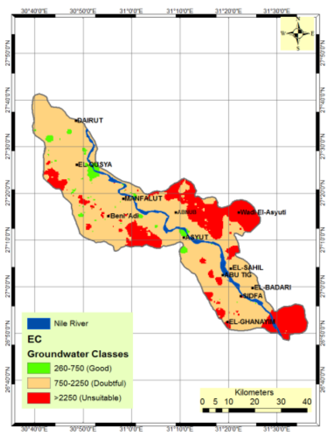

Fig7(a): Salinity hazard based on EC

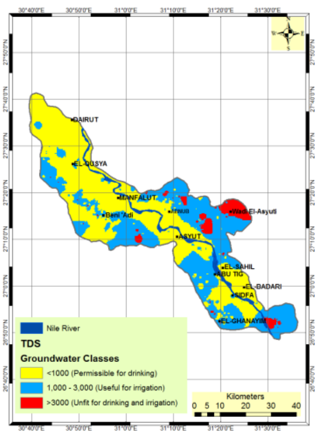

Fig7(b): Salinity hazard based on TDS

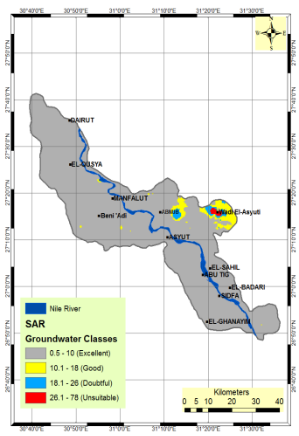

Fig7(c): Sodicity hazard based on SAR

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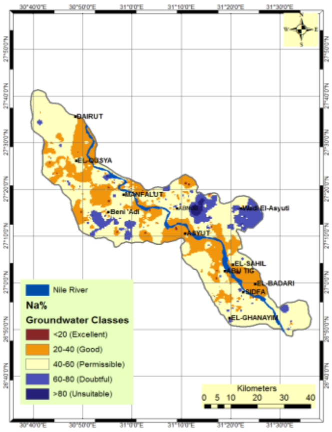

Fig7(d): Sodicity hazard based on Na%

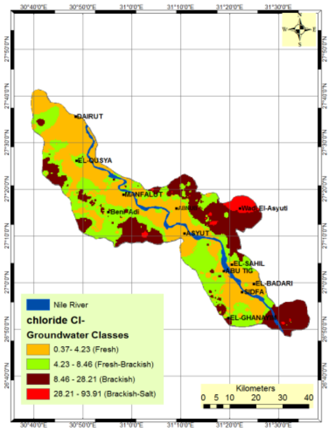

Fig7(e): Chlorinity hazard based on Cl-

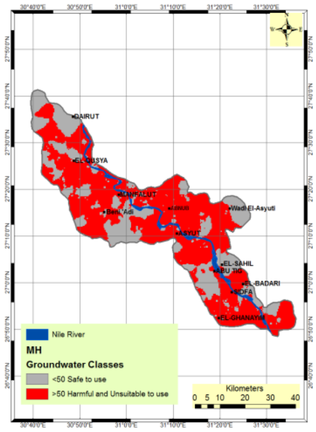

Fig7(f): Magnesium hazard map

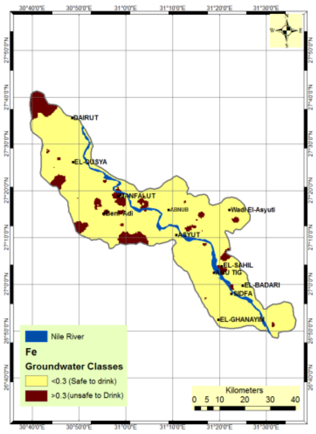

Fig7(g):Iron (Fe) hazard map

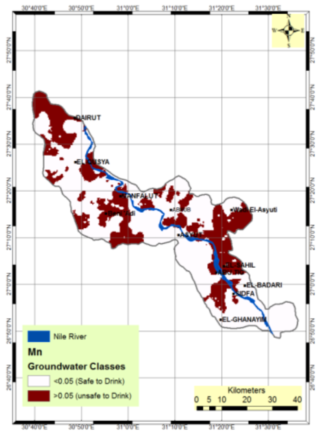

Fig7(h):Manganese (Mn) hazard map

Fig7: Spatial distribution of groundwater quality parameters using GIS tools

On the other hand, the salinity hazard map generated based on TDS (Figure 7.b) reveals that the central fringes of study area have TDS more than 3000 mg/l, this means that groundwater in such areas is considered as unfit for drinking or irrigation. It is clear there are a lot of areas that have TDS varying between 1000 to 3000 mg/l; so the groundwater there is classified as useful for irrigation only. These areas include Beni'Adi, Madabegh, El-Ghanaym, Abnub and Wadi El-Asyti.

Sodicity hazard maps have also been produced based on SAR and Na% (Figure 7.c, 9.d). it is illustrated that the same middle part has high sodicity hazard; i.e. the groundwater is unsuitable to use.

The chlorinity hazard map based on Cl^- (Figure 7.e) confirms that groundwater in the central part of the study area can be described as brackish water and brackish-salt water.

The magnesium hazard map (Figure 7.f) shows that most of the study area has MH more than 50; thus groundwater is unsuitable to use for irrigation. The hazard map of iron (Figure 7.g) illustrates that the highest rates of Fe appear in Al-Qussia, separate areas in Bani'Adi and Mafalout, Arab Al-Madabegh, and north of Dyrout region.

Finally, the hazard map of Mn (Figure 7.h) looks like the hazard map of Fe, but it seems much clearer where the areas restricted are bigger than those in the Fe hazard map. It has been observed by examining the wells data that the increased concentration of manganese is often associated with increased concentration of iron. According to the hazard map of Mn, it can be noted that manganese increases in the areas of Abu Tig, El-Sahel, Wadi Al-Assiuti, various parts of Abnoub, Bani 'Aday, Qusiya, and Dairout.

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V. CONCLUSIONS AND RECOMMENDATIONS

A statistical analysis of groundwater data from 796 wells in Assiut Governorate can summarize that these data do not distribute normally, but has positive skewness on the right side.Bicarbonate concentrations (HCO_3^-) exceed the threshold value in most of the study area due to the effect of the calcareous structural plateau surrounding the study area. So it is recommended to conduct the chemical analysis frequently with the utmost accuracy to monitor bicarbonate levels in the groundwater.The concentrations of Fe and Mn in groundwater exceed the permissible limits in all regions. The high concentrations of Fe and Mn due to dissolving them from the surrounding rocks and soil in water. It is recommended to set up treatment units for Fe and Mn in the drinking water stations spreading all over Assiut Governorate. The water type of most samples is Na-Ca-HCO_3-SO_4facies and Na-Ca-Cl facies.Groundwater in the Nile aquifer system in Assiut governorate can be described as "high salinity-low alkalinity hazard", therefore, it is suitable for irrigation. The high salinity is attributed to increased TDS in most samples. On the other hand, SAR is varying between 0.5 to 10 (Excellent), thus groundwater was also classified as low alkalinity. Based on the spatial analysis conducted using GIS, it was noted through the hazard maps that the most dangerous areas were found in Wadi Al-Assiuti, Bani 'Aday, and Arab Al-Madabeghwhich are located in the middle part of the study area, where wells are deeper than those near the river Nile. It is recommended to intensify future studies on these areas periodically to monitor the state of the groundwater to avoid any adverse effects on the surrounding environment.

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