GIS-Based Spatial Distribution of Groundwater Quality in the Western Nile Delta, Egypt

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Abstract Groundwater (GW) is an important source of drinking and irrigation water in Egypt, especially in some areas where the surface water is insufficient or unavailable. The present study presents the multivariate statistical analysis of groundwater quality of the western Nile Delta (ND) aquifer in order to investigate the factors controlling the groundwater quality. Also, it presents the suitability of groundwater in the western ND for drinking and irrigation. The available data, of 108 GW wells, includes 21 physicochemical parameters for each well (GW sample), viz., EC, TH, TDS, pH, Ca, Mg, Na, K, CL, SO_4, HCO_3, CO_3, Fe, Mn, Zn, Cu, Pb, Cd, Cr, NO_3, and NH_4. Nineteen physicochemical parameters are used as inputs for multivariate analysis. The World Health Organization (WHO) and Egyptian standards (ES) were used as reference standards for the suitability of water for drinking purposes. TDS, SAR, Na %, RSC, Mg %, PI %, KI, CRI, and CR were used to evaluate groundwater suitability for irrigation. ArcGIS was utilized to detect and visualize the spatial classification maps of different parameters. Multivariate analysis showed the existence of up to four significant factors which account for 77.0% of the total variance of hydrochemistry data. The computed water quality

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index (WQI) shows that 45.37% and 66.67% of GW wells fall in good drinking water categories according to WHO and ES, respectively. According to values of TDS, RSC, SAR, and PI, more than 58.83% of groundwater wells are suitable for irrigation. It is recommended to take the necessary actions to control the pollution sources of groundwater in western ND.

Contents

1 Introduction

Groundwater is the main source for domestic, industrial, and agriculture uses in most of the newly reclaimed areas in the western Nile Delta, which affect the groundwater quality. The freshwater in the western Nile Delta is concentrated in the central-eastern part, close to the Rosetta branch. The concentration of Cl and SO_4 ions acquires the higher concentrations of the anions, whereas the concentration of Na, Ca, and Mg acquires the higher concentrations of the cations [1]. However, the

Nile Delta saturated zone lies beneath several land uses which reflect variations in the aquifer characteristics within the delta basin. The agricultural and industrial activities in the Nile Delta region affect the groundwater quality [2]. On the other hand, Taha et al. [3] evaluated the water quality in the new communities of the southeast Nile Delta. The water resources include groundwater, surface water, and drainage water in the new communities located in the southeastern part of the Nile Delta, Egypt. The results showed that the available water resources were classified into different categories based on the content of major cations, anions, and total dissolved salts. Moreover, the microbial content of drinking groundwater water in Kafr al-Zayat region (Egypt) was assessed by Masoud [4]. The conducted factor analysis indicated that the microbial content is the most influential factor raising the variability of groundwater quality in the study area. The temporal and spatial variations of groundwater quality of the northern Nile Delta aquifer using multivariate statistical techniques was introduced by El Arabi et al. [5]. They found that four factors were controlling the groundwater quality within the study period of 4 years (2007–2010). Two of the factors were initially assigned to natural mineralization and salinity, whereas the other two were related to pollution as a result of agricultural and industrial activities. The ArcGIS was utilized to detect the spatial variations of the four factors. The study recommended a suitable environmental treatment for the industrial wastes.

Classification of the groundwater quality or its type can offer great advantages especially in regional groundwater management and provides a short, quick-processing interpretation for a lot of complete hydrochemical data sets and concise presentation of the results. GIS spatial clustering technique is used to the hydrochemical data in order to identify over geographical space the different homogenous groundwater quality and type classes present in an area north the Nile Delta [6]. Also, Mogren and Shehata [7] used GIS to present the groundwater vulnerability mapping of the quaternary aquifer system in the northeastern part of Nile Delta. GIS layers have been created to adopt the most indicative criteria for investigating the groundwater degradation trends from sea level rise and seawater intrusion. Groundwater is an important source of drinking water in rural areas in Egypt. Therefore, it is essential to assess the quality of water intended to be used for drinking purposes because clean drinking water is vital for a healthy life. And as a matter of fact, the chemical contaminants cause serious health problems. Recently, researchers have paid a great deal of attention to the contamination of GW [1, 8, 9]. Sharaky et al. [1] studied the hydrogeochemistry of groundwater in the western Nile Delta aquifers to obtain additional information on the possible contamination with major elements, nutrients, and trace elements. They found that the concentrations of the major ions in the western Nile Delta are higher than the maximum standard limits, according to the World Health Organization. They concluded that the freshwater in the study area is mainly concentrated in the central-eastern part, and most of the groundwaters are located in the high-salinity and low-sodium hazard zones.

Agrama and El-Sayed [8] evaluated the surface water quality in the western Nile Delta by using the Canadian Council of Ministers of the Environment Water

Quality Index (CCMEWQI). The GIS was used for mapping the WQI variations in different canals. The results showed an average for different site locations due to the fact of mixing low-quality water of agricultural drains with canal freshwater in the study area. They recommended that water use in the study area should be restricted due to its quality or to improve the water quality by increasing the freshwater discharge or reducing the water mixing ratio with drains. Recently, Armanuos et al. [10] investigated the factor controlling the groundwater quality in the western Nile Delta aquifer by using the multivariate statistical technique. The results showed that there were four factors that account for 77% of the total variance of hydrochemistry data. The first and second factors were related to mineralization, mining, and salinity due to saltwater intrusion. The other factors were assigned to industrial wastes, domestic wastes, and agriculture activities. They recommended that the authorities should take necessary actions to control the different sources of groundwater pollution. Also, Armanuos et al. [11] assessed the groundwater of the western Nile Delta, Egypt, for drinking purposes by using the water quality index. They used the WHO and Egypt standards (ES) as a reference to determine the suitability of groundwater for drinking purposes. The results showed that about 45.37% and 66.66% of groundwater wells fall in the good drinking water zone according to WHO and Egypt standards. Also, 37.03% and 15.07% fall in the poor drinking water zone according to WHO and ES, respectively, and 9.25% and 11.2% fall in unfit for DW category according to WHO and ES. They concluded that human activities such as agriculture activities and other industrial pollutants contributed to the degradation of groundwater quality of the Nile Delta aquifer.

The main objective of this study is to determine the factor controlling groundwater quality in the western Nile Delta based on multivariate analysis and ArcGIS. Also, to assess the suitability of groundwater for drinking and irrigation purposes.

2 Basics of Multivariate Analysis

2.1 Principal Components Analysis

The principal component analysis (PCA) method is a powerful tool used for extracting of different factors. The defined axis by PCA is rotated to decrease the contribution of variables with less significance [12]. PCA is used to transform the original variables into new uncorrelated variables (axes); they are called the principal components [13]. Each principal component (PC) combines the original variable linearities and describes a different source of information.

$$PC_i = W_1 x_1 + W_2 x_2 + W_3 x_3 + \ldots + W_n x_n \tag{1}$$

where x_i is the original variable, and w_i is the component weight.

2.2 Factor Analysis

Factor analysis is an important tool to extract latent information, such as relationships between different variables which are not observed directly [14]. In the factor analysis (FA) technique, each variable can be expressed as a linear combination of latent common factors and a single specific factor.

$$X_i = \sum_{i=1}^{n} \alpha_{ij} F_j + \beta_i e_i \tag{2}$$

where F_j is the common (error) factors, e_i is the specific error, and α_{ij} and β_i are the factor loadings of F_i and e_i, respectively. Factor analysis divides the correlation matrix into the two following matrices: a common factor matrix and a specific factor matrix. The main goal of factor analysis is not only to decrease the data dimensionality as with principal component analysis but also to interpret the revealed common factors [15].

3 Water Quality Indices

The water quality index (WQI) is one of the most effective tools to communicate information about water quality to the concerned citizens and policy makers [16]. WQI is a dimensionless number which is obtained from combining multiple water quality factors in a single number [17]. It is an important parameter for groundwater assessment and management [18]. The different samples for water quality can be compared to the basis of the index value of each sample [19]. The WQI estimation gives a single value which decreases the huge quantity of parameters and aims to represent data in a simple way [20]. Nowadays, numerous specific WQIs for any region are found where water quality criteria were defined by many national and international agencies for various uses considering different parameters in the assessment of water quality and pollution control [20]. The important methodologies of the water quality index determining were introduced below.

3.1 National Sanitation Foundation Water Quality Index

Brown et al. [21] developed the National Sanitation Foundation Water Quality Index (NSFWQI) by using the Delphi method. The method was used by several researchers to assess the quality of different water resources [22]. NSFWQI classification is done as excellent (index range 90–100), good (index range 70–90), moderate (index range 50–70), fair (index range 25–50), and poor (index range

0–25). The NSFWQI can be determined by the following given mathematical expression:

$$WQI = \sum_{i=1}^{i=n} W_i Q_i \tag{3}$$

$$I = \sum_{i=1}^{i=n} I_i W_i \tag{4}$$

where, $\sum_{i=1}^{i=n} W_i = 1$, $I_i =$ subindex of each parameters, $W_i =$ weighting factor, $Q_i =$ rating value of parameter i, and $n =$ number of subindices.

3.2 Canadian Council of Ministers of the Environment Water Quality Index

In the mid-1990s, the Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment introduced CCME water quality index [23, 24]. The CCMWQI combines three measures of variance (scope, frequency, and magnitude) to produce a single number which represents the overall water quality [25]. According to CCME water quality index, the water quality has been suggested into the following five classified categories: poor (0–44), marginal (45–64), fair (65–79), good (80–94), and excellent (95–100). The Canadian Council WQI is calculated using the following three factors:

$$WQI = 100 - \left(\sqrt{\frac{F_1^2 + F_2^2 + F_3^2}{1.723}} \right) \tag{5}$$

where

F_1 represents scope and equals [no. of variables whose objectives are not met/Total no of variables] $\times$ 100, F_2 represents frequency and equals [no. of tests whose objectives are not met/Total no of tests] $\times$ 100, and F_3 represents amplitude which equals the range to which the failed tests are above the guideline.

(a) Range/excursion$_i =$ [failed test value/objective$_j$] $- 1$
(b) nse $= \sum_{i=1}^{i=n} \dfrac{\text{Excurstion}}{\text{No of tests}}$
(c) $F_3 =$ [nse/0.01nse $+ 0.01$]

The constant, 1.732, is a scaling and ranges from 0 to 100.

3.3 Oregon Water Quality Index

In the late 1970s, the Oregon Department of Environmental Quality (ODEQ) developed the Oregon Water Quality Index [26]. The following parameters were covered in OWQI method: temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), pH, ammonia and nitrate nitrogen, total phosphorus, total solids, and fecal coliform [26]. The water quality can be classified into five categories according to OWQI such as very poor (0–59), poor (60–79), fair (80–84), good (85–89), and excellent (90–100). The calculation of OWQI can be obtained by using the following relationship:

$$\mathrm{WQI} = \sqrt{\frac{n}{\sum_{i=1}^{i=n} \frac{1}{SI_i^2}}} \tag{6}$$

where n is the number of subindices and SI is subindex of ith parameter.

3.4 Weighted Arithmetic Water Quality Index Method

The water quality can be classified by the weighted arithmetic water quality index method according to the degree of purity by using the most common water quality parameters [27]. The rating scale of this WAWQI method has also been categorized into five classes such as excellent (less that 50), good (50–100), poor (100–200), very poor (200–300), and unsuitable for drinking purposes (>300). #The following equations presented by Brown et al. [27] to determine the weighted arithmetic water quality index:

$$\mathrm{WQI} = \sum_{i=1}^{n} Q_i x W_i \tag{7}$$

in which Q_i is the ith quality rating and is given by Eq. (2) and W_i is the ith relative weight of the parameter I and is given by Eq. (3).

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100 \tag{8}$$

where C_i is the ith concentration of water quality parameter, and S_i is the ith drinking water quality standard according to the guidelines of WHO [28] in mg/l.

$$W_i = w_i / \sum_{(i=1)}^{n} w_i \tag{9}$$

where w_i is the weight of ith parameter, and n is the number of chemical parameters.

4 Suitability of Groundwater of Irrigation

The suitability of water for irrigation depends on the effect of the mineral constituents of water on both the plant and the soil. Salts may harm the plant growth physically by limiting the uptake of water through modification of osmotic processes or chemically by metabolic reactions such as those caused by toxic constituents. Irrigation of food crops presents a possible risk to food consumers if the quality of irrigation water is inadequate. The salinity of water suitable for irrigation also depends on the composition of soil, permeability, the topography of the land, the amount of water used and methods of application, the kind of growing crops, the climate of the region, and the nature of the groundwater and surface water drainage system. Poor drainage permits salt concentrations in the root zone to build up to toxic proportions [29].

The discussion of water quality for irrigation purposes is mainly based on the following factors:

1. Total dissolved solids (TDS)
2. Sodium adsorption ratio (SAR)
3. Sodium percentage (Na %)
4. Residual sodium carbonate (RSC)
5. Magnesium ratio
6. Permeability index
7. Kelly's ratio
8. Chloro-alkaline indices (CAI)
9. Corrosively ratio (CR)

4.1 Total Dissolved Solid

Increasing the total dissolved solids (TDS) in the irrigation water affects the soil efficiency and the growth and yield of plants. The total dissolved solids for long term of irrigation under average conditions should be less than 2,000 mg/l. Classification of water according to the values of total dissolved solids was shown in Table 1 [30].

4.2 Sodium Adsorption Ratio

One of the important parameter for determining the suitability of groundwater for irrigation is SAR. The U.S. salinity laboratory [31] defined the SAR where it is

Table 1 Classification of irrigation water according to TDS

TDS (mg/L)	Comment
200–500	Best quality water
1,000–2,000	Water involving a hazard
3,000–7,000	Water can be used for irrigation only with leaching and perfect drainage

Table 2 Alkalinity hazard of irrigation water

Water class	Alkalinity hazard	Sodium adsorption ratio (SAR)
Excellent	S1	2–10
Good	S2	10–18
Doubtful	S3	18–26
Unsuitable	S4	>26

Table 3 Sodium percentage of irrigation water

Water class	Sodium percentage
Excellent	<20
Good	20–40
Permissible	40–60
Doubtful	60–80
Unsuitable	>80

expressed in mill equivalents per liter. SAR predicts the degree to which water trends to enter into a cation – exchange reaction in soil. The increase of SAR implies a hazard of sodium replacing adsorbed with magnesium and calcium [32]. Table 2 presents the classification of irrigation water according to the alkalinity hazard. The SAR is expressed by the following formula, where the concentrations are expressed in meq/l (Richards 1954) as reported in [32].

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{++} + Mg^{++})}{2}}} \tag{10}$$

4.3 Sodium Percentage

The percentage of sodium (% Na) is also commonly utilized for assessing the suitability of water quality for irrigation [33]. In groundwater, the increase of sodium concentration generates undesirable effects as the sodium reacts with the soil in order to decrease the permeability of soil and growth of plants [34]. Table 3 presents the categories of irrigation water relates to values of sodium percentage. The concentrations of sodium ions are expressed in meq/l, using the following formula:

$$Na \% = \frac{(rNa + rK)\%}{rCa + rMg + rNa + rK} \tag{11}$$

Table 4 Classification of residual sodium carbonate of irrigation water

Water class	RSC meq/l
Safe	<1.25
Marginal	1.25–2.5
Unsuitable	>2.5

4.4 Residual Sodium Carbonate

The Residual Sodium Carbonate (RSC) considers the hazardous effect of bicarbonate and carbonate on the water quality for irrigation purpose. It can be calculated by the following equations in meq/l [35]. According to the values of RSC the irrigation water can be classified into three categories as shown in Table 4.

$$RSC = \left(Hco_3^- + CO_3^{-2}\right) - \left(Ca^{+2} + Mg^{+2}\right) \tag{12}$$

4.5 Magnesium Hazard

The presence of Ca^+ and Mg^+ maintains the state of equilibrium in groundwater. The increase of Mg^+ in water affects the quality of soil by converting it to alkaline and decreases the crop yield. Magnesium hazard values can be calculated by the following formula (where the concentrations are expressed in meq/l) (Szabolcs and Darab [36]). The magnesium ratio of more than 50% in a water body will make the water poisonous to plants.

$$Mg \ ratio = \frac{(Mg^+)}{(Ca^{2+} + Mg^{2+})} \times 100 \tag{13}$$

4.6 Permeability Index

The increase of soil permeability increases the presence of sodium, calcium, magnesium and bicarbonate in the soil [37]. The Permeability Index is used to indicate the suitability of water for irrigation. It has been proposed by Doneen [38] by the following formula, where the concentrations are expressed in meq/l.

$$PI = \frac{\left(Na^+ + \sqrt{HCO_3}\right)}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100 \tag{14}$$

According to the values of PI, groundwater can be classified in to three classes class I (>75%), class II (25–75%) and class III (<25%). Class I and class II water is

classified as good water for irrigation where Class III water classified as unsuitable for irrigation.

4.7 Kelly's Ratio

The suitability of groundwater for irrigation purposes is also valuated on the bases of Kelly's ratio depending on the level of Na measured against Ca and Mg [39]. It can be calculated by the following equations, where the concentrations are expressed in meq/l. Groundwater with KI less than 1.0 is suitable for irrigation; on the other hand, that with KI higher than 1.0 is unsuitable [40].

$$KI = \frac{Na^+}{(Ca^{2+} + Mg^{2+})} \tag{15}$$

4.8 Chloro-alkaline Indices

Chloro-alkaline indices (CAI) describe the ion exchange in the aquifer between the groundwater and its surroundings in case of residence or traveling. The following formula has evolved by Schoeller [41] to calculate CAI value (where all concentrations are expressed in meq/l).

$$CAI = \frac{(Cl^{-1} - (Na^+ + K^+))}{Cl^{-1}} \tag{16}$$

A positive value of CAI indicates the existence of cation-anion exchange and the absence of the base-exchange type of reactions, where the negative value of CAI indicates the existence of exchange between sodium and potassium $(Na^+ + K^+)$ found in water with calcium and magnesium $(Ca^{+2} + Mg^{+2})$ found in the rocks.

4.9 Corrosively Ratio

The corrosivity ratio is an important parameter to show whether the water can be transported in metallic pipes or not. When corrosively ratio <1, groundwater is considered to be safe for transport in any type of pipes, on the other hand corrosively ratio >1 indicates corrosive nature and hence not to be transported through metal pipes. The corrosive ratio is calculated by using the following formula, where all concentrations are expressed in meq/l.

$$C.R = \frac{\frac{Cl^{-1}}{35.5} + 2\left(\frac{SO_4^{-2}}{96}\right)}{2\left(\frac{HCO_3^- + CO_3^{-2}}{100}\right)} \qquad (17)$$

5   Case Study and Data Collection

The study area is located in the western Nile Delta as shown in Fig. 1. The study area is bounded by the Mediterranean border in the north, the Rosetta Branch to the east and Cairo-Alex desert road passing through it from the west northern area toward the south. Samples were collected from 108 wells and analyzed for physico-chemical parameters at the Research Institute for Groundwater (RIGW) laboratories [1]. The groundwater wells have depths varying from 27.0 to 120 m. Twenty hydrochemical variables, electrical conductivity (EC), total dissolved solids (TDS), pH, calcium (Ca), magnesium (Mg), chloride (CL), nitrate (NO$_3$), sulfate (SO$_4$), iron (Fe), sodium (Na), potassium (K), carbonate (CO$_3$), lead (pb), bicarbonate (HCO$_3$), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), and ammonium (NH$_4$), were selected.
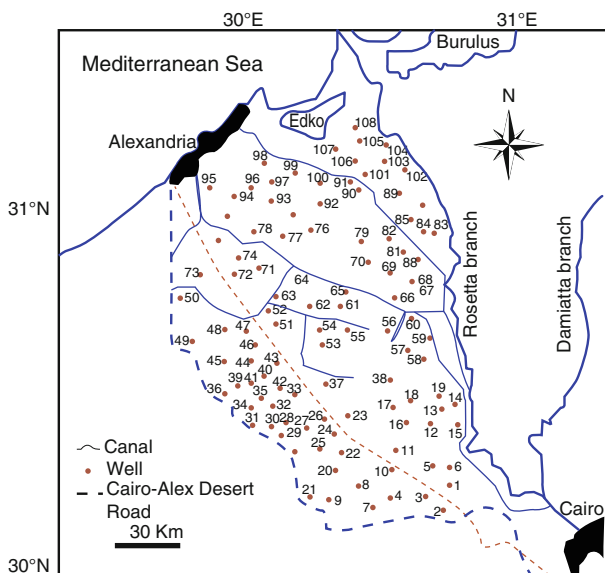

Fig. 1 Study area and groundwater wells locations [1]

6 Materials and Methods

Sixteen hydrochemical variables [1], including electrical conductivity (EC), total dissolved solids (TDS), pH, calcium (Ca), magnesium (Mg), chloride (Cl), nitrate (NO_3), sulfate (SO_4), iron (Fe), sodium (Na), potassium (K), bicarbonate (HCO_3), manganese (Mn), zinc (Zn), copper (Cu), and ammonium (NH_4), were selected as variables inputs for factor analysis. The Statistical Package for Social Sciences (SPSS) was used to carry out the statistical analyses. The correlation matrix is the first step in factor analysis and is used to account for the degree of mutually shared variability between individual pairs of groundwater quality variables. A perfect correlation coefficient is ranging 0.99–1.00. The strong correlation coefficient is ranging 0.80–0.98. Parameters showing correlation coefficients of $r > 0.5$–0.8 are considered to be moderate correlation. The weak correlation coefficient is considered when $r < 0.5$. The negative values show inverse relationships between chemical parameters. The strong to the perfect correlation between the chemical parameters is an indication of common source.

Factor analysis exposes the important factors responsible for variation in groundwater quality and eventually leads to source identification of groundwater pollution. Therefore, the factor analysis is applied to extract the most significant factors and to reduce the contribution of less significant variables to simplify even more of the data structure. In the present work, factor extraction was done by principal components, whereas varimax rotation with Kaiser normalization was used for orthogonal rotation and results in factors that are uncorrelated. The factor scores that are computed for each observation which express the importance of each factor at that observation site outlined the importance of factor scores and their relations to the potential of the processes described by each factor.

The water quality index was calculated for the 21 selected parameters of groundwater quality by the weighted arithmetic water quality index method. Values of desirable and maximum allowable limits of different parameters, according to WHO [28] and according to Egypt drinking water standards [42], are listed in Table 5. Each parameter is assigned a weight according to its relative importance for the quality of water for drinking purposes, as shown in Table 5. The maximum weight of 5 is assigned to total dissolved solids (TDS), EC, NO_3, and Pb; weight of 4 is assigned to SO_4, TH, Mn, and Cr; weight of 3 is assigned to pH, Cl, Na, and Cd; and weight of 2 is assigned to K, Mg, Ca, CO_3, HCO_3, Fe, Cu, NH_4, and Zn [19]. The spatial analysis module in ArcGIS 10.2 software is used to investigate the spatial distribution of groundwater quality parameters in western Nile Delta aquifer. Values of chemical parameters in each well were assigned according to its location as an input to spatial analysis tool in ArcGIS. The inverse distance weighted (IDW) technique is chosen to generate spatial interpolation maps for different parameters in the spatial modeling tool.

Table 5 Desirable limits of parameters and assigned relative weight

Parameters	WHO desirable limit (mg/L)	WHO allowable limit (mg/L)	Egypt limit (mg/L)	Weight (w_i)	Relative weight (W_i)
TDS	500 (mg/L)	1,000 (mg/L)	500 (mg/L)	5	0.0724
pH	6.5–8.5	8.5	7.0–8.5	3	0.0435
EC	1,500 µs/cm	1,500 µs/cm	–	5	0.0724
TH	300 (mg/L)	600 (mg/L)	500 (mg/L)	4	0.0579
Ca	75 (mg/L)	75 (mg/L)	75 (mg/L)	2	0.0289
Na	200 (mg/L)	200 (mg/L)	200 (mg/L)	3	0.0435
Mg	30 (mg/L)	30 (mg/L)	50 (mg/L)	2	0.0289
K	10 (mg/L)	10 (mg/L)	–	2	0.0289
CL	200 (mg/L)	200 (mg/L)	200 (mg/L)	3	0.0435
CO_3	100 (mg/L)	100 (mg/L)	–	2	0.0289
SO_4	200 (mg/L)	200 (mg/L)	400 (mg/L)	4	0.0579
NH_4	0.5 (mg/L)	0.5 (mg/L)	–	2	0.0289
Cr	0.05 (mg/L)	0.05 (mg/L)	0.05 (mg/L)	4	0.0579
Cu	1.0 (mg/L)	1.5 (mg/L)	1.0 (mg/L)	2	0.0289
Cd	0.005 (mg/L)	0.005 (mg/L)	0.005 (mg/L)	3	0.0435
HCO_3	100 (mg/L)	100 (mg/L)	–	2	0.0289
No_3	50 (mg/L)	50 (mg/L)	45 (mg/L)	5	0.0724
Fe	0.3 mg/L	1.0 (mg/L	0.3 (mg/L)	2	0.0289
Pb	0.01 (mg/L)	0.01 (mg/L)	0.05 (mg/L)	5	0.0724
Mn	0.05 (mg/L)	0.05 (mg/L)	0.1 (mg/L)	4	0.0579
Zn	5 (mg/L)	5 (mg/L)	5 (mg/L)	2	0.0289
				$\Sigma w_i = 66$	$\Sigma W_i = 1$

7 Results and Discussions

7.1 Spatial Distribution of Groundwater Quality Parameters Based on Multivariate Analysis

The correlation matrix as a first step of the factor analysis is presented in Table 6. From Table 6, perfect correlation is found between TDS and EC and with Na and EC. The correlation matrix shows a strong correlation between Mg, Ca, CL, and EC. Similar relations are found between Na, Mg, Ca, and CL with TDS and among Na and K, Mg, and Na and with CL and Na as well. A strong correlation is found between Ca and Mg, CL and Mg, SO_4 and Ca, and CL and Ca. Moderate correlation is observed between K and SO_4 with EC, K, and TDS and with SO_4 and TDS. A similar correlation is found between Mg, CL, and K and with Ca, SO_4, and Na and among SO_4, HCO_3, and Mg and with SO_4 and CL as well. On the other hand, Table 6 shows negative and weak correlation between HCO_3, Fe, Mn, Zn, Cu, NH_4, and NO_3 with EC, TDS, pH, K, Na, Mg, Ca, and CL.

Table 6 Correlation matrix

	EC	TDS	pH	K	Na	Mg	Ca	CL	SO₄	Hco₃	Fe	Mn	Zn	Cu	NH₄	NO₃
EC	1.0															
TDS	**0.99**	1.0														
pH	−0.41	−0.38	1.0													
K	**0.75**	**0.76**	−0.34	1.0												
Na	**0.99**	**0.98**	−0.41	**0.80**	1.0											
Mg	**0.94**	**0.95**	−0.34	**0.62**	**0.90**	1.0										
Ca	**0.84**	**0.84**	−0.35	0.44	**0.78**	**0.86**	1.0									
CL	**0.96**	**0.98**	−0.40	**0.79**	**0.95**	**0.93**	**0.82**	1.0								
SO₄	**0.77**	**0.79**	−0.30	0.42	**0.75**	**0.74**	**0.91**	**0.74**	1.0							
Hco₃	0.46	0.49	−0.04	0.31	0.45	**0.52**	0.22	0.41	0.12	1.0						
Fe	−0.08	−0.08	0.12	−0.06	−0.10	−0.04	−0.02	−0.08	−0.002	−0.07	1.0					
Mn	−0.06	−0.05	0.01	−0.01	−0.05	−0.06	−0.08	−0.05	−0.07	0.08	−0.24	1.0				
Zn	0.02	0.02	−0.06	−0.01	0.01	0.06	0.06	0.05	0.0	−0.11	0.25	−0.36	1.0			
Cu	0.01	0.03	0.28	0.10	−0.02	0.04	0.04	0.04	0.01	0.08	0.28	−0.14	0.12	1.0		
NH₄	0.15	0.20	−0.15	−0.02	0.20	0.10	0.17	0.13	0.41	−0.05	−0.07	0.0	−0.02	−0.22	1.0	
NO₃	0.31	0.30	−0.14	0.25	0.30	0.37	0.29	0.28	0.24	0.09	−0.04	−0.20	0.14	0.12	0.17	1.0

Fig. 2 The scree plot curve
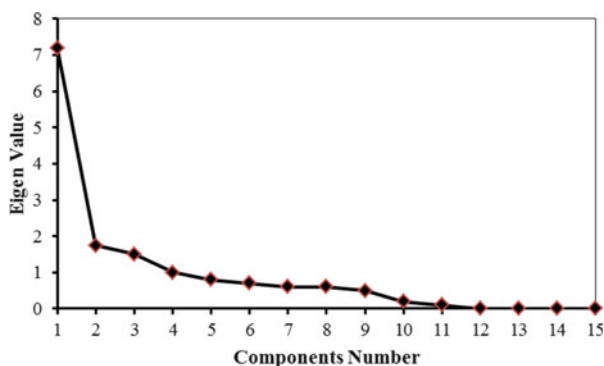
Table 7 Rotated components matrix

	Component			
Parameters	1	2	3	4
EC	**0.984**	0.008	−0.089	0.053
TDS	**0.991**	−0.009	−0.060	0.078
pH	−0.373	−0.176	**0.704**	−0.009
K	**0.774**	0.011	−0.124	−0.263
Na	**0.968**	−0.006	−0.125	0.054
Mg	**0.956**	0.022	−0.006	0.041
Ca	**0.841**	0.092	0.008	0.337
CL	**0.973**	0.035	−0.082	0.025
SO$_4$	**0.767**	0.045	0.021	**0.561**
HCO$_3$	0.521	−0.296	0.154	−0.375
Fe	−0.050	**0.522**	**0.475**	0.038
Mn	−0.051	**−0.737**	−0.066	−0.026
Zn	0.015	**0.794**	−0.051	−0.065
Cu	0.108	0.182	**0.769**	−0.198
NH$_4$	0.104	−0.062	−0.140	**0.814**
Eigenvalue	7.078	1.615	1.414	1.361
Variance (%)	**47.189**	**10.767**	**9.424**	**9.073**
Cumulative variance (%)	**47.189**	**57.956**	**67.380**	**76.453**

The examination of the scree plot shown in Fig. 2 indicated that four factors were responsible for the variance of 19 parameters.

Table 7 presents the loading of each variable under each one of the four factors. In factor analysis the first factor usually represents the most important process or mix processes controlling the hydrochemistry. It has the highest eigenvalue and accounts for the high variance among the factors. In this study, the first factor which accounts for about 47.2% of the variance has the highest positive loadings for EC, TDS, K, Ca, Mg, Na, CL, and SO$_4$. The second factor accounts for about 10.77% in the hydrochemistry and has a high positive loading for Fe, Mn, and Zn. The third
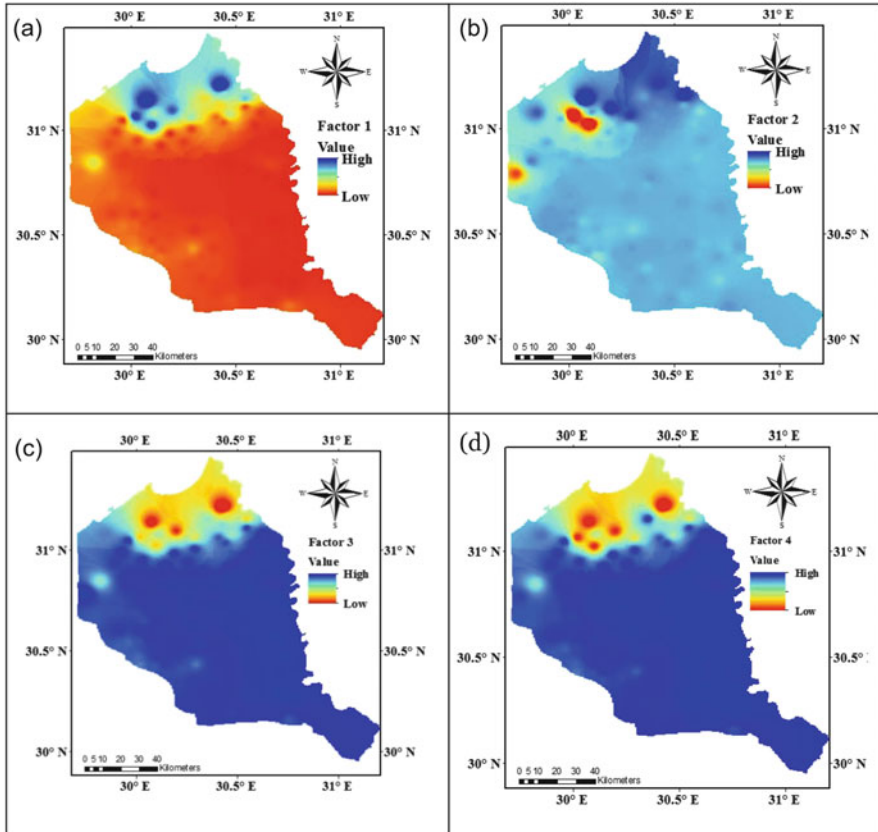
Fig. 3 Spatial distributions of factor scores. (**a**) Factor 1. (**b**) Factor 2. (**c**) Factor 3. (**d**) Factor 4

factor accounts for about 9.42% in the hydrochemistry and has high positive loadings for pH, Fe, and Cu. The fourth factor accounts for about 9.07% in the hydrochemistry and has high positive loadings for NH_4 and SO_4.

Figure 3a shows the spatial distribution of factor score 1. Factor 3.a has eigen-value with 7.078% and 47.189% of the variance. It has high loadings on EC, TDS, K, Na, Mg, Ca, CL, and SO_4, moderate loadings on pH and HCO_3, and low loadings on Fe, Mn, Zn, Cu, and NH_4. This suggests that the quality of groundwater is mainly controlled by high loading parameters. The high loading of TDS, Ca, Na, and CL is due to saltwater intrusion from the Mediterranean sea. The high loading of SO4 is related to the long history of the evaporation process; the high value of K suggests pollution from the application of potash fertilizers to agricultural lands. It is evident from Fig. 3a that the high loading for factor number 1 is in the northern part of the study area near the Mediterranean sea. The moderate loading of pH represents solubility of minerals. It is shown in Fig. 3a that the moderate loading for factor number 1 is in the western and southern part of the study area. The

combination of Fe, Mn, Zn, and Cu indicates weathering of country rocks. It is shown in Fig. 3a that the low loading for factor number 1 is in the central and eastern part of the study area.

Figure 3b shows the spatial distribution of factor score 2. Factor 3.b has eigenvalues of 1.62% and 10.77% of the variance. It has high loadings on Fe, Mn, and Zn; moderate loading on pH, Cu, and HCO_3; and low loadings on EC, TDS, K, Na, Mg, Ca, CL, and SO_4. The high loading for Fe, Mn, and Zn components is responsible for salinity due to cation-exchange processes at soil water interface and industrial wastes. Iron loading may be due to dissolution of lithogenic materials. It is clear from the figure that high value for factor 2 is concentrated in the northern part of the study area. Moderate loading is concentrated in the central, eastern, and southern part of the study area. On the other hand, low loading is concentrated in the western north part of the study area.

Figure 3c shows the spatial distribution of factor score 3. It has eigenvalue with 1.414% and 9.424% of the variance. Therefore, it has high loadings on pH, Fe, and Cu and low loadings on EC, TDS, K, Na, Mg, Ca, CL, HCO_3, Mn, Zn, NH_4, and SO_4. The high loading for Fe and Cu is due to salinity from cation-exchange processes at soil water interface and industrial wastes. Iron loading may be due to dissolution of lithogenic materials. The moderate loading pH represents solubility of minerals. It can be clear from the figure that high value for factor 3 is concentrated in the eastern part from the study area. Moderate loading is concentrated in the northern part of the study area with a small area, whereas low loading is concentrated in the northern part of the study area.

Figure 3d shows the spatial distribution of factor score 4. Factor 3.d has eigenvalue with 1.36% and 9.07% of the variance. It has high loadings on SO_4 and NH_4; moderate loadings on K, Ca, and Cu; and low loadings on EC, TDS, pH, Na, Mg, CL, Fe, Mn, and Zn. The high loading of SO_4 is related to the long history of evaporation process, while the high value of NH_4 suggests pollution from the application of potash fertilizers to agricultural lands. It is clear from the Fig. 3d that the high loading for factor 4 was concentrated in the eastern, central, and southern part from the study area. The moderate loading is concentrated in the northern part of the study area with a small area. On the other hand, the low loading is concentrated in the northern part of the study area.

7.2 Suitability of Groundwater for Drinking and Irrigation

7.2.1   Drinking

The results of using ArcGIS to indicate the spatial distribution of ten of water quality parameters are presented in Fig. 4a–j. The spatial distribution of TDS, Na, K, Ca, Mg, CL, SO_4, HCO_3, and NO_3 are presented in Sharaky et al. [1]. On the other hand, Table 8 and Figs. 5 and 6 present the values of the WQI and their spatial distributions.
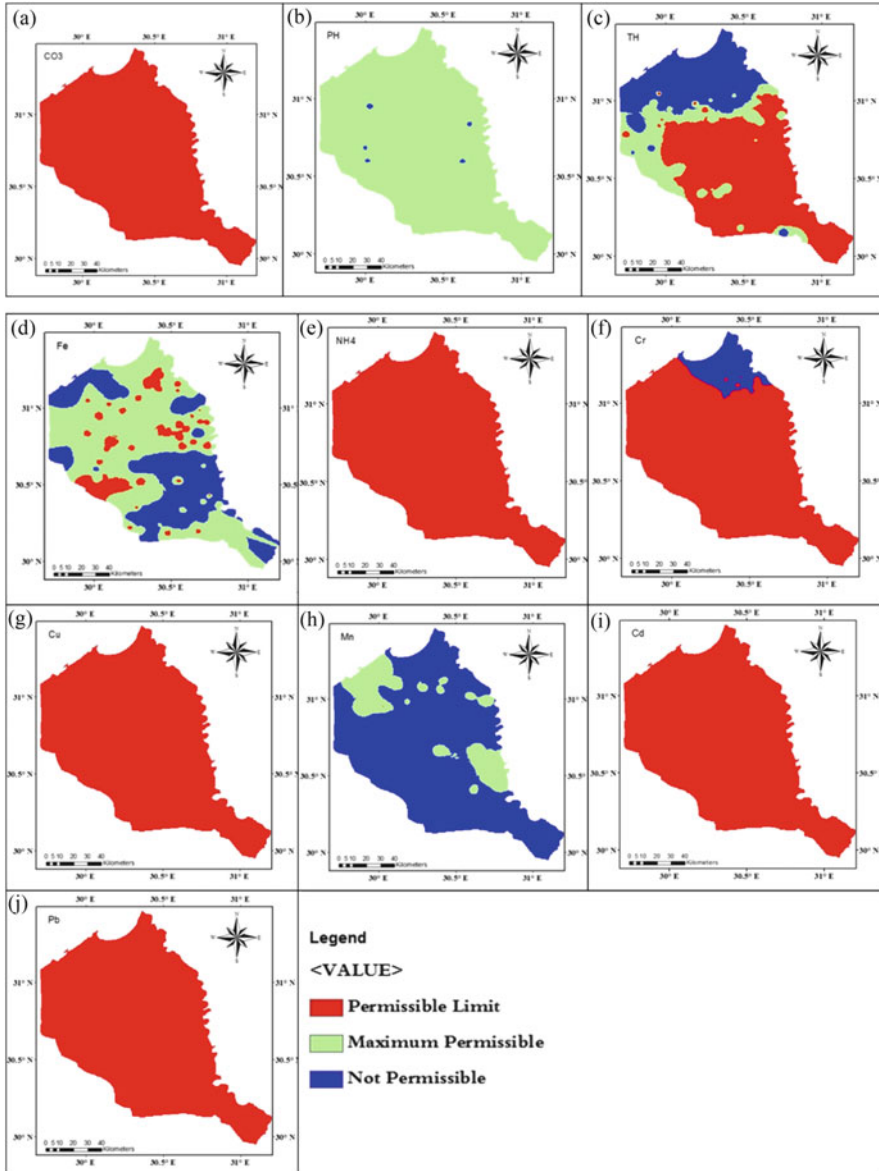
Fig. 4 Spatial variation of groundwater parameters. (**a**) Co$_3$. (**b**) PH. (**c**) TH. (**d**) Fe. (**e**) NH$_4$. (**f**) Cr. (**g**) Cu. (**h**) Mn. (**i**) Cd. (**j**) Pb

It can be clear from Table 9 and Fig. 4a–j that wells number 96, 98, and 108 that are near from the shoreline of the Mediterranean sea record high concentration of TDS, EC, TH, Ca, Na, K, Mg, Cl, and HCO$_3$; this is related to saltwater intrusion from the Mediterranean sea. About 100% (bold style in Table 8) of the total wells

Table 8 Results of chemical parameters characteristics

| Fig. No.	Title	Characteristics according to Sharaky et al. [1]				% Percentage limits of each parameters		
		Mini/well No.	Maxi/well No.	Ave.	SD	% Desirable limit	% Maximum permissible	% Not allowable
4.a	Variation map of CO_3	0.0	60.0/88	2.53	10.02	**100.0**	–	–
4.b	Variation map of pH	7.11/7	8.65/78	13.185	0.327	5.0	95.0	–
4.c	Variation map of TH	113.3/15	6379.1/98	612.85	1023.85	58.33	24.50	17.17
4.d	Variation map of Fe	0.05/7	7.0/20	0.850	1.11	13.89	62.96	23.15
4.e	Variation map of NH_4	0.01/48	0.5/104	0.035	0.046	**100.0**	–	–
4.f	Variation map of Cr	0.04/29	0.046/20	0.047	0.037	**100.0**	–	–
4.g	Variation map of Cu	0.004/103	0.1/8	0.061	0.027	20.37	79.63	–
4.h	Variation map of Mn	0.03/78	0.4/23	0.144	0.080	–	**100.0**	–
4.i	Variation map of Cd	0.0004/100	0.005/74	0.0025	0.0007	100.0	–	–
4.j	Variation map of Pb	0.002/90	0.005/7	0.0035	0.0006	**100.0**	–	–
–	Variation map of TDS, Sharaky et al. [1]	430/5	24407/108	7.9	4575	14.8	25.0	60.2
–	Variation map of Ca, Sharaky et al. [1]	12.0/51	1300/98	1000.3	153.54	62.03	18.5	19.47
–	Variation map of Na, Sharaky et al. [1]	35.0/68	7774/108	89.81	1348.56	48.15	–	51.85
–	Variation map of K, Sharaky et al. [1]	2.0/57	256/108	733.54	28.06	76.85	–	23.15
–	Variation map of Mg, Sharaky et al. [1]	7.0/62	851/96	97.84	164.44	48.15	38.15	16.67
–	Variation map of Cl, Sharaky et al. [1]	39.0/89	12173/108	422	2112	50.4	36.11	13.49
–	Variation map of SO_4, Sharaky et al. [1]	6.0/102	6272/98	9.35	816.5	58.35	18.15	23.14
–	Variation map of HCO_3, Sharaky et al. [1]	73.0/104	4775/96	372	635.27	–	–	**100.0**
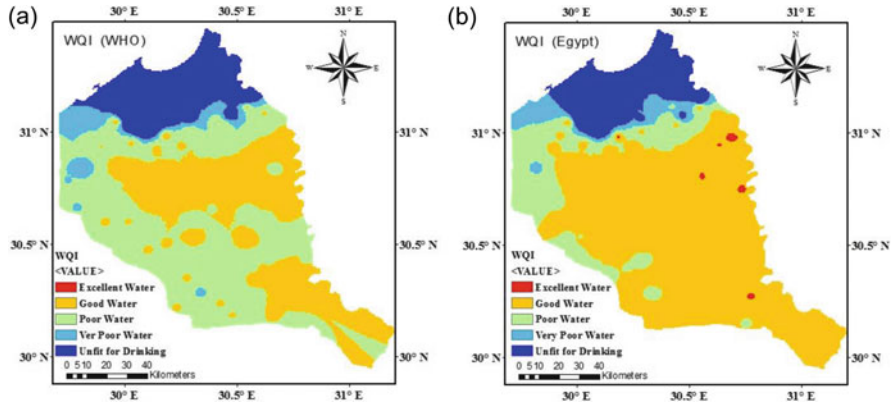
Fig. 5 Spatial distribution of WQI in western Nile Delta. (**a**) WHO standards. (**b**) Egypt standards
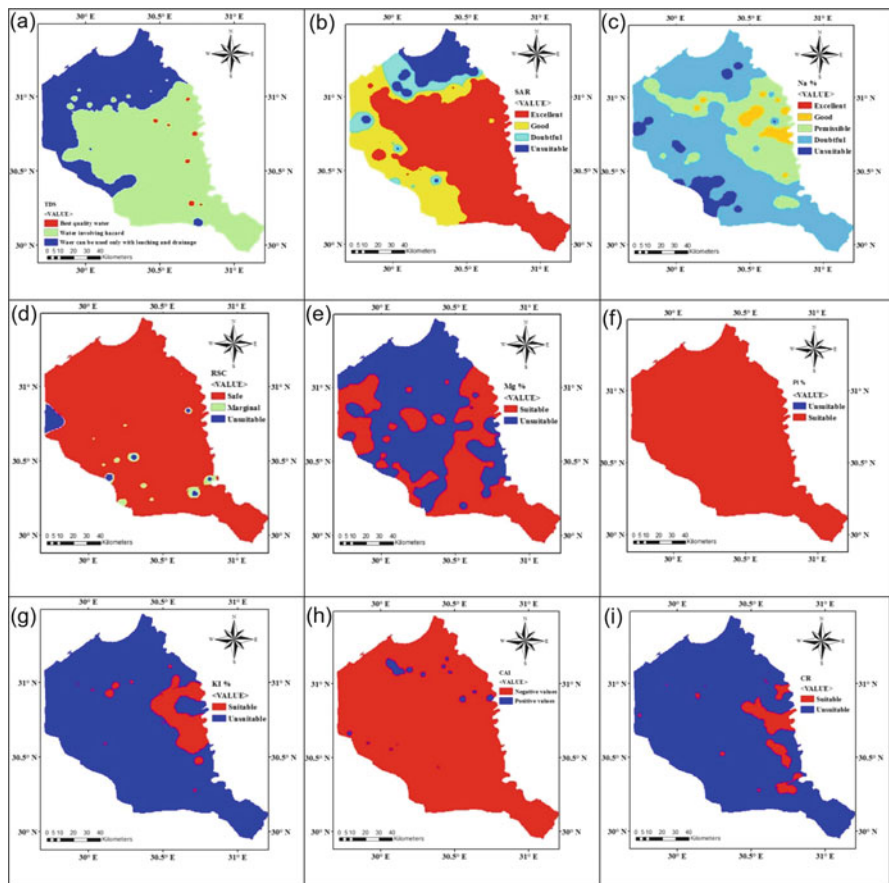

Fig. 6 Distribution of chemical parameters for determining suitability of groundwater for irrigation purposes. (**a**) TDS. (**b**) SAR. (**c**) Na %. (**d**) RSC. (**e**) Mg. (**f**) PI %. (**g**) KI. (**h**) CRI. (**i**) CR

Table 9 Water quality index values and suitability of GW for drinking purpose

No of well	WQI WHO	Type of water (WHO)	WQI Egypt	Type of water (Egypt)	No of well	WQI WHO	Type of water (WHO)	WQI Egypt	Type of water (Egypt)
1	94.31	Good water	62.86	Good water	55	103.87	Poor water	66.34	Good water
2	143.1	Poor water	111.4	Poor water	56	110.73	Very poor water	66.58	Good water
3	89.43	Good water	63.72	Good water	57	119.80	Very poor water	73.17	Good water
4	112.6	Poor water	75.48	Good water	58	151.04	Poor water	81.31	Good water
5	86.29718	Good water	56.97286	Good water	59	80.19932	Good water	56.89	Good water
6	66.00	Good water	47.22	Good water	60	97.465	Good water	65.31	Good water
7	97.90	Good water	79.19	Good water	61	79.766	Good water	59.7	Good water
8	93.44	Good water	67.50	Good water	62	87.845	Good water	62.1	Good water
9	112.9	Poor water	82.07	Good water	63	94.573	Good water	67.56	Good water
10	137.2	Poor water	76.50	Poor water	64	66.429	Good water	51.7	Good water
11	88.56	Good water	58.29	Good water	65	67.577	Good water	51.55	Good water
12	78.99	Good water	52.38	Good water	66	64.754	Good water	51.40	Excellent water
13	63.02	Good water	51.48	Good water	67	60.247	Good water	47.87	Good water
14	116.0	Poor water	67.26	Poor water	68	72.982	Good water	53.90	Excellent water
15	73.43	Good water	53.33	Good water	69	67.638	Good water	48.17	Good water
16	97.93	Good water	65.11	Good water	70	83.862	Good water	58.35	Good water
17	111.6	Poor water	65.18	Good water	71	84.651	Good water	61.81	Good water
18	121.5	Poor water	74.71	Good water	72	75.740	Good water	60.81	Very poor water
19	157.1	Poor water	86.15	Good water	73	274.75	Very poor water	231.7	Good water
20	244.7	Very poor water	127.5	Very poor water	74	87.852	Good water	65.07	Good water
21	94.04	Good water	77.09	Good water	75	98.454	Good water	75.16	Good water
22	124.0	Poor water	87.33	Good water	76	78.837	Good water	58.82	Good water
23	117.3	Poor water	79.31	Good water	77	75.260	Good water	55.76	Good water
24	106.6	Poor water	81.06	Good water	78	80.952	Good water	66.73	Good water
25	85.29	Good water	67.63	Good water	79	99.058	Good water	75.40	Excellent water
26	176.7	Poor water	141.5	Poor water	80	54.243	Good water	41.46	Good water

27	139.0	Poor water	104.7	Poor water	81	98.110	Good water	72.36	Good water
28	102.3	Poor water	74.35	Good water	82	84.217	Good water	61.6	Good water
29	148.3	Poor water	120.6	Poor water	83	67.982	Good water	52.8	Good water
30	135.7	Poor water	109.0	Poor water	84	65.926	Good water	51.71	Excellent water
31	191.5	Poor water	154.7	Poor water	85	64.700	Good water	49.16	Excellent water
32	79.43	Good water	62.64	Good water	86	52.241	Good water	40.88	Good water
33	92.67	Good water	71.23	Good water	87	124.93	Poor water	77.32	Good water
34	133.9	Poor water	111.7	Poor water	88	135.82	Poor water	89.49	Good water
35	110.7	Poor water	85.88	Good water	89	158.40	Poor water	89.19	Good water
36	124.1	Poor water	100.9	Poor water	90	108.97	Poor water	82.60	Poor water
37	76.50	Good water	58.18	Good water	91	132.74	Poor water	101.9	Good water
38	70.24	Good water	53.87	Good water	92	119.23	Poor water	83.67	Unfit water
39	124.4	Poor water	114.3	Poor water	93	783.23	Unfit water	689.5	Good water
40	100.8	Poor water	76.40	Good water	94	64.080	Good water	50.53	Very poor water
41	130.8	Poor water	101.9	Poor water	95	290.66	Unfit water	201.3	Unfit water
42	106.0	Poor water	76.81	Good water	96	818.59	Unfit water	724.1	Unfit water
43	108.2	Poor water	70.18	Good water	97	442.75	Unfit water	347.2	Unfit water
44	95.48	Good water	62.92	Good water	98	952.75	Unfit water	748.9	Unfit water
45	88.27	Good water	64.69	Good water	99	636.56	Unfit water	533.5	Unfit water
46	103.3	Poor water	86.33	Poor water	100	382.16	Unfit water	326.5	Unfit water
47	112.1	Poor water	86.37	Poor water	101	444.43	Unfit water	349.3	Good water
48	160.0	Poor water	120.4	Poor water	102	89.105	Good water	67.99	Good water
49	207.0	Very poor water	139.8	Poor water	103	97.740	Good water	74.99	Unfit water
50	201.4	Very poor water	166.6	Poor water	104	559.28	Unfit water	454.0	Unfit water
51	86.73	Good water	57.86	Good water	105	410.70	Unfit water	351.9	Poor water
52	64.90	Good water	50.68	Good water	106	203.58	Very poor water	176.2	Very poor water
53	124.2	Poor water	73.88	Good water	107	303.14	Unfit water	266.0	Unfit water
54	81.13	Good water	57.23	Good water	108	914.77	Unfit water	813.3	Good water

have water with values of EC, CO_3, NH_4, Cr, Cd, Pb, and Mn within the desirable limit of WHO standards for drinking water. About 23% of the total wells have water with values of TH, Ca, Mg, K, Cl, SO_4, and Fe above the maximum allowable limit given by WHO. HCO_3 is the only parameter that records that 100% (bold style) of the total well with water exceeds the maximum allowable limit according to WHO standards. Nearly 55% of the total wells have water with values of TDS and Na above the maximum allowable limit given by WHO. As mentioned above, the calculated values of water quality index according to WHO [28] and Egypt drinking water standards are tabulated in Table 9, and these values are used to generate the final water quality map of the study area.

Based on the results of WQI presented in Table 9 and in Fig. 5a, b, and according to WHO [28] standards, the GW of the wells in the study area is divided into four types of water, good water, poor water, very poor water, and unfit for drinking purpose. In most parts of the study area, water falls into good water category which is 45.37% of the total area of the western Nile Delta. The poor water quality area is about 37.03% of the total area. The very poor water quality in the study area is about 6.48% of the total area ,whereas 11.12% fall in to unfit for drinking water, as shown in Fig. 5a.

Similarly, the area domain of investigated wells is divided into five types according to the Egypt drinking water standards. The five categories include excellent water, good water, poor water, very poor water, and unfit for drinking purpose. In most parts of the study area, water falls into the good water category which is 66.66% of the total area of the western Nile Delta, while excellent water is about 4.62% of the total area. The poor water quality area is about 15.77% of the total area. The very poor water quality in the study area is about 3.7% of the total area, whereas 9.25% fall in to unfit for drinking water, as shown in Fig. 5b.

7.2.2 Irrigation

Figure 6 shows the spatial distribution of nine parameters for assessing the suitability of groundwater in the western Nile Delta for irrigation. TDS, SAR, Na %, RSC, Mg %, PI %, KI, CRI, and CR were used to evaluate groundwater suitability for irrigation purposes. Percentage classification of groundwater wells according to its suitability for irrigation purposes are shown in Table 10. Total dissolved solids have been presented before; it ranges between 108 and 24,487 mg/l. About 82.44% of groundwater wells have TDS less than 2,000 mg/L which is suitable for irrigation and drinking, whereas 17.56% of groundwater wells have TDS more than 2,000 mg/L which can be used for irrigation only with leaching and perfect drainage, as shown in Fig. 6a. The calculated values of sodium adsorption ratio (SAR) in the western Nile Delta vary from 0.91 to 59.1 classified into four categories, as shown in Fig. 6b. About 66.67% of groundwater wells are excellent water for irrigation, 16.67% is good water, 8.33% is doubtful water, and 8.33% is unsuitable for irrigation purposes. The analysis results of groundwater samples with respect to SAR are compatible with Sharaky et al. [1] based on the US Salinity

Table 10 Percentage classification of groundwater wells according to its suitability for irrigation purposes

Class. pattern	Categories	Ranges	Well name	No. of wells	Percentage
TDS	Best quality water	200–500	5,6,58,67,69	5	4.62
	Water involving a hazard	1,000–2,000	1,3,4,10,11,12,13,14,15,16,17,18,19,37,38,43,44,51,52, 53,54,55,56,57,59,60,61,62,63,64,65,66,67,68,69,70,71, 74,76,77,80,81,82,83,84,85,86,89,94,102, 2,7,8,9,20,21, 22,23,24,25,27,28,29,30,32,33,34,35,36,39,42,45,46,47, 48,49,50,72,78,79,88,90,91,92,103	84	77.78
	Water can be used for irriga-tion only with leaching and perfect drainage	3,000–7,000	26,31,73,75,93,95,96,97,98,99,100,101,104,105,106,107,108	19	17.56
SAR	Excellent	2–10	1,2,3,4,5,6,10,11, 12,13,14,15,16,17,18,19,32,33,37, 38,40,42,43,44,45,48,51,52,53,54,5205,56,57,58,59, 60,61,62,63,64,65,62,67,68,69,70,71,72,74,76,77,78, 72,80,81,82,83,84,85,87,88,89,91,9232,93,94,95,102,103	72	66.67
	Good	10–18	7,8,9,20,21,22,24,25,27, 58,30,34,35,36,39,41,49,90	18	16.67
	Doubtful	18–26	29,31,46,47,50,57,100,101,106	9	8.33
	Unsuitable	>26	26,73,96,98,99,104,105,107, 108	9	8.33
Na %	Excellent	<20	–	0.0	0.0
	Good	20–40	19,43,67,66,68,70,77,83,82,83,86,89,103	13	12.03
	Permissible	40–60	5,6,13,14,18,23,40,45,53,57,58,59,60,61,66,69,74,78,79,83, 84,85,92,95,102	25	23.15
	Doubtful	60–80	1,2,3,4,7,9,10,11,12,15,13,17,24,25,30,32,33,34,35,36,37,38, 39,40,41,42,44,46,47,48,49,50,51,52,53,54,56,62,63,64,65, 71,72,73,42,76,87,88,90,91,93,94,92,97,98,99,100,101	56	51.86
	Unsuitable	>80	8,20,21,22,24,27,28,29,31,47,50,73,88,107	14	12.96

(continued)

Table 10 (continued)

Class. pattern	Categories	Ranges	Well name	No. of wells	Percentage
RSC	Safe	<1.25	1,2,3,4,6,7,9,10,11,12,13,14,16,17,18,19,20,23,24,25,26,27,28,30,31,32,34,35,36,38,39,40,41,42,43,44,45,46,47,48,49,5721,52,53,54,55,56,57,58,59,60,61,63,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,80,81,82,83,84,85,86,87,89,90,91,92,93,94,95,96,97,98,99,100,101,102,103,104,105,106,107,108	95	87.96
	Marginal	1.25–2.5	8,21,22,32,33,62,64	7	6.4
	Unsuitable	>2.5	5,15,29,37,50,88	6	5.6
Mg %	Suitable	<50	1,2,3,6,7,8,10,11,15,16,17,18,19,21,24,25,29,32,34,38,41,45,46,50,52,56,59,60,62,64,65,68,69,74,75,79,80,83,84,86,87,88,89,90,91,102	46	42.59
	Unsuitable	>50	4,9,12,13,14,21,22,23,26,27,28,30,31,33,35,36,37,39,40,42,43,44,47,48,49,51,53,54,55,57,58,61,63,70,71,72,73,76,77,78,81,82,92,93,94,95,96,97,98,99,100,101,103,104,105,106,107,108	62	57.41
PI	Unsuitable	<25	–	0.0	0.0
	Good for irrigation	25–75	All wells	108	100
KI	Suitable for irrigation	<1.0	5,19,43,57,58,59,60,66,67,68,69,70,77,78,79,80,81,82,83,84,85,86,92,103	24	22.22
	Unsuitable	>1.0	1,2,3,4,7,8,9,11,12,14,16,17,18,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,38,39,40,41,42,43,44,45,46,47,48,49,51,52,53,54,55,56,61,62,63,64,65,71,72,73,74,75,76,77,87,88,89,90,91,92,93,94,95,96,97,98,99,101,102,104,105,106,107,108	84	77.78
CR	Safe for irrigation	<1.0	5,6,10,13,15,19,37,50,57,58,60,67,68,69,70,77,78,80,82,84,86,89,102	23	21.29
	Unsuitable for irrigation	>1.0	1,2,3,4,7,8,9,11,12,14,16,17,18,20,21,22,23,24,25,26,27,28,29,30,31,32,33,34,35,36,38,39,40,41,42,43,44,45,46,47,48,49,51,52,53,54,55,56,59,61,62,63,64,65,66,71,72,73,74,75,76,78,81,83,85,86,87,88,89,90,91,92,93,94,95,96,97,98,99,100,101,103,104,105,106,107,108	85	78.71

Laboratory diagram for groundwater samples in the Nile Delta aquifer. Most of the samples of groundwater are located in the category of the high-salinity and the low-sodium hazard zone. It can be used for irrigation in case of the moderate good permeable soils. On the other hand, wells with excessive salinity and very high SAR are observed near to the Mediterranean sea in the northern region (Sharaky et al. [1]). The calculated values of Na % of groundwater wells range between 22.21% and 92.33% classified into five categories as shown in Fig. 6c. About 12.03% is good for irrigation, 23.50% is permissible to use in irrigation, 51.86% is doubtful, and 12.96% is unsuitable for irrigation. Figure 6d shows the spatial distribution of residual sodium carbonate in the western Nile Delta. It can be observed that 87.96% of groundwater wells have RSC values less than 1.25 which are safe for irrigation, 6.40% have RSC values range between 1.25 and 2.5 which are marginal, and 5.60% have RSC values more than 2.5 which are unsuitable for irrigation. Results of the analysis of groundwater samples with respect to RSC are comparable with those of Sharaky et al. [1] based on the calculated values of RSC. Most of the groundwater samples has <1.25 meq/L; RSC lies in (Class 1) category, which is classified as good quality and it is also suitable for using in irrigation for different types of soils. Only seven samples are classified to be used with provision of good drainage system, and only the water of three wells is unsuitable for irrigation especially in case of poor calcium and drainage (Sharaky et al. [1]).

The calculated values of magnesium hazard in the western Nile Delta range from 21.51% to 88.79%. About 42.59% of groundwater wells are suitable for irrigation which have Mg % less than 50%, where 57.41% exceeds this value and classified as unsuitable for irrigation, as shown in Fig. 6e. The classification of groundwater wells with respect to the PI % confirmed that Na % in the western Nile Delta varied from 43.67% to 103.78%. It can be observed from Fig. 6f that all groundwater wells have PI % more than 25% which indicates that they are suitable for irrigation. The calculated values of KI ratio in this area range from 0.27 to 12.00 and have been classified as 22.22% of groundwater wells have KI ratio less than 1.0. Their water are suitable for irrigation, where 77.78% of groundwater wells have KI more than 1.0 and are not suitable for irrigation. Distribution of CAI, as shown in Fig. 6h, indicates that about 99.04% have negative values of CAI indicating the exchange between sodium and potassium ($Na^+ + K^+$) in water with calcium and magnesium ($Ca^{+2} + Mg^{+2}$) in the rocks by a type of base-exchange reactions. Classifications of groundwater wells in the western Nile Delta with respect to the values of CR ratio reveal that 21.29% of groundwater wells have CR less than 1.0 indicating that the water is suitable for irrigation while 78.71% of the wells have CR values higher than 1.0 which is unsuitable for irrigation, as shown in Fig. 6i.

8 Conclusion and Recommendations

The spatial distribution of groundwater quality parameters was performed using the spatial analyst module in ArcGIS 10.2 software. The inverse distance weighted (IDW) interpolation technique was used for spatial modeling. The Statistical Package for Social Sciences (SPSS) is used to carry out the statistical analysis. Both correlation and factor analysis are conducted. Correlation among the investigated parameters varied from perfect to weak. The factor analysis is applied to identify the origin of the water pollution sources. The multivariate analysis showed the existence of up to four significant factors which account for 77.0% of the total variance of hydrochemistry data. The first factor which accounts for about 47.2% of the total variance assigned to salinity due to saltwater intrusion from the Mediterranean sea. The second factor accounts for 10.77% of the total variance, and it is responsible for salinity due to minerals from sediment and rocks or from mining, industrial waste, and corroding metal. The third factor accounts for 9.42% of the total variance, and it is responsible for salinity due to cation-exchange processes at soil water interface, industrial and domestic waste, solubility of minerals, and dissolution of lithogenic materials. The fourth factor accounted for 9.07% of the total variance and related to the long history of evaporation process and pollution from application of fertilizers and pesticides to agricultural lands. The computed water quality indices for the water samples collected from the wells in the study area show that 45.37% and 66.66% of water sample have good drinking water according to WHO and Egypt standards, respectively. Only 4.62% according to Egypt drinking water standards have an excellent drinking water. About 37.03% and 15.07% fall in the poor drinking water category according to WHO and Egypt standards, respectively. Moreover, about 6.48% and 3.7% fall in very poor drinking water categories according to WHO and Egypt drinking water standards. About 10% of the wells have water which is unfit for drinking water categories according to both WHO and Egypt standards.

Nine selected criteria were used to evaluate the suitability of groundwater quality for irrigation purposes. These criteria are TDS, SAR, Na %, RSC, Mg %, PI %, KI, CRI, and CR. Groundwater wells in the western Nile Delta were classified according to TDS. About 82.40% of wells have TDS values less than 2,000 mg/l, in which groundwater is suitable for irrigation purposes. The calculated values of SAR in western Nile Delta indicate that about 66.67% of groundwater wells are excellent water for irrigation, 16.67% are good, 8.33% are doubtful, and 8.33% are unsuitable. According to values of RSC, 87.96% of groundwater wells have RSC values less than 1.25 safe for irrigation purposes. The classification of groundwater wells in western Nile Delta with respect to the PI % confirmed that all groundwater wells have PI % more than 25% which indicates that they are suitable for irrigation.

It is recommended that concerned authorities should take the necessary actions to control the pollution sources of groundwater such as human activities, agricultural activities, and other industrial units. These actions may include environmental treatment of the industrial and domestic wastes as well as regular environmental

checks of the industrial and human activities. Also, most contaminated areas such as those near the shoreline of the Mediterranean sea should benefit as the first priority from any monitoring programs, desalination, and development projects. Moreover, awareness of the concerned people should be increased to maintain and preserve the groundwater quality to be suitable for drinking and irrigation purposes.

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