GROUNDWATER QUALITY INVESTIGATION USING WATER QUALITY INDEX AND ARCGIS: CASE STUDY: WESTERN NILE DELTA AQUIFER, EGYPT

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ABSTRACT

Groundwater (GW) is an important source of drinking water (DW) in some areas of Egypt rather than for irrigation when the surface water is insufficient or unavailable. Therefore, it is essential to assess the quality of GW of Nile Delta Aquifer (NDA) as a source of DW. The Water Quality Index (WQI) is used to assess the groundwater of Western Nile Delta, Egypt. The available data of 108 GW wells including 21 physicochemical parameters for each well(GW sample) viz., Electric conductivity (EC), Total hardness (TH), Total dissolved solids (TDS), pH, Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chloride (CL), Sulphate (SO_4), Bicarbonate (HCO_3), Carbonate (CO_3), Iron (Fe), Manganese (Mn), Zinc (Zn), Cupper (Cu), Lead (Pb), Cadmium (Cd), Chromium (Cr), Nitrate (NO_3)and Ammonium (NH_4) are analyzed. Water Health Organization (WHO) and Egypt drinking water standards are used as reference standards for the suitability of water for drinking purpose.The ARCGIS was utilized to detect and visualize the spatial variation maps of different parameters and water quality index (WQI) for the study area. The computed WQI shows that 45.37% and 66.66 %of GW wells falls in good DW categories according to WHO and Egypt standards (ES) respectively. Only 4.62 % according to Egypt drinking water standards fall in excellent water category.About 37.03 % and 15.07 % fall in the poor DW categoryaccording to WHO and ES respectively. On the other hand 6.48 % and 3.7 % falls in very poor DW categories according to WHO and ES respectively.About 9.25 % and 11.2 % falls in unfit for DW category according to WHO and ES.It is highly recommended that decision and policy makers should consider the human activities, agricultural activities, and other industrial pollutants that contribute into the degradation of GWQ of NDA.Based on the conducted analysis using the WQI, it is recommended to provideproper treatment and to avoid these fell in unfit category.

Keywords: Groundwater, Water quality index, Drinking, Nile Delta Aquifer, GIS, WHO.

1 INTRODUCTION AND REVIEW OF LITERAURE

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 purpose 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 attention for the contamination of GW, Sharaky et al. (2007), Hassan (2010) and Agrama& El-Sayed (2013). Sharaky et.al(2007) studied the hydro geochemistry of groundwater in 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 western Nile Delta are higher than the maximum standard limits, according to the World Health Organization (WHO, 1996). They concluded that the fresh water in the study area is mainly concentrated in the central-eastern part and most of the groundwater is located in the high salinity and low sodium hazard zone.

Agrama and El-Sayed (2013) evaluated the surface water quality in the Western Delta region by using Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI). The (GIS) was used for mapping the WQI variations in different canals. The results showed an average for different sites location due the fact of mixing low quality water of agricultural drains with canals fresh water in the study area. They recommended that water use in the study area should be restricted to its quality or to improve the water quality by increasing the fresh water discharge or reducing water mixing ratio with drains.

On the other hand, Hassan(2010) preformed geostatistical analysis and used spatial distribution by the use of GIS to study the groundwater quality in Tehsil Sheikhupura. GIS was used for understanding the spatial distribution of each chemical parameter, mapping of the current situation of groundwater quality and compared the concentration of different chemical parameters to the guideline values presented by world health organization (WHO). Rao and Nageswararao(2013) used the water quality index in Greater Visakhapatnam city to know the groundwater quality. Salt water intrusion has been assessed by using various parameters. Rout and Sharma(2011) studied the physicochemical characteristics of groundwater of Ambala Cantonment area in India to assess its suitability for drinking purposes. The results were compared with the standards prescribed by World Health Organization (WHO) and founded within the desired limit for drinking water purposes.

Groundwater is the major source to meet the domestic, irrigation and industrial water demands. Excessive consumption and less recharge are two reasons for degradation of groundwater quality in India. Water quality index (WQI) and spatial distribution maps was generated to understand the groundwater quality. They observed that the groundwater in the area is hard and alkaline in nature and the recharge to the aquifer during monsoon period has diluted the geochemistry of the groundwater. They suggested that the use of GIS and WQI techniques are a promising tool to understand the spatial pattern of groundwater quality and its management,Magesh and Chandrasekar(2013).

Latha et.al(2012) studied the groundwater quality using water quality index and GIS mapping in Andhra Pradesh, India. They had generated the spatial distribution map of different parameters of water quality by using Inverse Distance Weighted (IDW) interpolation technique and delineated the areas water quality. Another work was done by Singh and Khan(2011) to assess the groundwater quality Pune, India by using (GIS). Spatial interpolation technique (IDW) was used to produce the spatial distribution of the ground water parameters and water quality index. Results showed that the groundwater in the study area is good enough for drinking and domestic purposes.

The main objective of the present study is to assess groundwater quality of Western Nile Delta by an integrated approach of traditional water quality analysis and GIS and to generate WQI map.

2 STUDY AREA DISCRIPTION

In the present study, the available data Sharaky et al. (2007) is re-analyzed to investigate the suitability of GW in western NDA for draining purpose using the WQI and ARCGIS.The study area is located in western Nile Delta as shown in Fig.1 .Samples were collected from 108 wells and analyzed for physiochemical parameters in RIGW 2007 by Sharaky et al. (2007).

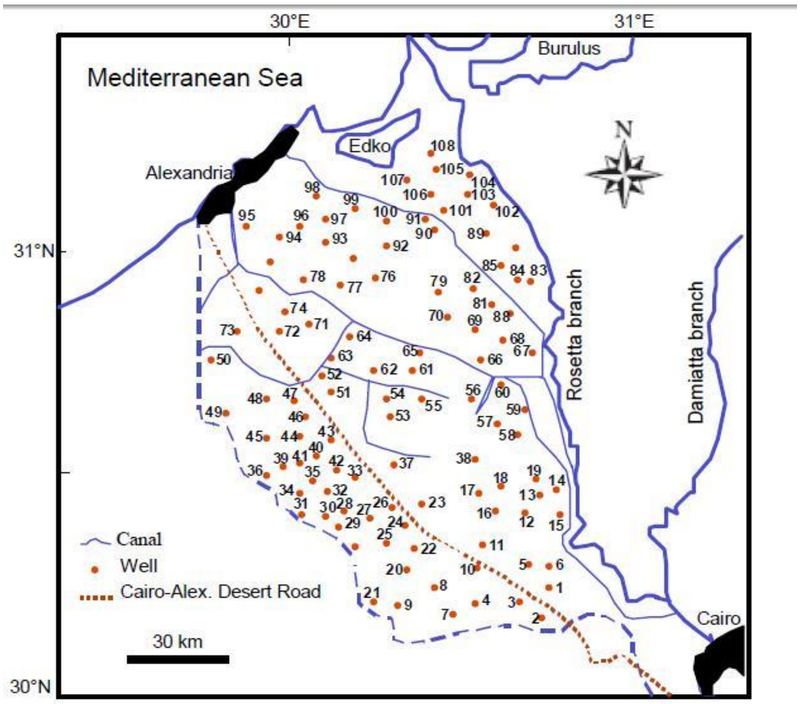

Figure 1. Map of the study area Sharaky et al. (2007).

3 MATERIALS AND METHODS

3.1 Selection of Chemical Parameters

Twentyone hydro chemical 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), cupper (Cu), Chromium (Cr), Cadmium (Cd) and ammonium (NH_4) were selected. Parameters including statistical measures, such as minimum, maximum, mean and standard deviation, are presentedin Sharaky et al (2007). The same data are used in this paper.

3.2 Estimation of Water Quality Index

Equation (1) is used to calculate water quality index for the 21selected parameters of groundwater quality. Values of desirable and maximum allowable limits of different parameters, according to WHO (2011)and according to Egypt drinking water standards (2006), are listed in Table 1. Each parameter is assigned a weight according to its relative importance for quality of water for drinking purposes, as shown in (Table 1). Maximum weight of 5 is assigned to Total Dissolved Solids (TDS), EC,(NO_3), (Pb), and 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) and (Zn),Abbasi and Abbasi(2012).

$$WQI = \Sigma\, Qi \times Wi \qquad (1)$$

In which Qi is the ith quality rating and is given by equation (2), Wi is the ith relative weight of the parameter I and is given by equation (3).

$$Q_i = (C_i/S_i) \times 100 \qquad (2)$$

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 (2011) and Egypt drinking water standards (2006) in mg/l.

$$W_i = w_i / \sum_{i=0}^{n} w_i \quad (3)$$

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

Table 1: 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)*	1000*(mg/L)*	500*(mg/L)*	5	0.0724
pH	6.5- 8.5	8.5	7.0 -8.5	3	0.0435
EC	1500 *µs/cm*	1500 *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
				Σw_i =66	ΣW_i = 1

Table 2: Classes of water quality

Range	*Type of water*
< 50	*Excellent water*
50-100	*Good water*
100-200	*Poor water*
200-300	*Very Poor water*
> 300	*Unfit For Drinking water*

3.3 WQI Contour Maps through ARCGIS:

The spatial analysis module in ARCGIS 10.2 software is used to investigate the spatial distributionfor groundwater quality parameters in Western Nile Delta Aquifer.Values of chemical parameters in each well were assigned in each well according to its location as an input of spatial analysis tool in ARCGIS. Inverse distance weighted (IDW) technique ischosen to generate spatial interpolation maps for different parameters in spatial modeling tool.

4 RESULTS

The results of using ARCGIS to indicate the spatial distribution of the 21 selected water quality parameters are presented in figures 2A to 2Q. On the other hand, table 4 and figures 3 and 4 present the values of the WQI and their spatial distributions.

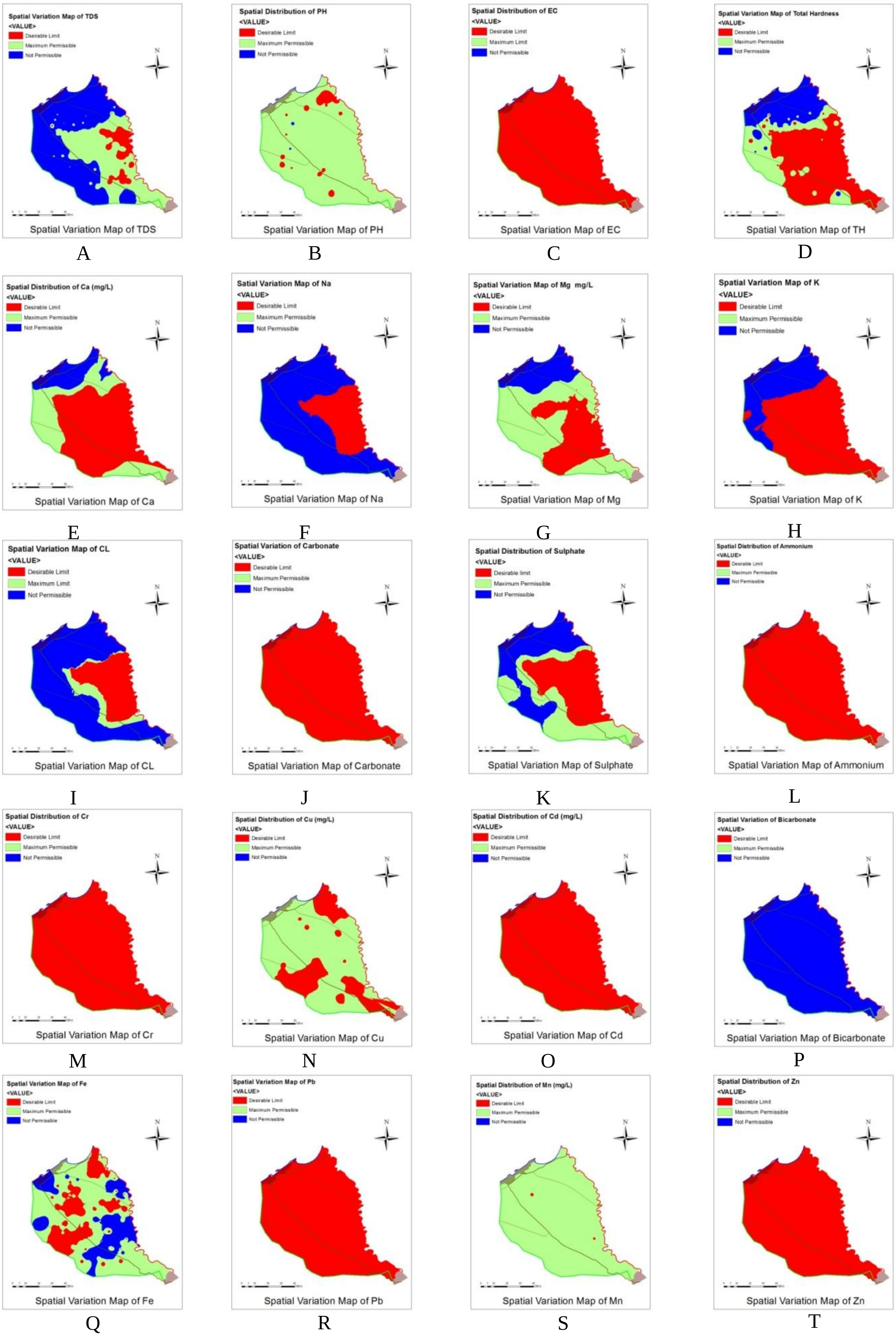

Figure.2 Spatial Variation of Groundwater Parameters

5 ANALYSIS AND DISCUSSIONS

5.1 Spatial Variation of Groundwater Parameters

Figure 2 shows the spatial variation of the different chemical parameters, the legend in each map classified into three classes, the first one is desirable limit with red color, and the second is maximum permissible with green color and finally the not permissible with blue color. Table 3 shows the percentage limits of each parameter as associated with the spatial distribution figure. Also, the basic characteristics of the parameters according to Sharaky et al. (2007) are presented to complete the picture.

Table 3: Results of Chemical Parameters Characteristics

Figure No.	Title	Charasterisics according to Sharaky et al. (2007)				% Percentage limits of each parametrs		
		Mini/Well No.	Maxi/Well NO.	avearge	SD	% Desirable limit	% Maximum Permissible	% Not allawable
2.A	Variation map of TDS	430/5	24407/108	7.9	4575	14.8	25.0	60.2
2.B	Variation map of pH	7.11/7	8.65/78	13.185	0.327	5.0	95.0	------
2.C	Variation map of EC	0.43/10	37.5/108	2684	7.31	**100.0**	------	------
2.D	Variation map of TH	113.3/15	6379.1/98	612.85	1023.85	58.33	24.50	*17.17*
2.E	Variation map of Ca	12.0/51	1300/98	1000.3	153.54	62.03	18.5	*19.47*
2.F	Variation map of Na	35.0/68	7774/108	89.81	1348.56	48.15	-------	51.85
2.G	Variation map of Mg	7.0/62	851/96	97.84	164.44	48.15	38.15	*16.67*
2.H	Variation map of K	2.0/57	256/108	733.54	28.06	76.85	---------	*23.15*
2.I	Variation map of Cl	39.0/89	12173/108	422	2112	50.4	36.11	*13.49*
2.J	Variation map of CO_3	0.0	60.0/88	2.53	10.02	**100.0**	-------	-------
2.K	Variation map of SO_4	6.0/102	6272/98	9.35	816.5	58.35	18.15	*23.14*
2.L	Variation map of NH_4	0.01/48	0.5/104	0.035	0.046	**100.0**	-------	-------
2.M	Variation map of Cr	0.04/29	0.046/20	0.047	0.037	**100.0**	-------	-------
2.N	Variation map of Cu	0.004/103	0.1/8	0.061	0.027	20.37	79.63	-------
2.O	Variation map of Cd	0.0004/100	0.005/74	0.0025	0.0007	**100.0**	------	-------
2.P	Variation map of HCO_3	73.0/104	4775/96	372	635.27	--------	--------	**100.0**
2.Q	Variation map of Fe	0.05/7	7.0/20	0.850	1.11	13.89	62.96	*23.15*
2.R	Variation map of Pb	0.002/90	0.005/7	0.0035	0.0006	**100.0**	--------	-------
2.S	Variation map of Mn	0.03/78	0.4/23	0.144	0.080	-----	**100.0**	------
2.T	Variation map of Zn	0.05/11	3.3/16	0.662	0.515	**100.0**	-----	------

It can be clear from table 3 and Figures 2A to 2Q that, wells number 96, 98 and 108,that are near from the shore line of 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 % of the total wells 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 100% of the total well with water exceeds the maximum allowable limit according to WHO. Nearly 55 % of the total wells have water with values of TDS and Na above the maximum allowable limit given by WHO.

5.2 Suitability of Groundwater for drinking purpose via WQI

As mentioned above, the calculated values by water quality index according to WHO (2011) and Egypt drinking water standards are tabulated in Table 4, these values are used to generate the final water quality map of the study area.

Table 4. Water quality index values and suitability of GW for drinking purpose

N of Well	*WQI WHO*	*Type of water (WHO)*	*WQI Egypt*	*Type of water (Egypt)*	*N 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	86.29	Good water	56.97	Good water	59	80.199	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 f 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	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	142.4	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	Good water	100	382.16	Unfit water	326.5	Unfit water
47	112.1	Poor water	86.37	Good 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	139.8	Poor water	103	97.740	Good water	74.99	Unfit water
50	201.4	Very Poor	166.6	Poor water	104	559.28	Unfit water	454.0	Unfit water
51	86.37	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

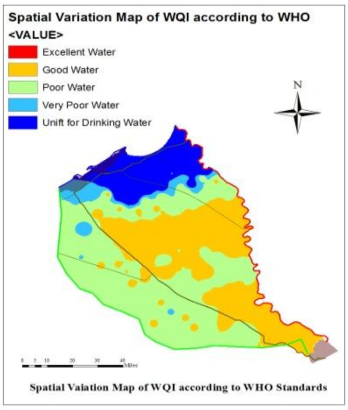

Figure 3. Variation Map of WQI according to WHO Standards

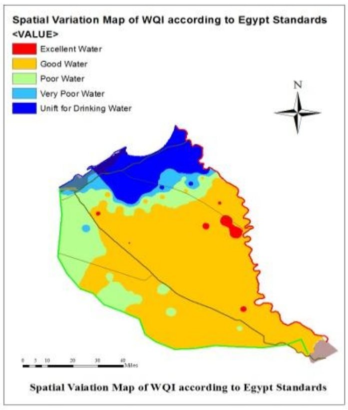

Figure 4. Variation Map of WQI according to Egypt Standards

Based on the results of WQI presented in Table 4 and in Figures 3 and 4, and according to WHO (2011) 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 fall into good water category which is 45.37 % of the total area of 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 whereas11.12 % fall in to unfit for drinking water, as shown in Figure 22.

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 fall into good water category which is 66.66 % of the total area of 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 whereas9.25 % fall in to unfit for drinking water, as shown in Figure 23.

6 CONCLUSIONS

The spatial distributionfor groundwater quality parameters in Western Nile Delta Aquifer are investigated using spatial analyst module in ARCGIS 10.2 software.Inverse distance weighted (IDW) interpolationtechnique is used for spatial modeling.The spatial variation mapsof different parameters show that the electrical conductivity and the concentration of carbonate, ammonium, chromium, cadmium, lead and zinc are all within the desirable limit of drinking water quality according to WHO (2011).

On the other hand, the spatial distribution maps of concentration for copper, manganese and distribution of Ph show that the values of these parameters are within the maximum permissible limit for drinking water quality given by WHO. Moreover, the spatial interpolation map of Bicarbonate indicates that the concentration of Bicarbonate in samples from all the wells in the study area exceeds the maximum permissible limit for drinking water according to WHO (2011).

The concentrations of total dissolved solid, total hardness, sodium, potassium, magnesium, calcium, chloride and sulphate shows that 44.37 % of the area lies below the desirable limit by WHO (2011) whereas,the 55.63% exceeds the maximum permissible limit for drinking water according to WHO (2011).

On the other hand, the computed water qualityindices 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 wateraccording 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 % falls in the poor drinking water category according to WHO and Egypt standards respectively. Moreover, about6.48 % 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 of WHO and Egypt standards.

It is highly recommended that the quality of ground water should be checked in comparison with at least the Egyptian standards of drinking before using it as a source of safe drinking water.

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ABBREVIATIONS

Electrical conductivity (EC), Total dissolved solids (TDS), Total Hardness (TH), pH, Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chloride (CL), Sulphate (SO_4), Bicarbonate (HCO_3), Carbonate (CO_3), Iron (Fe), Manganese (Mn), Zinc (Zn), Cupper (Cu), Nickel (Ni), Nitrate (NO_3) and Ammonium (NH_4), Lead (Pb), Water Quality Index (WQI), Geoghraphic Information System (GIS), Water Health Organization (WHO), Inverse distance weighted (IDW),Ground Water (GW) and Nile Delta Aquifier (NDA).

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