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Groundwater Quality Assessment for Heavy Metals: A Case Study in the Area between Abu Sweir and Abu Hammad, Ismalia, Egypt

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ABSTRACT

One of the global challenges in the water resources is the pollution as a result of urbanization, industrialization, climate change and other human activities. It is clear that, the anthropogenic activities are considered that main source of contamination in most aquatic environments, increasing the sources of heavy metals. In this context, we discussed the relevant finding of the heavy metals in groundwater in the area located between area between Abu Sweir and Abu Hammad, Ismalia, Egypt, and possible risk. A total of 20 groundwater samples were collected from the area between Abu Sweir and Abu Hammad, Ismalia governorate. Samples were collected for the assessment of water quality index (WQI) based on the heavy metals concentration. The heavy metals concentrations were reported in the following order: Fe > Al > Ni > Zn > Mn. The computation of WQI values across the study site for the heavy metals revealed that all the collected samples represent a low class except one sample. The calculation of the WQI for heavy metals in the study site showed all the studied and collected groundwater samples had an index under the critical pollution value except one sample (WQI value is 40) as result of higher iron concentration level. Therefore, no significant possible risk was observed across the study area for heavy metals.

1. Introduction

With the continuous grow in population and unplanned urbanization in many cases led to water resources contamination. Water resources are strongly impacted with anthropogenic activities creating potential health risk. Recently, Egypt has faced water shortage challenges with population growth and climate change conditions. Therefore, groundwater resources in Egypt plays a vital role to satisfy water requirements for different uses. Generally, when groundwater is enriched with heavy metals it is becomes worse and hazardous [1-3]. Natural geological processes such as weathering, erosion, and mineral dissolution can pollute groundwater. Furthermore, the anthropogenic activities, such as over-extraction of groundwater for irrigation, domestic and industrial uses, or contamination from untreated domestic and industrial effluents, can cause or increase the pollution. Previous studies on groundwater heavy metals assessments and risk analysis, among of them [4-10].

According to [11], [12] the contamination of groundwater is attributed to hazardous anthropogenic activities on the earth surface. However, several agricultural and industrial activities are observed in the area, which could be potential source of surface pollution, hence, to groundwater. [13] concluded that the irrigation system and agricultural activities have a great effect on quaternary aquifer groundwater levels and water quality in El-Salhyia area. According to [14, 15], the recharge source and amount, groundwater flow and sediments type, these are mainly the affecting factors for the geochemical properties of the Quaternary groundwater aquifer in El-Salhiya plain.

Various approaches were used to investigate and determine the heavy metals pollution in the groundwater. Statistical methods such as principal components analysis (PCA), cluster analysis (CA), and other statistical approaches have been used to determine the sources of metals and their association with groundwater contamination [16-21]. Recently, the water quality index (WQI) approach and multivariate statistical methods are commonly used in the hydrochemical studies and sediments as well [22-26]. Therefore, the WQI approach was used to determine the quality of groundwater for irrigation based on the heavy metals concentration.

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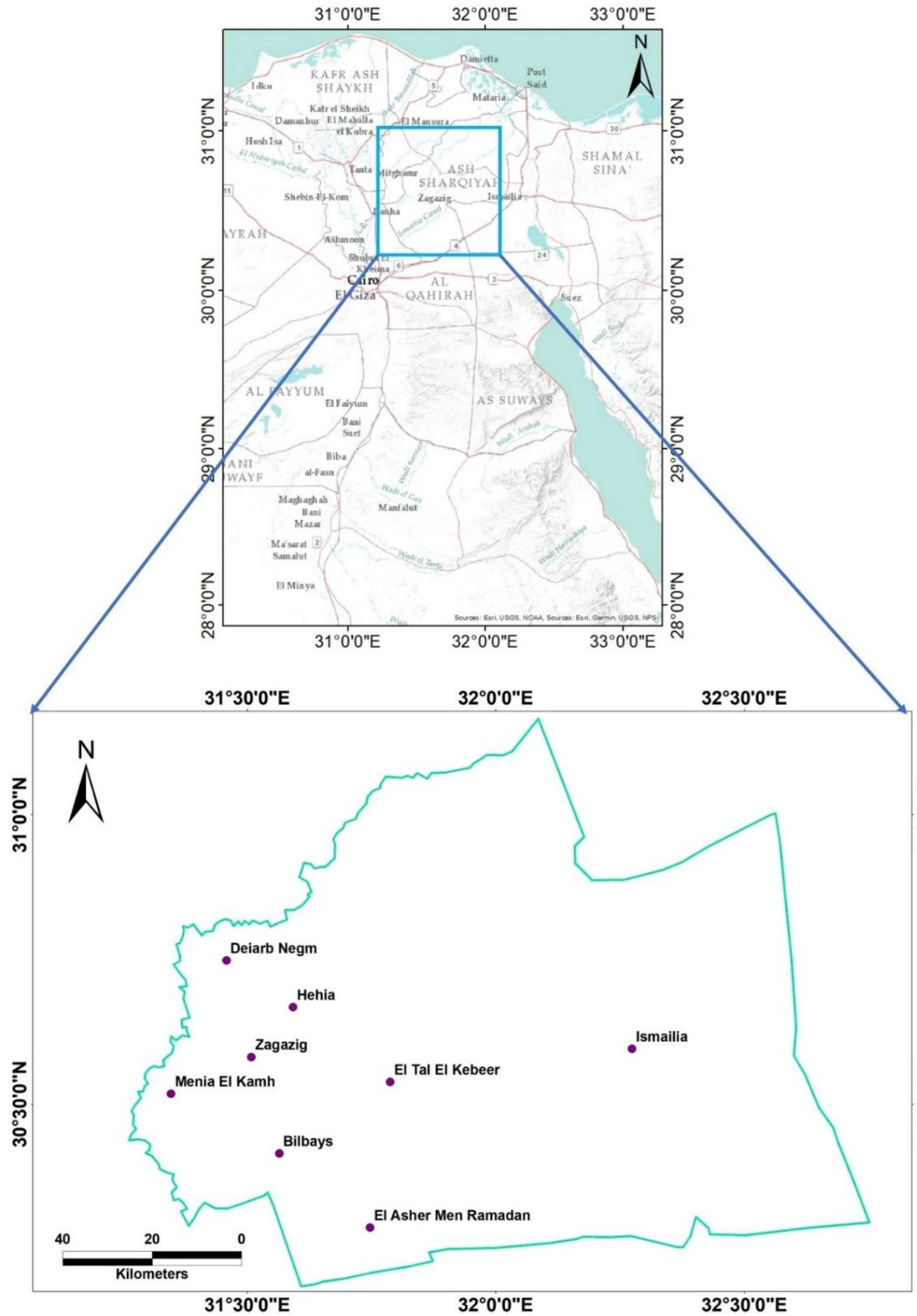

FIGURE 1: LOCATION MAP OF THE COLLECTED GROUNDWATER SAMPLES FROM THE STUDY SITE.

The main sources of irrigation are surface water and groundwater, with the Ismalyia, El Kassara and Salhia canals representing surface water. The primary sources of groundwater in the study area are the Quaternary groundwater aquifer. However, the uncontrolled use of groundwater results in a significant decrease in groundwater levels and changes in groundwater quality [27]. In this context, heavy metals in groundwater wells of the area between Abu Sweir and Abu Hammad were assessed according to the WQI approach to identify their suitability for irrigation purposes. Furthermore, the heavy metals spatial distribution patterns in the study site were investigated.

2. Site Description

The study site is bounded by latitudes 30^o 32` 24″ and $30^o$ 40` 12″ N and longitudes 31^o 49` 12″ and $32^o$ 11` 24″ E (Fig. 1). The study area characterized with gently slope to the northward and bounded by to major drains Ismaelia and ElKassara drains. A hot summer and a rare rainy winter characterize the climate of the area. The relative humidity is higher in the winter than in the summer, while the intensity of evaporation is higher in the summer than in the winter. Rock units belongs to Tertiary and Quaternary are occupied the study area (Fig. 2). The Miocene sediments are dominated by clastic facies in the southern part of study area however, it changed into shallow marine sandy limestone and marls towards the north which composed mainly of alternating sandy limestone, and loose quartz sand and marl. The Eocene rocks are underling the Quaternary sediment, it is mainly consisting of fissured and cracked carbonate rocks. Meanwhile, at the northeastern portions, the Pliocene sediments are outcropped. The Pliocene clay thickness of about 300 m, which is overlain by the Quaternary deposit in the Nile Delta flood plain. The Quaternary deposits while it is covers most of study area, that they are classified into two rock units; i) the upper unit is the Holocene Nile silt and clay (flood plain deposits) with Sabkha and fine sand deposits, while the lower one is ii) the Pleistocene sand and gravel. Some sand dunes and sand sheets distributed in the area and belonged to Holocene [28-33]. The regional geological structure of the study area increases the thickness of the Quaternary aquifer of 3 m/km towards north direction [34]. Hydrologically, the quaternary aquifer in the area is the main source of irrigation water. Thus, the aquifer composed of Pleistocene gravel and sands sediments with a thickness of ranging from 200 m to 600 m. The groundwater in the quaternary aquifer occurs under leaky conditions to semi-confined conditions. However, Seepage from different water sources such as canals and drains, excess from irrigation water are the main sources of aquifer recharge.

3. Hydrogeological setting

Hydrogeologicaly, one of the most important sources of groundwater in study area is the quaternary aquifer which composed mainly of sandstone and gravel intersected by clay lenses and siltstone (Fig. 3). Recharging of this aquifer depends on Nile water which coming from surface canals and river branches. There is a great impact of the mixing between surface water such as (lakes and irrigation canals) and groundwater at small depths. The hydrogeologic setting subdivided to main sectors: a) surface hydrology, and b) water bearing formations.

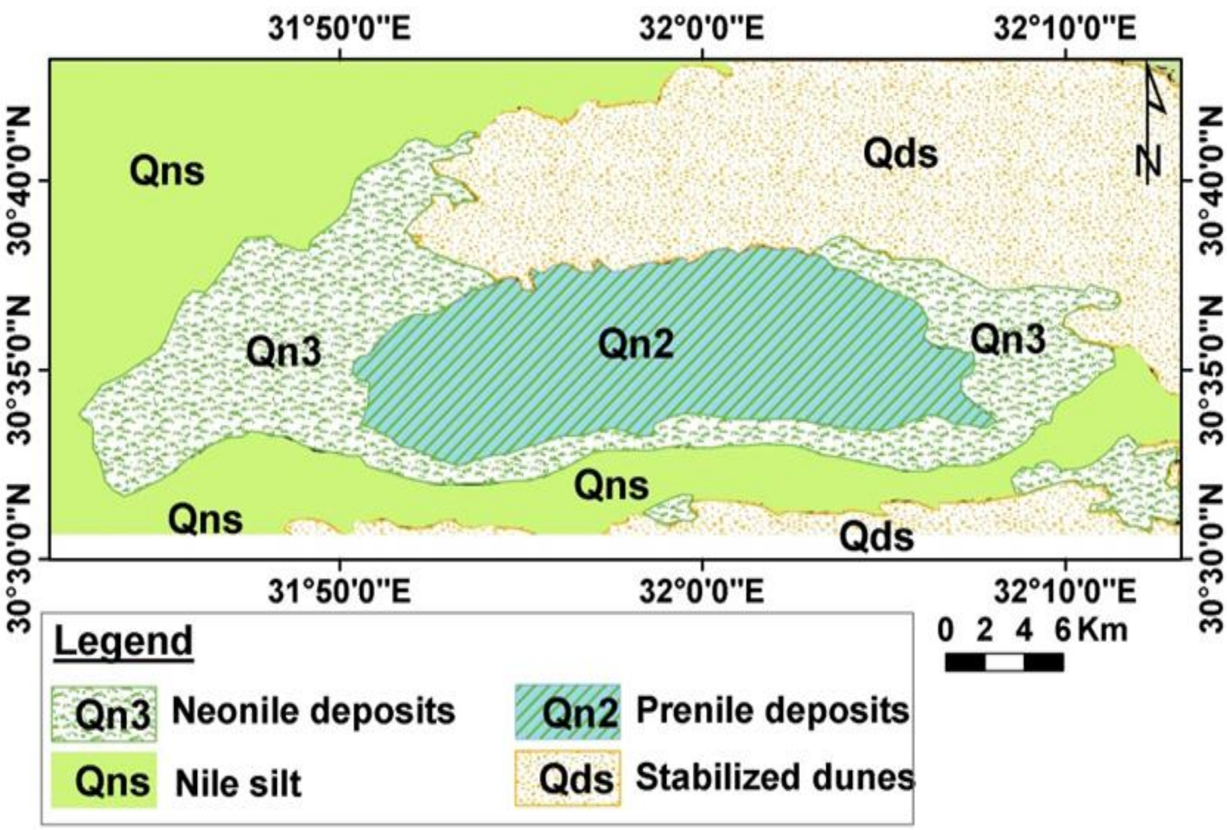

FIGURE 2: LITHOLOGICAL UNITS IN THE STUDY SITE.

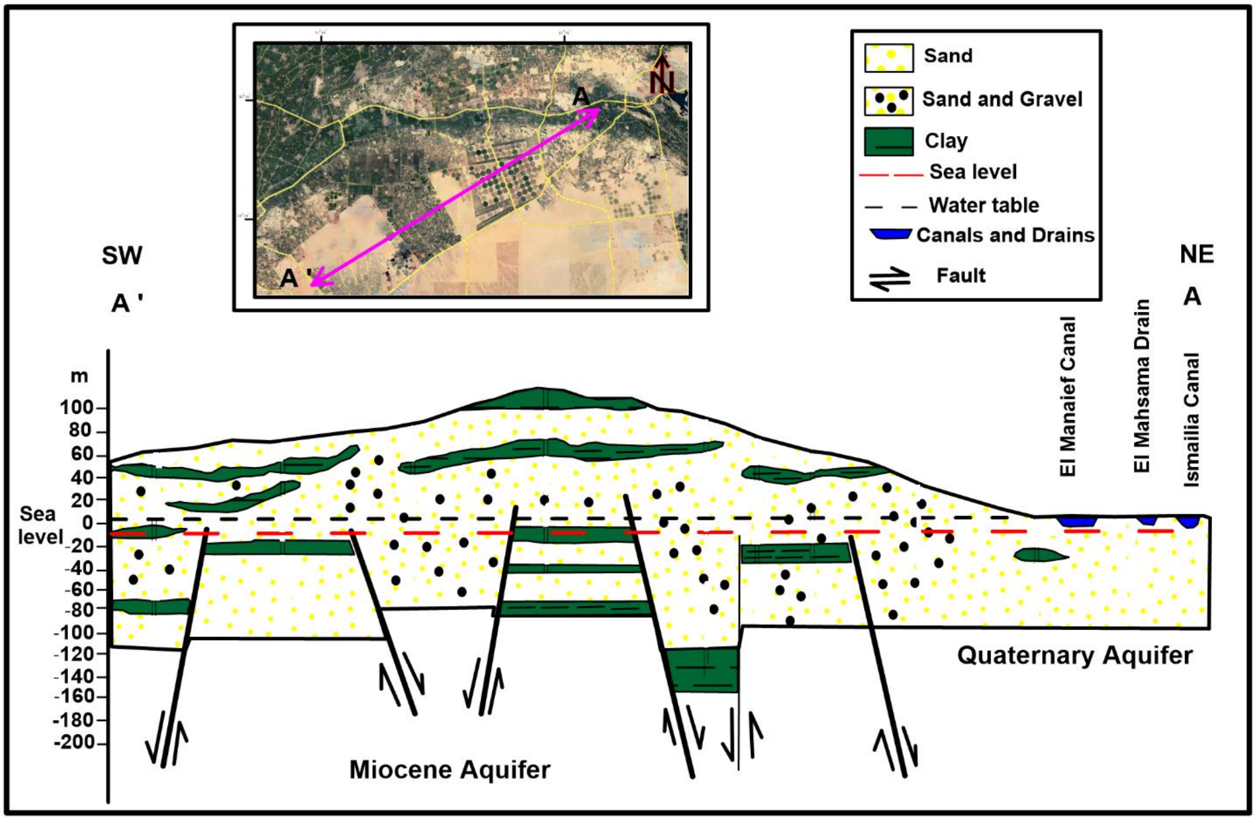

FIGURE 3: HYDROGEOLOGICAL CROSS SECTION NE-SW (MODIFIED AFTER GAD 1995).

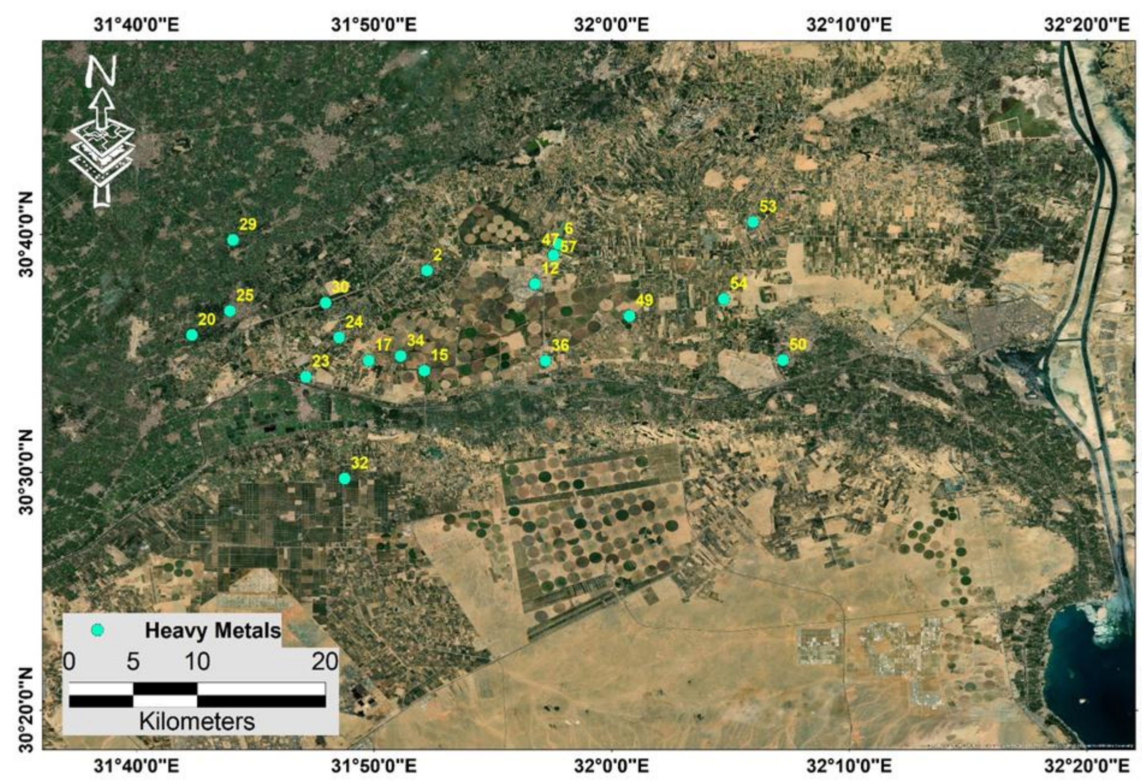

FIGURE 4: LOCATION MAP OF HEAVY METAL SAMPLES.

a) Surface hydrology, at which hydrologic parameters reflect and illustrate the hydrogeologic regime of the aquifer and controls the inflow and out flow groundwater system.
b) The quaternary aquifer in study area belongs to water bearing formations which affected by many sources related to the unsaturated zone and concentrated in the northern part of study area. The water bearing formation types, mode of occurrence of the ground water, flow direction of ground water in the area, and hydrogeologic characteristics of water formations are considered the main controlling hydrogeologic factors in ground water system.

4. Materials and Methods

The groundwater samples were collected cross over the site during the field trip (2020). A total twenty groundwater samples were collected in this work (Fig. 4). To obtain the representatives samples, the collected groundwater samples were collected after pumping the wells for five minutes. The collected groundwater samples were brought to the room temperature 24°C (±2°C) before performing the analysis. Inductively Coupled Argon Plasma (iCAP 6500 Duo, Thermo Scientific, England), was used to determine (5) heavy metals in groundwater samples [35]. The heavy metals assessed in this study are Al (Aluminum), Mn (manganese), Si (Silicon), Ni (nickel), Zn (zinc), and Fe (iron). Results of heavy metals analysis can be shown in Table (1), while the distribution of the collected samples from the study site is shown in Figure (2). In the current work WQI was used to describe the cumulative effect of the heavy metals on the groundwater quality for irrigation uses. The WQI for irrigation was calculated according to the measured heavy metal concentrations with respect to the reference standard of each element. The cumulative effects were calculated based on five heavy metals concentration levels from the collected groundwater samples (Al, Fe, Mn, Ni, and Zn) The numerical effects of WQI were calculated mathematically by equation (Eq. 1);

TABLE 1: CHEMICAL ANALYSIS OF HEAVY METALS IN COLLECTED GROUNDWATER SAMPLES (MG/L).

Sample	Al	Fe	Mn	Ni	Zn
2	0.158	0.071	0.0033	0.136	0.0171
6	0.073	<0.02	<0.002	0.004	<0.009
12	<0.01	<0.02	<0.002	0.0083	0.0029
15	<0.01	0.0607	0.0059	0.1488	0.026
17	0.037	<0.02	<0.002	0.0564	0.0273
20	0.01	0.0494	0.0201	0.0991	0.0171
23	0.047	0.0377	<0.002	0.0569	0.0056
24	<0.01	<0.02	<0.002	0.0142	<0.009
25	0.031	<0.02	<0.002	<0.002	0.0075
29	0.091	0.1194	0.0505	0.0489	0.0039
30	<0.01	0.0578	0.0091	0.1087	0.0224
32	0.056	0.3986	0.0087	0.0975	0.022
34	0.4	0.6147	0.0052	0.0494	0.0598
36	0.023	<0.02	0.0033	0.0778	0.0088
47	0.048	0.3758	0.0039	0.0735	0.0388
49	<0.01	<0.02	0.0044	0.0329	0.015
50	0.282	0.6158	<0.002	0.0505	0.0352
53	0.429	6.879	0.0057	0.097	<0.009
54	0.549	0.2441	0.0076	0.0874	0.0483
57	<0.01	0.2481	0.0096	0.0697	0.0022
Recommended Max. Concentration*	5	5	0.2	0.2	2

* FAO (1985)

$$WQI = \sum \left[\left(W_i / \sum_{n}^{i=1} w_i \right) \times \left(\frac{C_i}{S_i} \times 100 \right) \right] \qquad (1)$$

Where C_i refers to the estimated concentration of each metal, S_i is the standard limits and w_i refers to the allocated relative weight of each element.

5. Results and Discussion

5.1 Spatial distribution and statistical analysis

Usually trace elements occur in most water resources or supplies with low concentration levels. In many cases, the excessive concentration of heavy metals causes undesirable accumulation in the plant tissue and other issues. However, small quantities some heavy metals are essential for the living organisms and growth of plants (eg. Mn, Fe, Zn etc). [36] reported that the Mn is the fifth most abundant metal on the earth. Additionally, the impact of heavy metals varies from decreasing productivity to toxicity with excessive quantities. The mean concentration of Al, Fe, Mn, Ni, Si and Zn was 0.119, 0.007, 0.065, 13.07, 3.06 and 0.019 mg/l, respectively. Furthermore, the decreasing order of the mean values of heavy metals in the collected groundwater samples from the study site following this order; Fe > Al > Ni > Zn > Mn. In this context, the studies heavy metals were compared with the FAO concentration levels to assess the potential risk for the use of groundwater in irrigation purposes. Spatial distribution of the heavy metals for the collected water samples were developed using ArcGIS package. The spatial distribution of the Al concentration levels increasing in the west area (Fig. 5). Fe concentration levels increasing in the west (Fig. 6), Fe high concentration could be attributed to the iron oxides sediments in the aquifer. The iron levels in groundwater can be increased with dissolution of ferrous borehole and the components of handpump. The results shows that all the samples lower than the recommended range (5 mg/l) for irrigation except sample 50 according to food and agriculture organization [37] For Mn concentration levels the results showed that all the samples lower than the recommended max. concentration by FAO (Fig. 7). Ni and Zn (results indicates that the concentration levels less that the recommended max. concentration by FAO (0.20 and 2.00) respectively (Fig. 8 and 9). Furthermore, the spatial distribution of Mn and Zn showed undefined pattern for the samples. On the other hand, the leaching of infiltrated water from the unsaturated zone tends to increase the salinity and potential pollution. The correlation coefficient of the collected samples was determined, to study the relationship between the groundwater parameters (Table 2). The parameters were considered not significantly ($p > 0.5$). The Al is positive correlated with iron and zinc, where zinc is the most mobile heavy metals in groundwater.

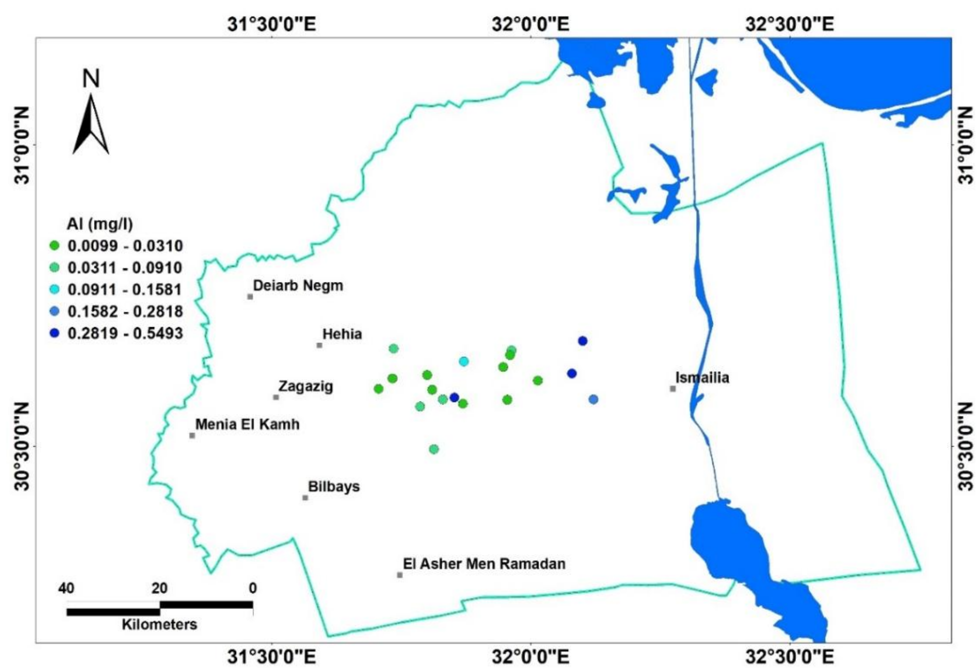

FIGURE 5: SPATIAL DISTRIBUTION OF AL CONCENTRATION IN THE STUDY SITE.

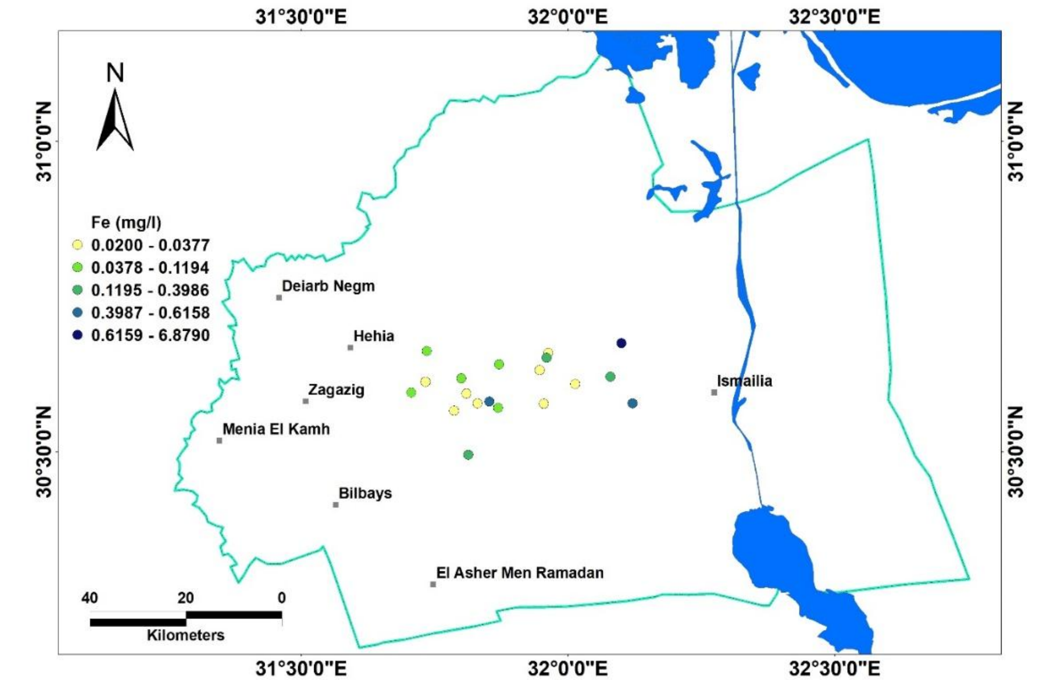

FIGURE 6: SPATIAL DISTRIBUTION OF FE CONCENTRATION IN THE STUDY SITE.

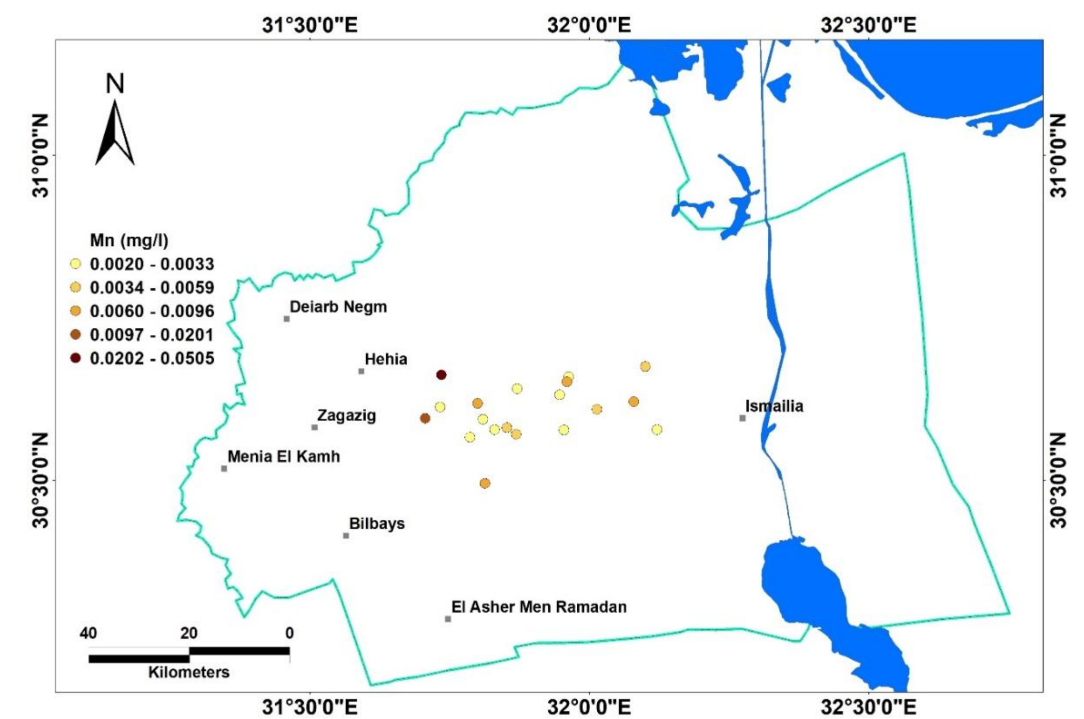

FIGURE 7: SPATIAL DISTRIBUTION OF MN CONCENTRATION IN THE STUDY SITE.

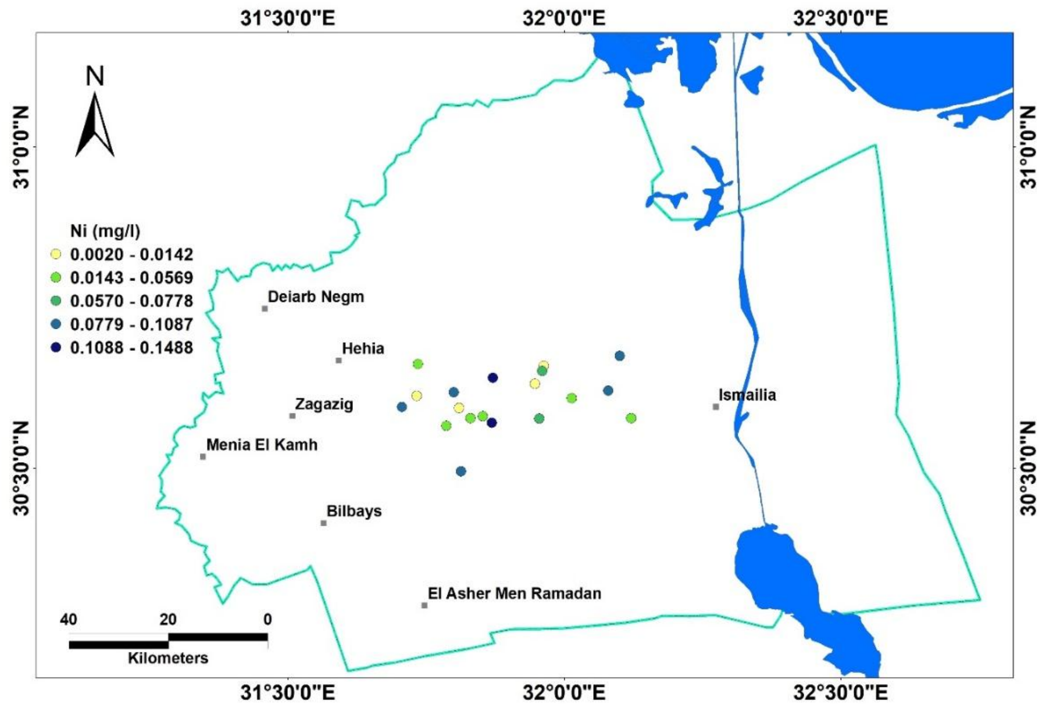

FIGURE 8: SPATIAL DISTRIBUTION OF NI CONCENTRATION IN THE STUDY SITE.

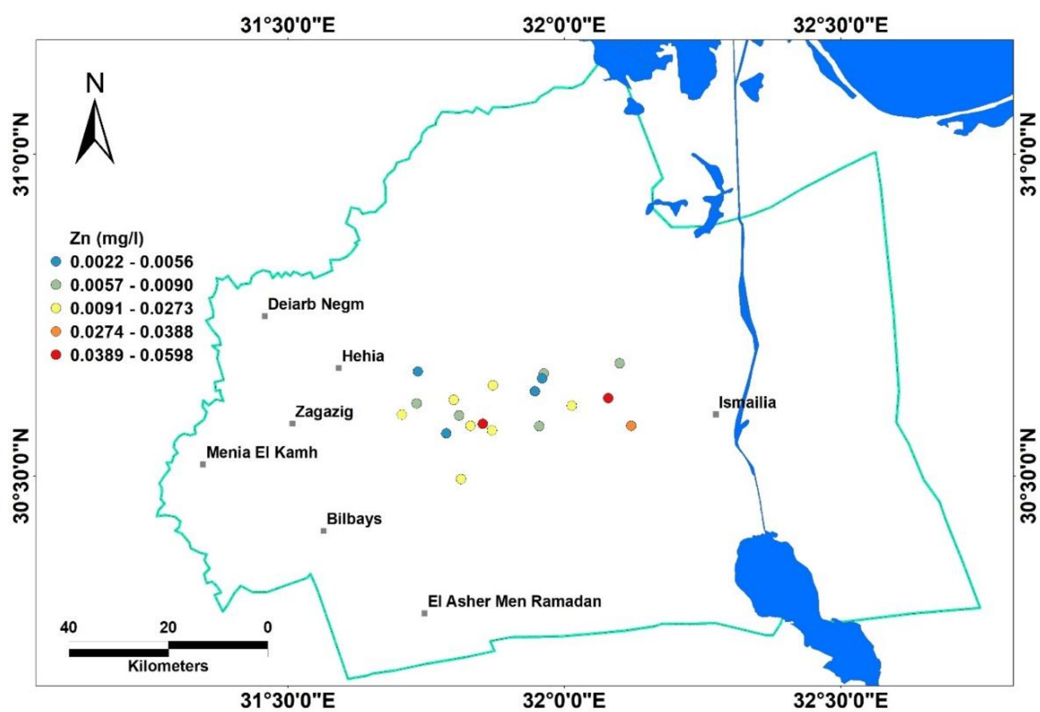

FIGURE 9: SPATIAL DISTRIBUTION OF ZN CONCENTRATION IN THE STUDY SITE.

TABLE 2: CORRELATION MATRIX OF THE HEAVY METALS IN THE STUDY SITE.

Element	*Al*	*Fe*	*Mn*	*Ni*	*Zn*
Al	1				
Fe	0.516865	1			
Mn	-0.03841	-0.04299	1		
Ni	0.145381	0.184043	0.098658	1	
Zn	0.589719	-0.06218	-0.17769	0.253545	1

TABLE 3: WATER QUALITY INDEX (WQI) OF THE STUDY SITE.

Sample	**QWI**					**Final index**
	Fe	**Al**	**Mn**	**Ni**	**Zn**	
2	0.316	0.527	0.367	11.333	0.190	12.733
6	0.089	0.243	0.222	0.333	0.100	0.987
12	0.089	0.033	0.222	0.692	0.032	1.068
15	0.270	0.033	0.656	12.400	0.289	13.648
17	0.089	0.123	0.222	4.700	0.303	5.438
20	0.220	0.033	2.233	8.258	0.190	10.934
23	0.168	0.156	0.222	4.742	0.062	5.350
24	0.089	0.033	0.222	1.183	0.100	1.628
25	0.089	0.103	0.222	0.167	0.083	0.664
29	0.531	0.303	5.611	4.075	0.043	10.563
30	0.257	0.033	1.011	9.058	0.249	10.609
32	1.772	0.186	0.967	8.125	0.244	11.294
34	2.732	1.332	0.578	4.117	0.664	9.423
36	0.089	0.077	0.367	6.483	0.098	7.113
47	1.670	0.160	0.433	6.125	0.431	8.820
49	0.089	0.033	0.489	2.742	0.167	3.519
50	2.737	0.939	0.222	4.208	0.391	8.498
53	30.573	1.431	0.633	8.083	0.100	40.821
54	1.085	1.831	0.844	7.283	0.537	11.580
57	1.103	0.033	1.067	5.808	0.024	8.035

TABLE 4: THE CLASSIFICATION OF WATER QUALITY ACCORDING TO WQI.

Water quality index	**Range**	**Water Class**	**Samples**
Water quality for irrigation	< 22	Low	All of the samples except 53
	22 - 37	Medium	
	> 37	High	53

5.2 Water Quality Index

The water quality for irrigation proposes was calculated according to equation (Eq. 1) based on the cumulative effect of five heavy metals. The calculated WQI for irrigation varies from 0.66 to 40.82 with mean value of 9.14 (Table 3). However, in Table (4) the water quality index for irrigation purposes were classified into three classes. The collected samples based on this classification are in the low class, while one sample (53) is in the high class. The high class attributed to high values of Fe concentration levels above the recommended max. concentration of FAO. Therefore, calculated water quality index for irrigation over the study area reflect low risk attributed to the heavy metals concentrations.

Conclusions

In the current paper the groundwater quality evaluated according to the heavy metals concentration form collected samples. In order to identify the groundwater quality, the WQI approach was applied. The quaternary groundwater aquifer in the present work represents the main groundwater resource for irrigation purposes. Our findings, with regard to trace element concentrations, most of the heavy metal concentrations are below the recommended max. concentration of FAO for irrigation purpose. Thus, the groundwater samples in the present work does not contain a significant amount excessive quantities or risk of the studied heavy metals for irrigation purposes according to FAO limits. Even the concentrations are below the limits, significant consideration to iron levels should be taken into account where one sample above the recommended max. limits. Thus, no significant hazard was observed across the study site. Hence, it is necessary to start and continue analysis and monitoring the plant tissue annually to confirm the presence or absence of heavy metals with desirable limits or not. Finally, in order to be able to satisfy the agriculture water with acceptable levels limits, a sustainable management system for this vital resource should now be applied.

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