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Use of Geographical Information System and Water Quality Index to Assess Groundwater Quality in El Khairat Deep Aquifer (Enfidha, Tunisian Sahel)

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Abstract: Groundwater is the most important natural resource required for drinking to many people around the world, especially in rural areas. The resource cannot be optimally used and sustained unless the quality of groundwater is assessed. Positioned in Enfidha City-in northeastern Tunisia, the watershed of El Khairat stretches geographically from 40.07° to 40.36° North latitude; and from 8.56° to 9.02° East Longitude. In this region, El Khairat aquifer is the most important groundwater aquiferous system which is considered a major source for drinking and irrigation. In Tunisia, since the quantity and the quality of water available for different uses is variable from one place to another, groundwater quality in El Khairat deep aquifer was evaluated for its suitability for drinking purposes. To this end, an attempt has been made for the first time in order to determine spatial distribution of groundwater quality parameters and to identify places with the best quality for drinking within the study area based on: (1) an integrated analysis of physical-chemical parameters, (2) use of Geographical Information System and (3) Water Quality Index calculation. The physico-chemical results were compared to the standard guideline values as recommended by the World Health Organization (WHO) for drinking and public health in order to have an overview of the present groundwater quality. According to the overall assessment of the basin, almost all the parameters analyzed are above the desirable limits of WHO. Using GIS contouring methods with Arcview 3.2a, spatial distribution maps of pH, TDS, EC, TH, Cl, HCO_3, SO4, NO3, Ca, Mg, Na and K, have been created. An interpolation technique, ordinary Inverse Distance Weighted (IDW), was used to obtain the spatial distribution of groundwater quality parameters. The spatial analysis of groundwater quality patterns of the study area shows that the TDS value increases from north-west to south-east following the general trend of the Khairat aquifer flow direction. The spatial distribution map of TH shows that a majority of the groundwater samples falls in the very hard category. WQI was used to assess the suitability of groundwater from the study area for human consumption. From the WQI assessment, over 82% of the water samples fall within the ‘‘Poor’’ and ‘‘Very poor’’ categories, suggesting that groundwater from the south-eastern of the El Khairat deep aquifer is unsuitable for drinking purposes.

Key words: Geographical Information System % Spatial analysis % Water Quality Index % El Khairat deep aquifer % Tunisia

INTRODUCTION

Groundwater resources are dynamic in nature and are affected by such factors as the expansion of irrigation activities, industrialization and urbanization; hence monitoring and conserving this important resource is essential. The quality of water is defined in terms of its physical, chemical and biological parameters. Ascertaining the quality is crucial before its use for various purposes such as drinking; agricultural, recreational and industrial uses; etc. [1, 2]. In Tunisia, the quality of groundwater has particularly received immense

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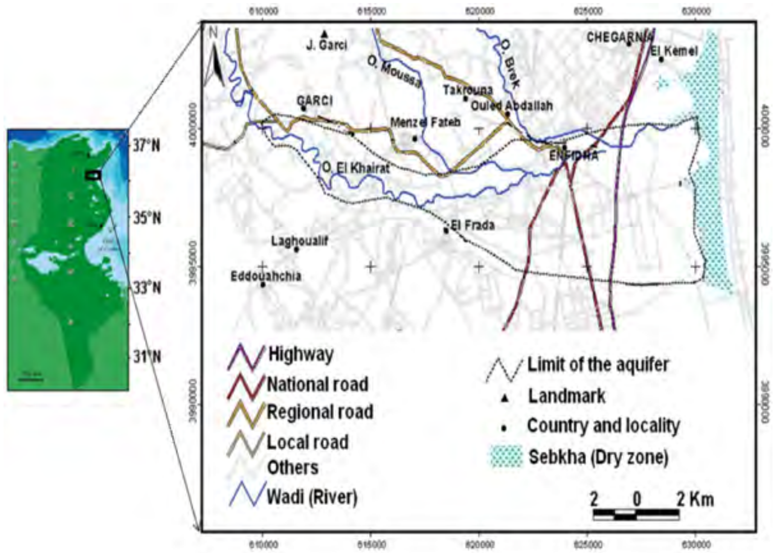

Fig. 1: Localization map of the study area

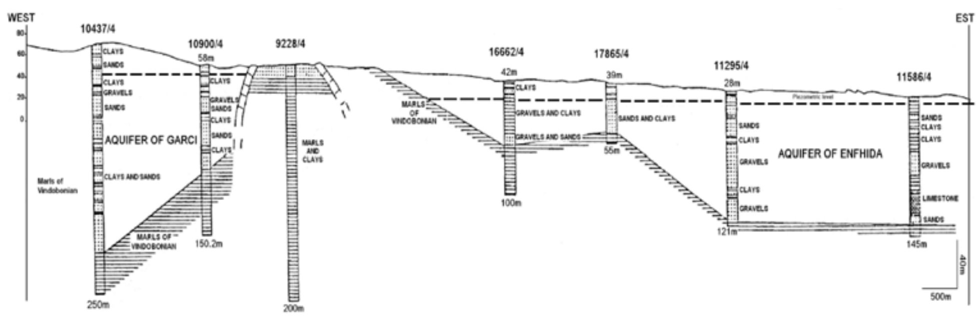

Fig. 2: Longitudinal section through the aquifer of El Khairat (Menaa *et al*., 1996).

attention since water of high quality is required for domestic and irrigation needs. Till recently, groundwater assessment has been based on laboratory investigation, but the advent of Satellite Technology and Geographical Information System (GIS) has made it very easy to integrate various databases. GIS can be a powerful tool for developing solutions for water resources problems, assessing water quality, determining water availability, preventing flooding, understanding the natural environment and for managing water resources on a local or regional scale [3]. The deep aquifer of El Khairat is situated on the oriental flank of the Tunisian Dorsal, in the extension towards the East of the synclinal of Saouef (Figure 1). This region is influenced by a semi-arid climate. The daily average temperatures vary between 11°C in winter (January); and 28°C in summer (August). The annual average total precipitation is 353mm. The wadi El Khairat takes birth in Djebel Khalifa-in the governorate of Zaghouan and crosses the alluvial plain of El Khairat. The latter has a surface area of 63Km² and contains an important aquiferous system that is subdivided, in Satour Bou Larga-fedjet El Hamma, by a hydraulic sill (the sill of Ain Garci) in two distinct zones (Figure 2): Ain Garci upstream and Enfidha-city downstream [4]. The zone of Ain Garci corresponds to an underflow aquifer lodged in an alluvial matrix (pebbles, gravels, sands) more or less detritic and clayey with a thickness reaching 100m. Laterally, the extension of these alluviums is often limited by the presence of the argilloarenaceous formations of the Mio-Pliocene. In upstream, the substratum of the alluvial aquifer corresponds to the marls of the Vindobonian; but, in downstream, it is generally characterized by clays and sandstones of Mio-Pliocene. The median zone presents a weak thickness of the aquifer (0-25m), corresponding to the ascent of the marly substratum. In the zone of Enfidha-city, the deep aquifer is contained in sands and gravels. The substratum of this horizon is constituted by the marls of the Vindobonian. The infiltration of flood water through the beds of wadi El Khairat constitutes a major source of aquifer recharge [5]. The infiltration of the rainwater and the recharge from the piedmonts of the south part constituted by the overflow of the waters of

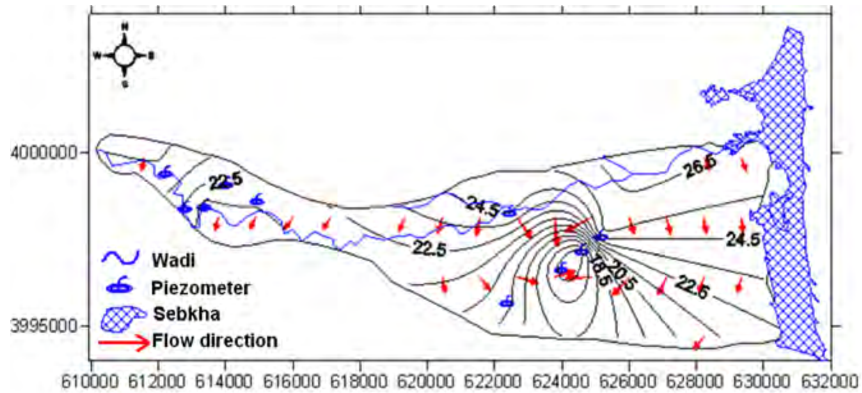

Fig. 3: Piezometric map of the study area

the Mio-Pliocene, incidentally participate in the aquifer recharge [6]. Waters mobilized in the dam of El Khairat built in 1999 contributed to the natural recharge of the aquifers to which they are associated. The groundwater flow in the study area is towards Sebkhat Assa Djiriba and the Mediterranean Sea (Figure 3). The piezometric map shows that the highest contour lines are at the north-west of the study area; whereas the lowest contour lines are close to the south-east. The natural discharges of this aquifer are the Mediterranean Sea and Sebkhat Assa Djiriba. The deep aquifer of El Khairat is exploited by boreholes. The exploitation, during the period of 1986-2004, is marked by an important increase in time. The total volume exploited increased from 2.75Mm^3/year in 1986 to 3.98Mm^3/year in 2004. The water of this aquifer is used by different economic activity sectors (agricultural and industrial) unevenly. Nevertheless, drinking water supply remains the major and primary use. As it is part of the Tunisian Sahel, the Enfidha region has a semi-arid climate with very irregular rainfall-which makes the groundwater resources quite fragile. This region has major difficulties in managing its water resources which are in decline; especially that during the last decades, it has been suffering from the scarcity of groundwater. This alarming situation necessitates the present study to evaluate groundwater quality for designing suitable water management plans in the Enfidha region.

For any city, a groundwater quality map is important for drinking purposes and as a precautionary indication of potential environmental health problems [7].

In this study, the authors' goal was to understand the groundwater quality of El Khairat deep aquifer by an integrated approach of traditional water quality analysis and Geographical Information Systems (GIS); and to generate a Water Quality Index map.

MATERIALS AND METHODS

Chemical Analysis: Water samples were collected in February 2007 from 17 boreholes capturing the deep aquifer of El Khairat and representing a homogeneous spatial distribution on the whole aquifer (Figure. 4). The water samples in question were collected in clean polyethylene bottles. At the time of sampling, the bottles were thoroughly two to three times rinsed with the groundwater to be sampled. In the case of bore wells and hand pumps, the water samples were collected after pumping for 10 mn. This was done in order to remove groundwater stored in the well. In situ, measurements included electrical conductivity (EC), TDS, pH and temperature-which were measured using a portable field kit as per the WHO's recommendations [8], since these parameters change along the storage time. Preservation and transportation of the water samples to the laboratory followed standard methods. The samples collected were brought to the laboratory, filtered using a 0.45µm Millipore filter paper, were acidified with nitric acid (Ultrapure Merck) for cation analysis and HBO_3 acid was used as a preservative for nitrate analysis [9]. For anion analysis, these samples were stored below 4°C. The chemical analyses (Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+ and K^+) were performed at the Laboratory of Geochemistry and Environmental Geology in the Faculty of Sciences in Tunis. Chloride dosing was either carried out by the standard titration method or the Mohr method. Water alkalinity is primarily attributed to the presence of bicarbonates (HCO_3^-) since the pH of most water samples ranges between 4.5 and 8.3. Bicarbonates were determined by a potentiometric method. Sulphate concentrations were measured by a gravimeter method using $BaCl_2$. Nitrate was determined by colorimetric method. The spectrometry of atomic absorption was used

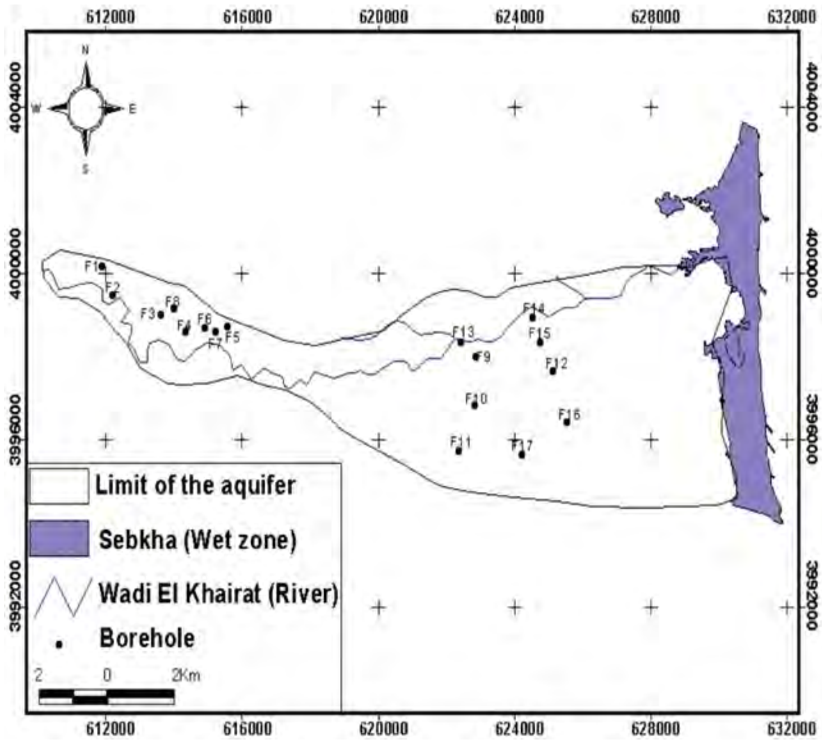

Fig. 4: Localization of groundwater samples

to measure the concentrations of calcium, magnesium, sodium and potassium. All the water quality parameters were expressed in mg/1, except EC and pH. The accuracy of the chemical analysis was verified by calculating ion-balance errors. The errors were generally around 10%. Each parameter was compared to the desirable standard limit of that parameter stipulated for drinking water as prescribed by the WHO [8, 10 and 11] for drinking and public health purposes.

GIS Analysis: The study is carried out with the help of topographic sheets, ERDAS and Arcview GIS 3.2. The paper map of the city has a 1:50,000 scale and was digitized to the UTM coordinate system by applying the on-screen digitizing method using ERDAS Imagine software. GPS is used to map the location of each sampling borehole; and finally, the results of each parameters analysed were added to the concerned boreholes. Spatial Analyst, an extended module of ArcGIS 3.2, was used to find out the spatio-temporal behavior of the groundwater quality parameters [12]. The various thematic layers on hardness, pH and ionic concentrations were prepared using a spatial interpolation technique through Inverse Distance Weighted (IDW). This contouring method has been used in the present study to delineate the locational distribution of water pollutants or constituents. This method uses a defined or a selected set of sample points for estimating the output grid cell value. It determines the cell values using a linearly weighted combination of a set of sample points; and, it controls the significance of known points upon the interpolated values based upon their distance from the output point, generating thereby a surface grid as well as thematic isolines [13]. Groundwater quality classification maps for pH, TH, EC, TDS, Cl, SO_4, HCO_3, NO_3, Ca, Mg, Na and K from thematic layers, based on the WHO Standards for drinking water, have been created for El Khairat deep aquifer.

Estimation of Water Quality Index (WQI): These last years, the Water Quality Index (WQI) was very used to determine the suitability of the groundwater for drinking purposes [14-20]. Water Quality Index (WQI) is a very useful tool for communicating the information on the overall quality of water [21-23]. The standards for purposes of drinking have been considered for the calculation of WQI as recommended by WHO [11]. The proposed methodology is summarized in the flowchart shown in Figure 5.

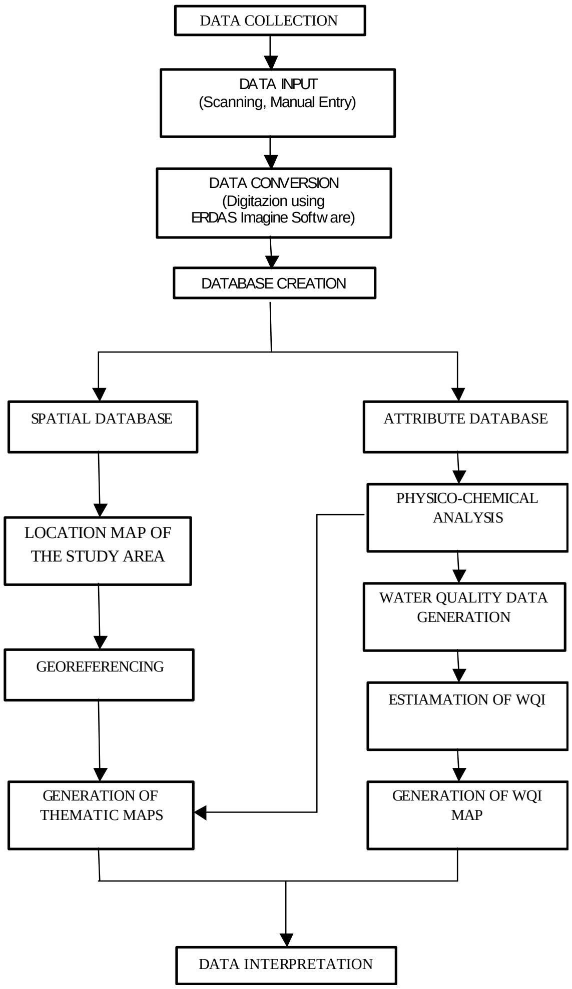

Fig. 5: Flow-chart of the methodology adopted

RESULTS AND DISCUSSION

Spatial Analysis of Groundwater Quality: Understanding the groundwater quality is important seeing that it is the main factor determining its suitability for drinking use [24, 25]. Physical and chemical parameters including statistical measures, such as minimum, maximum, mean and standard deviation, are reported in Table 1. The following water quality parameters were selected and their respective maps were prepared namely, pH, EC, TDS, TH, Cl^-, SO_4^{2-}, NO_3^-, Na^+, Ca^{2+},Mg^{2+} and K; using point data spatial analysis of GIS.

Usually, pH has no direct impact on consumers. It is one of the most important operational water quality parameters with the optimum pH required often being in the range of 7.0-8.5 [11]. The maximum permissible limit for pH in drinking water as given by the WHO is 9.2mg/l. The values of pH in the groundwater samples collected varied from 7.21 to 9.64 with an average value of 8.18 (Table 1). This shows that the groundwater of the study area is mainly alkaline. Spatial distributions of pH concentrations are shown in Figure 6a. It is shown that the majority of the samples displayed a pH value within the maximum permissible limit, except for three samples (F6, F8 and F11) which presented a pH value exceeding this limit. Low pH concentrations occur in north-west and east parts of the aquifer. The electrical conductivity (EC) of water at 25°C is due to the presence of various dissolved salts. The electrical conductivity varies widely and ranges between 653 and 5,120µS/cm at 25°C with a mean of 3,056µS/cm

Table 1:

Sample	T (°C)	pH	EC (µS/cm)	TDS	TH	Cl^-	HCO_3^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
				mg/l									
F1	19.6	7.21	2,770	1,108	423.81	362.61	146.4	772.9	12.46	86.4	51.9	457	9
F2	18.7	8.13	2,660	1,064	788.15	327.06	89.06	782.86	12.3	190.3	78.1	293.6	10.99
F3	19.4	7.46	2,430	972	598.3	284.4	115.9	676.67	14.25	122.2	73.2	274.9	9.94
F4	22.6	8.20	3,510	1,404	604.7	465.7	152.5	1,094	7.74	99	89.3	725.2	9.23
F5	22.3	8.21	3,660	1,464	771.7	490.59	132.98	1,015	0.01	136.2	107.8	563.2	11.32
F6	15.2	9.64	1,128	451	75.25	273.73	178.12	242.02	0.22	18.9	7	266.8	10.37
F7	20.7	8.16	3,430	1,372	494.65	497.7	181.78	1,105	5.15	90.7	66.9	772.2	9.84
F8	18.2	9.23	2,430	972	188.6	611.46	231.8	452.75	0.32	14.8	37.9	499.7	18.06
F9	21.0	7.55	3,060	1,224	421.14	476.37	157.38	182.43	28.62	74.3	58.8	338.1	6.38
F10	21.5	7.71	3,960	1584	1,190	713.84	246.44	1,018	16.76	265.8	131.6	602	11.54
F11	20.1	9.55	3,680	1,472	582.45	753.66	268.40	725.23	1.66	85.3	92.3	712.8	13.63
F12	21.1	8.90	1,603	641	14.74	273.73	264.74	328.3	0.36	0.3	3.4	469.4	8.29
F13	20.5	8.48	653	261	41.07	117.31	186.66	58.34	0.74	6.5	6.2	124.7	9.37
F14	19.4	7.84	4,110	1,644	760.89	647.01	25.62	1,064	31.29	40.8	164.7	664.9	7.84
F15	21.4	7.71	2,850	1,140	335.44	426.6	207.4	704.65	11.92	44.3	56.1	675.2	7.95
F16	19.5	7.65	5,120	2,048	950.25	1,073	103.7	1,833	5.92	165.7	134	765	13.2
F17	20.8	7.55	4,910	1,964	1,008	1,137	237.9	1,238	13.6	163.9	149.6	1,019	9.19
Min	15.2	7.21	653	261	14.74	117.3	25.6	58.3	0.01	0.3	3.4	124.7	6.38
Max	22.6	9.64	5,120	2,048	1,191	1,137	268.4	1,833	31.29	265.8	164.7	1,019	18.06
Mean	20.1	8.18	3,056	1,222	544	525.4	172.1	782.1	9.6	94.43	77	542.6	10.36
SD	1.74	0.73	1,209	483.72	346.45	276.13 67	448.32	9.59	73.14	49.3	233.09	2.72	

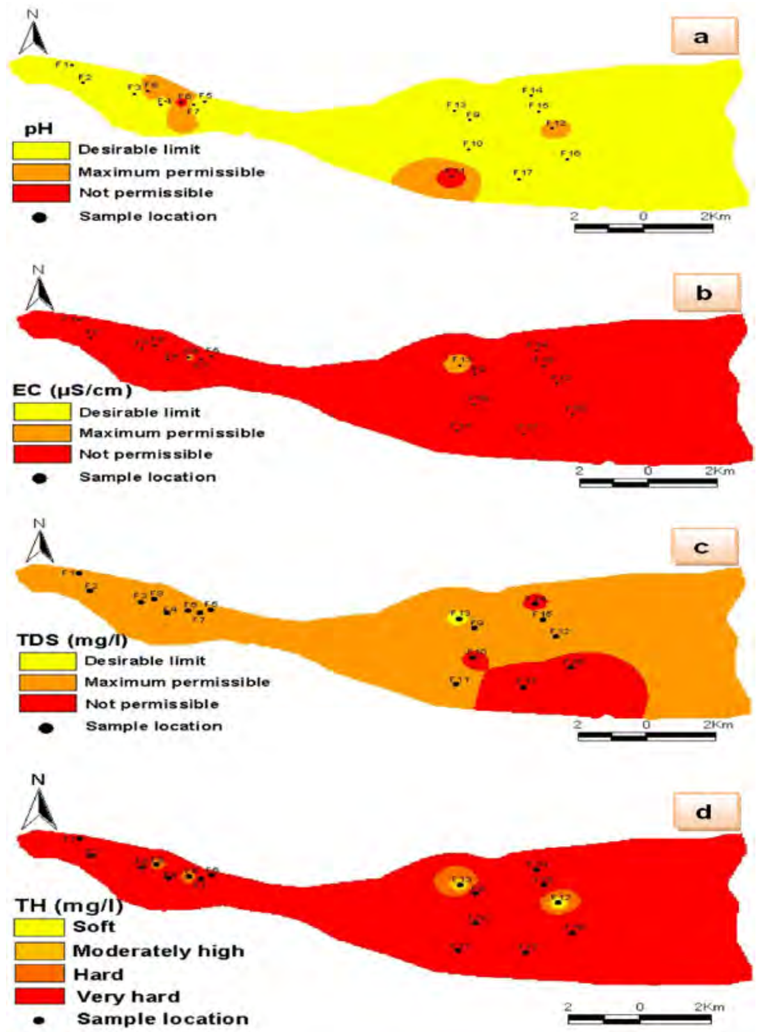

Fig.6: Spatial distribution of a pH, b EC, c TDS and d TH.

(Table 1). Knowing that the maximum limit of EC in drinking water is prescribed as 1,500µS/cm at 25°C [8-10], the interpreted water quality with respect to EC indicates that more than 90% of the study area groundwater lies in bad range for drinking water purposes (Figure. 6b). The TDS in water are represented by the weight of residue left when a water sample has been evaporated to dryness [26]. TDS are compound of inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and of small amounts of organic matter that are dissolved in water. Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubility of minerals [11]. The TDS amount ranges from 261mg/l to 2,048mg/l with an average of 1,222mg/l (Table 1). According to WHO specification, 23.52% of the sample locations exceeds allowable limits indicating, then, the unsuitability of some of the water for drinking purposes. As shown in Figure 6c, the TDS amount increases from the north-west to the south-east following the general trend of the Khairat aquifer flow direction. Water hardness is primarily caused by the presence in water of cations such as calcium and magnesium; and of anions such as carbonate, bicarbonate, chloride and sulfate [27]. The water with hardness above 200mg/l may cause scale formation in the distribution system. The high hardness of 150-300mg/l and above may cause heart diseases and kidney problems [28]. Groundwater exceeding the limit of 300mg/l is considered to be very hard [29]. In our study, total hardness (TH) is in the range of 14.74-1.191 with an average of 544 all in mg/l as $CaCO_3$ (Table 1). The spatial distribution map (Figure 6d) of TH shows that a majority of the groundwater samples (76.47%) falls in the very hard category.

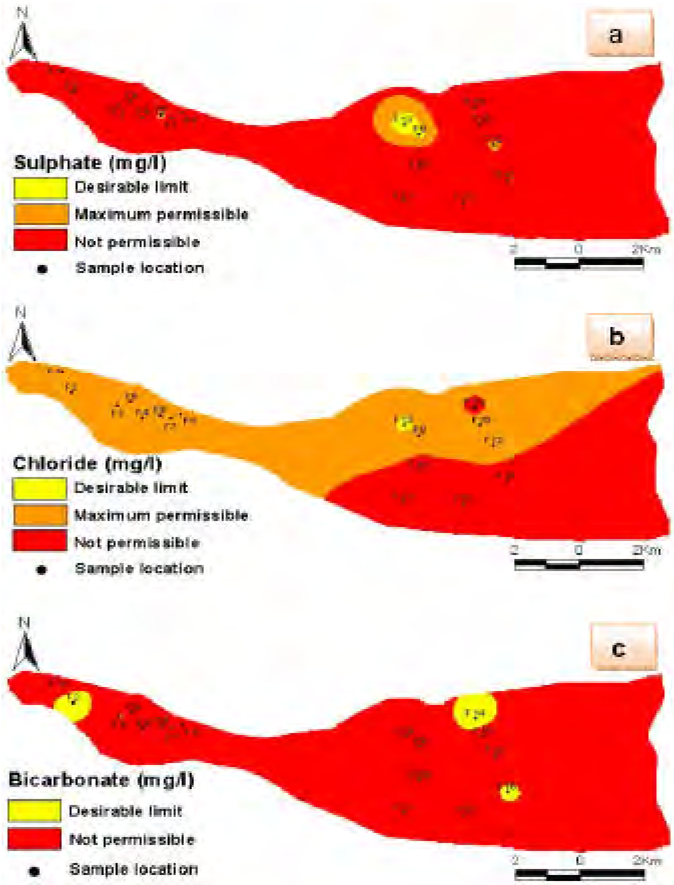

Fig. 7: Spatial distribution of a sulphate, b chloride and c bicarbonate concentrations

The abundance of the major anions in El Khairat aquifer is in the following order: SO_4^{2-}> Cl-> HCO_3^-> NO_3^-. The El Khairat deep aquifer is characterized by a high sulphate ion content-which is the dominant anion. Its concentration ranges between 58.3 and 1,833mg/l with an average value of 782.1mg/l (Table 1). The spatial distribution of sulphate concentration in groundwater of the study area is illustrated in Figure 7a. This map shows that only two samples are within the maximum allowable limit of 200mg/l. The second most dominant anion is chloride with a concentration ranging from 117.3 to 1,137mg/l and with an average value of 525.4mg/l (Table 1). The chloride ion concentration in groundwater of the study area exceeds the maximum permissible limit of 600mg/l in six locations only (Figure 7.b). Both chloride and sulphate ions (as well as total dissolved solids) generally increase from a north-west to a south-east direction in the study area, under the effects of the hydraulic gradient. The bicarbonate ion concentration is relatively low compared to chloride and sulphate ion concentrations (range: 25.6-268.4mg/l) (Table 1). According to US Public Health Service guidelines, only 23.52% of groundwater collected from the deep aquifer are within the permissible limit (Figure 7c). Nitrates are the end product of aerobic stabilization of organic nitrogen; and a product of conversion of nitrogenous material. This phenomenon occurs in polluted water. Nitrate concentration of groundwater samples varied from 0.01 to 31.29mg/l with an average value of 9.6mg/l (Table 1). In the studied aquifer, nitrate concentration is below permissible limit (45 mg/l).

The predominant cation trend in El Khairat aquifer is Na^+>Ca^{2+}>Mg^{2+}>K^+. Sodium is the dominant cation in El Khairat aquifer. Its concentration ranges between 124.7 and 1,019mg/l with an average value of 542.6mg/l (Table 1). According to the WHO guideline, the maximum admissible limit is 200mg/l. In the study area, almost all groundwater samples exceed the maximum permissible limit as far as sodium is concerned (Figure 8a). Calcium is the second most dominant cation; and its concentration range from 0.3 to 265.8mg/l with an average value of 94.43mg/l (Table 1). Ca ion distribution, (Figure 8b),

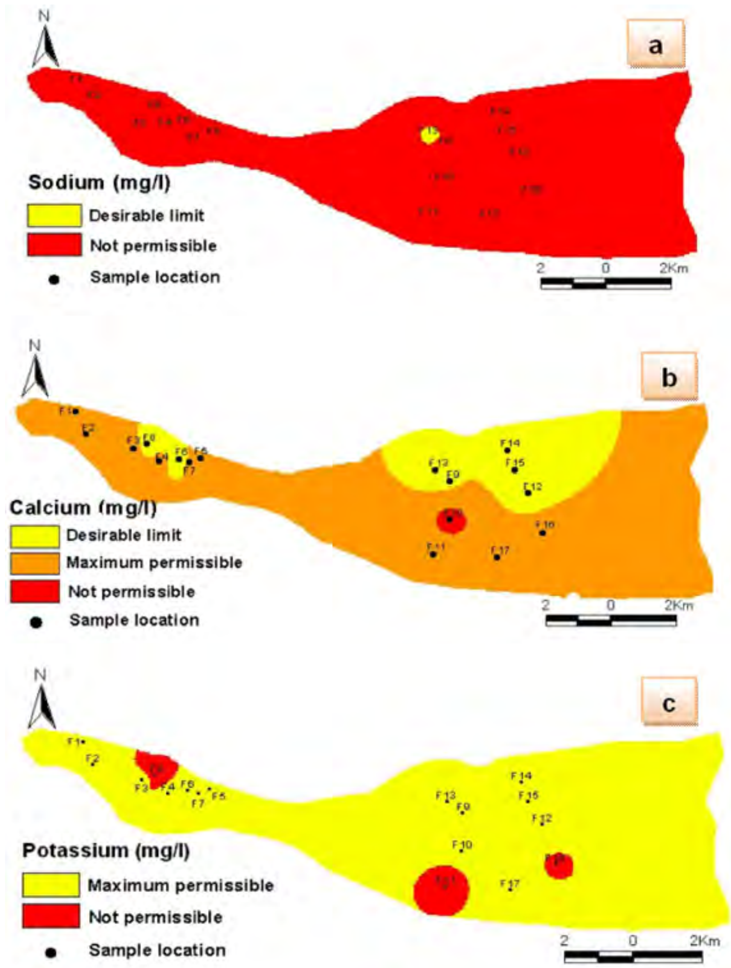

Fig. 8: Spatial distribution of a Sodium, b calcium and c potassium concentrations

is within the maximum permissible limits, except for one sample (F10)-which shows a Ca concentration exceeding this limit. The magnesium ion concentration is generally low compared to those of sodium and calcium; and it also falls in the range of 3.4 to 164.7mg/l with a mean value of 77mg/l (Table 1). The majority of the samples showed a magnesium amount within the maximum permissible limit, except for one sample (F14). The high total concentrations of Ca^{2+} and Mg^{2+} are important factors which increase the hardness of waters [30]. In the area of investigation, the potassium amounts range from 6.38 to 18.06mg/l with an average value of 10.36mg/l (Table 1); and, it was found that all the samples were having potassium values within the permissible limit, except for three samples (F8, F11 and F16) (Figure 8c).

Estimation and mapping of Water Quality Index: For computing WQI, three steps were followed [13, 22, 31-35]. In the first step, each of the 10 parameters (pH, TDS, Cl, SO_4, HCO_3, NO_3, Ca, Mg, Na and K) has been assigned a weight (wi) based on their perceived effects on primary health (Table 2). The maximum weight of 5 has been assigned to parameters like total dissolved solids, chloride, sulfate and nitrate due to their major importance in water quality assessment [36]. Bicarbonate is given the minimum weight of 1 as it plays an insignificant role in the water quality assessment. Other parameters like calcium, magnesium, sodium and potassium were assigned a weight between 1 and 5 depending on their importance in the overall quality of water for drinking purposes.

In the second step, the relative weight (Wi) of each parameter is computed using Eq. (1):

$$Wi = \frac{w_i}{\sum_{i=1}^{n} w_1} \quad (1)$$

Table 2:

Chemical parameters	WHO Standard	Weight (wi)	Relative weight (Wi)
pH			
TDS (mg/l)	8.5	3	0.103
	500	5	0.172
Cl^-(mg/l)	250	3	0.103
SO_4^{2}-(mg/l)	250	3	0.103
NO_3-(mg/l)	45	5	0.172
HCO_3^-(mg/l)	120*	2	0.068
Na^+ (mg/l)	200	3	0.103
Ca^{2+} (mg/l)	75	2	0.068
Mg^{2+} (mg/l)	50	2	0.068
K^+ (mg/l)	12	1	0.034
		$\sum w_i = 29$	$\sum w_i = 0.994$

*US Public Health Service values (WHO Standards are not available).

Table 3:

WQI Range	Type of water
< 50	Excellent water
50-100.1	Good water
100-200.1	Poor water
200-300.1	Very poor water
> 300	Unfit for drinking

Table 4:

Sample	WQI	Classification
F1	147,67	Poor water
F2	148,03	Poor water
F3	132,09	Poor water
F4	150,14	Poor water
F5	147,32	Poor water
F6	77,96	Good water
F7	149,78	Poor water
F8	139,07	Poor water
F9	132,20	Poor water
F10	231,82	Very poor water
F11	199,84	Poor water
F12	99,79	Good water
F13	47,86	Excellent water
F14	212,52	Very poor water
F15	160,14	Poor water
F16	283,97	Very poor water
F17	283,52	Very poor water

where, wi is the weight of each parameter, n is the number of parameters and Wi is the relative weight.

The weight (wi), the calculated relative weight (Wi) values and the WHO standards for each parameter are given in Table 1.

In the third step, quality rating scale (qi) was calculated for each parameter using Eq. (2):

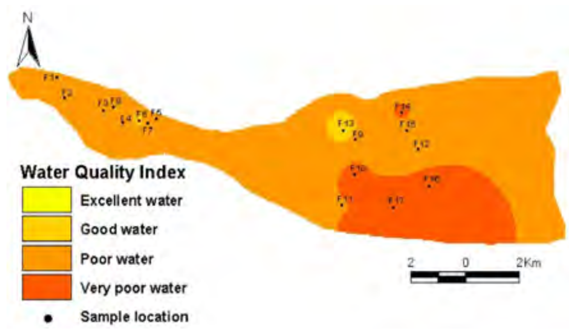

Fig. 9: Spatial distribution of Water Quality Index

$$qi = \frac{C_i}{S_i} \times 100 \quad (2)$$

where, qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l and Si is the WHO standard for each chemical parameter in mg/l (Table 2).

For computing the WQI, the SI is first determined for each chemical parameter using Eq. (3)-which is then used to determine the WQI as per the Eq. (4):

$$Sii = Wi \times qi \quad (3)$$

$$WQI = \Sigma\, Sli \quad (4)$$

where, Sii is the sub-index of ith parameter, qi is the rating based on concentration of i^{th} parameter and n is the number of parameters. Computed WQI values are usually classified into five categories (Table 3): excellent, good, poor, very poor and unfit for human consumption [20].

Calculation of WQI for individual samples is represented in Table 4. It is obvious from this classification that on the basis of the WQI, groundwater from the study area is not of acceptable quality for human consumption. There is only one sample with a WQI less than 50. The spatial distribution map of the WQI, (Figure 9), shows that the south-west of the city has very poor groundwater quality; and in general, the groundwater quality decreases from the north-west to the south-east of the El Khairat deep aquifer, under the effects of the hydraulic gradient.

CONCLUSION

In the present investigation, an attempt was made to evaluate and to map the groundwater quality of El Khairat deep aquifer. Spatial distributions of groundwater quality parameters were carried out through GIS. The analysis of the results drawn from the work revealed that GIS is an effective tool for the preparation of various digital thematic layers and maps showing the spatial distribution of various water quality parameters. Moreover, GIS makes the groundwater quality maps in an easily understood format. It is shown that the majority of the samples presented a pH value within the maximum permissible limit, except for three samples which reflected a pH value exceeding this limit. Low pH concentrations occur in north-west and in east parts of the aquifer. The interpreted water quality with respect to EC indicates that more than 90% of the study area groundwater lies in bad range for drinking water purposes. The TDS value increases from the north-west to the south-east following the general trend of the Khairat aquifer flow direction. In our study, spatial distribution map of TH shows that a majority of the groundwater samples falls in the very hard category. The predominant cation trend in El Khairat aquifer is $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$. Almost all groundwater samples exceed the maximum permissible limit of sodium. Ca ion distribution is within the maximum permissible limits, except for one sample which shows a Ca concentration exceeding this limit. The spatial distribution map of Mg concentrations illustrates that the majority of the samples are within the maximum permissible limit, except for one sample. All the samples were having potassium amounts within the permissible limit, except for three samples. The abundance of the major anions in El Khairat aquifer is in the following order: SO_4^{2}-> Cl-> HCO_3-> NO_3^{-}. The spatial distribution of sulphate concentration shows that only two samples are within the maximum allowable limit. The chloride ion concentration in groundwater of the study area exceeds the maximum permissible limit in six locations only. Both chloride and sulphate ions (as well as total dissolved solids) generally increase from a north-west to a south-east direction in the study area, down the hydraulic gradient. Nitrate concentration is below the permissible limit. The Water Quality Index is a very useful and an efficient tool to summarize and to report on the monitoring data to the decision makers in order to be able to understand the status of the groundwater quality; and to have the opportunity for better use in future as well. The overall view of the WQI of the present study zone shows a higher WQI value indicating the deteriorated water quality. But, only one location had a satisfactory result with a WQI below 50. This study demonstrates that the use of GIS and WQI methods could provide useful information for water quality assessment.

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