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Groundwater Quality and Health Risk Assessment in South Mut Area, New Valley, Egypt

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ABSTRACT

In the last years, some diseases have spread in Mut area in El Dakhla Oasis, which is located in the New Valley Governorate, Egypt. This study aims to investigate the correlation between the chemical characteristics of groundwater and the prevalence of certain diseases in the concerned area. So, this paper intends to assess the groundwater quality and its risks to human health for the local population in the investigated area. This was achieved through the integration of the hydrochemical characteristics approach with an assessment of the potential health risks associated with consuming groundwater containing trace elements, heavy metals, and some minor constituents. Fifteen water samples, including Mut Lake (one sample), and fourteen groundwater samples representing the Taref, Sabaya and Six Hills aquifers were collected from the study area. Chemical analyses of the major ions, including Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-} and Cl^{-}, as well as some trace elements and heavy metals such as Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sr, and minor constituents as B, were performed. Additionally, the biochemical and bacteriological analyses, such as total organic carbon (TOC), and total colony and coliform colony counts, were assessed to evaluate the degree of contamination. The human health risks caused by intake of the contaminated groundwater through the oral and dermal pathways were also assessed. To categorize the water quality, chronic daily intakes (CDI) and health risk (hazard quotient, HQ), as well as the noncancer hazard index value (HI), were computed for the collected water samples to assess the potential health risks associated with the groundwater in the study area. The obtained results indicated that all collected groundwater samples were classified as freshwater with salinity levels below 1105mg/l. Hypothetical salts combinations and Piper diagram revealed that there is seepage from Mut Lake to the Taref groundwater in the study area, and there is also a hydraulic connection between the Taref, Sabaya and Six Hills aquifers. By comparing the obtained results with the standard limits values in the valid drinking water guidelines, it was noticed that the majority of the groundwater (79%) in the study area was unsuitable for consumption due to excessive levels of these metals (Fe, Mn and Pb) than the permissible limits for drinking water. Additionally, the total organic carbon and microbiological examinations showed that the groundwater of the three aquifers was contaminated. It was shown that the HQ and HI values for trace elements and heavy metals and minor constituents (B) exceeded the value of 1, i.e., exposure to potentially toxic chemicals, such as iron, manganese and lead in groundwater can pose great risks to human health, i.e., the groundwater in the study area poses adverse risks on human health to the local population, which means that there is a strong relationship between the contaminants found in groundwater and some certain diseases, which is common in the study area.

Keywords: Hydrochemistry, Water quality, Health risk assessment, Mut area, Egypt.

1. Introduction

Water is one of the essential components of life, and without it there is no life. Water is essential to life because it heavily affects public health and living standards. Water is a very important required substance in order to sustain vital activities of human such as nutrition, respiration, circulation,

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excretion, and reproduction; it facilitates the work of the kidneys and other organs (Akın and Akin, 2007).

Only about 0.3% of the water resources in the world are usable. However, as a result of different effects, especially human activities, water resources are polluted and still used unconsciously (Kılıç, 2020). However, water is increasingly contaminated worldwide, accounting for over 1.8 million deaths yearly (Landrigan *et al*., 2018). Therefore, it is necessary to use water resources carefully.

In arid and semiarid areas, groundwater is an indispensable global resource for drinking, domestic, and irrigation purposes. So, many countries that depend on groundwater as a renewable resource are concerned with declining water quality and quantity in the aquifer (Mohammadi *et al*., 2018 and Qasemi *et al*., 2019).

The main pollutants encountered in water are detergents, household wastes and fertilizers, food industry wastes, various metals, oils, and organic toxic wastes, pathogens, and pesticides. Water pollution does not only stay in water; it passes to the soil and from the soil to plants, vegetables, and fruits through irrigation, and these harmful wastes also pass to the animals that drink from this polluted water, which in turn affects human health, where the human living in this environment drinks this polluted water and feeds on both polluted plants and animals, and then he becomes infected with diseases such as cancer and then dies.

In the last years, some diseases had spread in Mut area in El Dakhla Oasis, which is located in the New Valley Governorate. The concerned paper will answer the question: whether there is a relationship between the chemical characteristics of groundwater and these spread diseases in the study area or not. So, this study aims to investigate the potential link between the chemical characteristics of groundwater and the prevalence of diseases in the study area.

Groundwater represents the sole source of water supply in south Mut area. Where, the groundwater is often used for drinking and irrigation purposes. So, groundwater is the most precious natural resource for human survival in the study area. Groundwater quality, however, is deteriorating at an alarming rate due to the intensive human activities, which pose significant health risks to people who consume it and take baths with it.

This kind of practice is called a human health risk associated with exposures to iron, manganese, lead, boron, and many pollutants present in groundwater in the investigated area.

From the context of groundwater contamination issues, with a special emphasis on water resource contamination from potentially toxic metals (PTMs) such as Cd, Cu, Co, Cr, Pb, Zn, Fe, and B (Crevecoeur *et al*., 2011). Overexploitation, dissolution, and rock weathering increase the concentrations of PTMs in groundwater. Consumption of these PTMs causes acute and chronic diseases and affects human health in the long term, causing sterility, neurotoxicity disorders, and cardiovascular disease (Strachan, 2010 and WHO, 2017).

So, this paper aims to assess the groundwater quality and its risks to human health for the local population in the study area. This was achieved through the integration of a hydrochemical characterization approach and assessment of the potential toxic effects of trace elements and heavy metals, as well as some minor constituents, on human health as a result of direct water consumption.

To achieve the objective, the following were carried out: 1) collection of fifteen water samples, including Mut Lake (one sample), and fourteen groundwater samples representing the Taref, Sabaya and Six Hills aquifers; 2) performing the chemical analysis to determine the concentrations of major and minor constituents as well as trace metals in the collected surface water and groundwater samples from the study area. Additionally, biochemical and bacteriological analyses were conducted for the collected water samples; 3) studying the hydrogeochemical characteristics, hydrochemical facies of groundwater and their formation mechanisms; 4) assessing the integrated role of the hydrochemical processes, agriculture activities, and wastewater seepage on the groundwater system using Piper diagram; 5) identifying the factors affecting groundwater quality using the discussion of selected trace metals concentrations and total organic carbon as well as microbiological pollutants for the groundwater samples. In addition, the distribution of these selected pollutants parameters of groundwater; 6) assessing the status of groundwater quality and its potential risks to human health that are posed by drinking contaminated groundwater for adults by computing the health risk (HQ) and noncancer hazard index value ; 7) appraising the overall groundwater quality for drinking and irrigation purposes; and 8) suggesting solutions for mitigating the effect of using the polluted water on the human health in the study area.

This study will be helpful to local decision-makers for protecting the groundwater quality and utilizing the groundwater resource more effectively.

Description of the study area

El Dakhla Oasis is one of the oases of the Western Desert and it is considered the center of the New Valley Governorate in Egypt. It extends about 80km from east to west and 25km from north to south. It is located on the road linking Farafra in the north and Kharga in the east. Mut city is the capital of El Dakhla Oasis.

The study area is located south Mut city, in the southern part of El Dakhla Oasis. It is bounded by latitudes 25º 27′ 30″ and 25º 32′ 30″N and longitudes 28º 55′ 30″ and 29º 02′ 00″E covering an area of about 139km^2 (Fig. 1). According to Egypt Census Estimations, 2023, the total populations of El Dakhla Oasis are 75,356 people.

The area under investigation is characterized by an extremely arid climatic condition having very low annual rainfall (1.6mm). The minimum temperature (4.4ºC) was recorded during January, whereas the highest temperature (40.2ºC) was recorded during June. The minimum evaporation value was recorded in January (5.4mm/day) and its maximum value was recorded in June (16.9mm/day), (Mahmoud and Ghoubachi, 2017).

Physical setting

Topographically, the ground surface of the study area is covered by sand, silt, and clay that are derived from the decomposition of pre-existing Cretaceous rocks (Mut and Taref Formations) with low relief. Its surface elevation ranges from 114 to 180m above sea level with a general slope towards the northwestern direction. Some residual hills from the Taref Formation are exposed in the central and eastern parts of the study area (Mahmoud and Ghoubachi, 2017).

Geomorphologically, El Dakhla Oasis represents one of the famous depressions of the great sandstone-limestone plateau of the Western Desert. The tectonic action (faults and folds) followed by the weathering processes (physical and chemical) associated with the climatic changes of the Quaternary times made modifications and helped in forming the present shape of El Dakhla Oasis (Ball, 1927 and Ibrahim, 1957). El Dakhla Oasis exhibited three main geomorphologic units: the high plateau, the depression, and the structural plain (Ghoubachi, 2001). The following is a description of these units:

1- The high plateau unit bounds El Dakhla depression from the north; it is characterized by a wide extended surface and a precipitous escarpment. Its surface is generally rough and slopes regionally to the northward direction. This unit is divided into two subunits (the plateau surface and the escarpment subunits).

2- The depression unit is controlled structurally, and it is an erosionally low topographic area. It contains different landforms represented by the alluvial terraces, the piedmont plain, and the residual hills.

3- The structural plain unit resulted from the merging of El Dakhla depression gradually to the south into an extensive elevated plain sloping northward. The origin of this plain is either by weathering (Mitwally, 1953) or by erosion (Shata, 1953). This plain contains sand dune chains and isolated hills, which are affected by structures (faults and fractures).

Geologically, the exposed rocks in the study area and its vicinity range in age from Upper Cretaceous to Quaternary (Attia, 1970; Mansour *et al*., 1982 and Said, 1990). These rocks are represented by the Taref Formation, the Mut Formation and Quaternary deposits.

In general, from the structural point of view, Shata (1953) considered El Dakhla depression as a low area occurring between major structural highs. On the other hand, Hermina *et al*. (1961) stated that "El Dakhla depression is considered a major syncline located on the north plunge of the Nubia huge upwarping". This depression is affected by folds and faults, which are oriented in the NE-SW direction.

Aquifer system

El Dakhla Oasis has been studied by many authors, among those are; Koraney *et al*., 2001; Ebraheem *et al*., 2004 and Gad *et al*., 2011. According to these studies, the Nubian Sandstone succession was divided into three main water bearing formations separated by three alternative confining clay layers. These aquifers, from top to bottom, are the Taref sandstone, Sabaya sandstone and the Six Hills sandstone. Thorweihe and Heinl (1993) concluded that the groundwater of the Nubia aquifer system is fossil water. The Taref sandstone aquifer represents the most important water bearing formation in the study area, because it is located at shallow depths with good water quality. The average thickness of this aquifer attains 110m and its thickness increases towards the southwest direction. Groundwater in the study area occurs under confined and semiconfined conditions in the northern part of the study area where the confining Mut Formation (clay and sandy clay layers) overlays the Taref sandstone. By contrast, in the southern part of the study area, the groundwater occurs under unconfined conditions where the Mut Formation is absent and the Taref sandstone is exposed on the surface. The groundwater flow is from the southwest direction towards the northeast.

2. Materials and Methods

Water sampling collection

The field trip was carried out during December 2022, as a part of the geological, hydrogeological, and hydrogeochemical investigations of the study area. A total of 15 water samples were collected from the study area, one sample representing Mut Lake and fourteen groundwater samples representing the Taref, Sabaya and Six Hills aquifers, to assess the water quality and health risk of the groundwater in the study area on human health. The sampling sites (longitudes and latitudes) of the collected water samples were recorded using a portable Global Positioning System (GPS) model etrex 10 (German) and therefore plotted to generate the map of the sampling locations (Fig. 1). The water samples were collected in new, tightly capped 500ml polyethylene sterile bottles that were washed three to four times with the water sample before filling them to capacity to avoid unpredictable changes in characteristics as per standard protocols. After water collection, the collected water samples were tightly packed to protect them from atmospheric CO_2, and these bottles were labeled to avoid any possible error. The groundwater samples were collected from wells after pumping water for about 10-15 minutes to eliminate the influence of static water and minimize errors due to oxidizing and carbonating agents. The temperature, electrical conductivity (EC) and potential of hydrogen ion concentration (pH) were determined immediately after the collection of the samples using a portable electrical conductivity meter (Jenway, model 470) and a pH meter (Jenway, model 3150). Before each measurement, the pH meter was calibrated with a reference buffer solution of pH=4. The available hydrogeological data (depth to water, total well depth, lithology, and the water-bearing formations), as well as the geological information, were identified during the field trip.

Analytical techniques

Four sets of water samples were collected from each sampling site in the study area to be analyzed by the author; the first set was taken in a special container (100ml) for the measurement of major cations and anions according to Rainwater and Thatcher (1960). The second set was taken in another special container (100ml) for the measurement of minor constituents according to Fishman and Friedman (1985). The third set was taken and acidified with nitric acid (1%) and stored in pre-cleaned polyethylene bottles for the measurement of trace elements and heavy metals according to the methods adopted by the American Society for Testing and Materials (ASTM, 2002). Finally, the fourth set was taken in sterile bottles to recognize the total and fecal coliform bacteria as an indicator of potential bacterial contamination according to the standard methods adopted by the American Public Health Association (APHA, 1998).

The collected surface water and groundwater samples were transported to the laboratories of the hydrogeochemistry department at the Desert Research Center, Cairo, Egypt, and stored in a refrigerator at 4°C before analysis to perform the required chemical analyses. Total dissolved solids (TDS) were measured by the calculation method. The analysis of the major ions as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-) and sulfate (SO_4^{2-}) was performed using an Ion Chromatography device (DIONEX ICS-1100). While carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) were determined by titration using H_2SO_4. Trace elements and heavy metals contents (Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Sr) as well as minor constituent Boron (B) in the water samples were determined using inductively coupled plasma (ICP). The total microbial count and coliform

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count was determined using the Most Probable Number (MPN) index and MacConkey broth media. The positive tubes were streaked on the Eosin Methylene Blue (EMB) agar plates. Microscopic examination was carried out to ensure gram-negative, non-spore forming rods (APHA, 1998). MPN of fecal streptococci was determined using azide dextrose broth at 37°C for 48hr. Positive tubes were indicated by dense turbidity and confirmed using ethyl violet azide dextrose broth incubated at 37°C for 24hr. (APHA, 1998). Nine multiple tube dilution technique using double and single strength Bromo-Cresol Purple MacConkey medium for detection of *E. coli* (Thermotolerant coliform, TTC) with the production of yellow colored colonies on a membrane filter at 44.5^{0}C.

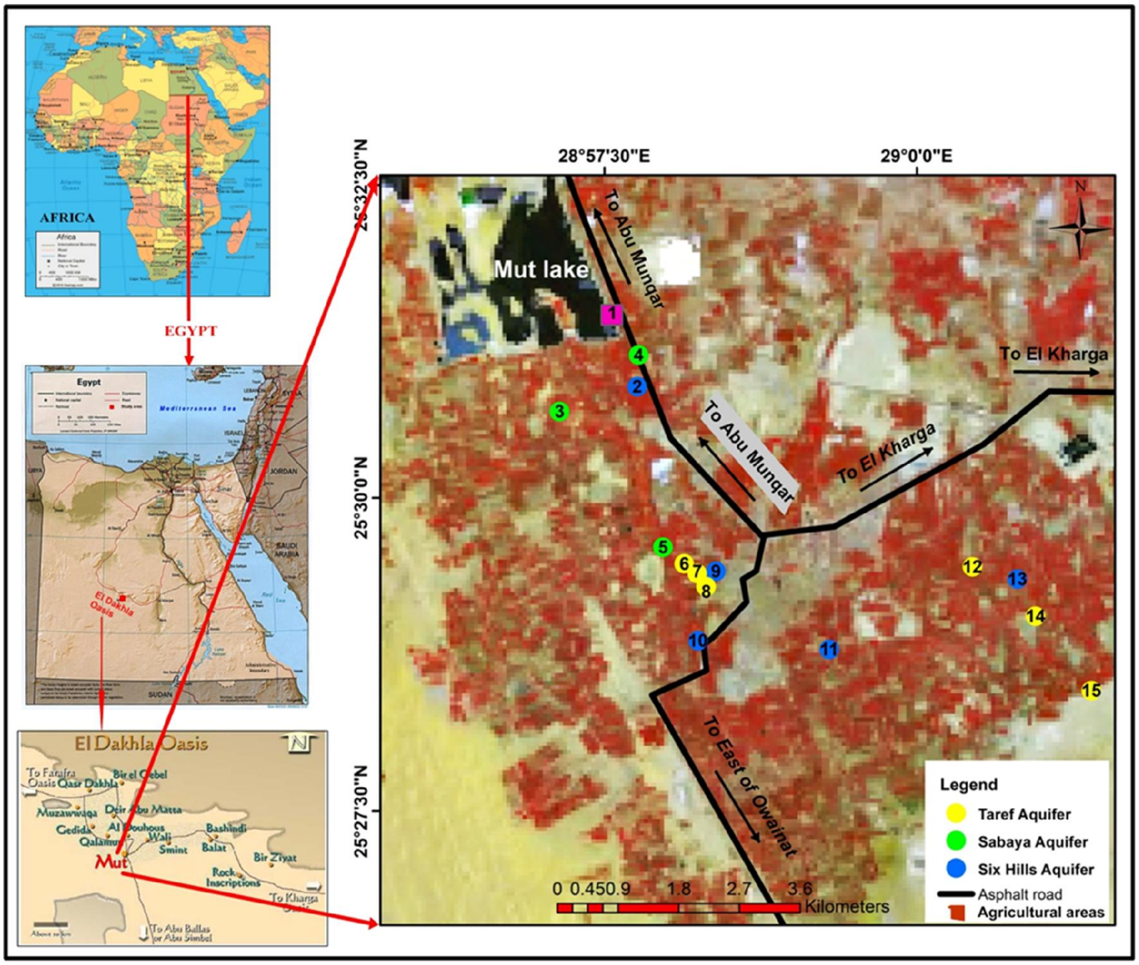

Fig.1: Water samples location map of south Mut area

Quality control

To ensure the accuracy of the data, the blank samples were analyzed after each five samples, and the analysis of standards as well as samples was performed in triplicate during the analysis process. The precision and accuracy of the analyzed constituents were assessed against standard reference materials for each constituent.

Quality assurance

For quality assurance of analytical techniques, the extra-pure analytical-grade reagents and chemical standards (Merck Grade) were used for the groundwater quality analysis by adopting standard procedures. For making reagents and standards, ultrapure water was used. Further, the accuracy of analytical results was tested by calculating the ionic balance error according to the following equation:

IBE = [(cations − anions) / (the smallest value either cations or anions)] × 100……………..……... (1)

The obtained chemical data were expressed in milligram per liter (mg/l) or part per million (ppm). All the obtained data was tabulated in tables (1, 3 & 4). It is worth mentioning that, the analytical precision for the measured major ions is ≤ 5%.

Data analysis methods

Collection of the geomorphological, geological, and hydrogeological data of the study area from the previous works and internal reports, and use of a topographic map (scale 1: 100,000) for preparation of the base map of the studied area as well as preparing the structural lineaments map. Computer programs such as Word and Excel 2007 for Windows and Surfer (v.13) as well as remote sensing and GIS techniques, were used. The wells' location map was created using a satellite image of Sentinel-2 that was produced by the European Space Agency with a pixel resolution of 10m. The wells' locations were identified by GPS and overlayed the satellite image to illustrate the spatial distributions of the collected samples within the Mut area. The map was produced and exported in Arc GIS (ver. 10.4).

3. Results and Discussion

Structural lineaments extraction

The careful analyses of the structural lineaments clarify the existence of trend NE-SW direction, (Fig. 2). The lineament may be geomorphological or tonal (caused by contrast differences) surface features. These linear features represent the weakness zones or structural displacement in Earth's crust (Hobbs, 1904 and 1912). The lineaments analysis suggests that most of the lineaments are homogeneously distributed over the area. Also, there are connections between Mut Lake water and the Taref aquifer. These lineaments are expected to provide a chance for groundwater recharge from Mut Lake water.

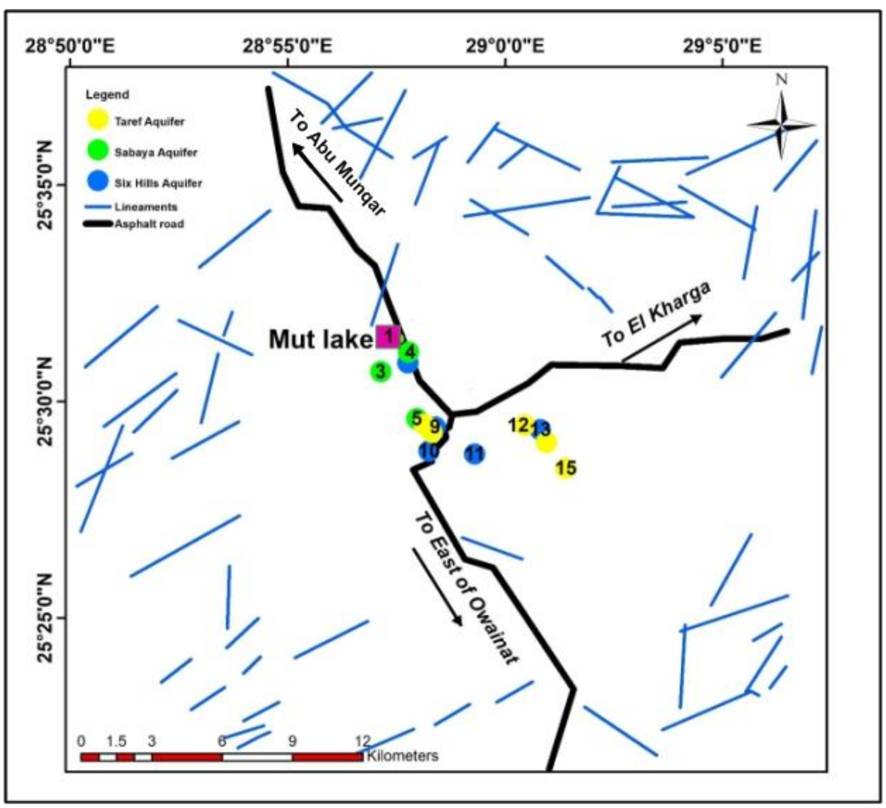

Fig. 2: Extracted structural photo-geologic lineaments (faults and/or joints) map of the study area overlaid by groundwater samples

Hydrochemical characteristics

Hydrochemical characteristics are widely used to indicate the source of the main components of ions, types of groundwater, water–rock interactions, and groundwater reservoir environments (Xu *et al*., 2019). Knowledge of hydrochemical characteristics is useful for evaluating groundwater quality because it provides an understanding of groundwater suitability for various purposes (Islam *et al*., 2017 and Li *et al*., 2016).

In the study area, the hydrochemical characteristics of Mut Lake water as well as Nubian sandstone groundwater will be discussed based on the physicochemical parameters, hypothetical salts combinations, and Piper diagram.

Physicochemical parameters

According to Chebotarev's classification (1955) and as in table (1), Mut Lake water is highly saline with a total dissolved solids content of 22163mg/l (TDS > 10,000mg/l), this elevated salinity is likely attributed to the evaporation processes. On the other hand, the groundwater in the study area is fresh water type, where they have salinities contents do not exceed 1105mg/l (TDS up to 1500mg/l). The Nubian sandstone groundwater salinities in the study area range from 131-1105, 255-257 and 131-242mg/l in Taref, Sabya and Six Hill aquifers, respectively.

Noteworthy to mention that the low salinity values of the Taref and Sabaya groundwater samples may be attributed to the hydraulic connection with the underlying Six Hills aquifer of low groundwater salinity through a fault plane (Fig. 2).

In general, it is obvious that the values of the groundwater salinities in the study area increase generally with the depth of wells, and this may be due to the following factors;

1. The effect of seepage of Mut lake water through faults and clastics (anthropogenic activity) especially to the Taref aquifer, (Fig. 2).
2. The overexploitation of water from the wells.
3. The mixing with the return flow after irrigation.
4. The continuous rock-water interaction during water flow upward as a result of the high piezometric pressure and the long period of exploitation of the shallow zone of the aquifer, which is characterized by shally materials (Hamza *et al*., 2000).

Also, it is clear that the values of the sulfate content in the groundwater samples in the study area increase generally with the depth of wells, and this may be due to the effect of seepage of Mut Lake water through faults and clastics (anthropogenic activity), (Fig. 2).

Hypothetical salts combinations

Hypothetically, there are chemical combinations between the major anions and major cations; to clarify such combinations, the relation between the anions and cations in the investigated surface water (Mut Lake water) and groundwater was illustrated in the form of main groups of hypothetical salt assemblages (Collins, 1923). The hypothetical salt assemblages of the surface water (Mut Lake water) and groundwater (Taref, Sabaya and Six Hills aquifers) in the study area were categorized into different groups (Table 2). As in table 2, it is obvious that Mut Lake water sample is characterized by the hypothetical salts assemblage (III), regardless of its total salinity. This salt assemblage (III) is characterized by the presence of one chloride and two sulfate salts and represents a more advanced stage of chemical development. This is attributed to anthropogenic and irrigation activities.

Table 1: The electrical conductivity (µs/cm) at 25^0C, pH, salinity and major cations and anions concentrations in Mut Lake water and the Taref, Sabaya, and Six Hills groundwater samples as mg/l

Sample No.	EC	pH	TDS	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}	HCO_3^-	SO_4^{2-}	Cl^-
Surface water (Mut lake water)											
1	41200	8.75	22163	1165.83	1367.65	4700	1550	0	305	6432.83	9858.34
Groundwater											
Taref aquifer											
6	492	7.79	290	35	17.496	37.6	6	0	61	115.686	48.0962
7	726	7.45	438	39	35	48	12.7	0	73.2	190.688	75.5151
8	227	7.89	131	16.08	3.91	20	9	0	48.8	26.5596	31.4837
12	1389	7.6	863	131.4	18.589	125	15	0	48.8	321.838	227.175
14	1741	7.45	1105	156.784	19.49	172.95	9	0	32.95	498.56	233.33
15	347	8.61	209	31.5	4.884	28	9	0	61	73.64	31.4837
Sabaya aquifer											
3	421	7.89	257	39.6	18.6	20	6.9	0	87.84	54.856	72.696
4	417	7.96	255	36	18.59	24	7.1	0	73.2	64.4695	68.1526
5	429	7.96	256	32.4	12.029	32.6	7.2	0	68.32	79.415	57.8076
Six Hills aquifer											
2	228	8.49	132	18	7.748	12	10	0	68.32	18.237	31.8045
9	416	8.00	242	31.9	15.01	28	7.1	0	61	54.856	74.55
10	222	7.84	131	22.5	4.88	12	7	0	48.8	32.34	27.6926
11	363	8.22	196	33.3	7.748	22	7.6	0	97.6	33.936	42.2702
13	261	7.93	152	18.09	8.55	20	7	0	68.32	32.34	31.4837

The combination between the major anions and cations in the Taref groundwater samples in the study area revealed two groups of hypothetical salts combinations (Table 2). As in table 2, it is clear that, about 83% of the Taref groundwater samples are characterized by the hypothetical salts assemblage (I), regardless of their total salinities. This salt assemblage (I) is characterized by the presence of three sulfate salts and represents an earlier stage of chemical development. The rest of the groundwater samples (17%) are characterized by the hypothetical salts assemblage (III), (with one chloride and two sulfate salts), regardless of their total salinities. Additionally, in Sabaya aquifer in the study area, the combination between the major anions and cations revealed two groups of hypothetical salts combinations (Table 2). As in table (2), 25% of the groundwater samples are characterized by the hypothetical salts assemblage (I), (with three sulfate salts) regardless of their total salinities, while the rest of the samples (75%) are characterized by the hypothetical salts assemblage (III), (with one chloride and two sulfate salts) regardless of their total salinities. Finally, in the Six Hills aquifer, in the study area, the combination between the major anions and cations revealed three groups of hypothetical salts combinations (Table 2). As in table (2), 20% of the groundwater samples are characterized by the hypothetical salts assemblage (I), (with three sulfate salts), regardless of their total salinities, and 20% of the groundwater samples are characterized by the hypothetical salts assemblage (II), regardless of their total salinities. This salt assemblage is characterized by the presence of one chloride, one sulfate, and one bicarbonate salts and represents an intermediate stage of chemical development. The rest of the groundwater samples (60%) are characterized by the hypothetical salts assemblage (III), (with one chloride and two sulfate salts) regardless of their total salinities.

It is clear that (as in table 2), both Taref and Sabaya groundwater samples have two stages of chemical development, whereas Six Hills groundwater samples have three stages of chemical development. This development stage may be due to the leaching and dissolution as well as cation exchange processes. In general, the Nubian sandstone groundwater in the study area evoluted from the earlier stages of chemical development (I) to the more advanced stages of chemical development (III), passing by the intermediate stages of chemical development (II).

The presence of the hypothetical salts assemblages (I and III) in Taref, Sabaya and Six Hills aquifers indicates that there are hydraulic connections between these aquifers. Also, the presence of the hypothetical salts assemblage (III) in the Taref aquifer as well as in Mut Lake indicates that there is recharge from the lake to the groundwater of the Taref aquifer due to seepage of the Mut Lake water through faults and clastics (anthropogenic activity), (Fig. 2).

Table 2: The hypothetical salts combinations of Mut Lake water and the Taref, Sabaya and Six Hills groundwater samples in the study area

Assemblages	Hypothetical salts combinations	Percentage%
	Surface water (Mut Lake water sample)	
III	$NaCl$, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	
	Groundwater El Taref aquifer water samples	
I	$NaCl$, Na_2SO_4, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	83
III	$NaCl$, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	17
	Sabaya aquifer water samples	
I	$NaCl$, Na_2SO_4, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	25
III	$NaCl$, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	75
	Six Hills aquifer water samples	
I	$NaCl$, Na_2SO_4, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	20
II	$NaCl$, $MgCl_2$, $MgSO_4$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$	20
III	$NaCl$, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$	60

Piper diagram

Groundwater genesis and evolution is affected by various factors through consumptive use (water supply and over-pumping) and pollution by any anthropogenic activities (wastewater). These conditions lead to threating the groundwater system in the study area. The groundwater genesis can be investigated through the graphical representation as Piper (1944) diagram. Moreover, identifying the controlling factors causing the evolution of groundwater components based on regional hydrogeological conditions and long-term water quality monitoring data and taking corresponding measures to better protect the underground environment are necessary to further reflect the evolution direction of the groundwater environment (Chen *et al*., 2022).

The plotting of chemical data on the Piper diagram (Fig. 3) provides a visual representation of cation and anion composition of the studied water samples to be shown on a single graph where the major data grouping can be discerned and investigated. The hydrochemical data of Mut Lake water sample and the Nubian sandstone groundwater samples in the study area were plotted on a Piper triangular diagram (Piper, 1944), (Fig. 3).

The results showed that Mut Lake water sample lies in the sub-area (7), while the majority of the groundwater samples (86%) in the study area lie in the sub-area (9) and the rest of the groundwater samples (14%) lie in sub-area (6). About 33% of the Taref groundwater samples in the study area are lying in sub-area (6), indicating that the groundwater of this aquifer is dominated by non-carbonate hardness (secondary alkalinity, $SO_4^{2-} + Cl^-$) exceeding 50%. This reflects that this groundwater is affected only by leaching and dissolution processes with no influence of surface water. The presence of 86% of the groundwater samples tapping the Taref, Sabaya and Six Hills aquifers in sub-area (9) and being clustered close to each other, indicating that these aquifers are hydraulically connected and this groundwater is affected by the continental conditions. Moreover, it was noticed that the Taref groundwater samples are located near to Mut Lake water sample, indicating that these groundwater samples are affected by the seepage from Mut Lake water through faults and clastics (anthropogenic activity), (Fig. 2).

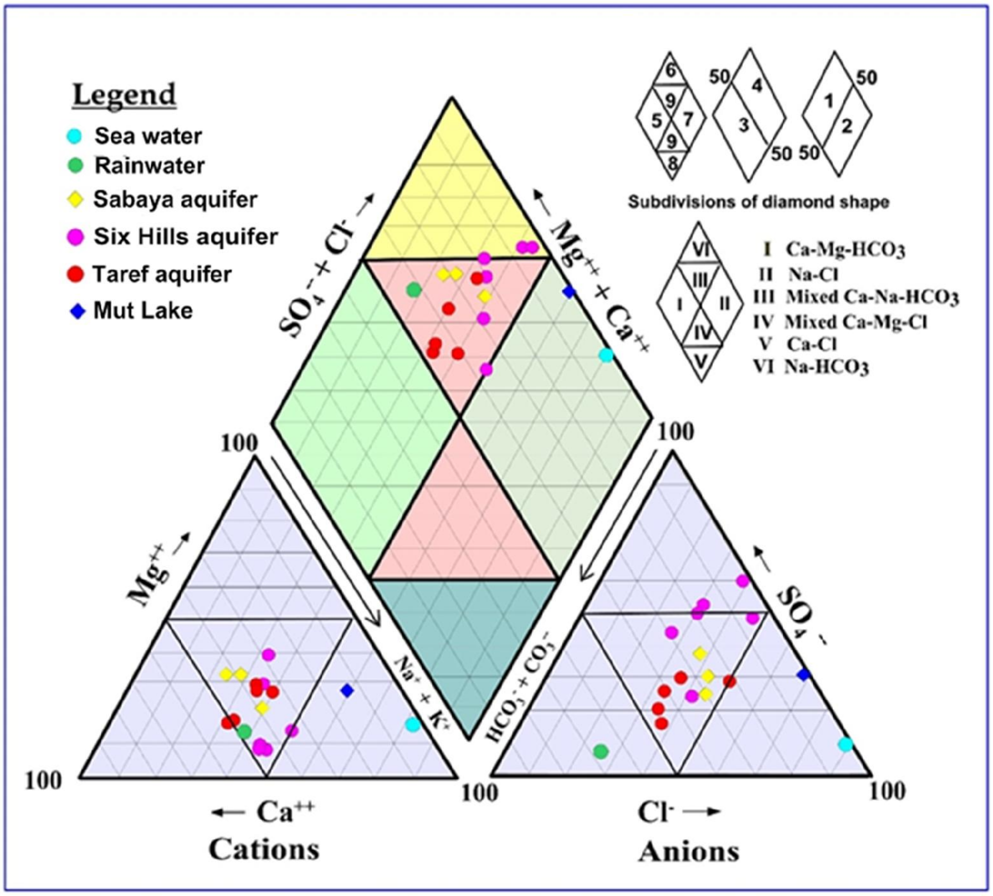

Fig. 3: Piper diagram for the surface water and groundwater samples in the study area

Water pollution

Water pollution is a major concern of developing countries, including Egypt, especially with increasing agricultural activities that are responsible for the generation of toxic pollutants (e.g., inorganic anions, metal ions, and synthetic organic chemicals), (Velizarov *et al*. 2004).

The water pollution in the study area was studied through discussion of heavy metals pollution, pollution indices and microbial content in water, this can be done by detecting the concentrations of selected trace elements and heavy metals as aluminum (Al), Barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb) and strontium (Sr), and selected minor constituents as boron (B), as well as the total organic carbon (TOC) and microbiological parameters (total microbial count and coliform count).

Heavy metals pollution

The term heavy metal (HM) refers to a group of metals or metalloids having toxic effects even at lower concentrations (part per billion levels) and possessing higher density (Sharma and Agrawal, 2005) and having a poisonous nature at lower concentrations. Based on the health relevance of heavy metals, they are classified as essential metals (Fe, Mn, Zn, Co, Cr and Cu) and non-essential metals (Al, Ba, Li, Pb, Cd, Zr and As), (Balali-Mood *et al*., 2021). Also, heavy metals can be classified as less toxic metals (Sn and As), and highly toxic metals (Hg, Cd, and Pb), (Duffus, 2002).

As in table (3), the obtained results clarified that Fe, Mn and Pb concentrations in the groundwater samples in the study area exceeded the allowed limits for drinking water according to WHO (2017), while Al, Ba, Cd, Co, Cr, Cu, Ni and Sr as well as B are within the allowed limits. So, the heavy metals pollution in the study area will be discussed by addressing the concentration of Fe, Mn and Pb as follows;

Iron and manganese are naturally occurring metals and they are considered essential metals required for proper body function. Groundwater quality is presently vulnerable to contaminants from natural and human activities (Onodera, 2011). Among many contaminants, iron (Fe) and manganese (Mn) are present in chemicals derived from both natural sources, such as soil and rock, and human activities, such as industrial wastewater and the overexploitation of groundwater, and can eventually pollute groundwater (Onodera *et al*., 2008).

There are several natural and anthropogenic activities responsible for the heavy metals contamination of water (Dewata and Adri, 2018). The domestic, and fertilizers, pesticides, and insecticides used in the irrigation field add pollutants to the environment, i.e., they also are responsible for hazardous metallic contamination in water.

The trace metals (Fe) and (Mn) are undesirable in clean water due to aesthetic problems, the deterioration of distribution networks, and health issues (WHO, 2017). At concentrations found in most natural water, and at concentrations below the aesthetic objective, iron and manganese are not considered a health risk.

In general, overexposure to the iron and manganese metals can cause adverse health risks, including Parkinson disease, Huntington disease, cardiovascular disease, hyperkeratosis, diabetes mellitus, pigmentation changes, Alzheimer disease, kidney, liver, respiratory and neurological disorders (Farina *et al*., 2013), multiple sclerosis, and muscular dystrophy (Neeti and Prakash, 2013). HM poisoning can either cause chronic effects like neurological disorders, physical abnormalities, muscular effects, genetic and hereditary problems, or acute effects like vomiting, dehydration, drowsiness, nausea, renal failure, and abdominal pain (Markich *et al*., 2001and Sun *et al*., 2018).

The concentrations of iron and manganese can range up to several mg/l, and the concentration of iron and manganese in well water can fluctuate seasonally and vary with the depth and location of the well and the geology of an area. Iron and manganese naturally occur in groundwater that has little or no oxygen, typically in deeper wells (but not always), in areas where groundwater flow is slow, and in areas where groundwater flows through soils rich in organic matter.

In the study area, the concentration of Fe in Mut Lake water sample is 0.173mg/l, while in the groundwater samples it varies between 0.2348-12.66, 7.572-8.454 and 3.222-8.219ppm for the Taref, Sabaya and Six Hills aquifers, respectively (Table 3 and Fig. 4). It is noticed that, Mut Lake water sample has a low value of Fe; this may be due to the deposition of iron on the lake bottom. Also, the majority of the groundwater samples (93%) in the study area have Fe concentrations that exceeded the permissible limit (0.3ppm) for drinking water (WHO, 2017), and the rest of the groundwater samples (7%) that tapping the Taref aquifer have Fe concentrations (0.2348ppm) less than the permissible limit.

Also, in the study area, the concentration of Mn in Mut Lake water sample is 0.1781mg/l, while in the groundwater samples it varies between 0.1508-7.416, 0.383-0.4152 and 0.1785-0.4117ppm for the Taref, Sabaya and Six Hills aquifers, respectively (Table 3 and Fig. 5). It is noticed that, Mut Lake water sample has a low value of Mn; this may be due to the deposition of manganese on the lake bottom. Also, most of the groundwater samples (65%) in the study area have Mn concentrations that exceeded the permissible limit (0.4ppm) for drinking water (WHO, 2017), and the rest of the groundwater samples (35%) that tapping the Taref and Six Hills Formations have Mn concentrations less than the permissible limit.

It can be concluded that the Taref and Sabaya aquifers are the more polluted than the Six Hills one. Also, the high iron content determined in the investigated groundwater samples provides an evidence of pyrite mineral.

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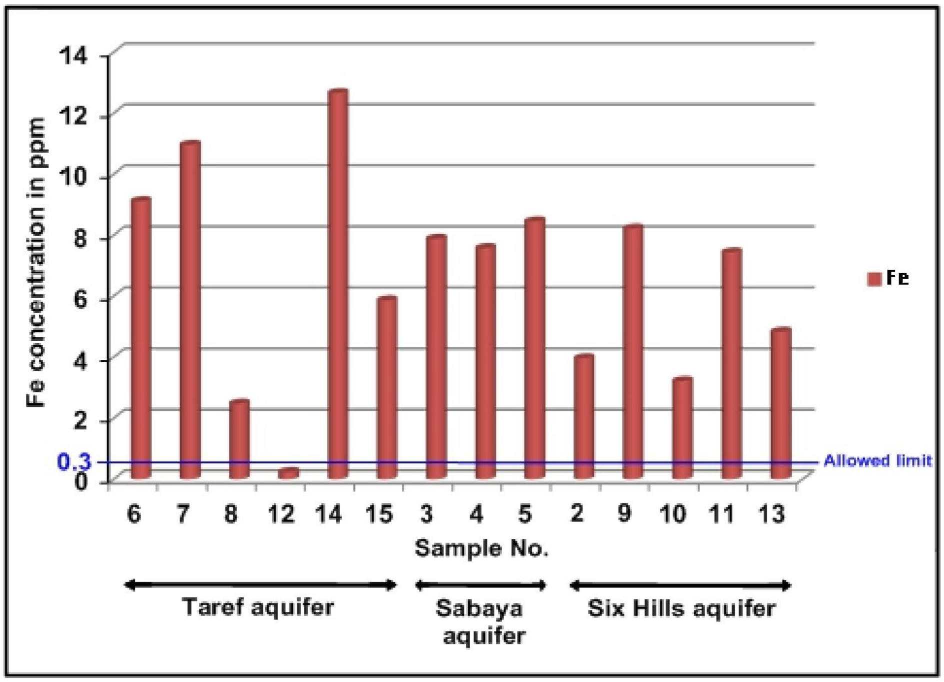

Fig. 4: The concentration of Fe in the Taref, Sabaya and Six Hills groundwater samples in the study area

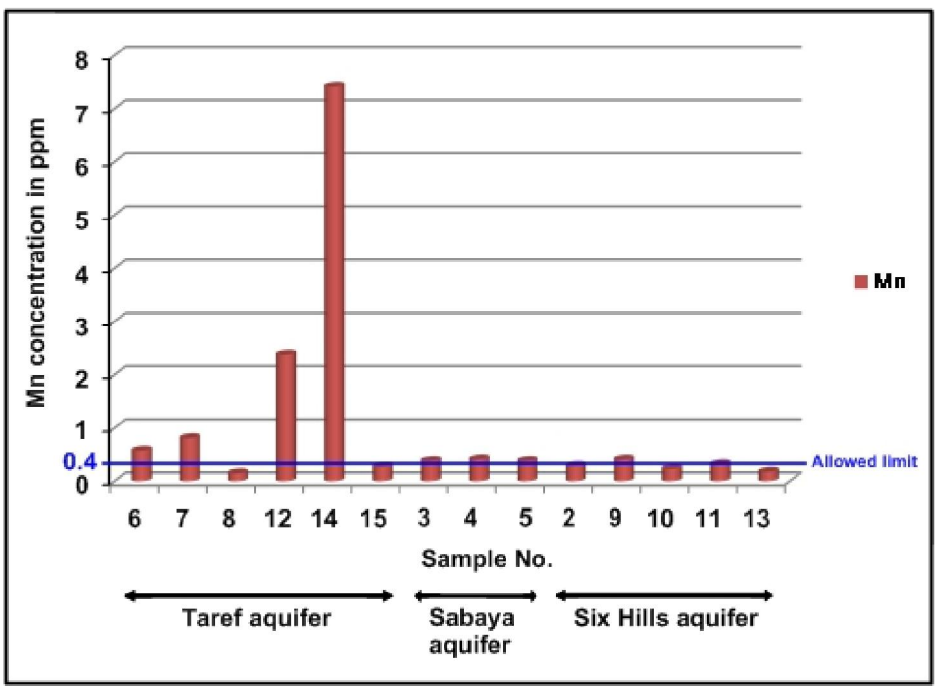

Fig. 5: The concentration of Mn in the Taref, Sabaya and Six Hills groundwater samples in the study area

Lead (Pb) is a naturally occurring metal. The lead is removed from the atmosphere by rain and transferred to soil or comes into contact with surface water. Moreover, lead is used as a pesticide during vegetable and fruit cultivation (Gall *et al.,* 2015). Lead enters water bodies or lakes when these soil particles are washed away by rainwater. Thus, lead is transferred to animals and plants from air, water and soil, and this cycle continues (Abadin *et al.,* 2007).

Common anthropogenic that contribute more in most cases of human Pb exposure are gasoline, car batteries, sewage sludge, and fertilizers (Singh and Kalamdhad, 2011).

Lead (Pb) is toxic to health by accumulating in the body and damages the central nervous system because the normal functioning of the nervous system is affected if an individual is exposed to lead for a long time. Noteworthy to mention that, most risky relative to children and pregnant women. Moreover, longer exposure also causes severe effects on the kidney as well as the brain. (Abadin *et al*., 2007 and Collin *et al*., 2022).

Lead is easily absorbed by the body. Children absorb higher amounts of lead than adults, which is highly dangerous as they are developing (Lidsky and Schneider, 2003). In children, lead is not absorbed by the bones like in the case of adults; therefore, they are at a higher risk of poisoning as the other soft tissues absorb the excess lead.

Lead affects the reproductive systems of both males and females, in the case of males, it causes a reduction in sperm count and volume, while in females who have high exposure to this metal, miscarriage, premature birth, and low birth weight problems are seen (Wu *et al*., 2012). Lead can damage cell structure, cell membrane, and most importantly, it interferes with DNA transcription (Yedjou *et al*., 2010).

The low amounts absorbed of Pb can accumulate in the human body system, resulting in lead poisoning or toxicity. Lead has a half-life of around 30 days in the blood, after which it diffuses into soft tissues such as the kidneys, brain, and liver and then distributed to bones, teeth, and hair as lead phosphate (Engwa *et al*., 2019). Lead (Pb) is carcinogenic and causes several types of cancers, including skin and gastric cancer. Moreover, toxicity of those trace metals are associated with respiratory disorders (Briffa *et al*., 2020).

In the study area, the concentration of Pb in Mut Lake water sample is 0.3734mg/l, while in the groundwater samples it varies between 0.2383-0.8361, 0.2055-0.8116 and 0.3202-0.57ppm for the Taref, Sabaya and Six Hills aquifers, respectively (Table 3 and Fig. 6). It is noticed that, Mut Lake water sample and all Taref, Sabaya and Six Hills groundwater samples in the study area have high values of Pb concentrations that exceeded the permissible limit (0.01ppm) for drinking water (WHO, 2017).

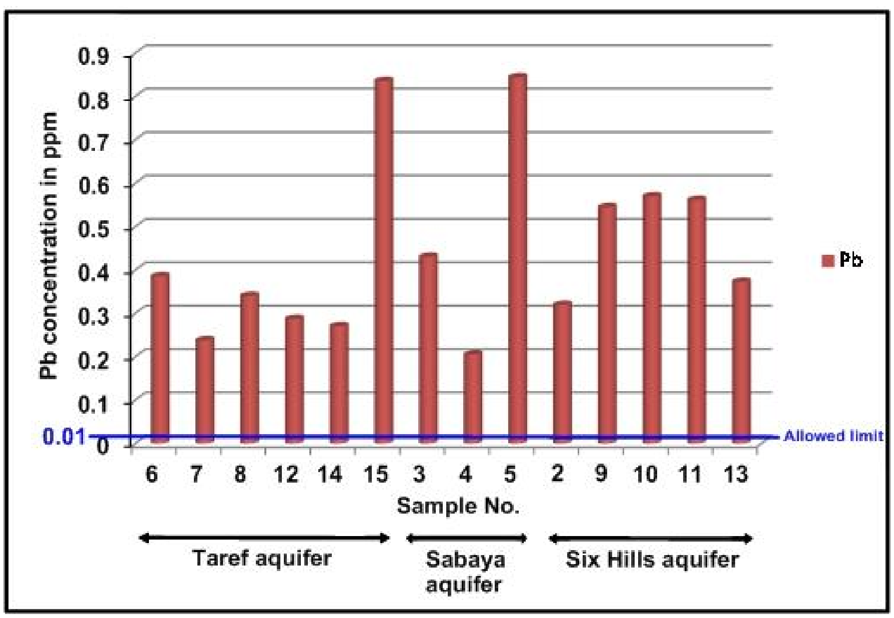

Fig. 6: The concentration of Pb in the Taref, Sabaya and Six Hills groundwater samples in the study area

Table 3: The concentrations of trace elements and heavy metals in Mut lake water and the Taref, Sabaya and Six Hills groundwater samples as mg/l

Sample No.	Al	Ba	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Sr
						Surface water (Mut lake)					
1	0.1061	0.0897	0.0341	0.0639	0.0987	0.0469	0.173	0.1781	<0.002	0.3734	16.55
						Groundwater					
						Taref aquifer					
6	0.3024	0.0444	0.0404	0.1106	<0.01	0.1647	9.12	0.5785	0.0088	0.3857	0.1724
7	0.1065	0.0397	0.0672	0.0246	<0.01	<0.004	10.97	0.8102	0.0031	0.2383	0.2637
8	<0.03	0.1605	0.0869	0.0839	<0.01	0.0313	2.472	0.1508	0.0867	0.3406	0.1204
12	0.3168	0.0249	0.0621	0.1739	0.047	0.0109	0.2348	2.387	0.1588	0.2874	0.2171
14	12.83	<0.008	0.0302	1.299	0.0396	0.3592	12.66	7.416	1.192	0.271	0.3512
15	0.3053	0.0532	0.0597	0.0526	<0.01	0.0533	5.871	0.2715	0.0867	0.8361	0.1338
						Sabaya aquifer					
3	0.0864	0.0567	0.083	0.0579	0.0544	0.0721	7.887	0.383	0.0525	0.4307	0.174
4	<0.03	0.0759	0.042	0.1106	<0.01	0.1537	7.572	0.4152	0.0525	0.2055	0.1727
5	0.0893	0.0582	<0.003	0.1033	0.0841	<0.004	8.454	0.383	0.0221	0.8116	0.1781
						Six Hills aquifer					
2	<0.03	0.2408	0.0503	0.0546	<0.01	0.0423	3.972	0.287	<0.002	0.3202	0.159
9	<0.03	0.0601	0.0585	0.0612	<0.01	<0.004	8.219	0.4117	<0.002	0.5454	0.176
10	<0.03	0.2365	0.0503	0.0459	0.0544	0.0548	3.222	0.2348	0.0563	0.57	0.1657
11	<0.03	0.0525	0.04	0.1093	<0.01	0.0423	7.438	0.3202	0.1	0.5618	0.1424
13	<0.03	0.2111	0.042	0.0646	0.0321	0.1882	4.839	0.1785	<0.002	0.3734	0.1836

Pollution indices

The pollution indices of the Taref, Sabaya and Six Hills groundwater samples in the study area can be discussed on the basis of the total organic carbon, where the total organic carbon (TOC) is used as water quality and pollution index. Also, the total organic carbon is a term used to describe the measurement of organic contaminants in a water system (Gedamy, 2015).

In the study area, the total organic carbon (TOC) in Mut Lake water sample is 352.44mg/l, while in the groundwater samples it varies between 55.692-371.28, 74.258-130.716 and 74.256-928.2mg/l for the Taref, Sabaya and Six Hills aquifers, respectively (Table 4). It was noticed that, Mut Lake water sample and all the groundwater samples in the study area have total organic carbon concentrations that exceeded the permissible limit (10mg/l) for drinking water (Egyptian organization for standardization and quality, 2007). This is due to the excessive use of fertilizers in the study area and return flow after irrigation. Also, this indicates that there are a seepage from Mut Lake to the Taref groundwater samples in the study area through the faults and clastics (anthropogenic activities), Fig. 2.

It was noticed that the high concentrations of trace metals are coupled with high dissolved total organic carbon (TOC), indicating reductive environmental conditions that arise due to the decomposition of organic matter.

Microbial content in water

The microbial content in water in the study area can be discussed by examining the total microbial count (colony-forming units per milliliter, cfu/ml) and coliform count (most probable number per 100 milliliters, mpn/100ml) in Mut Lake water and the Taref, Sabaya and Six Hills groundwater samples in the concerned area (Table 4).

The obtained results indicate that the total colony count (total viable counts, TVC) in Mut Lake water sample is 65cfu/ml, while in the groundwater samples in the study area it varies between 16-150, 30-50 and 19-43cfu/ml for the Taref, Sabaya and Six Hills aquifers, respectively (Table 4). It is noticed that, Mut Lake water sample and the majority of the groundwater samples (93%) in the study area have a total colony count that lies within the permissible limit (1×10^2 cfu/ml) for drinking water (WHO, 2008). The remaining groundwater samples (7%) that were tapping the Taref aquifer had a total colony count (150cfu/ml) that exceeded the permissible limit.

On the other hand, the coliform count (most probable number, mpn) in Mut Lake water sample is 6.1mpn, while in the groundwater samples in the study area it varies between 1.502-14.077, 2.815-4.692 and 1.783-7.4mpn for the Taref, Sabaya and Six Hills aquifers, respectively (Table 4). It is noticed that, Mut Lake water sample and the majority of the groundwater samples (86%) in the study area have a coliform count that exceeded the permissible limit (2 mpn/100ml) for drinking water (FAO, 1997), while the rest of the groundwater samples (14%) that tapping the Taref and Six Hills aquifers have a coliform count that did not exceed the permissible limit and was found to be (1.502 and 1.783, respectively). Owing to that, the coliform counts of these groundwater samples were grossly contaminated. Therefore, it was concluded that the majority of the studied groundwater samples in the study area may not be suitable for drinking unless treated.

Several bacterial species produce nutrients, digest food, and boost immune function (Zhang *et al*., 2015). On the other hand, some waterborne bacteria may cause diseases such as cholera, diarrhea, typhoid fever, and dysentery (Philip *et al*., 2018). The presence of coliforms in the Taref, Sabaya and Six Hills groundwater samples indicated that the groundwater was contaminated by environmental pollutants, particularly fecal matters. Most coliforms are harmless, while certain strains of Escherichia coli, which are the most common fecal coliforms often found in animal feces and may cause diseases, especially diarrhea (Gruber *et al*., 2014). Notably, the probable sources of microbial contaminants in the Taref groundwater samples are the Mut Lake water through faults and clastics (Fig. 2), agricultural activities, sewage water, illegal dumping of untreated domestic wastes, livestock management, animal wastes, human excrement and return flow after irrigation.

Noteworthy to mention that one of the causes of bacteriological pollution of the Nubian sandstone groundwater (Taref, Sabaya and Six Hills aquifers) in the study area is due to the presence of certain types of bacteria that use iron and manganese as part of their food or the presence of sulfur-reducing bacteria that are naturally present and thrive in the low oxygen environments present in groundwater wells and utilize sulfur in water in the decomposition of rocks, soil and plants and use it as a source of energy.

Human health risk assessment

Contaminated water with trace elements and heavy metals is responsible for several health issues in humans, like liver failure, kidney damage, gastric and skin cancer, mental disorders, and harmful effects on the reproductive system. Also, heavy metals exposure results in carcinogenic effects on humans (Jaishankar *et al*., 2014 and Singh *et al*., 2023). This process occurs when the heavy metals present in the aqueous medium bind to the microbial surface and enter the cell through the cell surface receptor (Zafar *et al*., 2007). When heavy metals ions enter the human body through food or water, they initiate various processes in the body and interfere with metabolic pathways or inhibit enzymatic activities (Witkowska *et al*., 2021). Consequently, both humans and animals suffer from a wide range of harmful effects as a result of these pollutants. Congenital disorders, immune system problems, and cancer are among the problems that can result (Ray *et al*., 2014).

The human health risk assessment can be discussed by interpreting the exceedance level and the health risk assessment as follows:

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Table 4: The concentrations of minor constituents, total organic carbon, and total microbial count and coliform count in Mut Lake water and the Taref, Sabaya and Six Hills groundwater samples as mg/l

Sample No.	B (mg/l)	TOC (mg/l)	Total microbial count (cfu/ml)	Coliform count (mpn/100ml)
Surface water (Mut lake)				
1	8.931	352.44	65	6.1
Groundwater Taref aquifer				
6	0.08	55.692	56	5.255
7	0.1958	148.512	29	2.722
8	0.1398	55.692	150	14.077
12	0.1865	111.384	25	2.346
14	0.3077	129.948	26	2.44
15	0.2891	371.28	16	1.502
Sabaya aquifer				
3	0.1958	92.82	30	2.815
4	0.4197	74.258	50	4.692
5	0.1491	130.716	31	2.909
Six Hill aquifer				
2	0.1491	74.258	32	3.003
9	0.08	928.2	27	2.534
10	0.0252	74.256	43	7.4
11	0.2984	74.256	33	3.097
13	0.1305	129.948	19	1.783

Exceedance level

The potential toxic elements of groundwater depend on the origin of the water, their journey to water reservoirs, nature of the land forming the reservoirs, the time of their formations, time spent inside the reservoir, the microflora and microfauna, the temperature, and other parameters (Khatri and Tyagi, 2015).

The toxicity of PTMs (Al, Ba, Cd, Cr, Cu, Fe, Mn, Ni and Pb) was evaluated on the basis of their exceedance values. Where potential toxic metals are the degree to which some of the PTMs exceed their respective World Health Organization (WHO, 2017) allowable limit, and it is expressed in terms of the exceedance level. It is a unit-less concept, expressed mathematically in equation 2;

$$\text{Exceedance level} = \frac{\text{Concentration of a quality parameter}}{\text{WHO acceptable limit}} \quad (2)$$

As shown in table (5), it is revealed that the exceedance values vary between 0 to 64.15, with an average value of 4.679 for Al; from 0 to 0.185, with an average value of 0.0748 for Ba; from 0 to 28.967, with an average value of 16.07 for Cd; from 0 to 1.682, with an average value of 1.087 for Cr; from 0 to 0.1796, with an average value of 0.0479 for Cu; from 0.783 to 42.2, with an average value of 22.05 for Fe; from 0.377 to 18.54, with an average value of 3.405 for Mn; from 0 to 17.029, with an average value of 1.733 for Ni and from 20.55 to 83.61, with an average value of 45.12 for Pb. This means that the majority of the investigated groundwater in the concerned area, especially that mainly tapping the Taref aquifer is contaminated as a result of the natural and anthropogenic actions in the study area.

Table 5: The Exceedance levels of trace elements and heavy metals in the Taref, Sabaya and Six Hills groundwater samples in the study area

Aquifer	Sample No.	Al	Ba	Cd	Cr	Cu	Fe	Mn	Ni	Pb
Taref aquifer	6	1.512	0.0342	13.467	0	0.0824	30.4	1.446	0.1257	38.57
	7	0.5325	0.0305	22.4	0	0	36.567	2.0256	0.0443	23.83
	8	0	0.1235	28.967	0	0.0157	8.24	0.377	1.2386	34.06
	12	1.584	0.0196	20.7	0.94	0.0055	0.783	5.9675	2.2686	28.74
	14	64.15	0	10.067	0.792	0.1796	42.2	18.54	17.029	27.1
	15	1.5265	0.0409	19.9	0	0.02665	19.57	0.6787	1.2386	83.61
Sabaya aquifer	3	0.432	0.0436	27.667	1.088	0.0361	26.29	0.9575	0.75	43.07
	4	0	0.0584	14	0	0.0769	25.24	1.038	0.75	20.55
	5	0.4465	0.0447	0	1.682	0	28.18	0.9575	0.3157	81.16
Six Hills aquifer	2	0	0.1852	16.767	0	0.0212	13.24	0.7175	0	32.02
	9	0	0.0462	19.5	0	0	27.396	1.0293	0	54.54
	10	0	0.1819	16.767	1.088	0.0274	10.74	0.587	0.8043	57
	11	0	0.0404	13.333	0	0.0212	24.793	0.8005	1.4285	56.18
	13	0	0.1624	14	0.642	0.0941	16.13	0.4463	0	37.34

Health risk assessment

As is necessarily known, the people living in the study area use the groundwater for different purposes, such as drinking and irrigation, since the groundwater in the study area was polluted by Fe, Mn and Pb. Accordingly, the human health risks were caused by the intake of this contaminated groundwater through the oral and dermal pathways. So, it must be investigated the toxicity effects of trace elements and heavy metals, as well as some selected minor constituents in the drinking groundwater, on human health in the concerned area using appropriate risk estimates. Therefore, this study attempts to investigate the toxicity risk for the elements Al, Cd, Co, Cr, Fe, Cu, Ni, Pb, Sr, Ba and Mn in the groundwater in the study area. In addition, the analysis results for the mentioned parameters refer to some of these parameters having concentrations above the limit values determined by the drinking water quality standards. In this study, non-carcinogenic health effects related to the use of this water were determined for the people of the area.

Health risk assessment is a consecutive method for assessing the possible adverse impacts of exposure to a specific chemical or microbiological agent over a particular duration (USEPA, 1989). To assess the health risk exposure of humans, chronic daily intake (CDI), health risk (hazard quotient, HQ) and noncancer hazard index value (HI). Chronic health risk indices concerning the consumption of water depend mainly on the consumption rate of trace metals concentrations and the nature of toxicity. Most PTMs enter the human body via several pathways, including ingestion, inhalation, and dermal exposure. Oral ingestion is considered the most significant pathway PTMs enter the human body. The CDI of PTMs by drinking groundwater was calculated according to Equation 3 modified by (Khan *et al*., 2013).

In the study, firstly, chronic daily intake (CDI) values due to ingestion and dermal contact were calculated for each trace metal according to the concentrations of trace metals before evaluating the type of risk. For this, the exposure values for trace metals depending on the amount of intake into the body were determined with Eqation (3) developed by USEPA (1989) and Chrostowski (1994).

$$CDI = C \times IR \times ED \times EF/Bw \times AT \qquad (3)$$

Equation (3) including chronic daily intake (mg/kg/day) is CDI, pollutant concentration in drinking water (mg/L) C, intake rate per unit time (L/day) IR , exposure time (years) ED, exposure frequency (day/year) EF, body weight (kg) Bw, and mean duration (30/70x365 days) AT.

Non-carcinogenic human health risk (HQ)

It is important to determine non-carcinogenic health effects on the groundwater in the study area. In this context, HQ (noncancer) values were determined to identify systemic effects that may develop due to chronic metal exposure through groundwater ingestion and contact in the local population. Equation (4) was proposed by the USEPA (1989) and can be used to make the HQ (noncancer) assessment.

$$HQ = CDI/RfD \quad (4)$$

Toxicity reference doses (RfD) were determined by the USEPA (2005, 2006) for the above mentioned parameters. Noncancer risk (health risk) is represented in terms of hazard quotient (HQ noncancer) for a single substance, for multiple substances and/or exposure pathways.

The United States Environmental Protection Agency (USEPA 2005) stated that the RfD is "an estimate of a daily oral exposure to the human population that is likely to be without an appreciable risk of deleterious effects during a lifetime." If a substance's exposure level exceeds the specified reference dose value (RfD), that is, if the HQ noncancer value exceeds 1, it indicates that it may have potential non-carcinogenic but harmful effects. The higher this value, the higher the negative and carcinogenic effects on health will be (USEPA, 1989).

Also, the sum of each HQ noncancer value from different exposure sources gives the noncancer hazard index (HI). In general, Equation (5) is used to calculate the HI index value (Rezaei *et al*., 2019a; Ghosh *et al*., 2020 and Toolabi *et al*., 2021).

$$HI = \sum_{k=1}^{n} HQ \quad (5)$$

If the HI value obtained from the formula is less than 1, this indicates that there are no significant non-carcinogenic risks in the environment. If the HI value is greater than 1, it indicates that the non-carcinogenic risk value is directly related to HQ and HI (Ghosh *et al*., 2020; Rezaei *et al*., 2019a and Toolabi *et al*., 2021).

In this study, the HI index value was calculated to express the general potential non-carcinogenic effects of Al, Cd, Co, Cr, Fe, Cu, Ni, Pb, Sr, Ba, Mn and B metals as important pollutant sources in the concerned area. The formula below can be written using Eq. (6).

$$HI = \sum_{k=1}^{n} HQ = HQ_{Al} + HQ_{Ba} + \cdots \text{ etc} \quad (6)$$

Based on the estimated results (Table 6), it is observed that the noncancer hazard index values (HI) for the summation of all trace elements and heavy metals as well as the selected minor constituent (B) range from 1.25 to 9.37, i.e., exceeded the value of 1, indicating that it may have potential non-carcinogenic and harmful effects on the local residents through groundwater drinking. This reveals that there are adverse health risks to humans posed by the ingestion of groundwater in the study area.

In general, this indicates that there are relations between the consumed contaminated groundwater and some certain diseases that existed in the study area.

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Table 6: The estimated values of the health risk (HQ) and health index (HI) in the Taref, Sabaya and Six Hills groundwater for adults in the study area

Sample No.	**Oral health risk (HQ) for the selected metals**												**Oral health risks index value (HI)**
	Al	Cd	Co	Cr	Fe	Cu	Ni	Pb	Sr	Ba	Mn	B	
Mut Lake water													
1	6.63E+00	1.71E-03	7.99E-02	8.23E-01	6.18E-03	3.17E-02	2.50E-04	2.59E+00	6.90E-01	1.12E-02	1.11E-02	3.19E+00	1.41E+01
Groundwater													
Taref aquifer													
6	1.89E+01	2.02E-03	1.38E-01	8.33E-02	3.26E-01	1.11E-01	1.10E-03	2.68E+00	7.18E-03	5.55E-03	3.62E-02	2.86E-02	2.23E+01
7	6.66E+00	3.36E-03	3.08E-02	8.33E-02	3.92E-01	2.70E-02	3.88E-04	1.65E+00	1.10E-02	4.96E-03	5.06E-02	6.99E-02	8.98E+00
8	1.88E+00	4.35E-03	1.05E-01	8.33E-02	8.83E-02	2.11E-02	1.08E-02	2.37E+00	5.02E-03	2.01E-02	9.43E-03	4.99E-02	4.64E+00
12	1.98E+01	3.11E-03	2.17E-01	3.92E-01	8.39E-03	7.36E-03	1.99E-02	2.00E+00	9.05E-03	3.11E-03	1.49E-01	6.66E-02	2.27E+01
14	8.02E+02	1.51E-03	1.62E+00	3.30E-01	4.52E-01	2.43E-01	1.49E-01	1.88E+00	1.46E-02	1.00E-03	4.64E-01	1.10E-01	8.07E+02
15	1.91E+01	2.99E-03	6.58E-02	8.33E-02	2.10E-01	3.60E-02	1.08E-02	5.81E+00	5.58E-03	6.65E-03	1.70E-02	1.03E-01	2.54E+01
Sabaya aquifer													
3	5.40E+00	4.15E-03	7.24E-02	4.53E-01	2.82E-01	4.87E-02	6.56E-03	2.99E+00	7.25E-03	7.09E-03	2.39E-02	6.99E-02	9.37E+00
4	1.88E+00	2.10E-03	1.38E-01	8.33E-02	2.70E-01	1.04E-01	6.56E-03	1.43E+00	7.20E-03	9.49E-03	2.60E-02	1.50E-01	4.10E+00
5	5.58E+00	1.50E-04	1.29E-01	7.01E-01	3.02E-01	2.70E-02	2.76E-03	5.64E+00	7.42E-03	7.28E-03	2.39E-02	5.33E-02	1.25E+01
Six Hills aquifer													
2	1.88E+00	2.52E-03	6.83E-02	8.33E-02	1.42E-01	2.86E-02	2.50E-04	2.22E+00	6.63E-03	3.01E-02	1.79E-02	5.33E-02	4.53E+00
9	1.88E+00	2.93E-03	7.65E-02	8.33E-02	2.94E-01	2.70E-03	2.50E-04	3.79E+00	7.33E-03	7.51E-03	2.57E-02	2.86E-02	6.19E+00
10	1.88E+00	2.52E-03	5.74E-02	4.53E-01	1.15E-01	3.70E-02	7.04E-03	3.96E+00	6.90E-03	2.96E-02	1.47E-02	9.00E-03	6.57E+00
11	1.88E+00	2.00E-03	1.37E-01	8.33E-02	2.66E-01	2.86E-02	1.25E-02	3.90E+00	5.93E-03	6.56E-03	2.00E-02	1.07E-01	6.44E+00
13	1.88E+00	2.10E-03	8.08E-02	2.68E-01	1.73E-01	1.27E-01	2.50E-04	2.59E+00	7.65E-03	2.64E-02	1.12E-02	4.66E-02	5.21E+00

Groundwater quality assessment for human drinking

Contaminated water is increasingly linked to diseases worldwide, necessitating the safety evaluation of the sources of domestic and drinking water in every locality (Yahaya *et al*., 2020). So, groundwater quality is a significant environmental concern globally and requires monitoring of a large number of physicochemical parameters (Tiwari *et al*., 2018), including salinity, heavy metals, and microbiological pollutants. Water degradation can occur due to dissolve to heavy metals in the water (Akhigbe *et al*., 2018). This causes water to become unsuitable for human use (Ternes *et al*., 2015).

Generally, water used for human drinking should be colorless and free of turbidity, excessive amounts of dissolved solids, and unpleasant odor or taste. Water quality depends on its physicochemical and biochemical as well as microbiological parameters. So, any changes in these parameters in water can render it unfit for human drinking. Therefore, a suitable water quality, especially for drinking water, is required for sustaining and enhancing socio-economic growth and development in this part of the country. However, groundwater is not always safe for living consumption, where many compounds and elements can run into it during its filtration through the soil and rocks.

By comparing the obtained results data (Table 1) with the international water quality guidelines standards (WHO, 2017), it is noticed that all of the collected groundwater samples in the study area are potable in terms of TDS, i.e., these groundwater are suitable for use as drinking water as they have TDS below the permissible limit of drinking water of 1000 mg/l, which is the TDS limit value specified in drinking water standards (WHO, 2017). In addition, the major ion concentrations of the groundwater samples in the study area were also evaluated in terms of use as drinking water. Accordingly, all water samples were below the acceptable limit values in terms of major ions.

Also, trace elements and heavy metals, as well as minor constituent concentrations in the groundwater in the concerned area, were evaluated as they are considered undesirable ions in drinking water in terms of pollutant sources. By comparing the obtained results data of Al, Ba, Cd, Co, Cr, Cu, Fe, Mn, Ni and Pb as well as B (Tables 3 & 4) with international standards (WHO, 2017), it was seen that the majority of the groundwater samples (79%) in the study area are unsuitable for drinking as they have Fe, Mn and Pb concentrations that exceeded the drinking water limit values of 0.3, 0.4 and 0.01mg/l, respectively (WHO, 2017).

Furthermore, all groundwater samples in the study area are polluted and unsuitable for use as drinking water as they have total organic carbon concentrations (Table 4) that exceeded the permissible limit (10mg/l) of drinking water (Egyptian organization for standardization and quality, 2007). In addition, the majority of the groundwater samples (93%) have coliform counts (Table 4) that exceeded the permissible limits (2 mpn/100ml) of human drinking (FAO, 1997).

Groundwater quality assessment for irrigation purpose

The quality of water used for irrigation is well recognized as an important factor in the productivity of crops. There are several classifications to assess the quality of the groundwater in the investigated area for use in irrigation purposes; from those is Eaton's classification (Eaton, 1950). This classification is based on the relation between the bicarbonate concentration and the concentrations of calcium and magnesium (Residual Sodium Carbonate). When the sum of carbonate and bicarbonate is in excess of calcium and magnesium, there is an almost complete precipitation of the latter (Eaton, 1950). This can cause an increase in the proportionate amount of sodium, and so, the effect on the soil is high sodium content. The term Residual Sodium Carbonate (RSC) is defined as follows:

$$RSC = (CO_3^{2-} + HCO_3^{-}) - (Ca^{2-} + Mg^{2+}) \text{ all in epm/l} \quad (7)$$

The RSC is used to distinguish between the different water classes for irrigation purposes because the high concentration of bicarbonate leads to an increase in the pH value, which causes the dissolution of the organic matter. Moreover, the high concentration of bicarbonate ions in the irrigation water leads to its toxicity and affects the mineral nutrition of plants.

Eaton (1950) stated that water with RSC greater than 2.5epm is considered unsuitable for irrigation, those with RSC 1.25-2.5epm are marginal, and those with less than 1.25epm are safe for irrigation.

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Noticeably, the negative values of RSC indicate no problem of carbonate and bicarbonate content in the irrigation water, i.e., the concentrations of carbonate and bicarbonate anions in groundwater samples in the study area are very low.

According to Eaton's classification, the majority of the groundwater samples (93%) in the study area have RSC values less than 1.25epm (Table 7). As a result, such a type of groundwater belongs to the possibly safe water for irrigation since it is free from residual sodium carbonate hazards. On the other hand, the rest of the groundwater samples (7%) in the study area have RSC value (1.493epm) more than 1.25epm and less than 2.5epm (Table 7), so such a type of groundwater belongs to the marginal water for irrigation.

Table 7: The evaluation of the groundwater samples in the study area for irrigation according to Eaton's classification

Aquifer	Sample No.	RSC
Taref aquifer	6	0.2135
	7	0.3356
	8	0.229
	12	-0.59
	14	1.493
	15	-0.98
Sabaya aquifer	3	-2.07
	4	-2.1253
	5	-1.4862
Six Hills aquifer	2	-0.415
	9	-1.836
	10	0.723
	11	0.013
	13	0.1898

4. Conclusions

An integrated approach to hydrochemical characteristics and assessment of the potential toxic effects of trace elements and heavy metals, as well as some minor constituents, on human health as a result of direct water consumption has been applied in the present study to determine the main sources responsible for the deterioration of water resources. Based on the hydrochemical results, all the collected samples were classified as fresh water, and it was proven that the salinization of some samples was mainly due to the dissolution of aquifer matrices beside the over-pumping. Additionally, Mut Lake is considered a recharging source for the Taref groundwater in the study area, and it is one of the threats that might pollute the groundwater. Furthermore, the results indicated that the majority of water samples were contaminated and exceeded the maximum permissible limits set by international standards in terms of Fe, Mn and Pb. On the other hand, the hazard risk index value (HI) values exceeded the value of 1, revealing that they likely cause adverse risk to the local population via ingestion of drinking water in the study area. Consequently, the study proved that groundwater in the study area is among the factors that contribute to the spread of some diseases in the Mut area, but it is not the only reason.

5. Recommendations

1- Urgent and must be to treat the contaminated groundwater before consuming as drinking water to reduce the iron, manganese and lead concentrations as well as the microbial contents with safe levels to reduce the human health risk in the study area.
2- The periodic monitoring of groundwater is essential to the prevention of diseases and disease outbreaks through the groundwater supply.

3- There is a need to manage and protect groundwater, particularly in arid areas in which groundwater has been contaminated.
4- Radioactive elements in groundwater in the study area must be determined to delinate whether this water is contaminated with radioactive elements or not. If it is contaminated with radioactive elements, this contributes to its effect on human health in addition to the chemical properties of groundwater.

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