Groundwater hydrogeology and quality in Helwan area and its vicinities in Egypt
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ABSTRACT
The study area includes Helwan city and its vicinities, south of Greater Cairo, between latitudes 29° 40’ and 29° 56’ N and longitudes 31° 15’ and 31° 24’ E, east of the River Nile. The main objective was to properly manage groundwater to protect it from deterioration. The hydrogeological and hydrochemical aspects were discussed, and the hazardous impacts of industrial, domestic and agricultural wastes on groundwater quality were evaluated. The main aquifer consists of Quaternary sediments of medium to coarse sand and gravel with clay intercalations. The average aquifer thickness is dominantly about 50 m, locally may increase near the Nile and becomes thinner eastward. TDS is more than 1000 mg/l in most groundwater samples increasing eastward reaching more than 3000 mg/l. High sulfate contents are caused by dissolution of highly soluble minerals as gypsum, mixing with sulfur water from springs and excess application of sulfate fertilizers. Groundwater in the southeast contains nitrate more than 50 mg/l which is high for drinking. Some groundwater and surface water samples contain high iron, manganese, aluminum, cadmium, chromium, copper, lead, nickel, selenium, and vanadium exceeding the drinking water guidelines and could affect sensitive crops. Microbiological pollution is also threatening groundwater in the area causing many diseases for people and animals. Mixed groundwater genesis indicated from domestic and industrial wastewater, excess irrigation water and sulfur water from springs.

Introduction
Nowadays, water pollution is a serious problem in the majority of the developing countries. It is usually caused by untreated sewage, industrial discharges, petroleum leaks and spills, dumping sites and agricultural chemicals. During the next decades, problems will associate with lack of water and pollution of water bodies will affect virtually everyone on the planet. In addition, without adequate quality and sufficient quantities of water, billions of people will continue to suffer illness arising from a poor environment, improper disposal of excreta and polluted water.

The main objective of the present work is to properly manage groundwater to protect it from deterioration by studying the hydrogeology and quality aspects of groundwater in the area between the River Nile to the west and the eastern Eocene Plateau to the east, between latitudes 29° 40’ and 29° 56’ N and longitudes 31° 15’ and 31° 24’ E (Figure 1). It is important to protect the groundwater from deterioration because of the prevention of deterioration is always less expensive than post-treatment and rehabilitation of deteriorated groundwater. To manage groundwater properly, it is important to understand the hydrogeological and hydrochemical aspects concerned with respect to the decision of future development in the region; the decision of the locations of groundwater extraction and cultivated crops, and the decision of safe groundwater management. Thus, it is needed to evaluate the hazardous impacts of industrial, domestic and agricultural wastes on groundwater quality. In addition, the study aims to raise awareness for safe drainage of wastes and groundwater protection.

Materials and methods
Geological, hydrogeological and hydrochemical data have been collected and inventoried in the fieldwork and used for the current study. Standard methods of water sampling and analyses were used for major cations and anions, nutrients, trace elements and microbiological contents in groundwater and surface water. All the analyses were carried out in the Central Laboratory, National Water Research Center (NWRC) according to the standard methods for the examination of water (APHA, 1999). Methods of chemical titration by standard indicators; flame photometer; spectrophotometer; and high sensitive Inductively Coupled Plasma (ICP) analytical instruments were used. Determination of total and fecal coliform bacteria was carried out using bacteriology farming under standard conditions.
Topography, geomorphology and land use

The ground level of the eastern plateau to the east of the study area is about 100 m + msl sloping westward in steep to gradational near the bounding cliffs and gentle near the Nile flood plain reaching about 18 m + msl (Figure 1). The eastern plateau is highly dissected by faulting and drained by a number of wadis (valleys) trending in E-W direction. These eastern parts of the study area are planned for development in the near future for industrial, agricultural and other urbanization projects. The alluvial plains cover the western portions of the study area constituting the old agricultural lands. The most populated areas are Helwan and El-Tabein cities where groundwater is the main source of water for agricultural and industrial purposes. Several canals and open drains are present cutting through the old lands.

Helwan and its surroundings were considered as an important industrial district in Egypt where some large national industrial facilities such as iron and steel, cement, car manufacturing, coal industry as well as red brick factories are present. These industries consume significant amounts of water and return in many cases highly polluted wastewater directly to the environment. Hence, these activities are considered as an important source of water pollution. Moreover, the area has some tourism activities due to the presence of mineral and sulfur water springs. The area includes a few small villages or Ezab, for example, Ezbt El-Walda, El Ezba El Baharya, and El-Qeblya, Arab Abu-Saed and others served with old and deteriorated sewerage network. Some of the scattered communities and houses dispose their domestic waste either in private septic tanks (latrines) or directly to the El-Khashab canal. The agricultural lands in the western and southern parts of the study area might exhibit some inputs from agricultural activities as discussed by Abdalla and Scheytt (2012); El-Sayed, Shawky, and Abdel Mottaleb (2004); Taha, El-Mahmoudi, and El-Haddad (2004) and Tawfik (2008).
Geology and hydrogeology

The study area is geologically complicated due to great changes in facies and geologic structures (Figure 2, 3). The Quaternary aquifer occupies the western part of the area adjacent to the Nile channel. This aquifer consists of Pleistocene sand and gravel sediments with a thickness dominantly about 50 m, may reach about 100 m locally adjacent to the River Nile and usually decreases eastward until vanishing near the eastern fringes. A thin semi-pervious silty clay cap aquitard occasionally covers the Quaternary aquifer near the Nile. The lower part of the Quaternary aquifer constitutes the Plio-pleistocene sediments of mixed shale, sand, and gravel (RIGW, 1997; RIGW, IWACO, 1998). Dominantly, thick Eocene carbonate is directly present under the aquifer deposits and crop out in the eastern high lands of the area. The thickness of the carbonate formations is about 1300 m in the area, and the Nubian sandstone aquifer is present deep in the subsurface (Said, 1990). The groundwater levels are more than 60 m + msl in the eastern parts of the area adjacent to the eastern plateau and decrease westward reaching less than 18 m + msl adjacent to the River Nile (Figure 4). Thus, the groundwater in the area could be recharged from different sources including leakage from canals, excess irrigation water, drained wastewater from the populated and industrial areas and upward flow from groundwater springs from deep Nubian sandstone aquifer recharging the Quaternary aquifer with sulfur water.

Helwan Sulfur bath is fed by a sulfur spring in the central part of the district and used for curing skin disorders since seventh century. On November 1991, new springs started to flow in streets No. 16, 5 located Southeast of Helwan Sulfur bath. On October 1992, after the famous earthquake in Egypt, many springs started flowing at other sites as El Ezba El-Baharya. Water temperature of Helwan Springs ranges between 23–32°C. In 1969, discharge of Helwan sulfur springs varied between 20 and 47 m³/h. In 1992, the total discharge of these springs reached about 400 m³/h. Most of this water is discharged to the sanitary system. Total dissolved solids and major cations and anions concentrations exceed the WHO maximum permissible limit for drinking water (Idris, 2000). Helwan springs are characterized by their high contents of H₂S, and an unpalatable saline taste.

Figure 2. Geologic outcrops in the Study Area (After EGPCO/CONOCO, 1987).
imparted by the high mineral content. The circulation of spring water through limestone, the biological activity and the presence of $\text{CO}_2$ in the porous soil are all factors responsible for the dissolution of carbonate rocks and generation of karst feature as caves under the Helwan area (Said, 1990).

Figure 3. Hydrogeological Cross Section Through the Study Area (After RIGW, 1997).

Figure 4. Groundwater Levels (m + msl) in the Study Area.
Results and discussion

Hydrochemistry and pollution with major elements

Descriptive statistics for the concentrations of major elements in surface water and groundwater samples are given in Tables 1, 2. Zonation on contour maps is used for determining the suitability of groundwater for use in drinking and irrigation purposes depending on the guideline values issued by EMH (2007), WHO (2011) and FAO (1985).

TDS is more than 1000 mg/l in most groundwater samples violating the guideline value for drinking water purposes (Figure 5). TDS increases eastward reaching more than 3000 mg/l and becomes unsuitable for irrigating many crops. Very high salinity in some locations is due to leaching processes and chemical interaction between water and the carbonate rocks and clay layers that are prevailing in the area. Major cations (calcium, magnesium, sodium, and potassium) increase eastward violating the guideline values for drinking water. Major anions as chloride and sulfate are usually high in groundwater exceeding the drinking water and irrigation water standards (Figure 5). The high anions concentrations are caused by dissolution processes and evaporation in water logged sites.

Total salt concentration of irrigation water should not be used as a single criterion for irrigation use. Even water with high salt concentration can still be used for irrigation without endangering soil productivity. High sodium content common to recycle water can cause deflocculating (breakdown) of soil clay particles, severely reducing soil aeration and water infiltration and percolation. In other words, soil permeability is reduced by irrigation with water high in sodium. It is, therefore, the best measure of a water likely effect on soil permeability is the waters SAR considered together with its EC (Abdul Hameed, Alobaidy, Al-Sameraiy, Kadhem, & Abdul Majeed, 2010).

In order to classify the groundwater samples for irrigation uses, a simple method of evaluating the danger of high sodium water is sodium adsorption ratio SAR (Freeze, Cherry, 1979)

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SAR = \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}}} \tag{1}
\]

Table 1. Major elements in surface water of the study area.

| Parameters | Nile Water | Khashab Canal at Tabein | Khashab Canal at El-Walda | Khashab Canal at Kafr El-Etw | Ezbt El-Walda Drain | Sewage water at El Ezba El Bahariya |
|------------|------------|-------------------------|--------------------------|-----------------------------|---------------------|-----------------------------------|
| EC (mmhos/cm) | 0.41 | 0.65 | 3.41 | 4.43 | 3.57 | 6.42 |
| TDS (mg/l) | 260 | 544 | 1502 | 1557 | 2080 | 3931 |
| pH (Value) | 8.1 | 8.1 | 8.1 | 8.3 | 8.9 | 7.86 |
| pHc (Value) | 8.1 | 7.1 | 7.1 | 7.2 | 6.9 | 6.7 |
| K⁺ (mg/l) | 5 | 4 | 15 | 16 | 18 | 44 |
| Na⁺ (mg/l) | 32 | 22 | 265 | 315 | 284 | 825 |
| Mg²⁺ (mg/l) | 10 | 6 | 40 | 41 | 99 | 78 |
| Ca²⁺ (mg/l) | 28 | 115 | 154 | 130 | 217 | 424 |
| Cl⁻ (mg/l) | 22 | 48 | 367 | 314 | 450 | 1187 |
| SO₄²⁻ (mg/l) | 21 | 32 | 259 | 356 | 534 | 974 |
| HCO₃⁻ (mg/l) | 142 | 317 | 400 | 378 | 468 | 384 |
| Na⁺ (mg/l) | 0 | 0 | 0 | 2 | 4 | 0 |
| NO₃⁻ (mg/l) | 0.5 | 0.4 | 2 | 4.6 | 6.1 | 15 |
| NO₂⁻ (mg/l) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 5.5 |
| SAR (Value) | 0.9 | 0.54 | 4.92 | 6.16 | 4.01 | 9.65 |
| Adj SAR (Value) | 1.43 | 1.25 | 11.31 | 13.56 | 10.02 | 26.06 |
| Adj RNA (Value) | 0.99 | 0.77 | 6.58 | 8.03 | 5.24 | 14.53 |

Table 2. Descriptive statistics for major elements in groundwater of the study area.

| Parameters | No. of samples | Min. | Max. | Mean | Standard deviation | Drinking water limits | Irrigation water limits |
|------------|----------------|------|------|------|--------------------|-----------------------|------------------------|
| EC (mmhos/cm) | 47 | 0.65 | 14.30 | 5.01 | 3.62 | 1.6 | 3.1 |
| TDS (mg/l) | 47 | 558 | 9582 | 3373 | 2404 | 1000 | 2000 |
| pH (Value) | 47 | 6.9 | 8.6 | 7.8 | 0.3 | 6.5–8.5 | 6.5–8.5 |
| pHc (Value) | 47 | 6.6 | 8.9 | 7.1 | 0.4 | 6.5–8.5 | 6.5–8.5 |
| K⁺ (mg/l) | 47 | 2 | 119 | 16 | 19 | - | - |
| Na⁺ (mg/l) | 47 | 60 | 2754 | 733 | 619 | 200 | - |
| Mg²⁺ (mg/l) | 47 | 2 | 559 | 92 | 94 | 150 | - |
| Ca²⁺ (mg/l) | 47 | 5 | 837 | 271 | 186 | 200 | - |
| Cl⁻ (mg/l) | 47 | 65 | 3206 | 930 | 799 | 250 | 355 |
| SO₄²⁻ (mg/l) | 47 | 5 | 4296 | 995 | 966 | 250 | - |
| HCO₃⁻ (mg/l) | 47 | 61 | 630 | 306 | 135 | 520 | - |
| CO₂⁻ (mg/l) | 47 | 0 | 120 | 3 | 18 | - | - |
| NO₃⁻ (mg/l) | 43 | 0 | 133 | 31 | 36 | 50 (NO₃) | 135 |
| NO₂⁻ (mg/l) | 31 | 0.2 | 0.2 | 0.2 | 0 | 1 | - |
| SAR (Value) | 47 | 1.42 | 36.87 | 9.61 | 7.24 | 10 | - |
| Adj SAR (Value) | 47 | 2.98 | 82.03 | 21.04 | 14.75 | 10 | - |
| Adj RNA (Value) | 47 | 1.86 | 42.68 | 11.94 | 8.20 | 10 | - |
For waters containing significant amounts of bicarbonate, Bower and Maasland (1963) proposed a modification in the old SAR procedure to include changes in soil water composition that are expected to result due to dissolution/precipitation of lime in the soil upon irrigation. Therefore, the adjusted sodium adsorption ratio (adj SAR) is an SAR value corrected to account for the removal of Ca$^{2+}$ and Mg$^{2+}$ by their precipitation with CO$_3^{2-}$ and HCO$_3^{-}$ ions in the water added. It can be calculated by using the following formula after Ayers and Westcot (1985), Abdul Hameed et al. (2010):

$$\text{adj SAR} = \text{SAR} \left[ 1 + (8.4 - \text{pHc}) \right]$$

where 8.4 is the approximate of a nonsodic saline soil in equilibrium with CaCO$_3$ and is substituted for the pH of water. This substitution reflects the high buffering capacity of calcareous soils. pHc is defined by:

$$\text{pHc} = (pK_2 + pK_3) + p(Ca^{2+} + Mg^{2+}) + p\text{Alk}$$

where $p$ refers to the negative logarithm, $K_2$ is the second dissociation equilibrium constant of carbonic acid, $K_3$ is solubility equilibrium constant for calcite. Concentrations of Ca$^{2+}$, Mg$^{2+}$, CO$_3^{2-}$ and HCO$_3^{-}$ in meq/L.

The pHc can be calculated from water analysis using the standard table given by Ayers and Westcot (1985). This concept has been found very useful for predicting the effect of sodium hazard of irrigation water on soil properties. Values of pHc above 8.4 indicate tendency to dissolve lime from soil through which the water moves; values below 8.4 indicate tendency to precipitate lime from waters applied (Abdul Hameed et al., 2010).

A new adj SAR method given by Suarez (1981) to adjust the calcium concentration of the irrigation water to the expected equilibrium value and includes the effects of carbon dioxide CO$_2$, carbonate (HCO$_3^{-}$) and of salinity (EC) upon the calcium originally present in the applied water but now a part of the soil water. The new adjusted SAR is termed widely as adj RNA, and the equation is as follows Abdul Hameed et al. (2010):

$$\text{adj RNA} = \frac{Na^+}{\sqrt{Ca^{2+} + Mg^{2+}}}$$

where Ca$_x^{2+}$, a modified calcium concentration value in meq/L expected to remain in near surface soil water following irrigation with water of given HCO$_3^{-}$/Ca$^{2+}$ ratio and EC available from the standard Table given by Ayers and Westcot (1985).

The calculated values of SAR in the groundwater in the study area range between 1.4 and 36.9 with an average value 9.6 (Table 2). Most of water samples have high

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**Figure 5.** TDS (Left view) and SO$_4$ (Right view) in Groundwater.
SAR content (>10) indicating harmful water for irrigation and the agriculture requires certain management techniques. High SAR is due to the high content of sodium especially in the southeastern part of the study area. The SAR values of all the surface water samples are less than 10 (Table 1). The adj SAR and adj RNa values in groundwater range from 2.98 to 82.03 (mean = 11.94) and from 1.86 to 42.68 (mean = 11.94) respectively (Figure 6 and Table 2). The comparison between SAR, adj SAR and adj RNa values and their standard values reflects water is dominantly unsuitable for irrigation without severe restrictions.

Wilcox classification diagram (Wilcox, 1955) was used as shown in Figure 7. Electrical conductivity (EC) is taken as salinity hazard and sodium adsorption ratio (SAR) as alkalinity hazard. Aquachem software program was used to give the plot of data on the wilcox diagram showing that some water samples of low sodium and medium salinity in classes C2-S1, C3-S1 indicate good water for irrigation on almost all soils without any restrictions. Sodium in water samples in class C3-S2 is considered medium with moderate Na⁺ problem in fine-textured (clay) soils and coarse-textured (sandy) soils. Salinity and sodium contents for water laying in classes C4-S2, C4-S3 and C4-S4 are high producing sodium problems in most soils for most crops under ordinary conditions, but certain crops are needed to be cultured in soils with adequate drainage and special circumstances for salinity control. Some samples indicate unsuitable water for irrigation due to very high salinity and SAR out of the present range of Wilcox diagram.

**Nitrates**

Nutrients increase in drainage water while in the Nile water and canals, these compounds are little and under the guideline values for drinking water (Table 1). Nitrate content in groundwater is less than 50 mg/l in the western and northern parts of the study area and near the River Nile (Table 2, Figure 8). Groundwater in the southeastern part contains nitrate more than 50 mg/l violating the drinking water limits. The increase of nitrate in such areas could be referred to contamination from the released wastewater.

**Trace elements (heavy metals)**

Concentrations of minor and trace elements in water resources are summarised in Table 3. Some groundwater wells, surface water in El khashab Canal and drainage water contain high iron, manganese, aluminum, cadmium, chromium, copper, lead, nickel, selenium, and vanadium violating the drinking water guidelines and could affect sensitive crops (Table 3, Figure 9). The seepage from the industrial waste disposal sites is most probably the main source of

![Figure 6. Adj RNA map for Groundwater in the Study Area.](image-url)
Figure 7. Wilcox Diagram for Groundwater and surface water in the Study Area.

Figure 8. Nitrate Content in Groundwater in the Study Area.
Table 3. Trace elements (mg/l) and microbiology (CFU/100 ml) in groundwater and surface water samples in the study area.

| Parameters | No. of samples | Min. | Max. | Mean | Std. dev. | River Nile | El Khashab canal | Drainage water | Drinking water limits | Irrigation water limits for old lands |
|------------|----------------|------|------|------|-----------|------------|------------------|------------------|----------------------|---------------------------------------|
| Alumenium  | 34             | 0.004| 1.690| 0.157| 0.008     | 0.104      | 0.119           | 0.2              | 2                    | 20                                    |
| Arsenic    | 17             | 0.001| 0.208| 0.020| 0.004     | 0.001      | 0.004           | 0.01             | 2                    | 2                                    |
| Barium     | 24             | 0.001| 0.207| 0.051| 0.001     | 0.001      | 0.001           | 0.7              | –                   | –                                    |
| Cadmium    | 19             | 0.001| 0.100| 0.018| 0.031     | 0.072      | 0.05            | 0.003            | 0.05                 | 1                                    |
| Chromium   | 19             | 0.001| 0.108| 0.025| 0.034     | 0.001      | 0.003           | 0.05             | 1                    | 1                                    |
| Cobalt     | 19             | 0.003| 0.060| 0.016| 0.001     | 0.001      | 0.005           | 0.1              | 5                    | 5                                    |
| Copper     | 27             | 0.001| 8.200| 0.390| 0.782     | 0.013      | 0.091           | 0.3              | 20                   | 20                                   |
| Iron       | 34             | 0.001| 4.030| 0.782| 0.013     | 0.022      | 0.091           | 0.3              | 20                   | 20                                   |
| Lead       | 27             | 0.000| 0.363| 0.006| 0.008     | 0.008      | 0.198           | 0.01             | 10                   | 10                                   |
| Manganese  | 30             | 0.005| 1.095| 0.175| 0.024     | 0.02       | 0.003           | 0.4              | 10                   | 10                                   |
| Nickel     | 17             | 0.001| 0.871| 0.181| 0.254     | 0.007      | 0.057           | 0.07             | 2                    | 2                                    |
| Selenium   | 19             | 0.001| 9.000| 1.261| 2.468     | 0.001      | 0.536           | 0.032            | 0.01                 | –                                    |
| Tin        | 17             | 0.004| 0.092| 0.011| 0.022     | 0.001      | 0.001           | 0.001            | –                   | –                                    |
| Vanadium   | 19             | 0.002| 11.44| 1.258| 3.569     | 0.004      | 0.005           | 0.004            | –                   | 1                                    |
| Zinc       | 18             | 0.001| 2.000| 0.317| 0.476     | 0.002      | 0.005           | 0.007            | 5                    | 10                                   |
| Total coliforms | 14 | 0 | 120 | 31 | 46 | 50 | 51 | 6300 | 50 | – |
| Fecal coliforms | 14 | 0 | 30 | 3 | 8 | 20 | 0 | 2500 | 0 | – |

Figure 9. Trace Elements Contents in Groundwater in the Study Area.
pollution causing the relative increase in the concentration of trace elements. Sometimes, high trace elements as iron and manganese in groundwater could be due to dissolution from the soil. High trace elements affect tolerant crops and severe restrictions must be taken in mind for the planted crops.

Microbiological pollution

The microbiological pollution of groundwater in the studied area was investigated. Total and fecal coliform bacteria were measured in 14 samples collected especially for microbiological measurements to check if there is microbiological pollution. The number of microbes per 100 ml of the water samples was measured (Table 3). According to WHO (World Health Organization) (2011) as well as most other published standard limits for drinking water, the drinking water must not contain any fecal coliform bacteria. Microbiological pollution is a serious threat to the quality of drinking water. From the bacteriological analyses for the groundwater samples, it is clear that most sampled groundwater wells contain polluted water with total and fecal coliform bacteria. The fate of microorganisms in the subsurface, especially pathogenic bacteria is determined by the retention by soil and their survival time. The absence of a covering clay layer above the aquifer and a high groundwater table result in intensive movement of microorganisms through soil especially in extensively populated areas. Bacteria may survive for more than six months in the proper subsurface environment (Bitton & Gerba, 1984; RIGW, IWACO, 1989). The microbiological pollution in the studied area can be referred to one or more of the following reasons:

- Intensively populated areas in towns and villages;
- Most of the towns without or with bad sewerage systems;
- Many of people use septic tanks without any cautions or protection control;
- Many of disposal sites and open drains, in which the wastewater and sewage usually disposed, are present extensively in the populated areas.

The drinking of water so contaminated or its use in the preparation of certain foods may result in further cases of infection. Between 20 and 30 different infective diseases may result due to microbiologically polluted drinking water supply (Feachem, McGarry, & Mara, 1977; Surtees, 1971; WHO, 1984).

Genesis of groundwater

As shown from the Piper diagram and schoeller diagram of the sampled water (Figure 10), the water samples from the River Nile, El khashab Canal and drainage water are dominated with alkalies (Na\(^+\) + K\(^+\)) and strong acids (Cl\(^-\) + SO\(_4^{2-}\)) indicating mixing from groundwater. Groundwater in the study area is a result of mixing of water from excess irrigation, seepage from surface water

![Piper Diagram for Water Samples of the Study Area](image)

![Schoeller Diagram for Water Samples of the Study Area](image)

**Figure 10.** Piper (Left view) and Schoeller (Right view) Diagrams for the Water Samples.
channels in the area and from deep sulfur water springs. In areas directly adjacent to the Nile, groundwater is dominated with alkaline earths (Ca\(^{2+}\)+Mg\(^{2+}\)) and weak acids (CO\(_3^{2-}\)+ HCO\(_3^{-}\)) indicating dominantly recharged groundwater from irrigation water and canals in the old lands. Generally, most of the samples indicate mixed groundwater genesis.

Conclusions

- The Quaternary aquifer, in Helwan area and its vicinities, consists of medium to coarse sand and gravel with clay intercalations. The average aquifer thickness is dominantly about 50 m, may reach 100 m locally adjacent to the River Nile and usually decreases eastward until vanishing near the eastern fringes.
- Total dissolved solids (TDS) is more than 1000 mg/l in most groundwater samples increasing eastward reaching more than 3000 mg/l and becomes unsuitable for irrigating many crops.
- High sulfate contents are caused by dissolution of highly soluble minerals as gypsum, mixing with sulfur water from springs and excess application of sulfate fertilizers.
- Nitrate content in groundwater is less than 50 mg/l to the west and north of the study area near the River Nile, but in the southeast, nitrate becomes more than 50 mg/l which is high for drinking.
- Some groundwater wells, as well as surface water in some canals and drains, contain high iron, manganese, aluminum, cadmium, chromium, copper, lead, nickel, selenium, and vanadium violating the drinking water guidelines and could affect sensitive crops. The seepage from the industrial waste disposal sites is most probably the main source of pollution with trace elements.
- Microbiological pollution is also threatening groundwater causing many diseases for people and animals in the area.
- Most samples indicate high and very high groundwater salinity for irrigation. It produces a sodium problem in most soils and not suitable for irrigation under ordinary conditions.
- Piper and schoeller diagrams showed that most of the groundwater samples show mixed groundwater genesis, and the groundwater aquifer is recharged from domestic and industrial wastewater, excess irrigation water and mixing with sulfur water from springs.

Recommendations

- Groundwater, closed to the industrial areas, should be periodically and continuously monitored and investigated with respect to the groundwater quality and its potential deterioration.
- Treatment of industrial wastewater has a large positive impact on the quality of different water resources.
- Other protection measures are required including a regular check on the pressure of transportation pipes and storage tanks and the lining of ditches and ponds for industrial liquids including wastewater.
- Application of legislations are considered the most active tools in groundwater protection.
- Human resources and public awareness should take utmost endeavor.

Disclosure statement

No potential conflict of interest was reported by the author.

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