Hydrochemical Characteristics and Pollution Potential of Groundwater in the Reclaimed Lands at the Desert Fringes, West of Sohag Governorate - Egypt

Yahia R. Gedamy

Desert Research Center, El-Matareya, Cairo, Egypt

ABSTRACT

This study aims to address the integrated impact of hydrochemical processes, sewage projects and agricultural activities on the groundwater quality to help in protection of groundwater resources in the study area. This is achieved by surveying and collecting of 87 water samples representing surface water (18 samples), and shallow and deep groundwater wells tapping the unconfined Pleistocene aquifer (69 samples) during June 2014. The hydrochemical characteristics as well as the geochemical classification and inorganic, and organic pollutants are assessed in this work. Also, geochemical modeling techniques, statistical analyses and evaluation of groundwater quality were investigated for different purposes. All surface water samples are related to the fresh zone. 52% of the groundwater samples lie in the fresh water type, 45% belong to the brackish water type and the rest of the groundwater samples (3%) belong to the saline water type. From the areal distribution maps, it is obvious that, the salinity as well as Ca²⁺, Mg²⁺, Na⁺, SO₄²⁻ and Cl⁻ ions concentrations increase gradually eastwards, from the Plateau toward the Nile River along the study area, i.e., in the same direction of the water flow. Piper diagram confirms that some groundwater samples are affected by the seepage from the adjacent semi-confined aquifer. The hydrochemical profile confirms that there is an unexpected metasomatic sequence (geochemical evolution) for the groundwater changes from a more advanced stage Cl⁻ > SO₄²⁻ > HCO₃⁻ at south of the study area to less advanced stage HCO₃⁻ > SO₄²⁻ > Cl⁻ at north of the study area. A multivariate statistical analysis confirmed that some groundwater samples are affected by wastewater projects at west Tahta and west Tama localities and other groundwater samples are affected by seepage from the adjacent semi-confined aquifer as at Gerga locality, while the rest of the groundwater samples are affected by leaching and dissolution processes, reclamation projects as well as agricultural activities. Majority of the Nile River water samples (67%) and 17% of irrigation canals water samples are still suitable for drinking, while 33% and 83% of Nile River and irrigation canals water samples, respectively, are unsuitable for drinking as they are polluted by Fe and Al. On the other hand, 46% of the groundwater samples are unsuitable for drinking as they are polluted by NO₃⁻, Fe, Pb, Cr, Al and Zn at variable percentages, while the rest of groundwater samples (54%) are still suitable for drinking. All Nile River and irrigation water samples as well as the majority of the groundwater samples (78%) are suitable for irrigation under ordinary conditions, while the rest of groundwater samples (22%) are suitable for irrigation under special conditions.

Key words: Hydrochemistry, groundwater, water pollution, west of Sohag governorate-Egypt

Introduction

Sohag governorate is located at the center of the Upper Egypt governorates where its distance from Cairo (467km) and from Aswan (412km), is divided by the Nile River into two parts east and west. Sohag governorate as well as its desert backer occupies 11022.01Km² (MIR, 2003) and extends the length of 125km and a width of 16-25km, and an inhabited area of about 1593.92Km², i.e., occupies approximately 14.5% of the total area of such governorate. According to Census estimation (2014) and GASG (2014), the total population of Sohag governorate is 4,645,000 representing 5% of the Egyptian population which reaches 94,000,000.

The studied area is situated west of the Nile River (floodplain) at Sohag governorate. It covers a part that extends from the western edge of the old cultivated lands of the Nile Valley up to the Lower Eocene limestone plateau. It extends from the northern edge of Qena governorate at latitude 26° 5’ 58” N to the southern edge of Assiut governorate at latitude 27° 00’ N, and it is bounded between longitudes 31° 15’ and 32° 00’ E (Fig.1).

In the Last few years, the Egyptian government has devoted attention to develop the area in the vicinity of Nile cultivated area (desert hinterland of upper Egypt governorates) in different forms including land reclamation, wastewater disposal projects, industrialization and urbanization activities meeting the population density in the Nile cultivated lands as well as to create new job opportunities for the youth and to decrease or prevent their migration to Cairo. Noteworthy, there are two artificial cities were constructed in the study area, one of them at west Tahta and the other at west Gerga.
The area to the west of the old cultivated land in Sohag governorate represents the major potential area for land reclamation and development. In this area, the groundwater is commonly the only water resource for drinking in addition to irrigation where surface water resource is insufficient and limited during the dry months of the year. Also, there is a large distance between the reclaimed lands and the surface water (Nile River and irrigation canals). So, it has become necessary to undertake a baseline study of its status for the identification of any future degradation for the groundwater.

Increased application of chemical fertilizers and pesticides in irrigated lands predicts the occurrences of groundwater contamination at shallow depths (30m), and when combined with sensitive groundwater sites, can have a large impact on the water quality. Noteworthy to mention that, soils of the newly reclaimed desert lands include fine sand and silt, siltstone, sandstone, claystone, sand, and gravel (Ahmed, 2007). Thus, soil conditions in the study area facilitate the transport of contaminants through the soil profile which affects groundwater quality.

The present study focuses on:
1- Chemical analysis of major, minor and trace constituents.
2- Hydrochemical characteristics of the groundwater.
3- Origin of the groundwater
4- Identification of the pollutants and determination of their sources.
5- Multivariate analyses for the groundwater.
6- Evaluation of the groundwater suitability for different purposes.

**Water resources:**

The study area belongs to the arid region of North Africa where it is characterized by long and hot summer (36.5°C) and cold winter (15.5°C). The rainfall over the area is very limited and variable except the occasional storms, where the yearly average value in Sohag was recorded as 2.25mm/year. The monthly evaporation intensity ranges from 96.1mm in December to 325.5mm in May (Egyptian Meteorological Authority, 2000). The evaporation intensity is higher than the rainfall intensity and this reflects that the studied area suffers from aridity conditions with great deficiency of moisture influx (Abu El-Magd, 2008). The topography of the study area ranged from 490m.a.s.l. at edges of the plateau to 50m.a.s.l. at the inland (Ahmed, 2009b).

Diab et al., 2002 stated that, there are five morphological units in the study area; the limestone plateau, the terraces, the pediment, the alluvial fans and the alluvial flood plain.

The surface water system in Sohag governorate is represented by the Nile River, irrigation canals and drains. The main irrigation canals take their water from Nile River upstream of Nag-Hammadi Barrages located ~ 15km south of Sohag governorate. The main canals are Nag-Hammadi El-Gharbia and Nag-Hammadi El-Sharqia canals with a total length of 130 and 150km, respectively. Other large canals that take water from the main canals include El-Balyana, El-Kasra, El-Girgawia and El-Tahtawia canals. The drainage system in the study area is mainly represented by Sohag El-Raesse drain, Akhmim El-Raesse drain, Tahta El-Raesse drain, El-Balyana drain, El-Kasra drain and El-Sheikh Marzok drain. These drains are running from south to north parallel to the irrigation canals (Fig.2).
Hydrogeologically, there are at least four formation layers in the study area; Dandara formation, Kom Ombo formation, Qena formation and Munehia formation, of which the most favorable water bearing unit in the study area is the Qena formation. In some localities, the lower part of Kom Ombo formation is acting as a water table aquifer. The water bearing sediments in the study area are represented mainly by the Pleistocene deposits, covered in most parts by the flood plain of the Nile (old cultivated land) and covered by Holocene layer in the desert areas (Abdel Moneim, 1999b). In old cultivated land, the lower aquifer (Pleistocene) is semi-confined aquifer while in the desert fringes the lower aquifer (Pleistocene) is unconfined aquifer (Fig.3). The upper member in the old cultivated land is formed of clay-silt layer (Neonile clay and silt) and extends laterally, with a great thickness near the river channel, and vanishing near the fringes where it is replaced by the desert sands (its thickness is about 10m). This layer (upper member) in the desert areas has low horizontal and vertical permeabilities (about 0.06 and 0.0086m/day, respectively). It functions as a semi-confining layer to the underlying aquifer (Pleistocene aquifer). The lower layer (Pleistocene aquifer) is mainly composed of gravels and sands of different sizes (fine, medium and coarse sands), silts, and intercalated by clays and shale forms the main aquifer having high horizontal permeability ranges between 40 and 100m/day and no vertical permeability, and the specific storage ranges between $6.7 \times 10^{-6}$ and $7.6 \times 10^{-6}$. The lower boundary of the aquifer may be considered impervious due the presence of extensive and thick deposits of Pliocene clays of very low permeability (Abdel Moneim, 1992).

The aquifer has an average thickness between 50 and 130m and the thickness decreases westward towards the Lower Eocene scarp until it reaches zero, where the clay base becomes shallower (Munchia formation) and the bottom layer (Pliocene clay) sub-crops. Generally, the saturated thickness of the aquifer is between 60 and 120m in the strip near the cultivated land (Abdel Moneim, 1999b). The extension of the aquifer is infinite to the north and south directions, while it is limited from the west by the edge of limestone Eocene plateaux. At the same time, the depth to the water table in the area increases westward, this is due to the increase of the surface elevation in that direction (Abdel Rahman, 2006). The depth to the water table lies between 5m and 140m. Ahmed (2009a) stated that the slope of the water table is mainly westward (Fig.4). Also, Abdel Moneim (1999a) stated that in the unconfined part of the aquifer, the most predominant flow direction is from
the southeast to the northwest.

Fig.3: General hydrogeologic section of Sohag (RIGW, 1990)

Fig.4: Groundwater table map of Sohag area (Ahmed, 2009a)

The main sources of the aquifer groundwater recharge in the study area are mainly due to the percolation of the return flow after irrigation (excess irrigation water) and the subsurface inflow across external boundaries, i.e., lateral groundwater underflow flowing into the aquifer from the south (following the ground topography). The seepage from the limestone fractures and fissured during the occasional rainstorms could be a secondary source of groundwater recharge. Furthermore, this aquifer is possibly recharged by vertical upward leakage from the deeper aquifer systems of older geologic times through the extended permeable layers and the fault planes respectively which have high-pressure such as fissured Eocene limestone and Nubian sandstone aquifers (Korany, 1984). Also, the aquifer is recharged by seepage from the adjacent semi-confined aquifer (Abdel Moneim, 1992). On the other hand, the main terms of groundwater discharge are groundwater pumping
from wells for the different purposes of water use, also, outflow across external boundaries, capillary upward flow from a shallow water table owing to evapotranspiration are some of the main discharge elements in the study area (Ibrahim, 1996 and Diab et al., 2002). Ahmed (2007) stated that the extraction from wells was calculated as 2.04×10⁶ m³/day.

**Water sampling, analyses and office work:**

The present work started by surveying the water points in the area under consideration. Co-ordinates (Longitudes and Latitudes) of the sampled water in the study area were recorded using Global Positioning System (GPS) model etrex 10 (Garmin) and therefore were plotted using software program to generate the map of the sampling locations (Fig.5). Some parameters as depth to water, temperature T°C, EC and pH were conducted in-situ for the collected water samples because some of these parameters (EC and pH) are likely to change on transit to the laboratory (Hem, 1985). The samples were collected in clean 500ml polyethylene bottles with all necessary precautions (the groundwater samples was collected after pumping the wells for about five minutes to ensure stable conditions and the bottle was capped immediately after sampling to minimize oxygen contamination and the escape of dissolved gases) and were divided into three aliquots to analyze in the laboratory of Desert Research Center; the first aliquot was taken in special container (100ml) for the measurements of major cations and anions (Ca²⁺, Mg²⁺, Na⁺, K⁺, CO₃²⁻, HCO₃⁻, SO₄²⁻, Cl⁻) according to Rainwater and Thatcher (1960), the second aliquot was taken in special container (100ml) for the measurements of minor elements as nitrate (NO₃⁻), ammonia (NH₃) and total organic carbon (TOC) according to Fishman and Friedman (1985). Finally, the third one aliquot was acidified with nitric acid (1%) and stored in pre-cleaned polyethylene bottles for the measurements of trace elements (Fe, Pb, Cu, Cd, Cr, Al and Zn) according to the methods adopted by American Society for Testing and Materials (ASTM, 2002). The obtained chemical data were expressed in milligram per liter (mg/l) or part per million (ppm). It is worth to mention that, the analytical precision for the measured major ions is about ±5%. Collection of the geomorphological, geological and hydrogeological data of the study area from the previous works and internal reports, and use of topographic map (scale 1: 100,000) for preparation of the base map of the studied area as well as preparing all the graphical representations and maps for the analytical results through using some computer programs such as surfer 8 for window, NETPATHXL for windows, Win, word and Excel 2007 for windows were done.

**Hydrochemical Characteristics:**

The hydrochemical characteristics are defined by the concentrations and trends of the various constituents in both surface water and groundwater in the area under consideration. They reflect an indication for groundwater recharge, discharge and movement. Also, hydrochemical study usually involves the consideration of the sum total of all possible groundwater contamination or ionic constituents of groundwater (Yidana et al., 2012). The hydrochemistry characterization of the collected surface water and groundwater samples is discussed under the following topics;

**Variation in ionic constituents' concentrations:**

The chemical compositions of surface water and groundwater samples were analyzed. According to Chebotarev (1955), the natural water is classified into three main categories of total salinity; fresh water (TDS up to 1500mg/l, μ=0.01-0.03); brackish water (1500 to 5000mg/l, μ=0.03-0.1) and saline water (TDS more than 5000mg/l, μ more than 0.1). The total salinity of the Nile River, irrigation canals and drains water samples ranges from 225 to 233ppm, 178 to 252ppm and 206 to 603ppm, respectively, with mean values of 230, 223 and 438ppm (table 1). So, all surface water samples are related to the fresh zone, and all TDS values of the surface water lie within the TDS safe limit (1000mg/l) as stated by WHO (2011). It is noticed that the drains water samples are less alkaline and more saline than the Nile River and irrigation canals water samples because of the wastes which has been received at the drains. Worth mentioning that, the TDS values increase in summer and decrease in the winter season, this is attributed to the higher rates of evaporation processes in summer than in winter.
The total dissolved solids (TDS) of the groundwater samples in the study area vary in the range of 173-6153 mg/l, with a mean value of 1883 mg/l (table 1). Twenty-eight percent of the Pleistocene aquifer groundwater samples have TDS values well within the permissible limit (1000 mg/l) as stated by WHO (2011). As per the TDS classification (Chebotarev, 1955), 52% of the groundwater samples lie in the fresh type as they have TDS less than 1500 ppm, 45% of the groundwater samples belong to the brackish type as they have TDS values ranged from 1500-5000 mg/l, while the rest of the groundwater samples (3%) belong to the saline type as they have TDS values more than 5000 mg/l. The very wide range of salinity suggests that the hydrochemistry of groundwater here is controlled by several intermixed processes including the natural water-sediment interaction and the anthropogenic activates.

Table 1: Water salinity classification according to Chebotarev (1955) and ionic strength values for the different surface water and groundwater samples in the study area.

<table>
<thead>
<tr>
<th>Water source kind</th>
<th>Total samples</th>
<th>Fresh water (%) ( \mu = 0.01-0.03 )</th>
<th>Brackish water (%) ( \mu = 0.03-0.1 )</th>
<th>Saline water (%) ( \mu &gt; 0.1 )</th>
<th>Range (mg/l)</th>
<th>Mean (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TDS&lt;1500mg/l</td>
<td>TDS=1500-5000mg/l</td>
<td>TDS=&gt;5000mg/l</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nile</td>
<td>3</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>225-233</td>
<td>230</td>
</tr>
<tr>
<td>Canals</td>
<td>12</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>178-252</td>
<td>223</td>
</tr>
<tr>
<td>Drains</td>
<td>3</td>
<td>100%</td>
<td>-</td>
<td>-</td>
<td>206-603</td>
<td>438</td>
</tr>
<tr>
<td>Pleistocene aquifer</td>
<td>69</td>
<td>52%</td>
<td>45%</td>
<td>3%</td>
<td>173-6153</td>
<td>1883</td>
</tr>
</tbody>
</table>

Fig. 5: Map of the water sampling locations in the study area.
The increase of salinity in the groundwater at the study area is attributed to the following factors;
i) The reclaimed lands that are located close to the exposed Lower Eocene limestone and Pliocene clay, where the leaching and dissolution process along the flow direction of these rocks which contains salts of sulfates, chlorides and carbonate materials that were transported from limestone plateau by weathering (occasional rainfall storms) may increase the salinity of the infiltrated water downward as well as the high rates of evaporation as at the area between Gerga and Sohag localities.

ii) The haphazard drilling and the uncontrolled continuous over-pumping activities (where the groundwater discharge is more than the groundwater recharge) that cause increasing salinity and reflect the impact of land reclamation projects on the groundwater as in north Sohag, west Tahta and south Tama localities.

iii) The groundwater is affected by the application of agricultural fertilizers and pesticides provide another contribution of salts and pollutants to the groundwater in the Pleistocene aquifer. This is emphasized by Ahmad (2009b) who stated that the Pleistocene aquifer is influenced by agricultural activities in old cultivated area and reclaimed lands, and development projects in the desert zone (El Dair wastewater disposal site in west Sohag governorate).

iv) The leaching of soluble salts from sediments and the surficial wadi deposits by means of the downward infiltrated water as a result of the surface irrigation regime (return flow after irrigation).

v) The soils in the reclaimed areas usually have high salinity contents which, in turn, provide the aquifer by dissolved salts through deep percolation. Moreover, the evaporation processes increase both the salinity of the irrigated water and the soil layers.

vi) The cultivated soils of the reclaimed area are mainly built up of permeable sands and gravels (Ahmad, 2007). Thus the percolation rate of water is extremely high. Consequently, the leaching process of the surface sediments (containing salts and minerals) increases the salt content of groundwater.

On the other hand, there was a decrease in the water salinity of wells that are located either close to the neighboring semi-confined aquifer as at Gerga locality, reflecting the dilution effect of the semi-confined groundwater that was recharged from nearby irrigation canals, and this refers to the mixing of groundwater from semi-confined and unconfined aquifers along the border between them or that located down flow from the sewage wastewater disposal projects as at west Tama and west Tahta localities which implies that the less saline wastewater is confirmed penetrating the permeable zone to reach and dilute the groundwater, this implies that anthropogenic factors, pollution or dilution, affecting salinity.

From the iso-salinity distribution map of the unconfined aquifer groundwater samples (Fig.6), it is obvious that, there is one general direction of water salinity increase from the Plateau toward the Nile River and canals along the study area, i.e., in the same direction of water flow. This is confirmed by Gupta et al. (2008) that stated that the higher the groundwater table and topography, the lower the concentration of TDS, this clearly supports the role of direction and amount of groundwater flow on variation in groundwater quality. The higher values of water salinity is strictly confined to the area between Gerga and Sohag, due to over-pumping activities and, leaching and dissolution processes, this reflects the impact of land reclamation projects on the groundwater.

The minimum, maximum and average values of the pH, major cations and anions (Ca\(^{2+}\), Mg\(^{2+}\), Na\(^+\), K\(^+\), CO\(_3\)\(^{2-}\), HCO\(_3\)\(^{-}\), SO\(_4\)\(^{2-}\) and Cl\(^{-}\)) for the surface and groundwater samples are indicated in table 2.

The pH of Nile River and irrigation canals water samples ranged from 7.65 to 7.83 and from 7.55 to 8.42, with mean values of 7.71 and 7.91, respectively, while the pH of the drains water samples ranges from 7.06 to 8.36, with a mean value of 7.89 (table 2). The pH values of all Nile River and irrigation canals water samples are located in the permissible limit of pH (6.5-8.5) as presented by WHO (2011).

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Nile River</th>
<th>Irrigation canals</th>
<th>Agricultural drains</th>
<th>Groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>pH</td>
<td>7.65-7.83</td>
<td>7.71</td>
<td>7.55-8.42</td>
<td>7.91</td>
</tr>
<tr>
<td></td>
<td>7.06-8.36</td>
<td>7.89</td>
<td>7.18-8.25</td>
<td>7.75</td>
</tr>
<tr>
<td>Ca(^{2+})</td>
<td>24.79-26.81</td>
<td>26.07</td>
<td>19.04-32.51</td>
<td>25.57</td>
</tr>
<tr>
<td>Mg(^{2+})</td>
<td>20.78-27.70</td>
<td>24.07</td>
<td>17.13-27.25</td>
<td>23.11</td>
</tr>
<tr>
<td></td>
<td>23.09-40.82</td>
<td>33.13</td>
<td>10-509</td>
<td>125</td>
</tr>
<tr>
<td>Na(^+)</td>
<td>18-26</td>
<td>21.3</td>
<td>14-26</td>
<td>21.5</td>
</tr>
<tr>
<td>K(^+)</td>
<td>2.74-3.91</td>
<td>3.39</td>
<td>2.67-3.04</td>
<td>3.61</td>
</tr>
<tr>
<td></td>
<td>2.74-17.98</td>
<td>7.82</td>
<td>0.59-27</td>
<td>5</td>
</tr>
<tr>
<td>HCO(_3)(^{-})</td>
<td>111.62-154.33</td>
<td>137.86</td>
<td>100.65-154.33</td>
<td>133.38</td>
</tr>
<tr>
<td></td>
<td>134.2-416.02</td>
<td>306.42</td>
<td>81-611</td>
<td>243</td>
</tr>
<tr>
<td>SO(_4)(^{2-})</td>
<td>50-74</td>
<td>58.67</td>
<td>30-74</td>
<td>53.17</td>
</tr>
<tr>
<td></td>
<td>46-64</td>
<td>52.67</td>
<td>20-1326</td>
<td>499</td>
</tr>
<tr>
<td>Cl(^{-})</td>
<td>24.32-32.16</td>
<td>27.57</td>
<td>18.11-40.16</td>
<td>29.56</td>
</tr>
<tr>
<td></td>
<td>24.11-120.14</td>
<td>72.13</td>
<td>22-2750</td>
<td>630</td>
</tr>
</tbody>
</table>

The pH values of groundwater in the study area ranged from 7.18 to 8.25, with a mean value of 7.75, indicating that the groundwater are neutral to moderately alkaline in nature (table 2). The pH values of all the collected samples are well within the safe limit of drinking water (6.5 - 8.5) as prescribed by WHO, 2011. The pH values indicate slightly alkaline nature of groundwater which may be due to the presence of fine aquifer
sediments mixed with clay and mud. The relatively high pH values in some samples are due to weathering of carbonate formation in the country rocks.

Fig. 6: Iso-salinity contour map of the unconfined Pleistocene aquifer groundwater samples in the study area.

The concentrations of both calcium and magnesium contents in groundwater increase due to the dissolution of carbonate formation (calcite, gypsum and dolomite) which are abundant among the country rocks (sedimentary rocks) at the west of the study area during runoff process. Also, calcium ions are also derived from cation exchange process that occurred on the surface of clay which is one of the components of the concerned aquifer. Moreover, the high concentration of magnesium is caused by the anthropogenic activities through the infiltrated wastewater.

The great variation in the sodium values proposed that the hydrochemistry of groundwater here is affected by the anthropogenic activities, in addition to leakage of salts from soil. Also, sodium concentration increases are due to intensive pumping. The potassium content in the groundwater reflects the effect of using potassium fertilizers in the reclaimed areas. Also, the leaching of K⁺ from the fine argillaceous sediments may be another factor elevating the potassium content in the groundwater. However, the higher concentration of potassium is recorded near the old cultivated land and this is likely due to silicate minerals and agricultural activities. Also, the high concentration of potassium may be due to the anthropogenic activities through the infiltrated wastewater containing potassic washing powder.

The increase of sulfate content may be due to the dissolution of gypsum mineral CaSO₄·2H₂O included in the water-bearing strata. Also, exceeded SO₄²⁻ concentration can be attributed to fertilizers and insecticides used in the surrounding farmlands, in addition to leaching of salts from soil close to the sulfate rich desert zone.
High concentration of chloride could be driven from dissolution and weathering of halite which are abundant among sedimentary rocks during the groundwater movement in the study area and from the natural sources as geologic strata that contain trapped chloride deposited from ancient marine sediments. Also, high values of Cl\(^-\) content seem to be related to anthropogenic local pollution through the penetrated domestic wastewater because they are associated with high NO\(^3\) and SO\(^4\)\(^-\) contamination, as well as irrigation drainage return flow are responsible for chloride content in the groundwater. The discharge of human, animal, or industrial wastes and the wells that located near the reclamation projects also may add substantial quantities of chloride to surface and groundwater.

On the other hand, the decrease in concentration of both calcium, magnesium, sodium, sulfate and chloride contents in the unconfined Pleistocene aquifer groundwater is due to the seepage of fresh water from the adjacent semi-confined aquifer groundwater that recharged from the irrigation canals. Also, the decrease in chloride concentration is recorded in the wells that located down flow from the sewage wastewater disposal project. While, the depletion of potassium concentration may be due to the consumption of potassium by different microorganisms which indicate the presence of organic pollution.

The areal distribution of both calcium, magnesium, sodium, sulfate and chloride constituents in the unconfined Pleistocene aquifer groundwater showed that the concentration of these ions increase from west to east with the general groundwater flow direction toward the Nile River, i.e., follow the direction of salinity increase (Figs.7, 8, 9, 10 and 11).

As known, sodium has different role in human body, where sodium is related to the function of nervous system, membrane system and excretory system. Excess sodium causes high pressure, nervous disorder, etc. According to WHO (2011) guidelines, the maximum admissible limit is 200mg/l. So, 65% of the groundwater samples in the study area have Na\(^+\) values well within the permissible limit, while the rest of the samples 35% have Na\(^+\) values more than the permissible limit. Worth mentioning that, 81% of the groundwater samples have SO\(^4\)\(^-\) values lie within the safe limit (250mg/l) that discussed by WHO (2011), while the presence of sulfate in drinking water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers WHO (2011).

Groundwater samples with high concentrations of bicarbonate ion characterize the recharging zones of the study area. As indicated from figure (12), the highest bicarbonate HCO\(^3\)\(^-\) contents may be due to down flow from the wastewater project as at west Tahta and west Tama localities or along the border with the semi-confined aquifer as at Gerga locality reflecting the effect of domestic wastewater infiltration and dilution effect, respectively. Large concentrations of carbonate and bicarbonate ions in the groundwater samples of the unconfined Pleistocene aquifer in the study area are probably the result of dissolution of carbonate minerals (calcite and dolomite) present in the area under investigation. Clay weathering and cation exchange could also contribute significant concentrations of carbonate and bicarbonate to groundwater as precipitation percolates through the unsaturated zone. The areal distribution of bicarbonate of Pleistocene aquifer groundwater increased from east to west, opposite to the general groundwater flow direction (toward the plateau), i.e., in the opposite direction of salinity increase and other ions (Fig.12).

**Geochemical classification using tri-linear plotting system (Piper’s tri-linear diagram, 1953):**

Piper’s tri-linear diagram method (1953) is used to classify the groundwater, based on basic geochemical characters of the constituent ionic concentrations. The diamond–shaped field shows the overall character of water through the relationship between the alkalis (Na\(^+\) K\(^+\)), the alkaline earth (Ca\(^2+\) Mg\(^2+\)), the alkalinity (CO\(^3\)\(^-\) HCO\(^3\)\(^-\)) and the salinity (Cl\(^-\) + SO\(^4\)\(^-\)). Based on the general pattern of the plotted data on the diamond-shaped field, four groups are differentiated as follows (Fig. 13).

Sub-area (7): This sub-area includes 52% of the unconfined Pleistocene aquifer groundwater samples, where the non-carbonate alkali (primary salinity) exceeds 50%, that is, chemical properties of the groundwater are dominated by alkalis and strong acids. The groundwater samples in sub area (7) were influenced by the effect of leaching and dissolution processes for the aquifer matrix and the catchment area as well as over-pumping activities.

Sub-area (9): This sub-area includes 39% of the unconfined Pleistocene aquifer groundwater samples, and also, 33%, 33% and 67% of the Nile River, irrigation canals and drains water samples, respectively. It is worth to mention that, sub-area 9, characterized by no one of the cation-anion pair exceeds 50%. It is obvious...
Fig. 7: Iso-calcium contour map of the Pleistocene aquifer groundwater in the study area

Fig. 8: Iso-magnesium contour map of the Pleistocene aquifer groundwater in the study area

Fig. 9: Iso-sodium contour map of the Pleistocene aquifer groundwater in the study area

Fig. 10: Iso-sulfate contour map of the Pleistocene aquifer groundwater in the study area

Fig. 11: Iso-chloride contour map of the Pleistocene aquifer groundwater in the study area

Fig. 12: Iso-bicarbonate contour map of the Pleistocene aquifer groundwater in the study area
that the surface water samples (Nile River and irrigation canals) are located near some groundwater samples in the upper portion of sub-area 9 which indicate that some groundwater samples are influenced by the effect of the seepage from the adjacent semi-confined aquifer, while the majority of the groundwater samples are affected by the leaching and dissolution processes of the aquifer matrix and the catchment area as well as the effect of reclamation projects.

Sub-area (6): This sub-area includes 6% of the unconfined Pleistocene aquifer groundwater samples where non-carbonate hardness (secondary salinity $\text{SO}_4^{2-}+\text{Cl}^-$) exceeds 50%. The groundwater samples in sub area (6) were influenced by the effect of leaching and dissolution processes of the terrestrial salts (sulfate minerals) and the excessive use of phosphate fertilizers.

Sub-area (5): This sub-area includes 3% of the unconfined Pleistocene aquifer groundwater samples and 67%, 67% as well as 33% of the Nile River, irrigation canals and drains water samples respectively, where carbonate hardness (secondary alkalinity) exceeds 50%, that is, chemical properties of the groundwater are dominated by alkaline earths and weak acids. It is noticed that the surface water samples located around the groundwater samples Nos. 28 and 51 in sub area (5), this indicates that these groundwater sample are influenced by the effect of wastewater projects at west Tahta and west Tama localities as well as the effect of the seepage from the adjacent semi-confined Pleistocene aquifer.

**Fig. 13:** Piper’s diagram for surface water and groundwater samples in the study area.

**Change in groundwater chemistry with distance (hydrochemical profile):**

The hydrochemical profile (Figs.14&15), is directed from southwest to northwest direction and starts from El-Balyna locality (sample No.19) to Tama locality (sample No.87) passing through nine surface water samples (seven irrigation canals water and two drains water) and seventeen unconfined Pleistocene aquifer groundwater samples showing an irregular pattern characterized by non conspicuous trend for increase or decrease of water salinity (the fluctuation of water salinity).
As previously mentioned, the flow of groundwater in the study area is moving from south to north and from west to east. The main changes in groundwater chemistry during its movement from south to north are well illustrated by the following profile.

The hydrochemical properties along this profile reveal that TDS show irregular pattern of decrease from brackish water (1588mg/l) at El Balyna locality (samples No.19) to fresh water (874mg/l) at west Tama locality (sample No.87) passing by saline water (6153mg/l) at El Monshaa locality (west Sohag), i.e., the salinity decreases in the groundwater flow direction. Generally, the lower water salinity is attributed to the closeness to the seepage from the adjacent semi-confined Pleistocene aquifer as at west Gerga locality and the effect of wastewater projects as at west Tahta and west Tama localities, while the wide range of water salinity at El Balyna and west El Monshaa (west Sohag) localities is due to over pumping, leaching and dissolution processes for the aquifer matrix and catchment area as well as return flow after irrigation and reclamation projects. Also, the irregularity in the content of the chemical species along the profile reflects the absence of the direct effect of surface water on the groundwater in the study area.

The ion dominance change follows a sequence from Cl > SO$_4^{2-}$ > HCO$_3^-$ (sample No.19) at El Balyna locality to HCO$_3^-$ > Cl$^-$ > SO$_4^{2-}$ at Tama locality (sample No.87), i.e., there is an unexpected dominant metasomatic sequence (geochemical evolution) for the groundwater along this profile, where it changes from a more advanced stage Cl$^-$ > SO$_4^{2-}$ > HCO$_3^-$ at south of the study area to less advanced stage HCO$_3^-$ > Cl$^-$ > SO$_4^{2-}$ at north of the study area, while the groundwater flow is from the south to the north, this is due to that the groundwater is affected by the seepage from the adjacent semi-confined aquifer to some groundwater samples as well as the wastewater projects effects at west Tahta and west Tama localities.

NaCl salt appears in all groundwater samples along the profile and it ranges widely between 17% in sample No.87 and 55% in sample No.23. Na$_2$SO$_4$ salt appears in samples Nos. 29, 32, 41, 58, 64, 72, 75, 83 and 87, where it ranges between 5% in sample No.32 and 26% in samples Nos. 58 & 83. MgSO$_4$ salt disappears in groundwater sample No.36, while it appears in the rest of groundwater samples along this profile and it ranges widely between 2% in sample No.27 and 30% in sample No.23. CaSO$_4$ salt appears widely in the groundwater samples Nos. 19, 23, 27, 32, 36, 39, 41, 42, 52 and 67, where it ranges widely between 1% in sample No.41 and 29% in sample No.27. MgCl$_2$ salt appears in groundwater samples Nos. 19, 23, 27, 36, 39, 42, 52 and 67, while it disappears in the rest of groundwater samples, and it ranges between 3% at sample No. 42 and 39% at samples Nos. 36 and 52. Mg(HCO$_3$)$_2$ salt appears only at groundwater samples Nos. 29, 58, 64, 72, 75, 83 and 87, while it disappears in the rest of groundwater samples, where it ranges between 1% in sample No.29 and 31% in sample No.72. (MgCO$_3$)$_2$ salt appears in all groundwater samples along the profile, and it ranges between 1% in samples Nos. 36 & 39 and 18% in sample No.32.

The presence of sodium sulfate salt in some groundwater samples during the profile is a true indication of dissolution of terrestrial salts, where water bearing formation was formed under continental conditions. The high sulfate and carbonate minerals in the aquifer sediments activate the geochemical processes. The presence of calcium sulfate salt in some groundwater samples is due to leaching and dissolution processes for sulfate minerals. The presence of magnesium sulfate salt in most of groundwater samples along the profile is due to the effect of gypsum deposits in the aquifer matrix and the effect of excessive use of fertilizers. The presence of bicarbonate salts in all water samples reflects the continental origin of groundwater and the effect of the seepage from the adjacent semi-confined aquifer as well as the effect of wastewater projects, as the Ca(HCO$_3$)$_2$ salt that increases in wells that located at west Gerga, west Tahta and west Tama localities. This characterizes the areas where sand and gravels dominate the aquifer and enables surface fresh water to percolates down to the groundwater. The presence of MgCl$_2$ salt in some groundwater samples is due to leaching and dissolution processes of Phiocene deposits.

Most of the groundwater samples are characterized by the assemblages of hypothetical salts combinations II and III (table 3), regardless of their total salinities. This reflects the effect of leaching and dissolution of terrestrial salts (continental facies groundwater) as well as the effect of seepage from the adjacent semi-confined aquifer and wastewater project. The rest of the groundwater samples are characterized by the assemblage of hypothetical salts combination V (table 3), regardless of their total salinities. This assemblage (V) contain two chloride salts, two sulfate salts and one bicarbonate salt, reflecting the effect of marine salt contamination (marine facies groundwater) with some contribution of leaching and dissolution processes of the Phiocene sediments as well as over-pumping activities and agricultural activities.

The heterogeneity of the hypothetical salts combinations (V, II and III) along this hydrochemical profile in the concerned aquifer indicates that the factors affecting groundwater quality are numerous as seepage from the adjacent semi-confined aquifer, reclamation projects and wastewater projects as well as leaching and dissolution processes for the aquifer matrix and catchment area.

Aggradations (to progress by steps) in chemical development is noticed in groundwater dominated by salt assemblages II and III (less stages of chemical development), where two and one bicarbonate salts exist, and then groundwater samples that dominated by assemblages V (more advanced stage of chemical development),
where two chloride salts are found. This indicates that meteoric water origin is influenced either by leaching of terrestrial salts or marine salts in this aquifer.

Fig. 14: Hydrochemical profile direction map

Fig. 15: Hydrochemical profile of surface water and groundwater samples in the study area

Table 3: Assemblages of the hypothetical salt combinations of the surface water and Pleistocene aquifer groundwater samples across the hydrochemical profile

<table>
<thead>
<tr>
<th>Assemblages of the hypothetical salt combinations</th>
<th>Samples Nos.</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-NaCl, Na₂SO₄, NaHCO₃, Mg(HCO₃)₂ and Ca(HCO₃)₂</td>
<td>16, 17,</td>
</tr>
<tr>
<td>II-NaCl, Na₂SO₄, MgSO₄, Mg(HCO₃)₂, and Ca(HCO₃)₂</td>
<td>5, 6, 7, 11, 12, 13, 14, 29, 58, 72, 75, 83, 87</td>
</tr>
<tr>
<td>III-NaCl, Na₂SO₄, MgSO₄, CaSO₄ and Ca(HCO₃)₂</td>
<td>32, 41</td>
</tr>
<tr>
<td>V- NaCl, MgCl₂, MgSO₄, CaSO₄ and Ca(HCO₃)₂</td>
<td>19, 23, 27, 39, 42, 52, 67</td>
</tr>
</tbody>
</table>
Water Pollution

Groundwater pollution is influenced by a number of factors like human activities, agricultural practices, topography, hydrogeology, the sources of groundwater recharge and the amount of groundwater pumping, sewage disposal, and other environmental conditions, with which it alters from point of its entry to exit. The pollution of the groundwater in the study area is discussed through the measurements of NO\textsubscript{3}\textsuperscript{-}, NH\textsubscript{3} and TOC as well as Fe, Pb, Cu, Cd, Cr, Al and Zn.

The minimum, maximum and average values of NO\textsubscript{3}, NH\textsubscript{3} and TOC as well as Fe, Pb, Cu, Cd, Cr, Al and Zn for the surface water and groundwater samples are indicated in table 4.

Nitrate content:
The nitrogen compounds play an important role in many processes that take place in natural water. In comparison with the WHO’s (2011) drinking water guideline of 50mg/l for NO\textsubscript{3}\textsuperscript{-}; it is clear that 100%, 33%, 33% and 85% of the Nile River, irrigation canals, agricultural drains water and groundwater samples, respectively, are located within the permissible limit while the rest of the samples 67%, 67% and 15% of the irrigation canals, agricultural drains water and groundwater samples, respectively, are polluted as they have NO\textsubscript{3}\textsuperscript{-} concentrations more than the safe limit. Burkart and Kolpin (1993), and Eckhardt and Stackelberg (1995) stated that groundwater with NO\textsubscript{3}\textsuperscript{-} concentration exceeding the threshold of 13mg/l is considered contaminated due to human activities (the so-called human affected value). So, 46% of the groundwater samples are contaminated as they have NO\textsubscript{3}\textsuperscript{-} concentrations more than the human affected value. Most of the groundwater samples that display valuable NO\textsubscript{3}\textsuperscript{-} concentrations are located either along the boundary with the adjacent semi-confined aquifer that recharged from the surface water as at Gerga locality or beside the wastewater disposal projects as at west Tahta and west Tama localities (Fig.16). Then the elevated contents of nitrate (NO\textsubscript{3}\textsuperscript{-}) in groundwater at the study area may be due to the anthropogenic activities and return flow after irrigation as well as the improper dumping of sewage wastewater disposal in some sites that reach the groundwater and from oxidation of nitrogenous waste products in human and animal excreta, including septic tank, fertilizer (where nitrogen fertilizers are used extensively in agriculture) or nitrogen-fixing bacteria. Also, some groundwater may also have nitrate contamination as a consequence of leaching from natural vegetation. The lower concentration (<50 mg/l) that indicate surface runoff might have decreased the nitrate concentration. So, surface water nitrate concentrations can change rapidly owing to surface runoff of fertilizer, uptake by phytoplankton and denitrification by bacteria, but groundwater concentrations generally show relatively slow changes. In addition, municipal and wastewater are not properly treated before discharged, which makes it easy for contaminants to reach groundwater. This is confirmed by Saba et al. (2006) who stated that, nitrates are extremely soluble in water and can move easily through soil into the drinking water supply. Therefore, large amount of N fertilizer and inadequate management of N fertilization coupled with low irrigation efficiency are mainly responsible for the nitrate concentrations in groundwater. The effect of high NO\textsubscript{3}\textsuperscript{-} concentrations on human health is very dangerous; this is manifested by Spalding and Exner (1993) who stated that NO\textsubscript{3} concentration is responsible for several diseases as hypertension, cancer and birth defects. Also, the concentration of water with high nitrate concentration causes blue babies or methemoglobinemia disease in infants, gastric carcinomas, abnormal pain, central nervous system birth defects and diabetes (Saba et al., 2006).

Ammonia content:
The term ammonia includes the non-ionized (NH\textsubscript{3}) and ionized (NH\textsubscript{4}\textsuperscript{+}) species. In comparing with the natural level (0.2mg/l) as stated by WHO, 2011, it is clear that 33%, 83% and 67% of the Nile River, irrigation canals and agricultural drains water samples were polluted as they have ammonia concentrations more than natural level, this reflects the excessive amount of nitrogen fertilizers used and intensive rearing of farm animals. On the other hand, 87% of the groundwater samples in the study area have concentrations less than the natural level of pollution while the rest of the groundwater samples (13%) are polluted by ammonia as they have ammonia concentrations more than natural level. The groundwater samples displaying an extent valuable NH\textsubscript{3} concentrations are located either along the boundary with the adjacent semi-confined aquifer that recharged from the surface water as at Gerga locality or beside the wastewater disposal projects as at west Tahta and west Tama localities, i.e., the relative high content of ammonia in the groundwater is mostly due to anthropogenic activities and excessive use of nitrogen fertilizers in cultivation processes. Noteworthy to mention that, the low concentration of ammonia in groundwater may be due to oxidation of a significant part of ammonia (NH\textsubscript{3}) to nitrate (NO\textsubscript{3}\textsuperscript{-}).

Total organic carbon (TOC) content:
Total Organic Carbon is a term used to describe the measurement of organic (carbon based) contaminants in a water system. All surface water samples have TOC concentrations less than the acceptable limit 10mg/l (Egyptian Organization for Standardization and Quality, 2007) except the irrigation canals water samples Nos. 4 and 15 that contain TOC concentration more than 10mg/l, this is due to excessive use of
fertilizers in the study area. On the other hand, 83% of the groundwater samples in the study area have TOC concentrations less than the natural level of pollution while the rest of the groundwater samples (17%) are polluted as they have TOC concentrations more than natural level. The groundwater samples display to an extent valuable TOC concentrations are located either along the boundary with the adjacent semi-confined aquifer that recharged from the surface water as at Gerga locality or beside the wastewater disposal projects as at west Tahta and west Tama localities or due to return flow after irrigation and the excessive use of fertilizers that infiltrate to the groundwater as at El-Balyna locality (Fig.17).

Fig.16: Iso-nitrate contour map of the unconfined Pleistocene aquifer groundwater samples in the study area

Trace elements contents:
Fe, Pb, Cu, Cd, Cr, Al and Zn trace elements have also been investigated to further clarify the characteristics and chemical composition of surface water and groundwater in the study area. The results indicate that 67% and 17% of the Nile River and irrigation canals water samples have Fe, Pb, Cu, Cd, Cr, Al and Zn concentrations less than the safe limits 0.3, 0.01, 2, 0.003, 0.05, 0.2 and 0.01mg/l, respectively, as presented by WHO, 2011, while the rest of the Nile River and irrigation canals water samples, 33% and 83%, respectively, are polluted as they have Fe and Al concentrations more than the safe limits. The high contaminations are due to the wastes that received in the Nile River and irrigation canals as well as the seepage from the waste artificial lake of the aluminum company at Nag Hammadi city to Nile River (the waste artificial lake of the aluminum company located at a distance of about 10Km to the Nile River) which in turn transport these pollutants to the irrigation canals that take water from Nile River upstream of Nag-Hammadi Barrages located ~ 15km south of the study area. For the agricultural drains, it is obvious that 33% of the drains water samples are polluted by iron, lead and zinc due to the wastes that received in the drains.
Also, the results indicate that the groundwater in the study area are seriously contaminated by iron and lead as well as, chromium, aluminum and zinc. While, 23% of the groundwater samples have iron concentrations more than the safe limit (0.3mg/l). Reviewing the compositional characteristics of the Pleistocene sands in the Nile basin throughout the study area (Omer, 1996), two different types of sands are recorded; sands of local derivation and sands of Ethiopian sources. Sands of local derivation are derived from Egyptian deposits and they are extremely poor in the ferromagnesian minerals. Dissolution of these minerals is the main source of iron in groundwater of the Quaternary aquifer, i.e., the source of iron in the study area is the water bearing formation. In addition, iron can be originated from the anthropogenic activities. So, as shown in Fig.(18) most of groundwater samples display to some extent higher iron concentrations are located either at west of Sohag and north of Gerga localities due to the effect of land reclamation projects or at south Tama wastewater project. It is worth to mention that, high Fe concentration is responsible of kidney failure.

Lead present in the water is in two states, Pb$^{2+}$ and Pb$^{4+}$. The former divalent form constitutes the more stable in most aquatic environment. While, 74% of the groundwater samples have lead concentrations more than the safe limit (0.01mg/l). The high Pb concentrations in the groundwater is referred to the sediments and from excessive use of fertilizers (return flow after irrigation), atmospheric fallout, runoff or wastewater, as well as anthropogenic activities at extreme limit, where little is transferred from natural ores. Groundwater samples display to some extent higher lead concentrations are distributed in whole the area under study, Fig.(19). Noteworthy to mention that, specifically lead affects the growth of a child's brain, leading to a decline in the rate of his intelligence and changes in behavior, such as shortening attention span and increased anti-social behavior and low level of educational attainment. As exposure to Pb leads to anemia, high blood pressure and kidney failure and cause poisoning of immune system and reproductive organs.

19% of the groundwater samples have chromium concentrations more than the safe limit (0.05mg/l). Groundwater samples display to some extent higher chromium concentrations are located at El Balyna, Gerga, Sohag and Tahta localities due to the excessive use of fertilizers. Worth to mentioning that, increase in chromium may harm the kidneys.

19% of the groundwater samples have aluminum concentrations more than the safe limit (0.2mg/l). Most of groundwater samples display to some extent higher aluminum concentrations are located either at west Sohag locality due to the reclamation projects and agricultural activities (return flow after irrigation) as well as...
the excessive use of fertilizers that infiltrate to the groundwater or at west Tama locality due to wastewater project (Fig.20). It has been hypothesized that aluminum exposure is a risk factor for the development or acceleration of onset of Alzheimer disease in humans.

The levels of zinc in surface water and groundwater normally do not exceed 0.01 and 0.05mg/l, respectively, (WHO, 2011). While, 4% of the groundwater samples have zinc concentrations more than the safe limit (0.05mg/l). The zinc content in groundwater of the study area is originated from anthropogenic activities especially at the wastewater disposal sites and the excessive use of fertilizers. The low concentration of zinc in groundwater is referred to that zinc is mainly sorbed on the mineral grains, therefore, it has limited chance to reach the groundwater. Noteworthy to mention that, Increase in zinc concentration causing a defect in the function of iron and thus a lack of immune system. Also, at higher concentrations, zinc is harmful to plants.

While, zinc in small concentrations is an essential element for living organisms. The diet is normally the principal source of zinc.

In general, 46% of the groundwater samples are contaminated with iron, lead, chromium, aluminum and zinc at variable percentages as they have Fe, Pb, Cr, Al and Zn concentrations more than the safe limits, while the rest of the groundwater samples have concentrations less than the safe limits. The high concentrations of iron, lead, chromium, aluminum and zinc are due to several factors; the seepage from wastewater, the reclamation projects, return flow after irrigation and the excessive use of fertilizers especially, phosphate fertilizers as they have pronounced concentrations of these elements in its formation.

In conclusion, Gerga locality is considered one of the polluted localities in the study area as it is affected by excessive use of fertilizers in agriculture in addition to the seepage from the adjacent semi-confined aquifer as well as return flow after irrigation, while west Tama and west Tahta localities are considered the more polluted localities due to the effect of the waste water disposal projects at those localities.

Fig.18: Iso-iron contour map of the unconfined Pleistocene aquifer groundwater in the study area.
Fig.19: Distribution histogram of Pb in the unconfined Pleistocene aquifer groundwater samples of the study area

Fig.20: Iso-aluminium contour map of the unconfined Pleistocene aquifer groundwater in the study area.
This is due to the effect of the leaching and dissolution processes, over by the following ion dominance; high salinity than the previous three clusters, where the salinity ranges from 5203 ppm. The groundwater samples are distributed all over the study area, table 5, they are characterized by salinity within the fresh zone, where the TDS ranges from 701 to 1080 mg/L, with the following anion dominance; HCO₃⁻, Cl⁻, and Na⁺. This is due to the effect of the leaching and dissolution processes in west Sohag and west Tahta localities, as well as seepage from the adjacent semi-confined aquifer. The groundwater samples in cluster No.1 are affected by the seepage from wastewater disposal projects as at west Tahta and west Tama localities, i.e., the high salinity is confirmed by the following anion dominance; Cl⁻, SO₄²⁻, and Na⁺.

The cluster analysis (CA) grouped 87 sampling locations into 4 clusters named as 1, 2, 3 and 4. Clusters of samples are listed in table 5. The results of the cluster analysis (Dendrogram) for the samples are presented in Fig.21. The CA grouped 87 sampling locations into 4 clusters named as 1, 2, 3 and 4. Clusters of samples are listed in table 5, which indicate that each cluster has a water quality of its own which is different from the other clusters, with all the points falling along a straight line joining the highly saline water at one end and the cluster of fresh water points at the other end.

Cluster No.1 is subdivided into two sub-clusters, one of them is represented by 7 groundwater samples in addition to surface water samples (Nile River, irrigation canals and agricultural drains), table 5. The groundwater samples are distributed due the northwestern part of the study area, they are characterized by low TDS concentration ranging from 173 to 1080 mg/L, with the following anion dominance; HCO₃⁻ > SO₄²⁻ > Cl⁻, SO₄²⁻ > Cl⁻ > HCO₃⁻ and HCO₃⁻ > Cl⁻ > SO₄²⁻ and cation dominance; Ca²⁺ > Mg²⁺ > Na⁺, Na⁺ > Mg²⁺ > Ca²⁺ and Mg²⁺ > Na⁺ > Ca²⁺. The other cluster is represented by 26 groundwater samples which are distributed all over the study area, table 5, they are characterized by salinity within the fresh zone, where the TDS ranges from 701 to 1522 mg/L, with anion dominance; Cl⁻ > HCO₃⁻ > SO₄²⁻, Cl⁻ > SO₄²⁻ > HCO₃⁻, SO₄²⁻ > Cl⁻ > HCO₃⁻ and SO₄²⁻ > HCO₃⁻ > Cl⁻ and cation dominance; Na⁺ > Mg²⁺ > Ca²⁺, Na⁺ > Ca²⁺ > Mg²⁺ and Mg²⁺ > Na⁺ > Ca²⁺. The groundwater samples in cluster No.1 are affected by the seepage from wastewater disposal projects as at west Tahta and west Tama localities, as well as seepage from the adjacent semi-confined Pleistocene aquifer groundwater in the old cultivated area which is directly recharged from the Nile River and irrigation canals as at Gerga locality.

Cluster No.2 is subdivided into three sub-clusters, the first, second and third sub clusters contain 6, 7 and 11 groundwater samples, respectively, (table 5). The groundwater samples are distributed all over the study area. They are distinguished by higher salinity than the previous cluster, where the salinity ranges from 1183-3049 mg/L, with anion dominance; Cl⁻ > HCO₃⁻ > SO₄²⁻, SO₄²⁻ > Cl⁻ > HCO₃⁻ and Cl⁻ > SO₄²⁻ > HCO₃⁻ and cation dominance; Na⁺ > Mg²⁺ > Ca²⁺, Mg²⁺ > Na⁺ > Ca²⁺ and Mg²⁺ > Ca²⁺ > Na⁺. This is attributed to the effect of reclamation projects at west Tama, west Tahta, west Sohag and El-Balayna localities, i.e., the high salinity is due to agricultural activities and return flow after irrigation.

Cluster No.3 is subdivided into two sub-clusters; that contain 2 and 8 groundwater samples, respectively, (table 5). They are distinguished by higher salinity than the previous two clusters, where the salinity ranges from 3358-4452 mg/L. This is confirmed by the following anion dominance; Cl⁻ > SO₄²⁻ > HCO₃⁻ and SO₄²⁻ > Cl⁻ > HCO₃⁻ and cation dominance; Na⁺ > Ca²⁺ > Mg²⁺ and Na⁺ > Mg²⁺ > Ca²⁺. This is due to the effect of the leaching and dissolution processes in west Sohag and west Tahta localities.

Cluster No.4 is represented by the samples Nos. 36 and 39 (table 5), they are distinguished by very high salinity than the previous three clusters, where the salinity ranges from 5203-6153 mg/L. This is confirmed by the following ion dominance; Cl⁻ > SO₄²⁻ > HCO₃⁻ and cation dominance; Na⁺ > Mg²⁺ or Mg²⁺ > Na⁺ > Ca²⁺. This is due to the effect of the leaching and dissolution processes, over-pumping and return flow after irrigation in west Sohag locality.

### Table 4: Minimum, maximum and mean values (mg/l) of the major constituents of the surface water and groundwater samples in the study area.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Nile River</th>
<th>Irrigation canals</th>
<th>Agricultural drains</th>
<th>Pleistocene aquifer groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
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<td>12.34-72.18</td>
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<tr>
<td>NH₄</td>
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<td>0.00-16.30</td>
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<td>0.00-52.82</td>
<td>22.83</td>
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<td></td>
<td>0.00-9.61</td>
<td>0.27</td>
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<td>TOC</td>
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<td>4.65-27.4</td>
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<td></td>
<td>0.52-16.28</td>
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<td>0.001-0.01</td>
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<td></td>
<td></td>
<td>0.001-0.194</td>
<td>0.03</td>
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<tr>
<td>Al</td>
<td>0.02-0.205</td>
<td>0.118</td>
<td>0.02-0.740</td>
<td>0.361</td>
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<td></td>
<td></td>
<td></td>
<td>0.02-0.445</td>
<td>0.193</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.02-2.51</td>
<td>0.18</td>
</tr>
<tr>
<td>Zn</td>
<td>0.002-0.007</td>
<td>0.004</td>
<td>0.002-0.016</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.002-0.099</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.002-0.191</td>
<td>0.012</td>
</tr>
</tbody>
</table>

### Statistical analysis:

The multivariate statistical techniques are used in making the relationships between variables to interpret the water quality in the study area and to give meaningful results. In this study, statistical Netpath software version 10 is used to carry out the Cluster Analysis (CA).

### Cluster Analysis (Q-mode cluster analysis)

The cluster analysis (CA) technique is used to classify the examined parameters of groundwater into categories or clusters based on their similarities or dissimilarities in the variation of the datasets using Hierarchical cluster analysis (HCA). The degree of association between two objects is maximal if they belong to the same group and minimal otherwise. In Hierarchical cluster analysis the distance between samples is used as a measure of similarity (Vega et.al., 1998). One of the main purposes of cluster analysis in this study is to identify samples affected by wastewater projects, agricultural activities and seepage from the adjacent semi-confined aquifer. The results of the cluster analysis (Dendrogram) for the samples are presented in Fig.21. The CA grouped 87 sampling locations into 4 clusters named as 1, 2, 3 and 4. Clusters of samples are listed in table 5, which indicate that each cluster has a water quality of its own which is different from the other clusters, with all the points falling along a straight line joining the highly saline water at one end and the cluster of fresh water points at the other end.
Quality of Groundwater for Utilization

Understanding the groundwater quality is important as it is the main factor determining its suitability for different purposes, and this is discussed as follows:

Human drinking water suitability

The evaluation of water quality for drinking is based on the total dissolved solids (TDS) and the concentrations of minor and trace elements. This was done using water quality guidelines of World Health Organization (WHO, 2011). So, by applying these guidelines, it is obvious that:

According to the water salinity (TDS), all Nile River and its irrigation canals water samples are suitable for drinking as they have water salinity less than the permissible limit (1000mg/l). On the other hand, most groundwater samples of the unconfined Pleistocene aquifer (72%) are unsuitable for drinking since they have water salinity higher than the permissible limit, while the rest of the groundwater samples (28%), are suitable for drinking as they have water salinity less than the permissible limit (1000mg/l).

According to the minor and trace elements; 33% and 83% of the Nile River and irrigation water samples, respectively, are unsuitable for drinking as they are polluted by Fe and Al. 46% of the groundwater samples are unsuitable for drinking as they are polluted by nitrate, iron, lead, chromium, aluminum and zinc at variable percentages. So, it must be treated by available techniques before use for drinking.

Irrigation water suitability

The suitability of groundwater for irrigation is mainly based upon factors as soil texture and composition, crops grown, and irrigation practices in addition to chemical characteristics of the water. Excessive concentrations of dissolved ions in the water used for irrigation affect plants and, the physical and chemical parameters of soil by lowering the osmotic pressure in the plant structural cells (Rao et al., 2012). This process prevents water from reaching the branches and leaves, thus reducing the agricultural productivity. Another important chemical parameter for judging the degree of suitability of water for irrigation like as alkali hazard which is expressed in sodium adsorption ratio (SAR) and sodium content (Na%). There is a close relationship between SAR values in irrigation water and the extent to which Na+ is absorbed by soils. Sodium adsorption ratio (SAR) is an important parameter for determining the suitability of groundwater for irrigation because it is a measure of alkali/sodium hazard to crops. High values of SAR imply a hazard of sodium replacing absorbed Ca2+ and Mg2+ and this replacement causes damaging of soil structure. If water used for irrigation is high in Na+ and low in Ca2+, the ion exchange complex may become saturated with Na+, which destroys soil structure, because of dispersion of clay particles. As a result, the soils can be very difficult to cultivate (Subba Rao, 2006).

The US Salinity Laboratory’s diagram (US Salinity Laboratory Staff 1954) is used widely for rating the irrigation water. The United States salinity laboratory staff has diverse a system for classifying the irrigation water depending on the relationship between the sodium adsorption ratio (SAR) and the electrical conductivity (EC) of the water, which is a function of the dissolved solids concentration.

By applying the US Salinity Laboratory staff classification for the surface and groundwater samples in the study area (table 6 and Fig. 22), it can be concluded that;

- All Nile River and irrigation canals water samples, and also, 1% of the groundwater samples are located in the good water class for irrigation C2-S1, indicating water of medium salinity and low sodium, which can be used for irrigation in almost all types of soil with little danger of exchangeable sodium.

- 38% of the Pleistocene aquifer groundwater samples are located in the good water classes for irrigation C2-S1, C3-S1 and C4-S1 indicating water of medium to high and very high salinity and low sodium hazard, which can be used for irrigation in almost all types of soil with little danger of harmful levels of exchangeable sodium, i.e., it is suitable for plants having good to moderate salts tolerance and soils of medium to moderate permeability with leaching for most plants.

- 39% of the Pleistocene aquifer groundwater samples are located in moderate water classes for irrigation C3-S2 and C4-S2, indicating high to very high salinity and medium alkalinity hazard, which can be used to irrigate salt tolerant and semi-tolerant crops on soil of moderate permeability under favorable drainage conditions, where it is good for coarse-grained permeable soils, and unsatisfactory for high clayey soils with low leaching.

- 16% of the Pleistocene aquifer groundwater samples are located in intermediate water class for irrigation C4-S3, indicating very high salinity and high sodium hazard. This water is not suitable for irrigation under ordinary conditions but requires special soil management, good drainage, high leaching and organic matter addition.

- 6% of the Pleistocene aquifer groundwater samples are located in bad water class for irrigation C4-S4, indicating very high salinity and very high sodium hazard. The bad waters are generally undesirable for irrigation and should not be used on clayey soils of low permeability, i.e., water in this location is not suitable
for irrigation under ordinary conditions but it can be used under very special circumstances of drainage and with certain crop types.

In conclusion, all Nile River water and irrigation canals water samples and the majority of the groundwater samples (78%) are suitable for irrigation under ordinary conditions, while the rest of groundwater samples (22%) are suitable for irrigation under special conditions.

Fig. 21: Dendogram of cluster analysis
Table 5: Cluster groups and their members of the surface water and groundwater samples in the study area

<table>
<thead>
<tr>
<th>Cluster group</th>
<th>Sub-clusters / Members (sample No.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87</td>
</tr>
<tr>
<td>2</td>
<td>19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87</td>
</tr>
</tbody>
</table>

Table 6: Evaluation of the surface water and groundwater in the study area for irrigation according to US Salinity Laboratory staff, 1954

<table>
<thead>
<tr>
<th>Grade of classification</th>
<th>Nile River</th>
<th>Irrigation canals</th>
<th>Groundwater</th>
</tr>
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<tbody>
<tr>
<td>Good water class</td>
<td>100%</td>
<td>100%</td>
<td>39%</td>
</tr>
<tr>
<td>Moderate water class</td>
<td>0%</td>
<td>0%</td>
<td>39%</td>
</tr>
<tr>
<td>Intermediate water class</td>
<td>0%</td>
<td>0%</td>
<td>16%</td>
</tr>
<tr>
<td>Bad water class</td>
<td>0%</td>
<td>0%</td>
<td>6%</td>
</tr>
</tbody>
</table>

Fig. 22: Classification of irrigation water (after US Salinity Laboratory staff 1954) for the surface water and groundwater in the study area.
Conclusion

The study area is located to the west of the Nile cultivated lands west of Sohag governorate. The water bearing sediments in the study area is represented by Pleistocene deposits. Majority of the groundwater samples of the unconfined Pleistocene aquifer lie in the fresh and brackish zones, while the saline water is less pronounced.

There is a general direction of water salinity, calcium, magnesium, sodium, sulfate and chloride increase from the Plateau to Nile River in all the study area, i.e., the salinity depends on calcium, magnesium, sodium, sulfate and chloride.

Changes in groundwater quality are due to rock-water interaction and oxidation-reduction reactions during the percolation of water through the aquifers. In addition to these processes, water-born pathogens, toxic and nontoxic pollutants that are the major water quality degradation parameters which are transported from recharge area to discharge area through aquifers by groundwater motion. So, groundwater is commonly of critical economical and social significance. Continued population growth in Egypt is rapidly depleting groundwater supplies in some areas, in addition to, intense agricultural, sewage disposal projects, also the tendency of farmers to flood irrigation requires a large quantity of water impose a negative impact on groundwater. This means that, these resources at greater risk to contamination, which has been recognized as one of the most serious problems in Egypt.

Noteworthy to mention that, agricultural activities are frequently associated with water contamination. The spreading and storage of fertilizers, for instance, may result in groundwater contamination due to pollutants leaching into an aquifer. Nitrites, iron, lead, chromium, aluminum and zinc in irrigation water are important contaminants associated with agriculture. Thus, the development of efficient strategies for groundwater protection in agricultural areas requires an assessment of these contaminants.

Excess sodium in drinking water causes high pressure, nervous disorder, while the presence of sulfate in drinking-water can cause noticeable taste, and very high levels might cause a laxative effect in unaccustomed consumers.

In general, 46% of the groundwater samples are contaminated with iron, lead, chromium, aluminum and zinc at variable percentages. The high concentrations of iron, lead, chromium, aluminum and zinc are due to several factors; the seepage from municipal water and wastewater, the reclamation projects, return flow after irrigation and the excessive use of fertilizers especially, phosphate fertilizers as they have higher concentrations of these elements in its formation.

Increase in NO$_3$ concentration is responsible for several diseases as hypertension, cancer and birth defects, while the increase in Fe concentration is responsible of kidney failure. Specifically Pb concentration affects the growth of a child’s brain, leading to a decline in the rate of his intelligence and changes in behavior. Also, the increase in chromium may harm the kidneys. Aluminum is responsible of Alzheimer, and finally the increase in zinc concentration causes a defect in the function of iron and thus a lack of immunity. Specific Pb concentration affects the growth of a child’s brain, leading to a decline in the rate of his intelligence and changes in behavior.

Specifically Pb concentration affects the growth of a child’s brain, leading to a decline in the rate of his intelligence and changes in behavior. Also, the increase in chromium may harm the kidneys. Aluminum is responsible of Alzheimer, and finally the increase in zinc concentration causes a defect in the function of iron and thus a lack of immunity. Specifically Pb concentration affects the growth of a child’s brain, leading to a decline in the rate of his intelligence and changes in behavior.

The majority of Nile River water samples (67%) in the study area are still suitable for drinking purpose, while the majority of irrigation canals water samples (83%) in the study area are unsuitable for drinking as they are polluted by iron and aluminum. On the other hand, 46% of the groundwater samples are unsuitable for drinking as they are polluted by nitrate, iron, lead, chromium, aluminum and zinc. So, both the canals water and groundwater must be treat before use. All Nile River and irrigation water samples and the majority of the groundwater samples (78%) are suitable for irrigation under ordinary conditions, while the rest of groundwater samples (22%) are suitable for irrigation under special conditions.

So, the unconfined Pleistocene aquifer groundwater in the study area is currently under contamination stress due to agricultural activities in the reclaimed lands as well as the impact of the development projects, then the prevention of contamination and management of aquifer groundwater in the study area is urgently needed.

Recommendations

For decreasing the contamination risk of groundwater in the study area, the following recommendations should be taken into consideration:

1- Rational use of fertilizers and pesticides as much as possible.
2- Use of modern methods for irrigation such as drip and sprinkler methods instead of the flood method used.
3- Carry out the treatment processes (primary, secondary and tertiary) for wastewater disposed to prevent the contamination of groundwater.
References


Abdel Moneim, A.A., 1999b. Geoelectrical and hydrogeological investigations of the groundwater resources on the area to the west of the cultivated land at Sohag, the Nile Valley, Upper Egypt. Egyptian Journal of Geology, 43/2: 253-268.


