Groundwater: evaluation and hydrogeochemistry aspects

Environment, Water

Hydrogeologically; Eocene aquifer represents the main water resource of water supply for domestic, industrial and irrigation purposes in the study area. The Eocene aquifer is mainly composed from The Eocene sediments of different of limestone, marl and fissured L. S overlying shale, represents the main aquifer in the area east of the Nile River. The thickness of the water bearing layers varies from well to another and the same in another (50 to 80 m.). The thickness of the aquifer increases to the east and south reaching its maximum value at Wadi Sharounna. However, the depth to water in the study area ranged between 58 and 72m and water level ranges between 8 to 25m.

Hydrogeochemistry aspects:

The pH in the groundwater depends mainly on the composition of the rock and sediment which the water are migrating during it. In the study area, the pH value varies from 7. 2 to 9. 3 in the Quaternary aquifer and from 7. 5 to 8. 35 in the Eocene aquifer. The pH values of 65% of the Quaternary samples and 90% of Eocene samples are of the permissible limits of the Egyptian Standards for water (ES, 2007) and World Health Organization standards guidelines for drinking water (2011).

Electrical conductivity is a measure of water’s capability to pass electrical flow. This ability is directly related to the concentration of ions in the water (EPA, 2012). The groundwater samples collected from the Quaternary aquifer have a wide electric conductivity concentration, where they are varies from 658 to 3917 µs/cm with an average 2287. 5 µs/cm. while it varies from 1042 to 4375 in the Eocene aquifer with an average 2708. 5 µs/cm.

Total dissolved solids (TDS) are a measure of the combined content of all inorganic and organic substances contained in a liquid as a molecular, ionized, or micro-granular (colloidal sol.) suspended form (Hem, 1970). Water salinity is the sum of all mineral substances detected by the chemical analysis. The quantity of the dry residue exhibits the total amount of ions. TDS of the Quaternary samples vary from 421 to 2507 ppm with an average 1464 ppm. WhileTDS of Eocene samples vary from 667 to 2800 ppm with an average 1733. 5 ppm. According to Hem's classification(1985), the collected groundwater of Quaternary and Eocene aquifers ranged from fresh to slightly saline water (Table1).

Table (1): Classification of groundwater types according to Hem (1985).

Class. No	TDS	Quality	Quaternary Samples	Eocene Samples
1	<1000	Fresh	61%	20%
2	1000-3000	Slightly saline	39%	80%
3	3000-10000	Moderately Saline	–	–
4	10000-35000	Very Saline	–	–
5	> 35000	Brine	–	–

Isosalinity contour maps of the Quaternary and Eocene aquifer show the increase ofthe salinity in the east and in the west, which reflects the impact of the leaching effect on the limestone in the east and west portions. While the decrease ofthe salinity in both aquifers is in the portions near the River Nile and it is due to the direct recharge from it.

The total hardness in mg/L is determined by the following equation:

$CaCO_3 = 2.497\ Ca^{2+} + 4.118\ Mg^{2+}$ (mg/L)

The Quaternary samples contain total hardness values varies from 124. 2 to 1043 mg/l with an average of 583. 6 mg/l, TH values of Eocene samples varies from 199 to 943. 4 mg/l with an average 571. 2 mg/l. According Sawyer and McCarty (1987) classification, the groundwater samples which collected from Quaternary aquifer ranged from slightly hard to very hard, while Eocene samples ranged from moderately to very hard.

The ion dominance and water type; composition of water is used to classify it into ionic types based on the dominant dissolved cation and anion, expressed in milliequivalent per liter (meq/L). Concerning the ion dominant, sodium is the dominant cation, while the dominant anions are bicarbonate. The dominant chemical water types of Quaternary samples are $NaHCO_3$, NaCl, Na_2SO_4 and $Ca(HCO_3)_2$ while the dominant chemical water types of Eocene samples are $NaHCO_3$and NaCl.

Hydrogeochemical Classification of Groundwater:

The results of chemical analyses are plotted on the piper’s diagram (1944), this diagram was developed to investigate the origin of the water, the source of its dissolved salts and explain different processes affecting groundwater characters. The studied groundwater samples are represented by four categories.

The first category (1) represents 26% of the quaternary samples and30% of Eocene samples. The second category (2) represents 26% of the quaternary samples and40% of Eocene samples. Category 3 has 19% of the quaternary samples and20% of Eocene samples. The last category (4) represents 29% of the quaternary samples and10% of Eocene samples.

The Durov diagram plots the major ions as percentages of part per millions (ppm %) in the two base triangles. The main purpose of the Durov diagram is to show clustering of data points to indicate samples that have similar compositions. This diagram can display some possible geochemical processes that could affect the water genesis (Lioyd and Heathcoate, 1985).

The collected samples are represented on Durov diagram and it shows that, 23 % of Quaternary samples and 20 % of Eocene samples full in zone No. 4 reflecting ion exchange and dissolution processes. Field No. 5 represented by 39 % of Quaternary samples and 40 % of Eocene samples indicates that there is no dominate anion or cation, where they exhibit simple dissolution of gypsum, halite and anhydrite. 3 % of Quaternary samples are located in field No. 7 has a meteoric origin and developed due to leaching of evaporates. Field No. 8 represented by 32 % of Quaternary samples and 40 % of Eocene samples where the dominance ion and cation are Cl and Na reflecting the reverse ion exchange process. 3 % of Quaternary samples and 20 % of

Eocene samples are located in field No. 9, which indicates that Na and Cl are dominant and the end point water.

The representation of data on Druov diagram confirms the presence of connected two aquifers, the Quaternary aquifer which is represented by the meteoric water origin and the Eocene aquifer which is represented by the saline water origin. The two types of water are subjected to mixing and dilution in the quaternary aquifer in the study area especially in restricted localities along deep seated faults.

EVALUATION OF GROUNDWATER FOR DIFFERENT PURPOSES

Water quality is extremely important because constant access to good quality water is necessary for life as well as the economy. Quality of groundwater is defined as the physical, chemical and biological properties of the groundwater. One of the main goals of the present study is the evaluation of groundwater quality for domestic, drinking and irrigation purposes. This is based on the results of chemical analysis of 41 groundwater samples and the correlation of these results with the Egyptian Higher Committee of water (2007) andWorld Health Organization (2011) of different purposes.

Evaluation of Groundwater for Drinking:

To determine the suitability of groundwater for drinking, it is essential to classify the groundwater depending upon their hydrochemical properties based on their TDS values.

By examining the Quaternary and Eocene sample in the context of the Egyptian Standards for water (ES, 2007) and World Health Organization (2011). It is clear that the majority of the of Quaternary samples (71%) and 20% of Eocene samples are suitable for drinking due to their low levels of salinity (< 1200 mg/l) and also the major ions within the permissible limits. 29% of Quaternary samples and 80% of Eocene samples are unsuitable due to their high salinity (1200 mg/l to 1460 mg/l). and also the major ions above the permissible limits.

Evaluation of Groundwater for Domestic Purposes:

According(Sawyer and McCarty, 1987), the collected groundwater samples of Quaternary aquifer are ranged from 75 to 300 ppm, while the Eocene samples are ranged from 150 to 300 ppm. This indicates that all the collected groundwater samples are unsuitable for domestic uses.

Evaluation of Water Quality for Irrigation Purposes:

The chemical quality of the water is an important factor affecting its usefulness for irrigation purposes, salts in water may affect the growth of plants physically and chemically and may disrupt the soil structure, permeability and aeration. Drainage of water is an important factor affecting the crops growing, where poor drainage permits salt concentration in root zones decreasing highly the plants growth. The classification of groundwater for irrigation is based on the total dissolved solids that cause osmotic pressure, which should be less than plant roots osmotic pressure, where TDS value usually varies with the variation of plant types. The collected groundwater samples in the area under study are evaluatedfor irrigation uses according to salinity index (EC), sodium adsorption ratio (SAR), U. S Salinity Laboratory staff Classification (Richards 1954), sodium percent (Na %), chloride hazard, residual sodium carbonate (RSC), Kelly's Ratio (KR), Soluble Sodium Percentage (SSP), Magnesium Hazard (MH), Permeability Index, and Potential salinity.

Salinity index; According to the classification of irrigation water by Bauder et al. (2007)74% of the Quaternary samples and 20% of the Eocene samples are suitable water. 26% of the Quaternary samples and 80% of the Eocene samples are unsuitable for use in irrigation (Table 2).

Table (2): Classification of collected Quaternary and Eocene samples for irrigation based on electrical conductivity (Ec) by Bauder et al. (2007).

Class. No EC

(m. mohs/cm) at 25º Water Class Quaternary Samples% Eocene Samples%

1 <250 Excellent - -

2 251-750 Good 3% –

3 751-2000 Permissible 71% 20%

4 2001-3000 Doubtful 19% 40%

5 > 3000 Unsuitable 7 % 40%

AccordingSodium adsorption ratio (SAR); the sodium adsorption ration (SAR) is commonly used as an index for evaluating the sodium hazard associated with an irrigation water supply. Siamak and Srikantaswamy (2009) classifiedthe irrigation water to four classes according to SAR values, as shown in Table (3). 97% of Quaternary samples and 100% of Eocene samples are excellent to good for irrigation. 3% of the Quaternary samples represent the third class that has SAR vary between 18 and 26 and it unsuitable for irrigation.

Table (3): Classification of waters irrigation according to SAR values(Siamak and Srikantaswamy, 2009)

SAR

Water quality

Precaution and management suggestions

Quaternary Samples%

Eocene

Samples%

<10

10-18

18-26

> 26

Excellent

Good

Doubtful

Unsuitable

Little danger

Problems on fine texture soils and sodium sensitive plants, especially under low-leaching conditions. Soils should have good permeability

Problems on most soils. Good salt tolerant plants are required along with special management such as the use of gypsum

Unsatisfactory except with high salinity (> 2. 0 dS/m), high calcium levels and the use of gypsum

90%

7 %

3%

–

100%

–

–

–

According U. S Salinity Laboratory staff Classification (Richards 1954):

By plotting the studied water samples on the US Salinity Laboratory (USSL) diagram, we found that, 45% of Quaternary samples and 50% of Eocene samples are lies in C3S1, while 26% of Quaternary samples and 20% of Eocene samples are lies in C3S2. 10% of Eocene samples are lies in C3S3 and 10% of Quaternary samples lie in C4S1. 13% of Quaternary samples and 10% of Eocene samples are lies in C4S2 while 6% of Quaternary samples lie in C4S3. 10% of Eocene samples lie in C4S4 class. This indicates that most of the collected groundwater samples (Quaternary and Eocene) are suitable for irrigation purposes.

Percent sodium; Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. When the concentration of sodium is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg2+ and Ca2+ ions. This exchange process of Na+ in water for Ca2+ and Mg2+ in soil reduces the permeability and eventually results in soil with poor internal drainage. Hence air and water circulation is restricted during wet conditions and such soils usually become hard when dry (Saleh et al., 1999). Wilcox’s classification, 1995 (table 4) shows that 74% of Quaternary samples and 20% of Eocene samples are considered as suitable for irrigation purposes. 26% of Quaternary samples and 80% of Eocene samples are unsuitable.

Table (4): Classification of the collected Quaternary and Eocene samples for irrigation uses based on Wilcox's classification (1995).

Suitability for irrigation	Quaternary Samples %	Eocene Samples %
Excellent to Good	3%	–
Good to permissible	29 %	20 %
Permissible to Doubtful	42 %	–
Doubtful to Unsuitable	19 %	40 %
Unsuitable	7 %	40 %

The chloride content is very important for suitability of groundwater for irrigation purposes. Most plants are very sensitive to chloride ions and certain plants have the ability to accumulate chlorides even from water of low chloride content with harmful effect. Ayers (1975) classified irrigation water according to their chloride content into three classes (Table 5). According to Ayers classification, 84 % of the Quaternary samples and 50% of the Eocene samples are suitable for irrigation purpose. 16 % of the Quaternary samples and 50% of the Eocene samples are unsuitable for use in irrigation.

Table (5): Suitability of the collected Quaternary and Eocene samples according to chloride content (after Ayers, 1975).

Class. No Chloride content

Water quality Quaternary Samples% Eocene Samples%

1 <142 ppm No problem 45% 20%

2 142-355 ppm Increasing problem 39% 30%

3 > 355 ppm Severe problem 16% 50%

Residual Sodium Carbonate (RSC); it used to distinguish between the different water classes for irrigation purposes because the high concentration of HCO3 lead to an increase in PH values causing the dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface when it dries. According to Ragunath (1987), 84% of the collected Quaternary samples and 90% of Eocene samples are suitable for irrigation purposes. 16% of Quaternary samples and 10% of Eocene samples are unsuitable for irrigation purposes (table 6).

Table (6): Suitability of the collected Quaternary and Eocene samples according to R. S. C (Ragunath, 1987):

RSC

Water quality Quaternary Samples% Eocene Samples%

< 1. 25 epm Water of good quality used for the irrigation of all soils

77%

90 %

25-2. 5 epm Water of medium quality used in case of good drainage especially rich with calcium

7%

–

> 2. 5 epm Unsuitable water, especially in poor drainage or when soluble calcium

16%

10 %

Kelly's Ratio (KR): Sodium measured against Ca2+ and Mg2+ was considered by Kelly and Paliwal (1967) to calculate this parameter. A Kelley's Ratio (KR) of more than one indicates an excess level of sodium in waters. 71% of quaternary samples and 80% of Eocene samples have Kelley's ratio (KR) values less than 1 and indicate good quality water for irrigation purpose, while 29% of Quaternary samples and 20% of Eocene samples have Kelley's ratio (KR) values more than 1 indicates the unsuitable water quality for irrigation (Table 7).

Table (7): Classification of the collected water samples according to KR:

KR

Water quality

Quaternary Samples %

Eocene Samples %

<1 Good quality water 71% 80%

> 1 Unsuitable water 29% 20%

Soluble Sodium Percentage (SSP); This is an important factor for studying sodium hazards. Sodium has the potential of reacting with soil thereby reducing its permeability and supports little or no plant growth. Based on SSP values (Joshi, 2009), 52 % of quaternary samples and 80% of Eocene samples have Soluble Sodium Percent (SSP) value less than 50 epm that indicate good quality water for irrigation purpose while 48 % of quaternary samples and 20% of Eocene samples have Soluble Sodium Percent (SSP) value over 50 epm that indicate the unsuitable water quality for irrigation uses(Table 8).

Table (8): Classification of the studied water samples on the basis of SSP (Joshi, 2009):

SSP Water quality Quaternary Samples% Eocene Samples%

<50 Good quality water 52 % 80%

> 50 Unsuitable water 48 % 20%

Magnesium Hazard (MH); Szabolcs and Darab (1964) had proposed a magnesium hazard for assessing the suitability of water quality for irrigation. Normally, a high level of Mg^{2+} is caused by exchangeable Na in irrigated soils. An increased proportion of Mg^{2+} relative to Ca^{2+} increases sodication in soils which causes the dispersion of clay particles thus damages soil structure and decreases the relative hydraulic conductivity of soils. A magnesium ratio of more than 50 is considered to be harmful and unsuitable for irrigation use. This would adversely affect the crop yield, as soils become more alkaline. Based on Paliwalclassification(Table 9), 39% of the Quaternary samples and 10% of Eocene samples fall in “ Acceptable” while 61% of the Quaternary samples and 90% of Eocene samples fall in “ Non-Acceptable” for irrigation usage.

Table (9): Classification of the studied water samples on the basis of MH (Paliwal, 1972):

MH Water quality Quaternary Samples % Eocene Samples %

<50 Suitable water 39 % 10%

> 50 Harmful and Unsuitable water 61 % 90 %

Permeability Index (PI); Soil permeability is affected by long-term use of irrigation water with high salt content. Permeability is influenced by sodium, calcium, magnesium, chloride, and bicarbonate contents of the soil. Doneen (1964) and Ragunath (1987) classified irrigation waters based on the PI. The groundwater may be classified into classes 1 (Excellent), 2 (Good), and 3 (Unsuitable) based on the permeability indices. According to the permeability index values of Doneen’s chart (Domenico and Schwartz, 1990), 64 % of Quaternary samples and all the Eocene samples Fall in class 1 (Excellent), 29% of Quaternary samples fall in class 2 (Good) and 7 % of Quaternary samples fall in Class III which is unsuitable for irrigation purposes.

Potential Salinity (PS); Potential salinity (PS) was defined as the chloride concentration plus half of the sulfate concentration Doneen (1962). The potential salinity of groundwater samples were classified such as following 3 classesTable (10); “ Excellent to Good (<5)”, “ Good to Injurious (5 - 10)”, “ Injurious to Unsatisfactory (> 10)”. 78 % of the Quaternary samples and 20 % of Eocene samples are suitable for irrigation purposes and 22 % of the Quaternary samples and 80 % of Eocene samples are unsuitable for irrigation purposes.

Table (10): Classification of groundwater on the basis of PS:

PS	Water quality	Quaternary Samples %	Eocene Samples %
<5	Excellent to Good	39%	20%
5-10	Good to Injurious	39%	–
> 10	Injurious to Unsatisfactory	22%	80%