Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2018.22687

123 (2018) 101–108
August

Assessment of groundwater quality in West Sohag, Egypt

E. Ismail[a,*], M. El-Rawy[b]

[a]*Department of Geology, Faculty of Science, Minia University, Minia 61111, Egypt, email: essam.ismail@mu.edu.eg*
[b]*Civil Engineering Department, Faculty of Engineering, Minia University, Minia 61111, Egypt, email: mustafa.elrawy@mu.edu.eg*

Received 16 December 2017; Accepted 28 June 2018

ABSTRACT

Groundwater in West of Sohag represents the second source for freshwater used for agricultural, domestic, and industrial purposes. The main objectives of this study are to assess the hydrochemistry characteristics of groundwater resources and evaluate it for different uses. This study is based on chemical analyses of 166 groundwater samples that were collected from the investigated area in 2014.The result of analysis has been used to evaluate the collected groundwater for drinking and irrigation purposes by comparing those parameters with the World Health Organization (WHO) and Egyptian standards. 56% of the collected groundwater samples are suitable for drinking, and 44% are unsuitable due to their high levels of salinity (>1,000 ppm). Most of the collected groundwater samples of the studied area are unsuitable for domestic or industrial purposes due to the high level of hardness (84% hard to very hard). The quality of collected water for irrigation was evaluated using salinity hazard, US Salinity Laboratory diagram, sodium percent (Na %), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium hazard (MH), Kelly's ratio (KR), soluble sodium percentage (SSP), and potential salinity (PS). The majority of the collected groundwater samples are safe for irrigation based on salinity, SAR and US salinity diagram. About half of the collected samples are suitable for irrigation, while the other half is unsuitable based on Na %, RSC, KR, and PS. According to MH and SSP, most of the collected samples are unsuitable for agriculture under ordinary conditions.

Keywords: Sohag governorate; Water resources; Groundwater quality; Major elements; Drinking and irrigation purposes

1. Introduction

Groundwater preservation and protection measures have been generally overlooked in the majority of practices [1]. Water resources are the most important factor in the development of any region, especially in arid areas. Future developments and planning are needed to understand these resources, especially in the areas suffering from water budget deficit attributed to rare rainfall and high evaporation rates. Egypt is located in the arid zone of North Africa and characterized by limited freshwater resources, which come from the River Nile and groundwater systems. The large numbers of population, extensive reclamation projects, and urbanization have placed a heavy demand on water resources. Groundwater in Sohag Governorate represents the main water resource since it provides about 85% of the water supply [2]. During 2002/2003, about 11,445 m^3 was pumped from the Quaternary Aquifer in Sohag for drinking purposes [3]. Groundwater quality is a function of physical and chemical parameters that are greatly affected by geological formations and human activities [4]. Hydrochemical analysis reveals the quality of water suitable for drinking, irrigation, and industrial purposes. This analysis is also useful for understanding the change in quality due to rock–water interaction or any type of anthropogenic influence [5] and [6]. The chemical parameters of groundwater have an important effect on classifying and evaluating the water quality.

Groundwater quality is based upon the physical and chemical soluble parameters due to weathering from source rocks and anthropogenic activities [7]. The hydrogeological and hydrogeochemical properties of the aquifer are very

* Corresponding author.

important to evaluate groundwater resources. The groundwater of the investigated area is affected by contamination that is a result of agricultural and urbanization activities. In addition, the quality and compositions of the groundwater are modified due to its movement through sediments, dissolution, leaching, precipitation, ion exchange, the impact of agriculture, and urbanization. The groundwater qualities of the Western Desert were studied by many authors [8–14]. The main objective of this paper is to address the hydrochemical characteristics to evaluate the groundwater composition and its impact on groundwater quality to help in the management and protection of groundwater resources in Sohag Governorate.

2. Area under study

The area under study represents a part of the Nile Valley of Egypt and it extends from the northern border of Qena Governorate at latitude 26°07′ N to the southern border of Assiut Governorate at latitude 26°57′ N. It is bounded between longitudes 31°20′ and 32°14′ E (Fig. 1).

3. Geologic setting

The geology of the area under study has been studied by many authors, including Refs. [15–20]. This area is covered by sedimentary rocks which range in age from Lower Eocene to Recent (Fig. 2), and this succession from old to young is briefly as follows:

- The Lower Eocene limestone rocks form the plateau bounding the Nile Valley on both sides and it consists of massive to laminated limestone with flint bands and marl.
- The Early Pliocene rock consists of fluvial sediments that are composed of clay beds with grains of quartz, and it forms the base of the water-bearing formation in the Nile Valley. The Pliocene clay is dissected by shrinkage cracks which are filled with gypsum and anhydrite [21].
- Early Pleistocene rocks (Qena Formation) are composed of sand and gravel with clay lenses, and they represent the main aquifer in the area under study (Quaternary Aquifer).
- The Early Pleistocene–Middle Pleistocene (Kom-Ombo Formation) is composed of sand and gravels, and it overlies the Qena Formation. In the area under study, this formation is represented by very coarse cross-bedded sand together with gravel intercalations [20].
- The Middle Pleistocene (Ghawanim Formation) consists of cross-bedded fluvial sand and gravel that are inter-bedded with bands and lenses of conglomerate and sandstone [20].
- The Late Middle Pleistocene (Dandara Formation) is composed of poorly sorted coarse, medium, and fine to very fine sand [22].
- Recent sediments are represented by wadi (valley) deposits found on the surface of the older sediments.

4. Hydrogeologic setting

Sohag Governorate has a hot summer and a mild winter, with rare rainfall. Air temperature varies from 36.5°C (summer) to 15.5°C (winter), relative humidity is between 51% and 61% (winter), 33% and 41% (spring), and 35% and 42% (summer) [23]. The hydrogeology of the area under study has been studied by many authors, among whom are Refs. [24–31]. The main aquifer of the area under study is the Quaternary Aquifer, which is formed from the alluvial deposits of the River Nile and has two layers. The upper layer is the clay-silt layer, which has low permeability (horizontal and vertical), is laterally extended, and its greater

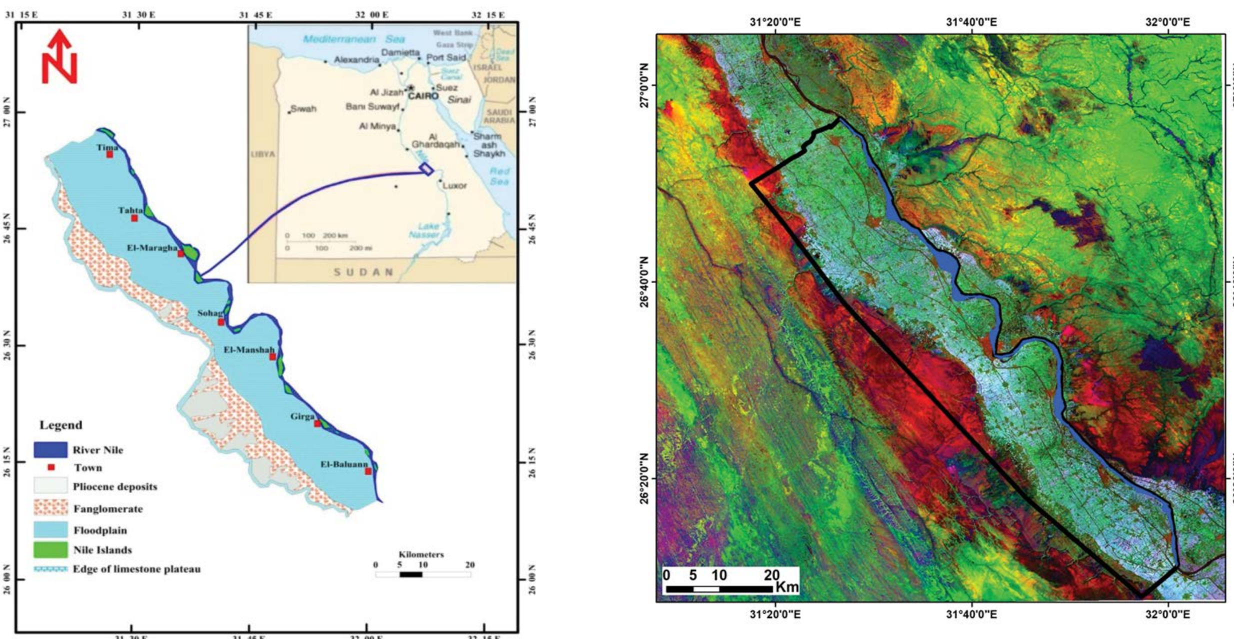

Fig. 1. Location and geologic map of the study area.

thickness is located near the river channel, with the thickness decreasing further from the River Nile (Fig. 2). The lower layer is composed of graded sand and gravel, which forms the main aquifer and has high horizontal and vertical permeability. The base of this aquifer is represented by thick deposits of the Pliocene clays that have very low permeability.

The thickness of this aquifer differs from one locality to another [26]. This aquifer is characterized by its presence under semiconfined conditions in the old agricultural land and under unconfined conditions in the desert fringes (newly reclaimed land) due to the absence of the Nile silt. The main source of the Quaternary Aquifer recharge is surface water (River Nile and irrigation canals), while the discharge is done through evaporation, drilling wells, and the underlying aquifer.

5. Materials and methods

166 groundwater samples were collected from pumping wells tap the Quaternary Aquifer during 2014 (Fig. 3). The samples were collected after pumping the wells for enough time, at least 1°h, and transferred into new, dry, and precleaned polyethylene bottles. Physicochemical parameters including hydrogen ion concentration (pH), total dissolved solids (TDS), and electrical conductivity (EC) of the water samples were measured immediately in the field after sampling using a pH meter, a portable EC meter, and a TDS meter because it was strongly affected by climate conditions. The electrodes of instruments were calibrated before and after each measurement. The collected samples were then labeled, transported to the laboratory, and stored at 4°C for further analysis. The complete chemical analysis which includes major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) and major anions (HCO_3^-, SO_4^{2-}, and Cl^-) were carried out during the winter season at the Environmental Water Lab, Faculty of Engineering, Minia University, Egypt. Methods of collection and analysis of the samples are essentially the same as given by American Public Health Association [33]. The concentration of calcium and magnesium were determined by atomic absorption, while the flame photometer was used for sodium and potassium. The concentrations of bicarbonate and chloride were determined by titration, and sulfate was measured by colorimetric method.

Total hardness and irrigation quality parameters such as sodium absorption ratio (SAR), sodium percentage (Na %), residual sodium carbonate (RSC), magnesium hazard (MH), soluble sodium percentage (SSP), potential salinity (PS), and Kelly's ratio (KR) were calculated. All the equations used are shown in Table 1. The values of different water quality parameters are compared with the water quality guidelines set out by Ref. [34] and those of Ref. [35] to evaluate water suitability for drinking, domestic, and irrigation uses.

6. Results and discussion

6.1. Groundwater chemistry

The analytical results of the major cations and major anions in the area under study as the minimum, maximum, and average are shown in Table 2. This table shows that pH of the collected water samples varies from 6.7 to 8.95, and this indicates a slightly basic nature. According to Ref. [43], most of the studied wells showed pH values within the permissible limit of 6.5–8.5. The EC ranges from 277 to 5,941 µS/cm. About 89% of the studied water showed conductivity values within the permissible limit of Ref. [43] and the rest (11%) above the permissible limit 3,000 µS/cm. The total dissolved salts of the studied groundwater range between 186 and 3,981 ppm. According to Ref. [44] classification, TDS of the collected groundwater samples varies from fresh to moderately saline water (56% freshwater, 42% slightly saline water, and 2% moderately saline water). The high values of TDS in

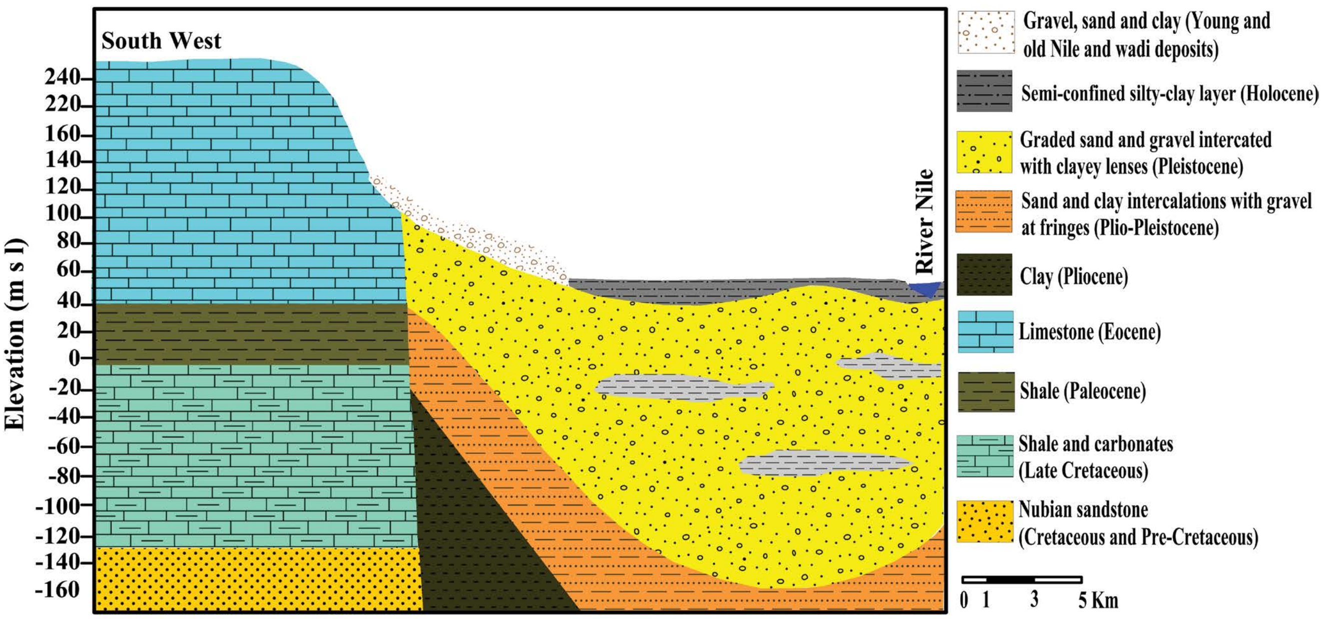

Fig. 2. Hydrogeologic cross section of the area under study (modified after [32]).

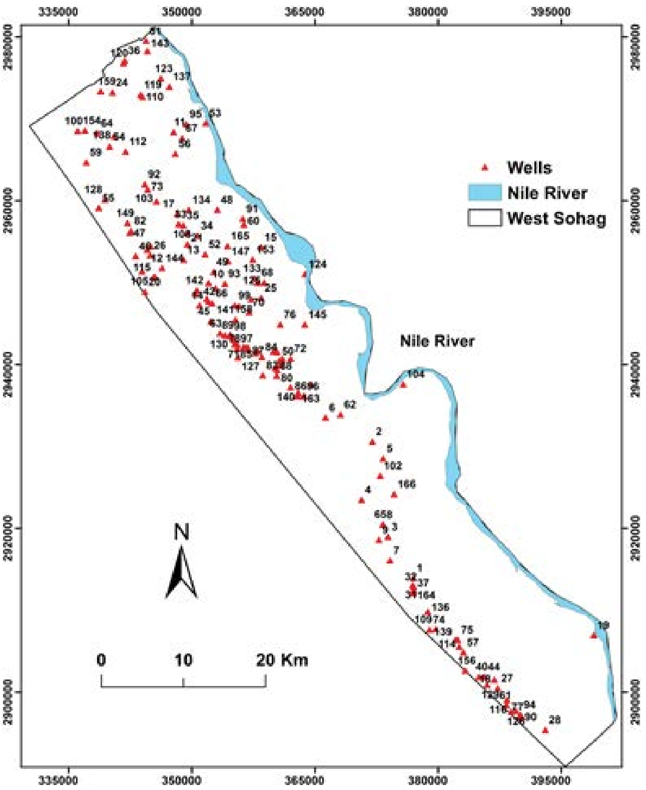

Fig. 3. Map of the studied groundwater samples.

some water samples are attributed to the leaching and dissolution of limestone that are present in the west of the area under study, while the low values of TDS are present in the eastern part because this latter part is directly recharged from surface water (River Nile and irrigation canals). The TDS map (Fig. 4) shows that the salinity increases toward the west direction, which reflects the leaching and dissolution of limestone, as well as the farness from the surface water.

The total hardness of water is divided into two types: carbonate and noncarbonate hardness. Carbonate hardness (temporary hardness) dissipates in water by heating. The noncarbonate hardness (permanent hardness) remains after heating and it is caused by the combination of calcium and magnesium with sulfate, chloride, and nitrate ions.

The total hardness of the collected water samples varies from 18 to 2,158 mg/L with an average 422 mg/L. According to Hem (1985), 4% of the collected water sample are present under soft water, 12% under moderate hardness, 13% under hard water category, and 71% under very hard category. The high values of total hardness (84% under hard to very hard category) reflect the high dissolution of the limestone rocks which are present in the area under study.

The chemical character of the groundwater and the relationships between the dissolved ionic constituents are clear through the representation on Piper diagram [45], using GWW software (Fig. 5(a)). Generally, six hydrochemical water types can be defined based on the dominance of different cations and anions in the groundwater (NaCl, $CaHCO_3$, mixed $CaNaHCO_3$, mixed CaMgCl, $NaHCO_3$, and CaCl)

Table 1
Equations used for calculating irrigation quality parameters

Items	Equations	References
TH	$TH = 2.497\ Ca^{2+} + 4.115Mg^{2+}$ ions in meg/L	[36]
SAR	$SAR = Na / \sqrt{(Ca + Mg)/2}$ all ions in meq/L	[37]
Na (%)	$Na\% = \frac{(Na + k)}{Ca + Mg + Na + K} \times 100$ all ions in meq/L	[38]
RSC	$RSC = (HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++})$ all ions in meq/L	[37]
MH	$MH = \frac{Mg}{(Ca + Mg)} \times 100$ all ions in meq/L	[39]
SSP	$((Na^+ + K^+)/ (K^+ + Na^+ + Ca^{2+} + Mg^{2+})) \times 100$ all ions in meq/L	[40]
PS	$PS = Cl + \sqrt{SO_4}$ all ions in meq/L	[41]
Kelly's ratio	$KR = \frac{Na}{(Ca + Mg)}$ all ions in meq/L	[42]

Table 2
Chemical analysis and hydrochemical parameters of collected water samples

Parameter	pH	E.C	TDS	Ca^{++}	Mg^{++}	Na^+	K^+	HCO_3^-	Cl^-	SO_4^{2-}
Min.	6.7	277	186	1	3.8	8	0	22	15	18
Max.	8.95	5,941	3,981	400	243	902	19.2	527	1,689	604
Average	7.90	1,798	1,194	70.2	58.3	210.7	2.2	209	378	172

(Figs. 5(a) and (b)). The collected groundwater samples are present in five water fields. About 50% of the studied samples fall under the NaCl field, 19% under the CaCl field, 14% under mixed CaMgCl, 11% fall under the mixed $CaNaHCO_3$ field, and 6% under the $CaHCO_3$ field. The sodium chloride water type reflects the dissolution and leaching of halite, which is present in the area under study [46]. The presence of calcium chloride and mixed calcium magnesium chloride water types is a result of the dissolution of carbonate rocks (limestone), which are present in the west of the area under investigation, as well as the extensive use of fertilizers, especially on the newly reclaimed land.

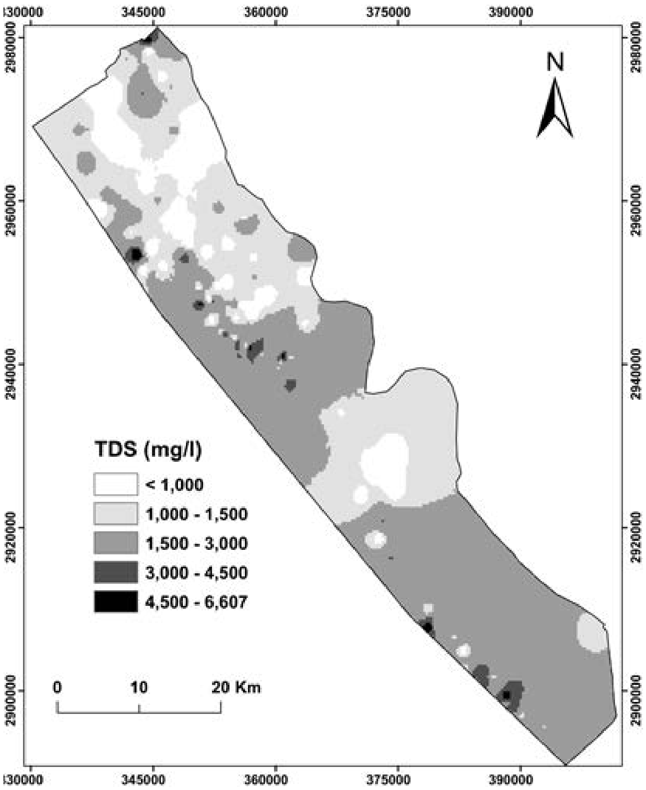

Fig. 4. TDS zonation map for the area under study.

6.2. Evaluation of water quality for drinking

Drinking water should be free from color, specific taste, turbidity, and excessive amounts of dissolved salts. In terms of the international standards for human drinking water, the standards set out by Refs. [34,35] show that about 56% of the collected groundwater samples are suitable for drinking because they have low salinity (TDS < 1,000 ppm) and the major ions values are less than the permissible limits. The remaining samples (44%) are unsuitable due to their high salinity (TDS > 1,000 ppm).

6.3. Evaluation of water quality for domestic and industrial purposes

Hardness is an important factor in evaluating groundwater for domestic and industrial purposes. 84% of the collected water samples lie in hard to very hard water, which reflects their unsuitability for domestic and industrial purposes due to the high level of hardness, while the rest 16% are suitable.

6.4. Evaluation of the collected water samples for irrigation uses

The suitability of groundwater for irrigation mainly depends on the effect of mineral constituents of water on

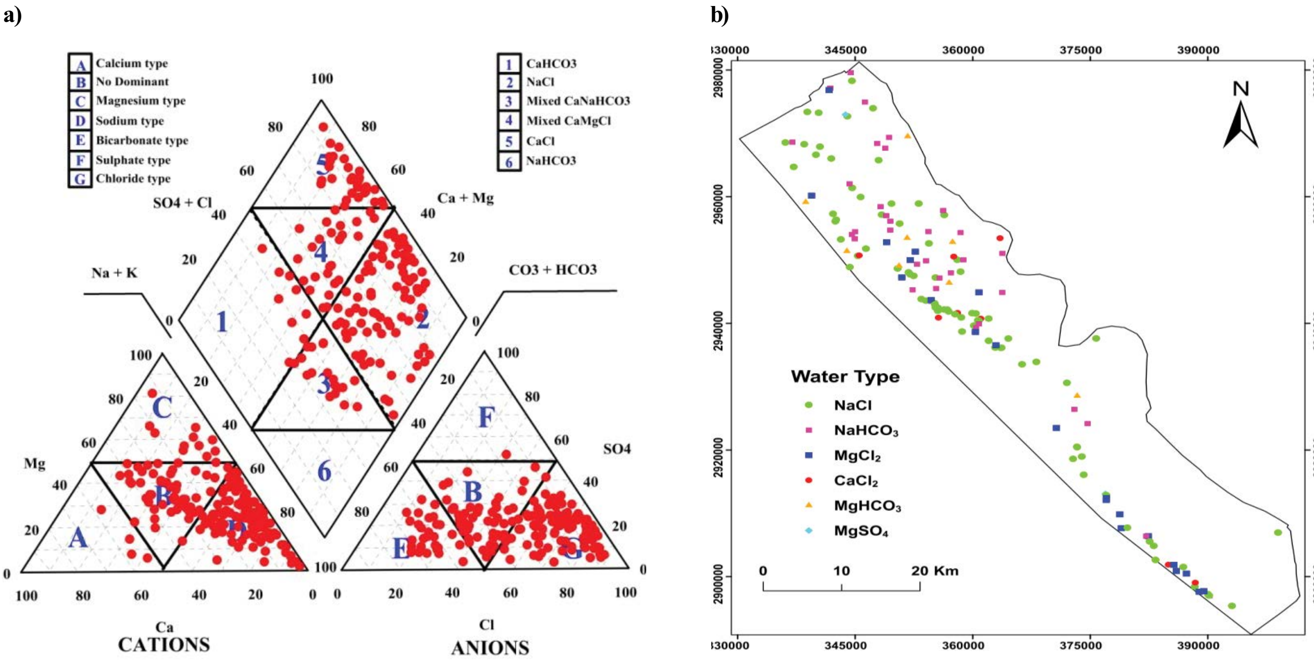

Fig. 5. Piper diagram (a) and chemical water type (b) of the studied water samples.

plants and soil. Salts cause changes in soil structure and permeability. Aeration also indirectly affects the growth of plants. The important hydrochemical parameters of groundwater used to determine its suitability for irrigation are Salinity hazard, US Salinity Laboratory diagram, percent sodium (Na %), sodium adsorption ratio (SAR), RSC, MH, KR, SSP, and PS.

- *Salinity index or salinity hazard*: high concentrations of salinity in irrigation water affect crop yield through the inability of plants to complete with ions in the soil solution for water. Based on the classification of Ref. [47], most of the studied water samples (70%) are categorized under good to permissible quality for irrigation, and 30% are categorized under doubtful to unsuitable for use.
- *US Salinity Laboratory staff*: there is a relationship between SAR values for irrigation water and the extent to which sodium is absorbed by the soils. If the water used for irrigation is high in sodium and low in calcium, the cation exchange may become saturated with sodium, and this leads to destroying the soil structure [48]. The SAR and EC relations are represented on the US salinity diagram [37]. It was found that 98% of the studied samples are suitable for irrigation, while 2% lie outside the diagram (Fig. 6) due to high salinity, which reflects unsuitability for irrigation under ordinary conditions.
- *Sodium percent (Na %)*: sodium percent is very important in evaluating water for irrigation uses because it reacts with soils and reduces the water permeability. In the area under investigation, according to Ref. [49], 57% of the collected groundwater samples is excellent to permissible for irrigation, while 43% are doubtful to unsuitable water.
- *SAR*: SAR is the very important parameter in evaluating groundwater suitability for irrigation. According to Ref. [37] classification of groundwater, it was found that 87%, 11%, and 2% of the samples fall under excellent, good, and doubtful classes, respectively.
- *RSC*: wells which have RSC < 1.25 are safe and suitable for irrigation but if the value is greater than 2.5, they are unsuitable for irrigation uses [50]. As for the collected groundwater samples, 56% are unsuitable for irrigation, while 44% are suitable for irrigation purposes.
- *MH*: Ref. [51] proposed MH value for irrigation water; when MH values < 50, water is considerably suitable; and when MH > 50, water is considered harmful and unsuitable for irrigation purposes. 75% of the collected water samples are unsuitable for irrigation, while the rest 25% is suitable.
- *KR*: water with a KR < 1 is suitable for irrigation, but it is unsuitable if the ratio is greater. According to KR, 58% of the collected water samples are unsuitable for irrigation, while 42% are suitable for irrigation.
- *SSP*: this parameter is used in the assessment of the water quality for irrigation purposes. Based on Ref. [6] classification, 7% of the collected groundwater samples lie in the excellent category, 22% in the good category, 63% in the fair category, and 8% in the poor category for irrigation purposes.
- *PS*: PS is calculated as the chloride concentration plus half of the sulfate concentration. Low soluble salts are precipitated in the soil and, with irrigation; they increase and accumulate in it, while the highly soluble salts concentration increases the salinity of the soil [41]. According to Doneen's classification of PS, 29% of the collected samples fall under the excellent to good category, 25% fall under the good to injurious category, and 46% fall under the injurious to the unsatisfactory category.

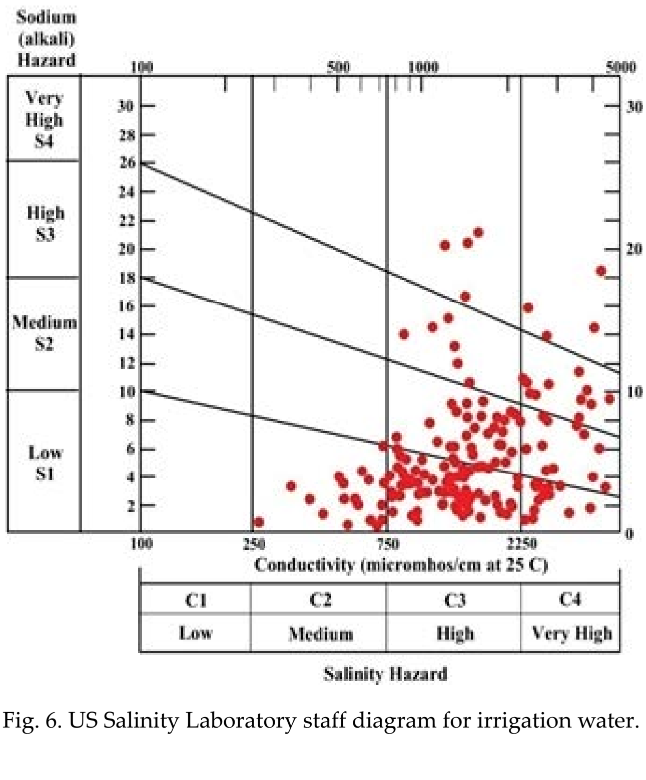

Fig. 6. US Salinity Laboratory staff diagram for irrigation water.

7. Conclusions

The Quaternary Aquifer represents the main source of freshwater in the area under study beside the River Nile. This aquifer is mainly recharged from surface water (River Nile and irrigation canals), while it loses water during the evaporation process, extensive withdrawal and connected with the underlying aquifer. The water salinity of the groundwater in the area under study ranges from fresh to moderately saline, and the aerial distribution of TDS shows an increase toward the west direction due to leaching and dissolution of limestone. Most of the collected water samples are unsuitable for drinking due to their relatively high levels of salinity (>1,000 ppm) and the fact that their major ions exceed the permissible limits. 84% of the studied water samples are present under hard to the very hard category, which reflects its unsuitability for industrial and domestic uses. Based on salinity, SAR, and the US salinity diagram, it is clear that the majority of the collected groundwater samples are suitable for irrigation. Based on Na %, RSC, KR, and PS, half of the collected samples are suitable for irrigation and the other half is unsuitable. According to MH and SSP, most of the collected samples are unsuitable for agriculture under ordinary conditions.

References

[1] A. Shaibani, Hydrogeology and hydrogeochemisrty of a shallow alluvial aquifer, West Saudi Arabia, Hydrog. J., 16 (2008) 155–165.
[2] A.A. Abdel Moneim, Numerical Simulation and Groundwater Management of Sohag Aquifer, the Nile Valley, Egypt, Ph.D. Thesis, Civil Eng. Dept. Strathclyde Univ., Glagov, Scotland, 1992.
[3] A.A. Gomaa, Hydrogeologic and Geophysical Assessment of the Reclaimed Areas in Sohag, Nile Valley, Egypt, Ph.D. Thesis, Geology Dept. Faculty of Science, Ain Shams University, 2006, 272 pages.
[4] L. Belkhiri, A. Boudoukha, L. Mouni, T. Baouz, Application of multivariate statistical methods and inverse geochemical modeling for characterization of groundwater – a case study: Ain Azel plain (Algeria), Geoderma, 159 (2010) 390–398.
[5] W.P. Kelly, Permissible composition and concentration of irrigation waters, Am. Soc. Civil Eng., 66 (1940) 607–613.
[6] L.V. Wilcox, The Quality Water for Irrigation Use, US Department Agricultural Bulletin, 962, 1948, 40 pages.
[7] A. Aydin, The microbial and physicochemical quality of groundwater in West Thrace, Turkey, Pol. J. Environ. Stud., 16 (2007) 377–383.
[8] E. Ismail, A. Faid, E. Niesner, H. Mauritsch, Comparison of the groundwater quality in the West Tahta Area, Upper Egypt in 1989 and 2011, J. Environ. Prot., 3 (2012) 1442–1457.
[9] M. Sultan, N. Struchio, F. Hassan, M. Hamdan, A. Mahmoud, Z. El-Alfy, T. Stien, Precipitation source inferred from stable isotopic composition of Pleistocene groundwater and carbonate deposits in the Western Desert of Egypt, Quat. Res, 48 (1997) 29–37.
[10] A.A. Abdel Moneim, S. Zaki, M. Diab, Groundwater conditions and the geoenvironmental impacts of the recent development in the south eastern part of the Western Desert of Egypt, J. Water Resour. Prot., 6 (2014) 381–401.
[11] M. Redwan, A.A. Abdel Moneim, Factors controlling groundwater hydrogeochemistry in the area west of Tahta, Sohag, Upper Egypt, J. Afr. Earth Sci., 118 (2016) 328–338, doi: 10.1016/j.jafrearsci.2015.10.002.
[12] E. Ismail, E. El-Sayed, S. Sakr, E. Youssef, Characteristic of groundwater potentialities in West Nile Valley South, Minia Governorate, Egypt, Arabian J. Geosci., 10 (2017) 521, doi: 10.1007/s12517-017-3302-8.
[13] R.E. Rabeiy, Assessment and modeling of groundwater quality using WI and GIS in Upper Egypt area, Environ. Sci. Pollut. Res., 24 (2017) 1–10, doi: 10.1007/s11356-017-8617-1.
[14] Y. Mohamed, B. Ashraf, M.H. Fares, A. Samir, G. Ahmed, Natural radioactivity and groundwater quality assessment in the northern area of the Western Desert of Egypt, J. Hydrol., 12 (2017) 331–334.
[15] F. Wendorf, R. Schild, Prehistory of the Eastern Sahara, Academic, New York, 1980, p. 414.
[16] B. Issawi, M.W. Hassan, R. Osman, Geological studies in the area of Kom Ombo, Eastern Desert, Egypt, Ann. Geol. Surv. Egypt, V.VIII, (1978) 187–235.
[17] B. Issawi, Ancient river of Eastern Egyptian desert, Episodes, 2 (1983) 3–6.
[18] M. Paulissen, P.M. Vermeersch, Earth, Man and Climate in the Egyptian Nile Valley during the Pleistocene, A. Close, Ed., Prehistory of North Africa, Southern Methodist University Press, Dallas, 1987, pp. 29–67.
[19] B. Issawi, J.F. McCauley, The Cenozoic Rivers of Egypt: The Nile Problem, R. Freidman, B. Adams, Eds., The Followers of Hours, Oxford Press, Oxford,1992, pp. 121–138.
[20] A.A.M. Omer, Geological, Mineralogical and Geochemical Studies on the Neogene and Quaternary Nile Basin Deposits, Qena-Assiut Stretch, Egypt, Ph.D. Thesis, Geol. Dept, Fac. Sci., South Valley Univ, 1996, 320 pages.
[21] A.A.M. Omer, A.A. Abdel Moneim, Geochemical characteristics of the Pliocene and Pleistocene Nile basin deposits and their influence on the groundwater Chemistry in Sohag area, Ann. Geol. Surv. Egypt, 24 (2001) 567–584.
[22] R. Said, The Geology Evaluation of the River Nile, F. Wendorf, A.E. Marks, Eds., Problem in Prehistory of Northern Africa and the Levant, Southern Methodist, University Press, Dallas, TX, 1975, pp. 1–44.
[23] Egyptian Meteorological Authority, EMA, Annual Meteorological Reports, Cairo, 2012.
[24] F.R. Attia, Management of Water Systems in Upper Egypt, Ph.D. Thesis, Faculty of Engineering, Cairo Univ., Egypt, 1985.
[25] W. Barber, D.P. Carre, Water Management Capabilities of the Alluvial Aquifer System of the Nile Valley, Upper Egypt, Technical Report No. 11, Water Master Plane, Ministry of Irrigation, Cairo, Egypt, 1981, 145 pages.
[26] A.A. Farrag, Hydrogeological Studies on the Quaternary Water-Bearing Sediments in the Area Between Assiut and Aswan, M. Sc. Thesis, Geol. Dept., Assiut, Univ., Egypt, 1982.
[27] A.A. Farrag, The hydraulic and hydrogeological impacts of the Nile system on the groundwater in Upper Egypt, Assiut Univ. Bull. Environ. Res., 8 (2005) 87–102.
[28] F.A. Attia, A.M. Amer, K. Hefny, Groundwater Conditions in Upper Egypt after the Construction of the HAD, Proc. Intern. Conf. on: Water Resources Development in Egypt, Cairo, Egypt, 1983.
[29] F.A. Attia, M.N. Allam, M.A. Amer, A hydrologic budget analysis for the Nile Valley in Egypt, Groundwater, 4 (1986) 453–459.
[30] J.W. Warner, T.K. Gates, F.A. Attia, W.F. Mankarious, Vertical leakage in Egypt's Nile Valley: estimation and implication, J. Irrig. Drain. Eng., 4 (1991) 515–533.
[31] E. Ismail, Studied the Environmental Investigation in the West Tahta Region, Upper Egypt: Hydrochemical, Geophysical and Remote Sensing Study, Ph. D. Dep. Angewandte Geo-wissenschaften Geophsik, Montanuniversitat Leoben, Austria, 2013, pp. 85–86.
[32] Research Institute of Groundwater, RIGW, Hydrogeological Maps of Egypt, scale 1:100, Water Research Center, Ministry of Public Works and Water Resources, Egypt, 1990.
[33] APHA "American Public Health Association" Standard Methods for the Examination of Water and Wastewater, A.D. Eaton, L.S. Clesceri, A.E. Greenberg, 20th ed., APHA, AWWA, WPCF, New York, 2005.
[34] EHCW Egyptian Higher Committee for Water Egyptian Standards for Drinking and Domestic Uses, 2007.
[35] World Health Organization Guidelines for Drinking-Water Quality, 4th ed., WHO, Geneva, 2011, p. 541.
[36] D.K. Todd, Groundwater Hydrology, 2nd ed., Wiley, New York, p. 315. U.S. Salinity Laboratory Staff (1954) Diagnosis and Improvement of Saline and Alkali Soils, USDA, Handbook 60, U.S. Government Printing Office, Washington, D.C., 1980.
[37] L.A. Richards, (US Salinity Laboratory), Diagnosis and Improvement of Saline and Alkaline Soils, US Department of Agriculture Hand Book, 1954, p. 60.
[38] L.V. Wilcox, Classification and Use of Irrigation Waters, vol. 969, U.S. Department of Agriculture Circular, Washington, DC, 1955, p. 19.
[39] K.V. Paliwal, Irrigation with Saline Water, Monogram No. 2 (New series), IARI, New Delhi, 1972, p. 198.
[40] D.M. Joshi, A. Kumar, N. Agarwal, Assessment of the irrigation water quality of River Ganga in Haridwar District India, J. Chem., 2 (2009) 285–292.
[41] I.D. Doneen, Notes on Water Quality in Agriculture, Published as a water Science and Engineering, Paper 4001, Department of Water Sciences and Engineering, University of California, 1964.
[42] W.P. Kelly, Use of saline irrigation water. Soil Sci., 95 (1963) 355–391.

[43] BIS, Drinking Water Specifications, Bureau of Indian Standards IS: 10500, 1998.
[44] J.D. Hem, Study and Interpretation of the Chemical Characteristics of Natural Water USGS, Water Supply paper no. 2254, 1985, pp. 117–120.
[45] A.M. Piper, A graphical interpretation of water analysis, Eos Trans. Am. Geophys. Union, 25 (1944) 914–928, doi: 10.1029/TR025i006p00914.
[46] A.A. Ahmed, M.H. Ali, Hydrochemical evolution and variation of groundwater and its environmental impact at Sohag, Egypt, Arabian J. Geosci., 4 (2011) 339–352.
[47] T.A. Bauder, R.M. Waskom, J.G. Davis, Irrigation Water Quality Criteria, Extension Fact sheet No. 0.506, Colorado State University, 2007 15 pages.
[48] A.K. Singh, Quality assessment of surface and sub-surface water of Damodar river basin, India, J. Environ. Health, 44 (2002) 41–49.
[49] H.M. Ragunath, Groundwater, Wiley Eastern, New Delhi, 1987, p. 563.
[50] K. Ramesh, L. Elango, Groundwater quality and its suitability for domestic and agricultural use in Tondiar river basin, Tamil Nadu, India, Environ. Monit. Assess., 184 (2012) 3887–3899, doi: 10.1007/s10661-011-2231-3.
[51] I. Szabolcs, C. Darab, The Influence of Irrigation Water of High Sodium Carbonate Content on Soils, I. Szabolics, Ed., Proc. 8th International Congress Soil Science Sodics, Soils, Res. Inst. Soil Sci. Agric. Chem. Hungarian Acad. Sci., ISSS Trans II, 1964, pp. 802–812.