The hydrochemical characteristics and evolution of groundwater and surface water in the western part of the River Nile, El Minia district, Upper Egypt

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ABSTRACT

A combination of major and trace elements have been used to characterize surface water and groundwater in El Minia district, Egypt. The major object of this research is to investigate the groundwater quality and hydrochemical evaluation. The investigated aquifer is the Pleistocene, which composed of sand and gravel of different sizes, with some clay intercalation. The groundwater flow generally from south to north and diverts towards the western part from the River Nile. Fifty-sex, 11, 5, and 2 water samples were collected from the Pleistocene aquifer, River Nile, Ibrahimia canal, and Al Moheet drain, respectively. The water was analyzed for major and trace elements. The toxic metal concentrations of Al Moheet drain are higher than those in the River Nile and the Ibrahimia canal. Cr, Hg, As, and Cd concentrations in the River Nile and Ibrahimia canal are fluctuated above and below the WHO drinking standards. Se concentration in River Nile and Ibrahimia canal is below WHO drinking and irrigation guidelines. Total dissolved solid concentration in groundwater is generally low, but it is increased due the western part of the study area. The geographic position of the River Nile, Ibrahimia canal, and Al Moheet drain impact on the groundwater quality. The PHREEQC confirm the high mixing proportions from the River Nile into the groundwater and decline away from it. In addition to the thicknesses of the Pleistocene aquifer and aquitard layer enhance the River Nile and agricultural wastewaters intrusion into the aquifer system. The toxic metal concentrations (Pb, Cd, Cr, PO_4, Se, Mn, As, Hg, Ni, Al, Fe, and SIO_2) in groundwater were increased mainly in the northwestern and southeastern part (far from the River Nile). It is attributed to anthropogenic, high vulnerability rate (unconfined), and partially lithogenic. Most groundwater are unsuitable for drinking and irrigation purposes with respect to Se concentration, while they are unsuitable for dinking according Mn, As, and Hg contents. There are some Cd and Pb anomalies concentrations, which cause severe restriction if used in irrigation.

1. INTRODUCTION

Groundwater preservation and protection measures have been generally overlooked in the majority of the practices (Shaibani 2008). Groundwater chemistry depends on geology, degree of chemical weathering of various rocks, quality of recharge waters, and anthropogenic. The evaluation of groundwater resources for development requires an understanding of the hydrogeology and hydrogeochemical properties of the aquifer. The investigated Pleistocene aquifer is highly vulnerable to contamination because of unconfined permeable aquifer and fractured thin soils (Holocene). The heavy metals are widely distributed as an anthropogenic pollutant (Rangsivek and Jekel 2005). Cd is often present in artificial fertilizers and this heavy metals may accumulate in soils in areas that have been used for agriculture for long period (Rattan et al. 2005; Mahvi et al. 2005; Nouri et al. 2006). The objective of this study was to evaluate and map regional patterns of major elements and toxic metals (Pb, Cd, Cr, PO_4, Se, Mn, As, Hg, Ni, Al, Fe, and SIO_2) in groundwater system, River Nile, Ibrahimia canal, and Al Moheet drain in the western part of El Minia district **(Fig. 1).** The study area is delineated by latitudes 27° 30' and 28° 40' N and longitudes 30° 30' and 31° 00' E. The area is arid to semi arid, hot climate, dry, rainless in summer and mild with rare precipitation in winter. The rainfall average value for 15 y ranged from 23.05-33.15 mm/y, evapotranspiration in El Minia is 4897.91 mm/y (Korany 1980 and 2008). The min. and max. temperature are 4.5 (January) to 20.5 °C (August) and 20.7 (January) to 36.7 °C, respectively. The mean monthly relative humidity during daytime ranged from 36 % in May to 62 % in December (Korany 1984). The waterlogging problem is common in Nile Valley and affect plant growth and soil degradation. Therefore, the groundwater degradation resulted from waterlogging, lithogenic, and anthropogenic impact.

2. GEOLOGY AND HYDROGEOLOGY

The River Nile passes through high eastern and western calcareous plateaus with a general slope from south to north about 0.1 m/km (Korany et al 2008). The Nile tends to represent the eastern part of the Valley, therefore, the cultivated area is wider in western part than in the eastern. The investigated area was west of the River Nile (floodplain). Geomorphologically, the study area is moderately elevated plateau with respect to River Nile and composed of mainly limestone covered with alluvial deposits of sands and gravels **(Fig. 2).** The Eocene rocks constitute the main outcrops, capped by poorly consolidated sand, gravel, and clay (Quaternary aquifer). The Pleistocene sediments is the main aquifer in the Delta and Nile valley, it composed of massive cross bedded fluvial sand with gravel and clay sediments. The stratigraphic sequence is built up of from base to top as follows (Tamer et al., 1974); Middle Eocene limestone intercalated with shale; Pliocene undifferentiated sands, clays, and conglomerates; Plio-Pleistocene sand and gravel with clay and shale lenses; Pleistocene sand and gravel with clay lenses; and Holocene silt and clay. The groundwater exists in different aquifers; Pre-Tertiary Nubian sandstone; Eocene limestone; and Quaternary. The investigated aquifer is the Pleistocene, which composed of sand and gravel of different sizes, with some clay intercalation. The thickness of the aquifer ranged from 25 to 300 m, from desert fringes to central Nile Valley, respectively (Sadek 2001). The aquifer is overlained and underlained by semi pervious silt and clay and Pliocene clay, respectively. The semi confined bed (1-15 m thickness) is missed outside the floodplain and the aquifer become unconfined. The groundwater flow generally from south to north and diverts towards the eastern part, where large volume of groundwater are drained from the River Nile (Tantawi 1992). The aquifer is recharged by Nile water, irrigation system, drains, agricultural wastewater, vertical upward leakage from the deeper saline aquifers (Korany 1984). The study area is highly affected by faulting mainly in NW-SE direction **(Fig. 3)**. The Nile Valley is essentially of structural origin (Beadnell 19900; Ball 1909; Sandford and Arakell 1934; Attia 1954; Said 1962, 1981, 1993).

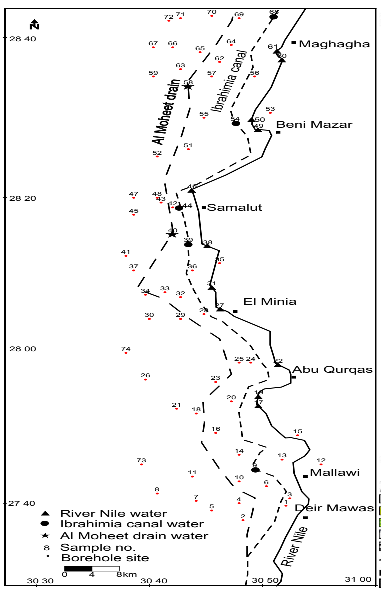

Fig. 1 Location map of the El Minia district

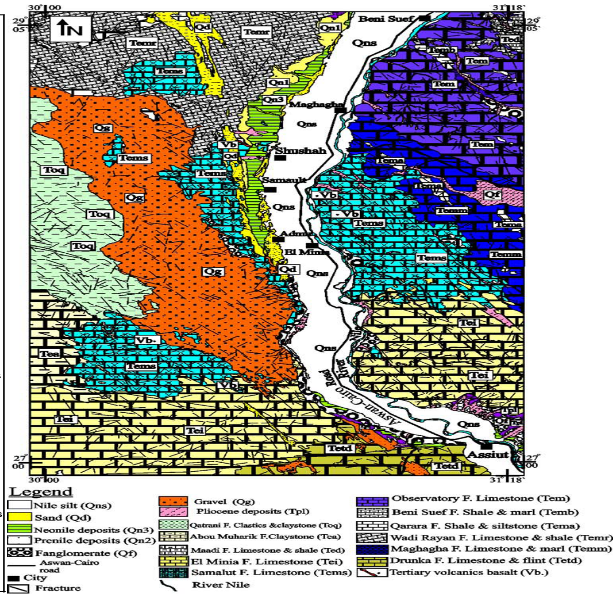

Fig. 2 Geologic map of the study (Conoco Coral Egypt 1987 and Heleika and Niesner 2008**)**

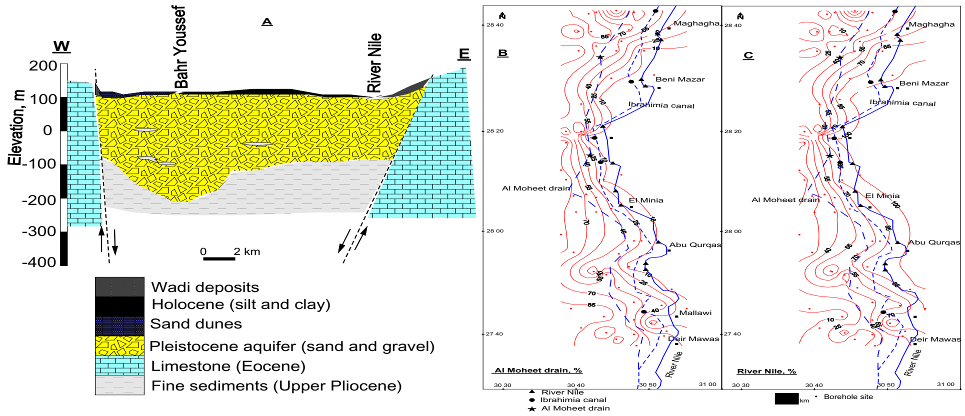

Fig. 3 Cross section across the Nile Valley (A) (modified after IWACO and RIGW 1986); percent proportions of River Nile (B); and Al Moheet drain (C) in groundwater, El Minia district.

3. MATERIALS AND METHODS

Fifty-sex groundwater samples were collected from the Pleistocene aquifer, 11 water samples from River Nile, 5 water samples from Ibrahimia canal, and 2 water samples from Al Moheet drain in El Minia district. Water analyses were completed during summer season (2009). The groundwater samples were taken by means of well pumps after a pumping period of at least 1 hr. The location site is determined by GPS instrument. Pre-rinsed polypropylene bottles were filled with the samples, sealed tightly. pH, electrical conductivity, and temperature are measured in situ using portable field kite. Cl, HCO_3, Ca, and Mg were measured by titration, while SO_4 is estimated by turbidity, and Na and K were analyzed by flame photometer. The samples were acidified with ultra pure nitric acid, after filtration, to avoid complexation and adsorption. The acidification was accomplished in situ and in case of toxic metals determination. Then the samples transported to laboratory and then stored in a refrigerator at approximately – 20 ^{0}C to prevent change in volume due to evaporation The toxic metals (Pb, Cd, Cr, PO_4, Se, Mn, As, Hg, Ni, Al, Fe, and SIO_2) were determined by the ICP (Inductive Couples Plasma)-AES (Optima 3000; Perkin Elmer). The analyses were carried out at Environmental monitoring in Embaba.

4. RESULTS AND DISCUSSION

4.1. Surface waters chemistry (River Nile, Ibrahimia canal, and Al Moheet drain)

Cr, Hg, As, and Cd concentrations are fluctuated below and above the WHO standards for drinking in River Nile and Ibrahimia canal **(Fig. 4a, b, c, and d)**. It is attributed to fertilizers applied that contained some impurities of these toxic metals. The Hg level for drinking water is 1 µg/l (Government of Nepal 2005), which is stricter than the WHO guideline (2004) 2 µg/l (Nathaniel et al. 2008). Cd seems to be related to agricultural activity, especially the use of fertilizers, which are dominantly of the super-phosphate type manufactured from marine phosphorite that contains up to 20 ppm Cd (El Kammar, 1974). Pesticides also could contribute to the high Cd content in the study area (Bowen, 1966). Cd was clearly remobilized from all marine sediments (Calmano et al. 1988). Symptoms of chronic As poisoning have been recorded in populations reliant on water supplies containing >50 µg/l As in several countries. This value currently constitutes the permissible limit of the European Union, the United States Environmental Protection Agency (1976) and most national governments with respect to As in potable water. Epidemiological evidence of adverse effects at lower exposure levels has, however, prompted the WHO (2004) to promote an interim guideline of 10 µg/l (Van Leeuwen 1993). They are much increase in Al Moheet drain than those in River Nile and Ibrahimia canal, cause by sanitary and agricultural wastewaters dump. They are below the WHO guideline for irrigation in River Nile and Ibrahimia canal, while Al Moheet drain exceeds the guideline. Therefore Al Moheet drain unsuitable for drinking and irrigation purposes. Se concentration in River Nile and Ibrahimia canal is below WHO guidelines for drinking and irrigation **(Fig. 4e)**. Ni and Pb are below guidelines for irrigation and drinking purposes, respectively **(Fig. 4f and g)**. Se, Ni, Pb, and PO_4 **(Fig. 4h)** concentrations increase in Al Moheet drain due to anthropogenic sources.

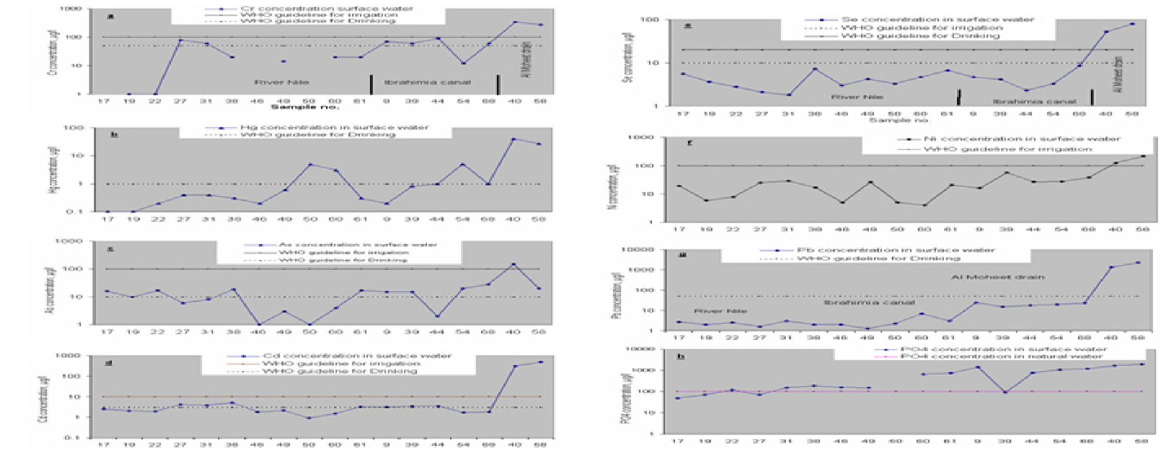

Fig. 4 Toxic metal concentrations in surface waters compared with WHO standards

4.2. Groundwater chemistry

The total dissolved solids (TDS) concentration is generally low, attributed to contribution from River Nile and Ibrahimia canal. The TDS concentration increased due the western zone of the study area, caused by low River Nile recharge, Al Moheet drain wastewater infiltration and agricultural wastewater leaching in the western part. The Quaternary aquifer thickness increased due the River Nile area and decreased in the desert fringes (western part). The aquifer receive low volume of fresh recharge water due the western part (low thickness), meanwhile the wastewaters infiltration increase the groundwater salinity. On the other hand, in the eastern part (high thickness), the aquifer receive much more recharge from the River Nile, which dilute the aquifer in the eastern part. The semi confined silt and clay bed (Holocene) increase in thickness due the River Nile area that decline the wastewaters infiltration than in the western part (low aquitard thickness and unconfined).

The aquifer in the western part is vulnerable to pollution than in the eastern part. The percent mixed proportions from the River Nile and Al Moheet drain, determined by PHREEQC model (AquaChem), was shown in **Fig. 3B & C**. It indicate that the mixing proportion from the River Nile and Al Moheet drain increased due the eastern and the western part, respectively. It confirm the aquifer dilution from the River Nile in the eastern part and aquifer contamination from the agricultural and sanitary wastewaters in the western part. Concentrations of Na, K, Ca, Mg, HCO_3, Cl, and SO_4 exhibits the same trend of the TDS concentration. They derived mainly from anthropogenic and partially from lithogenic sources. Overall, the water chemistry is characterized by Na (mean 27 mg/l) and Ca (mean 36 mg/l) as the dominant cations**.** The HCO_3 (mean 220 mg/l) and Cl (mean 25 mg/l) are the predominant anions. These fluctuated concentration ions vary geographically with groundwater flow, geomedia, River Nile, anthropogenic sources, and the interaction between the different aquifers.

The values of distribution of Pb, Cd, Cr, PO_4, Se, Mn, As, Hg, Ni, Al, Fe, and SIO_2 concentrations in groundwater of the studied region were presented in **Fig. 5a-l**. These maps provide a basis for making area-wide generatizations concerning the distribution of water quality parameters and serve to isolate water quality problem areas. There were differences between the contents of groundwater and heavy metals in each sub region, especially northwestern and southeastern part. The latter areas tended to be more concentrated in most toxic metals **(Fig. 5a-l)**, attributed to Al Moheet drain wastewater, agricultural infiltration, and partially lithogenic. Most of the groundwater are unsuitable for drinking and irrigation purposes with respect to Se **(Fig. 5e)** and unsuitable for drinking with respect to Mn, As, and Hg concentrations **(Fig. 5f-h)**. There are also some anomalies spots of Pb and Cd concentrations **(Fig. 5a and b)**, led to severe impact if used in irrigation. Most toxic metals derived from Al Moheet drain, agricultural wastewater (fertilizers, manures, and pesticides), and lithogenic dissolution. The latter process may contributed mainly to Mn, Fe, and Hg. The aquifer was enhanced by unconfined type in the western part to semi confined in the central and eastern part, therefore, the vulnerability rate is increased due the western part. The low concentration of SiO_2 in groundwater, reflect low solubility of feldspars, quartz, clay minerals and other common silicate minerals. The US Department of Health and Welfare (1962) recorded 10 ppm as safely values for household uses, which found in surface and ground waters. The phosphorus concentration in natural water is 100 µg/l (Bouwer 1978), the extensive use of super phosphate fertilizers contributed the PO_4, Cd, and Pb concentrations in groundwater.

4.3. Exchangeable estimated ratio and Hydrochemical ratios

The exchangeable sodium ration and magnesium hazard distribution increased in the eastern and western part, respectively. The magnesium hazard was attributed to contamination from lithogenic and anthropogenic in the western part. The sodium adsorption ratio (SAR) is low (SAR 0.69 to 1.5). Ca/Mg ratio decreased due the western part, indicate a contamination from the lithogenic (dissolution of carbonate sediments) and anthropogenic (agricultural wastewater). Girdhar and Yadav (1986) have reported that the lower Ca/Mg ratios in irrigated water (poor or good quality) and /or soil solution of both productive as well as salt affected soils induce dispersion and subsequently decrease crop yields. The Ca/Mg values below unity (northwestern part) may reflect the interaction between the groundwater and the host rock, which contain dolomite (Plummer et. al. (1976). Furthermore, values above unity (in the western part) clarify the dissolution of calcite/or gypsum minerals, which are actually represented in the lithological units. The Ca/SO4 ratio increased in the northern part and more or less due the western part. It attributed to the dissolution from limestone Eocene and agricultural impact, meanwhile the SO4 concentration decline by reduction. The Na/Cl equivalent ratios were > 2 in the northeastern part , indicate a sodium source rather than halite or surface irrigated water, such as rock-bearing minerals according to the following equation:

$$Ca^{2+} + 2Na\text{-clay} \rightarrow aNa^{+} + Ca\text{-clay}$$ (Afzal et. al. 2000)

Furthermore, the Na/Cl ratio is always above unity indicates that Na+ has been enriched in the water and of meteoric origin. The total hardness in groundwater ranged from moderately hard in the eastern part to hard and very hard due the western part.

5. SUMMARY AND CONCLUSIONS

The Pleistocene aquifer is vulnerable to contamination due to unconfined condition especially due the western part of the study area. The total dissolved solids concentration increased in the western part, attributed to geology, hydrogeology, and anthropogenic. Poor water quality irrigating water occurs mainly in the southwestern and northwestern part. Al Moheet drain contains higher toxic metal concentrations than Ibrahimia canal and River Nile.

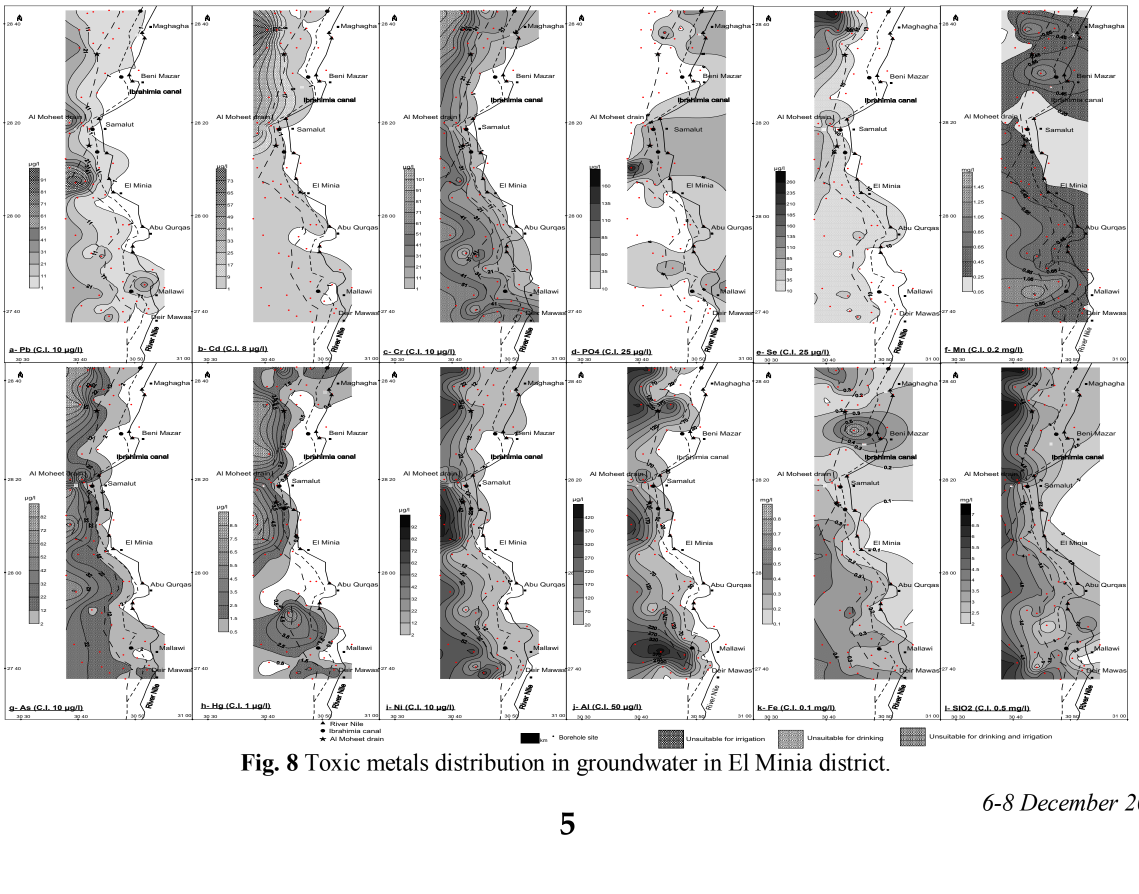

Fig. 8 Toxic metals distribution in groundwater in El Minia district.

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