

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- and groundwater in El Minia district, Egypt. Surface water versus groundwater chemistry data enabled geographical zonation and chemical types to be differentiated. The main target of this research is to investigate the groundwater quality and hydrochemical evaluation. The situation is further complicated by contamination with lithogenic and anthropogenic (agricultural and sewage wastewaters) sources and low plan exploitation techniques. The investigated Pleistocene aquifer is composed of sand and gravel of different sizes, with some clay intercalation. The semi-confined condition was around the River Nile shifted to unconfine outside the floodplain. The groundwater flow generally from south to north and locally diverts towards the western part from the River Nile. Fifty-six, 11, five, and two water samples were collected from the Pleistocene aquifer, River Nile, Ibrahimia canal, and Al Moheet drain, respectively. The collected water samples were 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 content in groundwater is generally low, but it is increased due to 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, PO₄, Se, Mn, As, Hg, Ni, Al, Fe, and SiO₂) 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 to lithogenic. In most localities, the 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. The results suggested that significant changes are urgently needed in water use strategy to achieve sustainable development.

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Introduction

In a typical arid country like Egypt, groundwater is the major source of water for most uses. The availability and

quality of groundwater resources have been affected by activities and projects associated with rapid development. Groundwater preservation and protection measures have been generally overlooked in the majority of the practices (Shaibani 2008). Groundwater chemistry depends on hydrogeology, degree of chemical weathering of various rocks, quality of recharge waters, and anthropogenic sources. 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). This research is aimed to understand the local relations among groundwater chemistry, geology, and the groundwater flow system, as well as to define the hot spots of toxic metals and their environmental impact. Since groundwater moves through rocks and subsurface soil, it dissolves elements with moving. Furthermore, they are widely distributed as an anthropogenic pollutant (Rangsviek and Jekel 2005). Heavy metals are usually associated with industrial, transportation, urban activities, and agricultural practices (Brantley and Townsend 1999; Romić and Romić 2003), which have a negative impact. Land disposal of municipal and industrial wastes and application of fertilizers and pesticides for agriculture have contributed to a continuous accumulation of heavy metals in soils (Alloway and Ayres 1993). Fertilizers are usually not sufficiently purified during the processes of manufacture; for economic reasons, they usually contain several impurities, among them heavy metals (Santos et al. 2002; Tanji and Valoppi 1989). Also, heavy metals often form a part of the active compounds of pesticides. Surpluses of heavy metals in soils are frequently caused by the use of fertilizers, metallo-pesticides, and sewage sludge. Among the fertilizers that are being used in farmlands, super phosphate contains the highest concentrations of Cd, Cu, and Zn as impurities. Copper sulfate and iron sulfate have the highest contents of Pb and Ni (Eugenia et al. 1996). With sufficient surface water infiltration, soil contaminants, such as heavy metals, can leach to underlying groundwater. Unconfined aquifers with shallow water tables, overlain by permeable soils, or another aquifer are especially vulnerable to various contaminants. The anthropogenic developments and the fact that most contaminants penetrate into soils or aquifer and eventually groundwater have caused pollution increase, all acting as a threat to today's world. Cd is a heavy metal with chemical properties similar to Zn but is much less common in the environment than Zn. Cd occurs in igneous rocks and some sedimentary rocks, which is generally associated with Zn ore minerals like sphalerite and with a range of Cu ore minerals (Picker et al. 1992; Pogotto et al. 2001). Cd is often present in artificial fertilizers and these 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). Information on the quality of water sources is of great importance in water quality management of water supplied fields. The objective of this study was to evaluate and map regional patterns of major elements and toxic metals (Pb, Cd, Cr, PO₄, Se, Mn, As, Hg, Ni, Al, Fe, and SiO₂) 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 the last 15 years ranged from 23.05 to 33.15 mm/year, while the evapotranspiration at El Minia is 4897.91 mm/year (Korany 1980; Korany et al. 2008). The average temperatures during January are 4.5°C to 20.5°C and 20.5°C to 37.7°C during August. 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 affects plant growth and soil degradation. Therefore, the groundwater degradation resulted from waterlogging, lithogenic, and anthropogenic impact.

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 is located to the west of the River Nile (floodplain). Geomorphologically, the study area is moderately elevated limestone plateau with respect to River Nile 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 is composed of massive cross-bedded fluvial sand with gravel and clay sediments. The stratigraphic sequence is built up 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

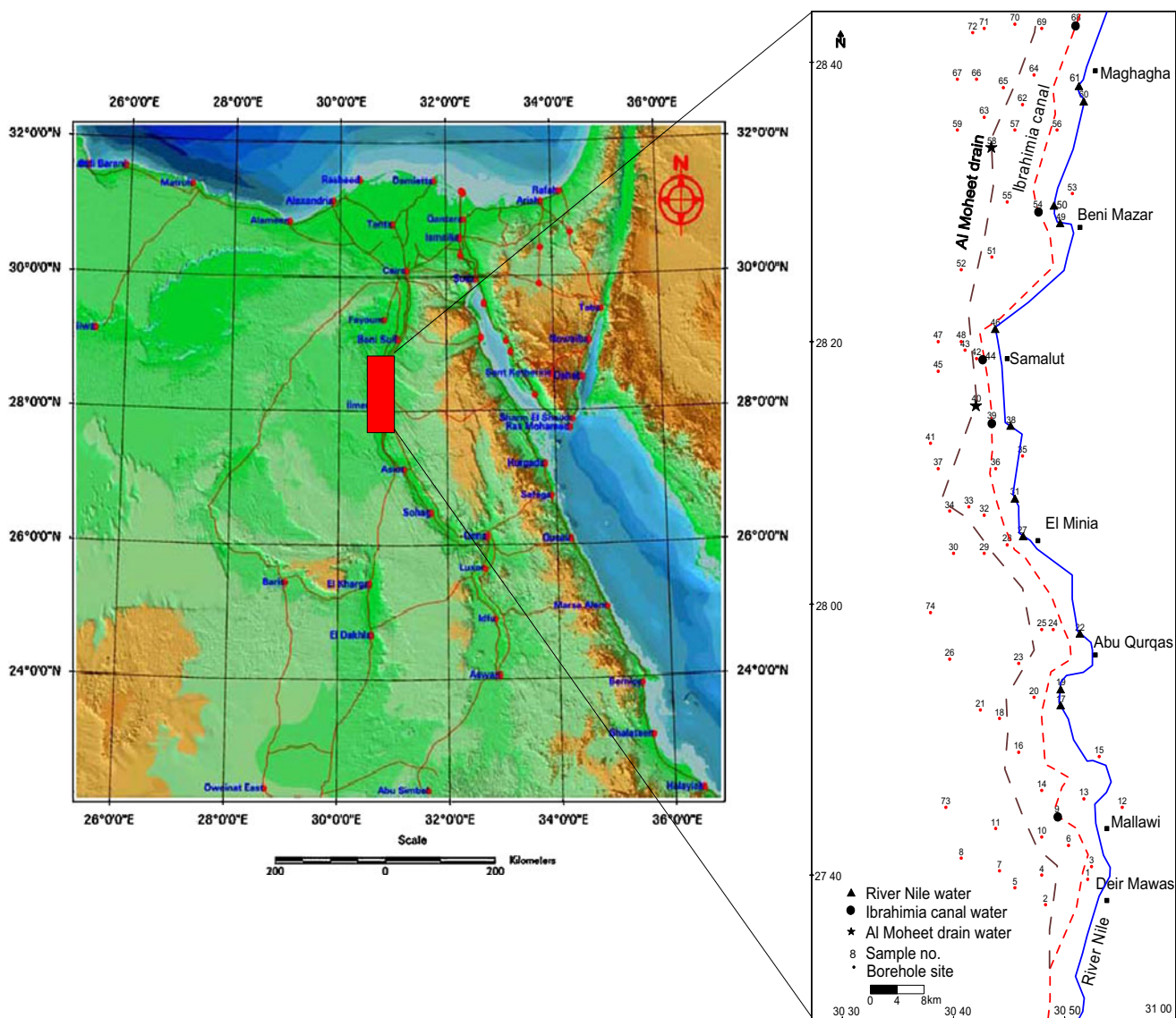


Fig. 1 Location map of the El Minia district

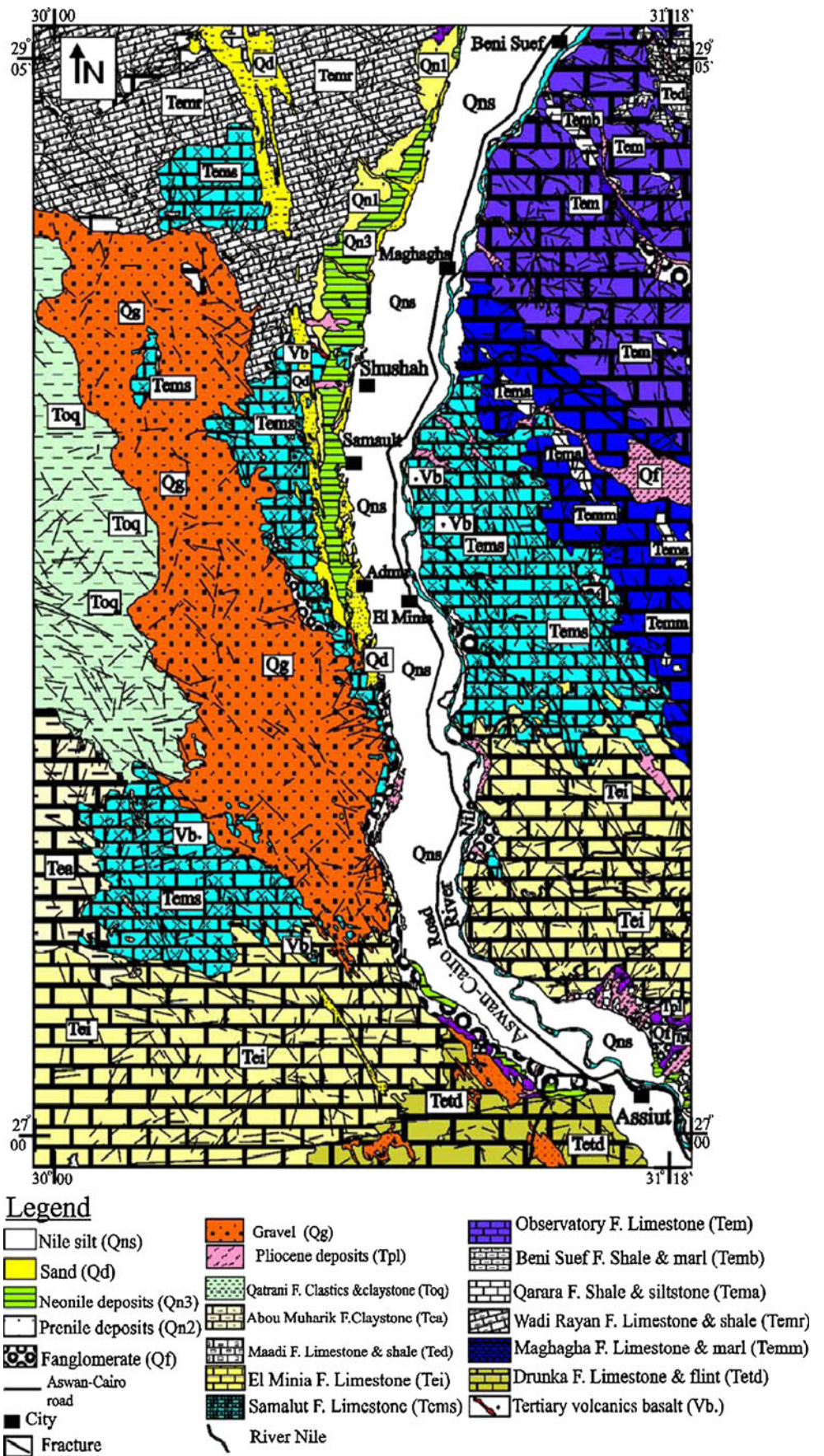
clay intercalations. The thickness of the aquifer ranges from 25 to 300 m, from desert fringes to central Nile Valley, respectively (Sadek 2001). The aquifer is overlain by semi-pervious silt and clay and underlain by Pliocene clay. The semi-confined bed (1–15 m thickness) is missed outside the floodplain and the aquifer become unconfined. The groundwater flow generally from south to north and locally diverts towards the eastern part, where large volume of groundwater are drained from the River Nile (Tantawi 1992). Nile water, irrigation system, drains, agricultural wastewater, and vertical upward leakage from the deeper saline aquifers (Korany 1984) recharge the aquifer. The study area is highly affected by faulting mainly in NW–SE direction (Fig. 3). The Nile Valley is essentially of structural origin (Beadnell 1900;

Ball 1909; Sandford and Arakell 1934; Attia 1954; Said 1962, 1981, 1993).

Materials and methods

Fifty-six groundwater samples were collected from the Pleistocene aquifer, 11 water samples from River Nile, five water samples from Ibrahimia canal, and two water samples from Al Moheet drain in El Minia district. Water analyses were carried out during summer season (2009). The groundwater samples were taken by means of well pumps after a pumping period of at least 1 h. The location site is determined by GPS instrument. Pre-rinsed polypropylene bottles were filled with the samples, sealed tightly. pH,

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



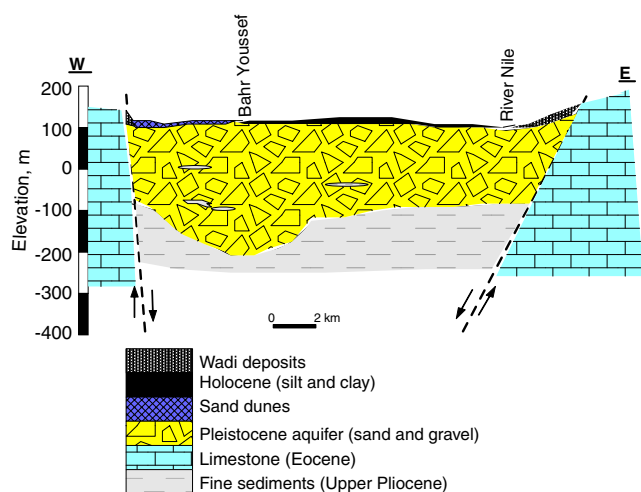


Fig. 3 Cross section across the Nile Valley at El Minia district, modified after IWACO and RIGW (1986)

electrical conductivity, and temperature are measured in situ using portable field kite. Cl, HCO₃, Ca, and Mg were measured by titration, while SO₄ 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, precipitation, and or adsorption. The acidification was accomplished in situ and in case of toxic metals determination. Then, the samples were transported to the laboratory, where they stored in a refrigerator at approximately -20°C to prevent change in volume due to evaporation. The toxic metals (Pb, Cd, Cr, PO₄, Se, Mn, As, Hg, Ni, Al, Fe, and SiO₂) were determined by the ICP-AES (Inductive Couples Plasma; Optima 3000; Perkin Elmer). The analyses were carried out at Environmental monitoring in Embaba.

Results and discussion

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–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

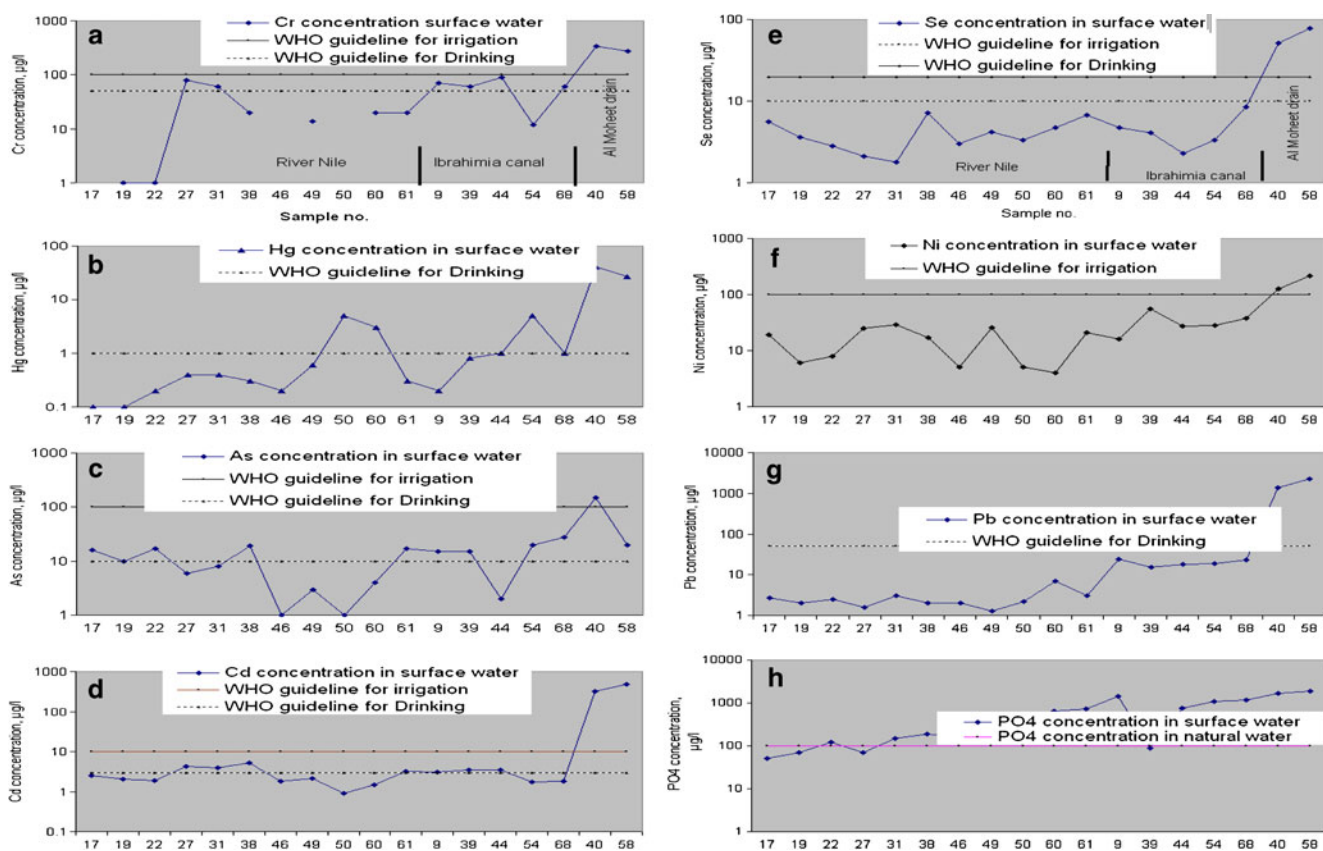


Fig. 4 Toxic metal concentrations in surface waters compared with WHO standards

related to agricultural activity, especially the use of fertilizers, which are dominantly of the super-phosphate type manufactured from Egyptian 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 $>50 \mu\text{g/l}$ 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 $10 \mu\text{g/l}$ (Van Lecuwen 1993). They are much increased in Al Moheet drain than those in River Nile and Ibrahimia canal, caused by sanitary and agricultural wastewaters dump. Cr, Hg,

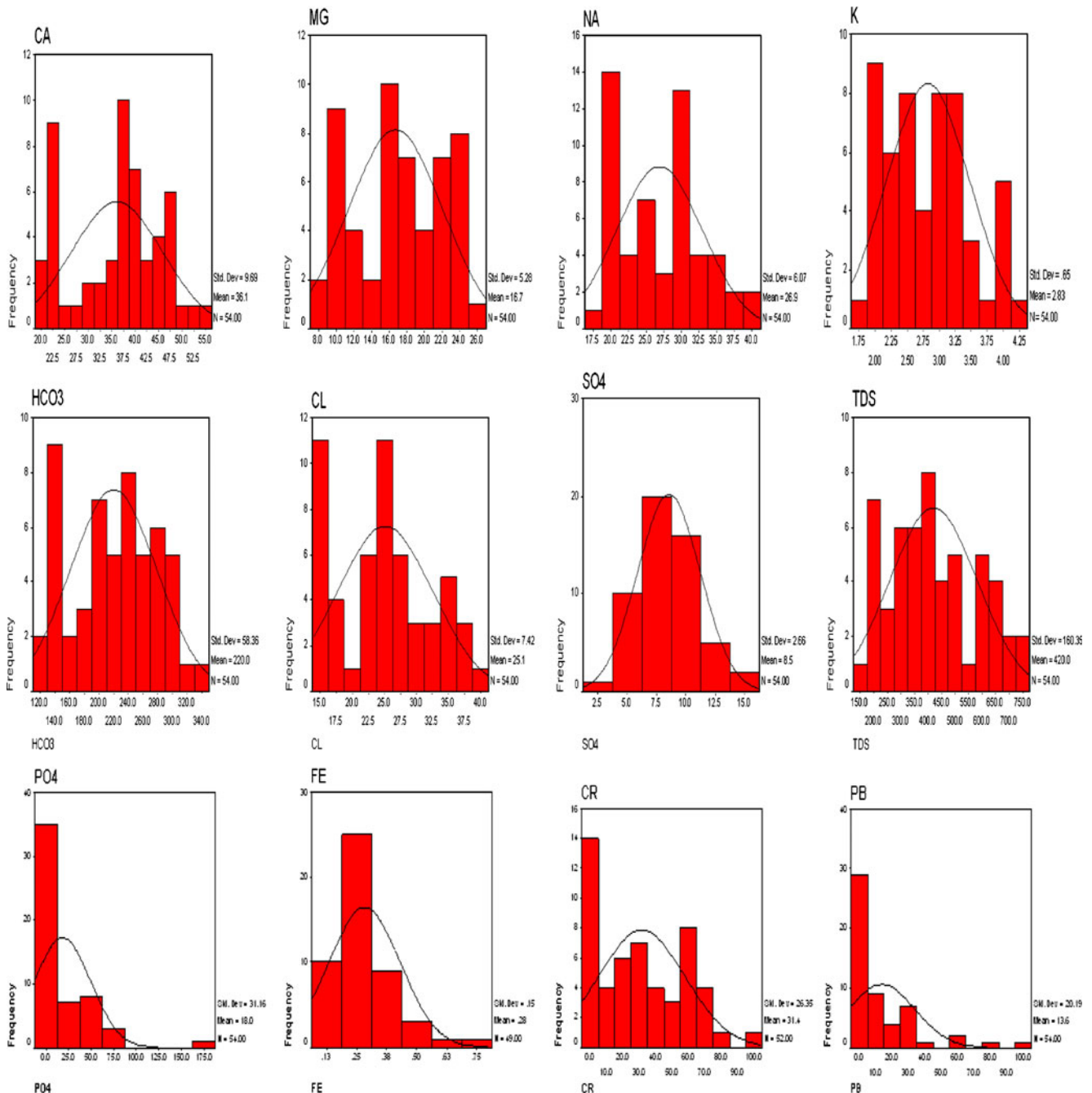


Fig. 5 Frequency of the major and toxic elements in groundwater, El Minia district

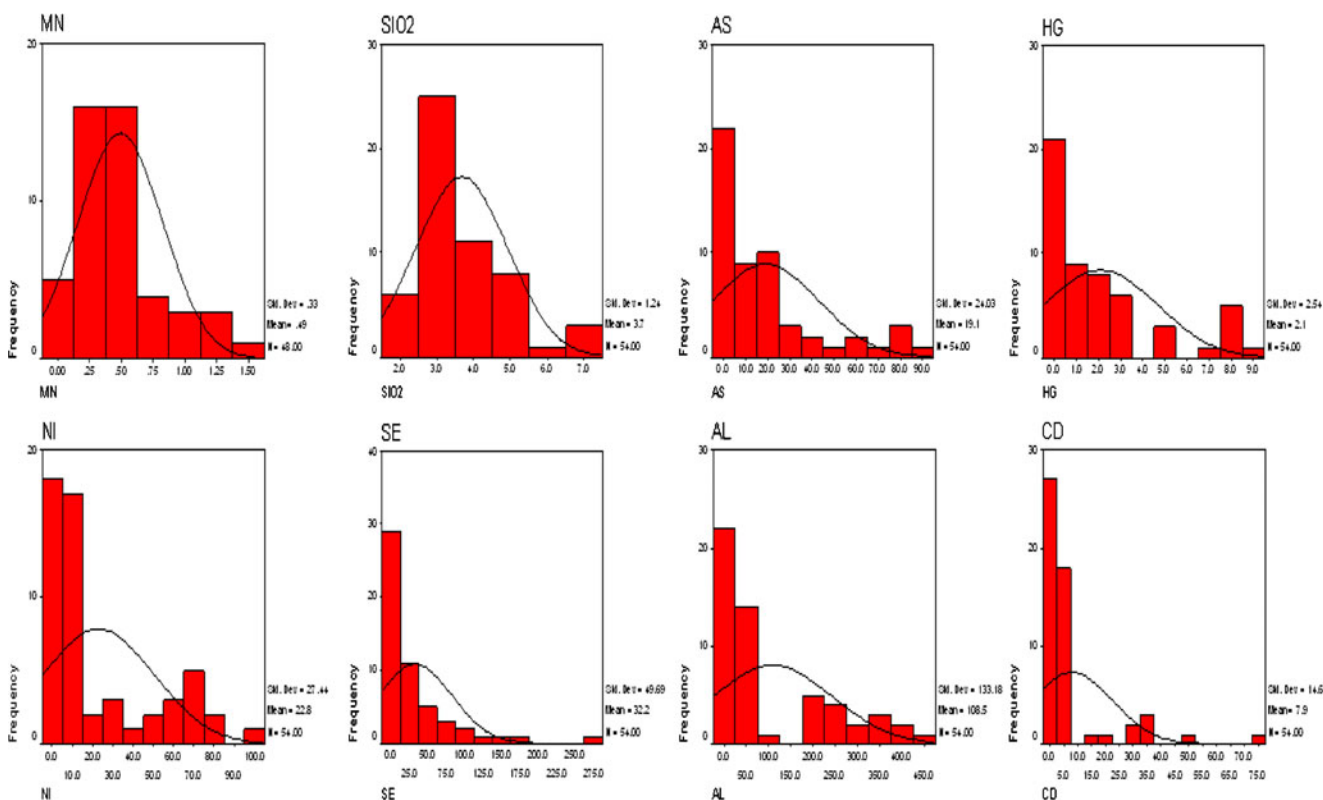


Fig. 5 (continued)

As, and Cd concentrations are below the WHO guideline for irrigation in River Nile and Ibrahimia canal, while Al Moheet drain exceeds the guideline. Therefore, Al Moheet drain is 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 PO₄ (Fig. 4h) concentrations increase in Al Moheet drain due to anthropogenic sources.

Groundwater

Summary statistics

A summary of the results of the survey is plotted as frequency in Fig. 5, which indicate that the water is fresh, and the Ca, Mg, and HCO₃ ions are dominant. Although not reaching a dominance level, the Pleistocene aquifer contains large percentage of Cl and SO₄ ions, whereas K and Na ions are considerable below the dominance level (Fig. 5). The groundwater of the Pleistocene aquifer is thus principally of Ca or Mg (HCO₃)₂ facies and has a tendency towards NaCl and Na₂SO₄. The mean and

standard deviation of the toxic metals was shown in Fig. 5.

Chemistry

The total dissolved solids (TDS) concentration is generally low (Fig. 6a), attributed to contribution from River Nile and Ibrahimia canal. The TDS concentration increased due to the western zone of the study area (Fig. 6a), 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 to the River Nile area and decreased in the desert fringes (western part). The aquifer receive low volume of fresh recharge water due to 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 receives much more recharge from the River Nile, which dilutes the aquifer in the eastern part. The semi-confined silt and clay bed (Holocene) increases in thickness due to 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.

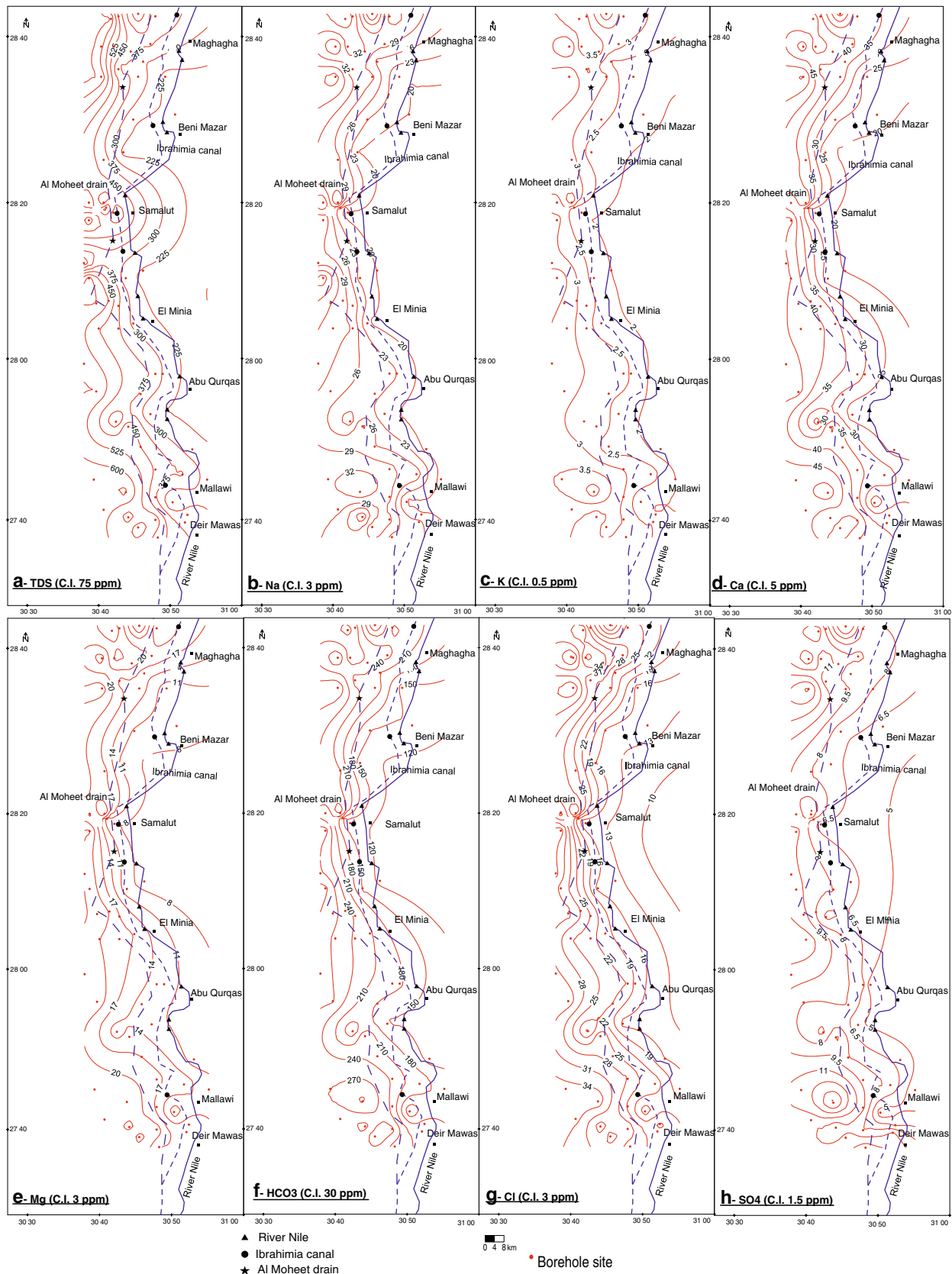


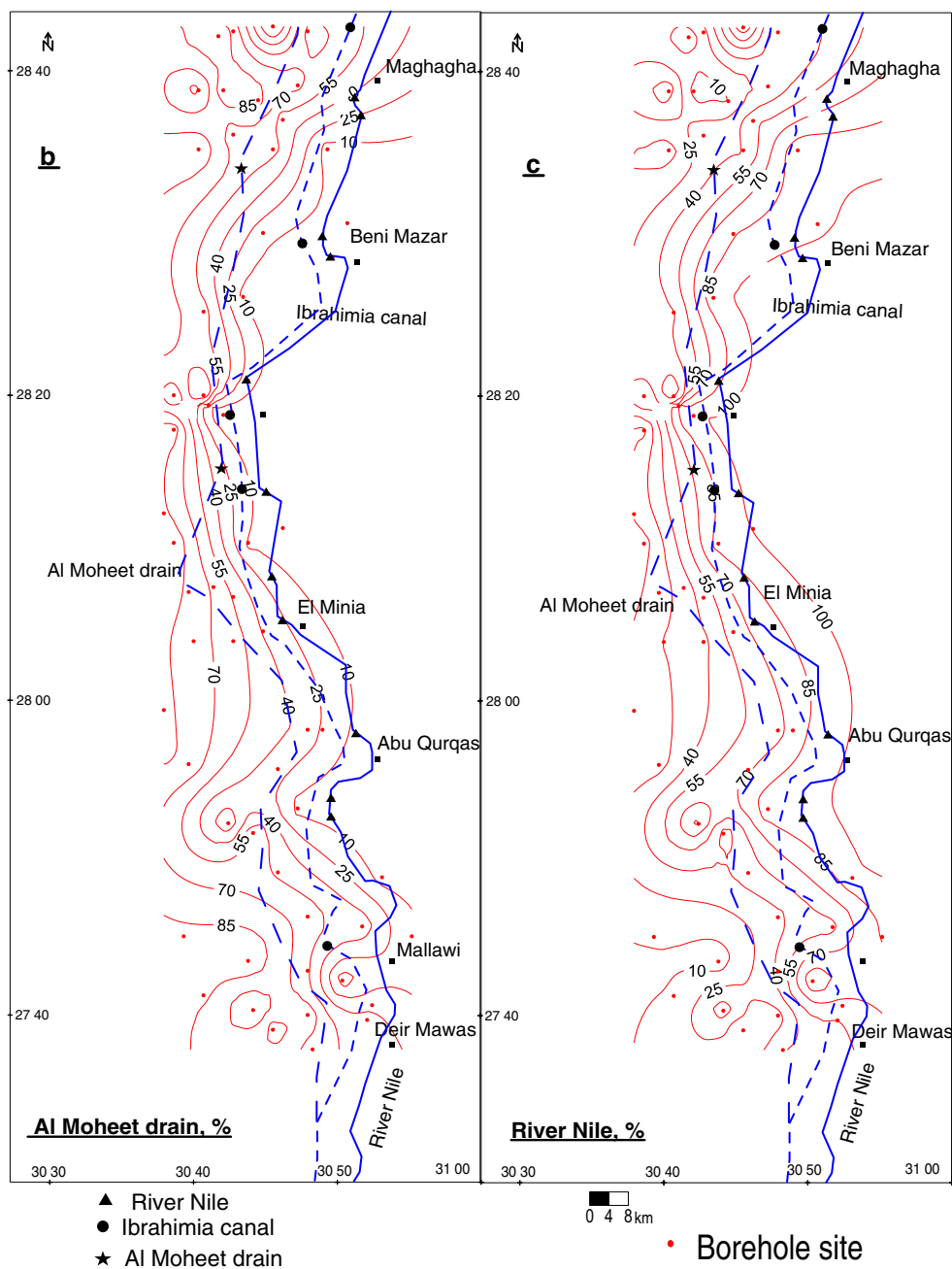
Fig. 6 Major ions distribution in groundwater in El Minia district

The percent mixed proportions from the River Nile and Al Moheet drain, determined by PHREEQC model (AquaChem), was shown in Fig. 7. It indicates that the mixing proportion from the River Nile and Al Moheet drain increased due to the eastern and the western part, respectively. It confirms 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, HCO₃, Cl, and SO₄ (Fig. 6b–h) exhibits the same trend of the TDS concentration. They derived mainly from anthropogenic and

partially from lithogenic sources. Overall, Na (mean 27 mg/l) and Ca (mean 36 mg/l) characterize the water chemistry as the dominant cations. The HCO₃ (mean 220 mg/l) and Cl (mean 25 mg/l) are the predominant anions. These fluctuated concentration ions vary geographically with groundwater flow, geomeidia, River Nile, anthropogenic sources, and the interaction between the different aquifers.

The values of distribution of Pb, Cd, Cr, PO₄, Se, Mn, As, Hg, Ni, Al, Fe, and SiO₂ concentrations in groundwater of the studied region were presented in Fig. 8a–l. These maps provide a basis for making area-wide generalizations

Fig. 7 Percent proportions of River Nile (a) and Al Moheet drain (b) in groundwater, PHREEQC model



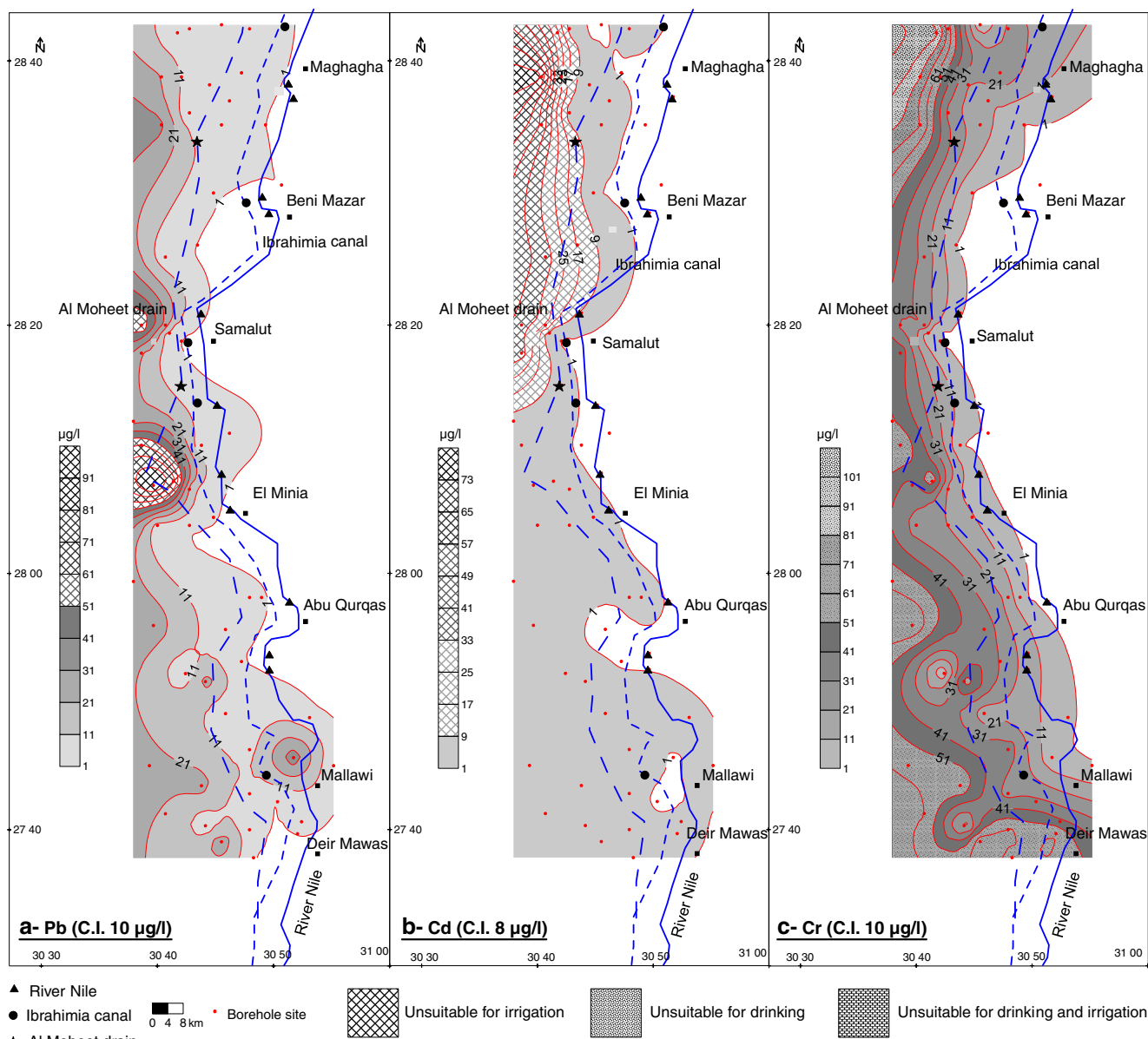


Fig. 8 Toxic metals distribution in groundwater in El Minia district

concerning the distribution of water quality parameters and serve to isolate water quality problem areas. There were differences in the contents of heavy metals in groundwater in each sub region, especially northwestern and southeastern part. The latter areas tended to be more concentrated in most toxic metals (Fig. 8a–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. 8e) and unsuitable for drinking with respect to Mn, As, and Hg concentrations (Fig. 8f–h). There are also some anomalies spots of Pb and Cd concentrations (Fig. 8a and b) led to severe impact if used in irrigation. Most toxic metals are derived from Al Moheet

drain, agricultural wastewater (fertilizers, manures, and pesticides), and lithogenic dissolution. The latter process may contribute mainly to Mn, Fe, and Hg. The aquifer was affected by unconfined condition in the western part to semi-confined in the central and eastern part; therefore, the vulnerability rate is increased due to 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 of SiO_2 as safely values for household uses, which found in surface and ground waters. The phosphorus concentration in natural water is 100 $\mu\text{g/l}$ (Bouwer 1978); the extensive use of super

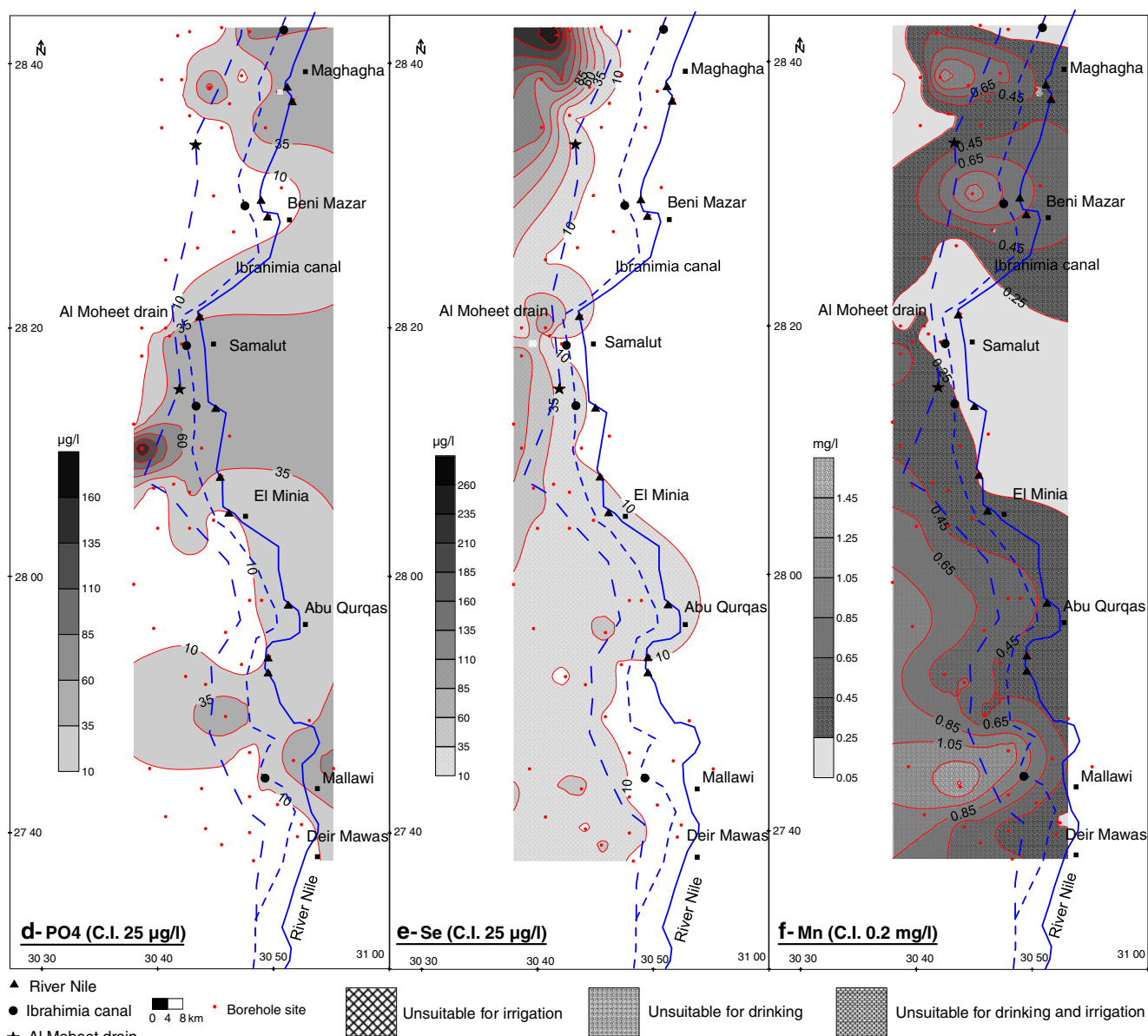


Fig. 8 (continued)

phosphate fertilizers contributed the PO₄, Cd, and Pb concentrations in groundwater.

Exchangeable estimated ratio and hydrochemical ratios

The exchangeable sodium ration and magnesium hazard distribution increased in the eastern and western part (Fig. 9a and b), 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 to the western part (Fig. 9c); this indicates a contamination from the lithogenic (dissolution of carbonate sediments)

and anthropogenic (agricultural wastewater). Girhhar and Yadav (1982) 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, Fig. 9c) 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, Fig. 9c) 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 to the western part (Fig. 9d). It attributed

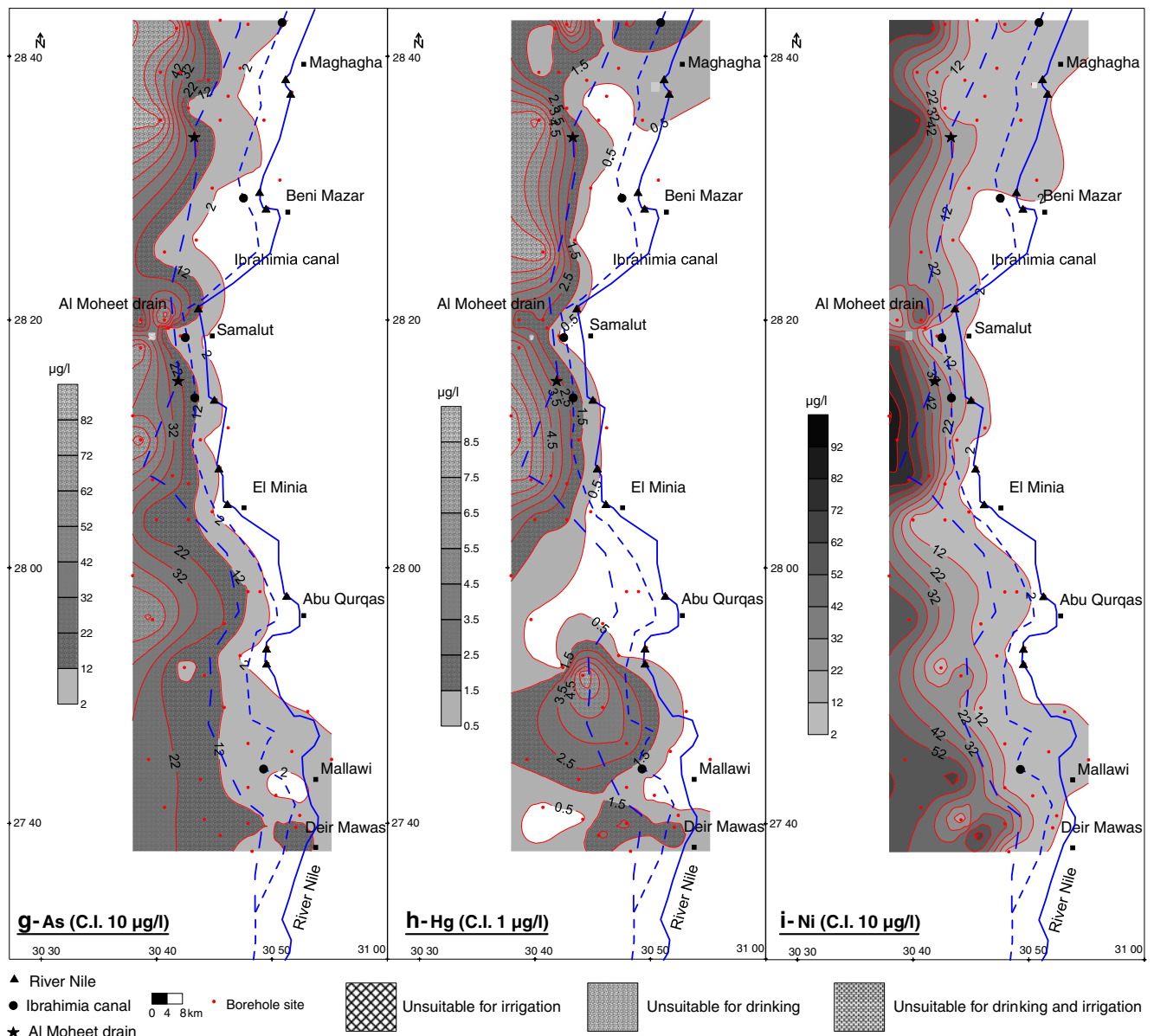
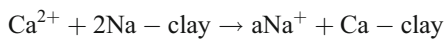


Fig. 8 (continued)

to the dissolution from limestone Eocene and agricultural impact, meanwhile the SO_4 concentration decline by reduction. The Na/Cl equivalent ratios were >2 in the northeastern part (Fig. 9e); indicate a sodium source rather than halite or surface irrigated water, such as rock-bearing minerals according to the following equation:



(Afzal et al. 2000) Furthermore, the Na/Cl ratio is always above unity (Fig. 9e) 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 to the western part (Fig. 9f). All groundwater samples fall in one zone indicating a similar chemical signature (Fig. 10). The cationic composition of the waters is Ca and Mg ions, while the anionic is HCO_3 dominated. This chemistry resulted from the rock water interaction and anthropogenic impact. The main water types are $\text{Ca}(\text{HCO}_3)_2$ and $\text{Mg}(\text{HCO}_3)_2$.

Summary and conclusions

The Pleistocene aquifer is vulnerable to contamination due to unconfined condition especially due to the western

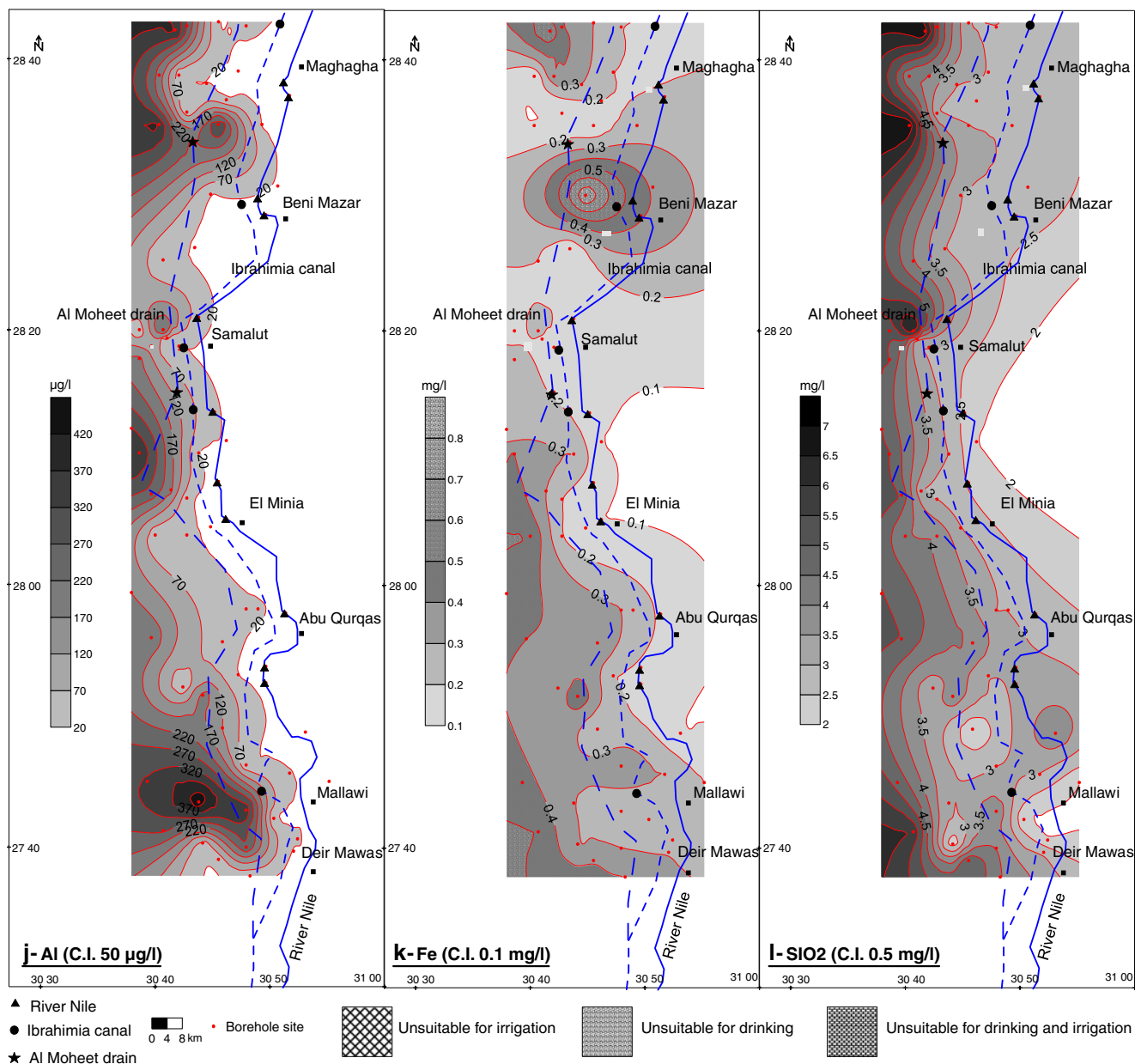


Fig. 8 (continued)

part of the study area. The total dissolved solids concentration increased in the western part, attributed to geology, hydrogeology, and anthropogenic. Contamination of the aquifer resources does not occur throughout the entire study areas. Although limited, good quality irrigating water for rural water supply occurs in the eastern part. Poor quality irrigating water occurs mainly in the southwestern and northwestern part. Al Moheet drain contains higher contents of toxic metal than Ibrahimia canal and River Nile. Groundwater quality assessment for the development of rural drinking and

irrigating water supplies systems should give high priority to reduce toxic metal pollution. Toxic metals are healthy important and they significantly exceed WHO levels for drinking and irrigation purposes. The development of an adequate national environmental information system linking the various drinking and irrigating water assessment programs is of vital importance. Drinking and irrigating water sampling and monitoring should be critical elements of program planning, implementation, and evaluation. Also regular consultation with and participation of the main stakeholders has proven to be

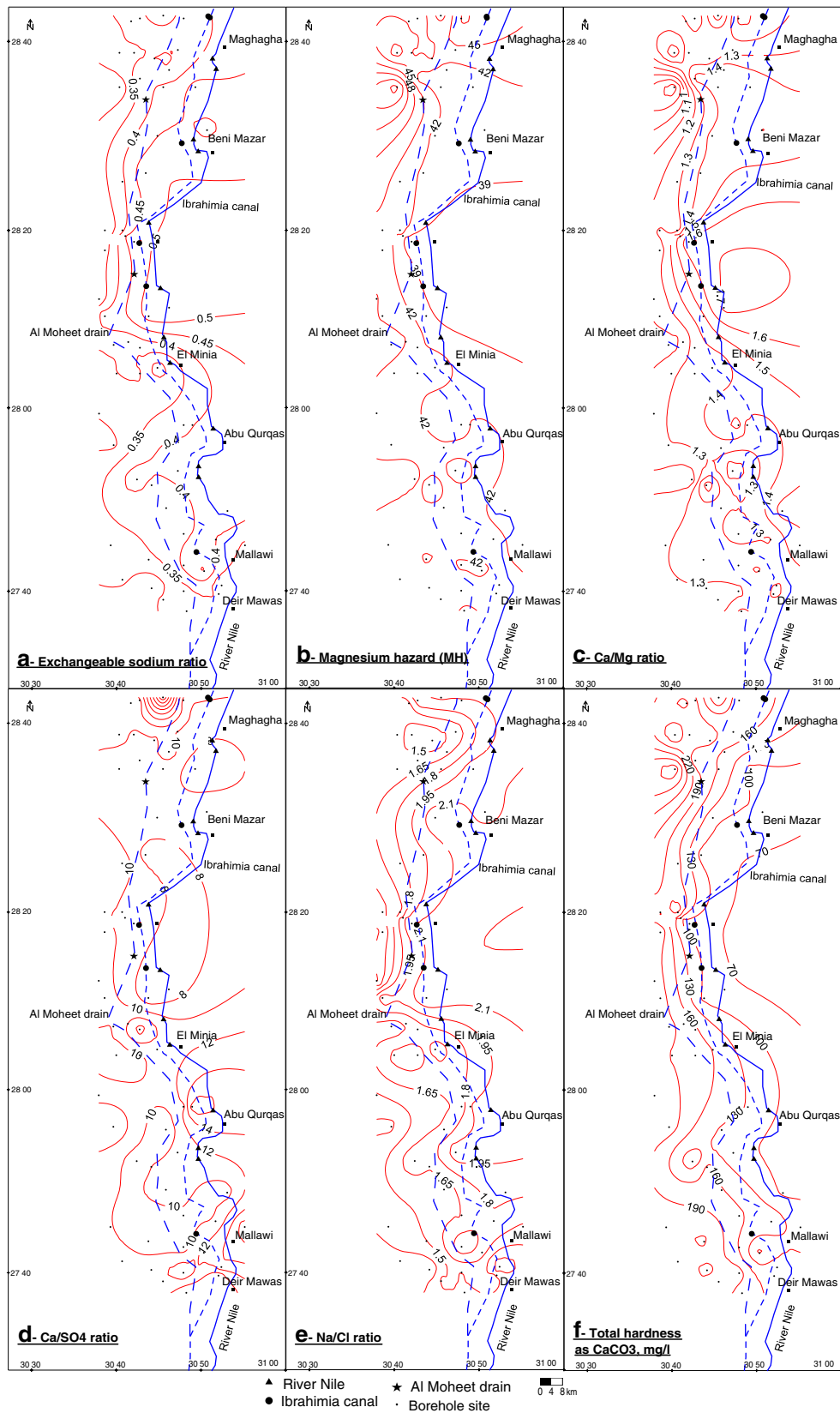


Fig. 9 Selected parameters estimated by AquaChem of groundwater in El Minia district

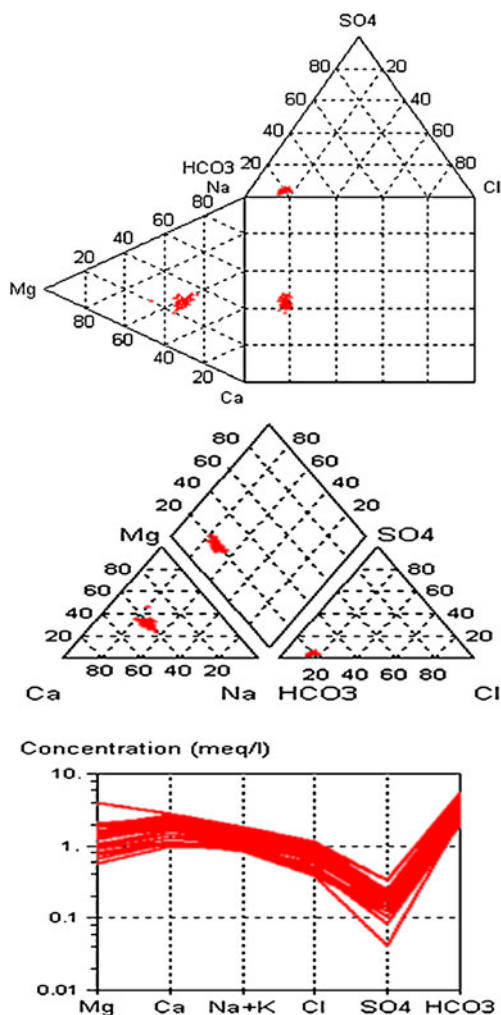


Fig. 10 Hydrogeochemical representation of the groundwater, El Minia district

very useful in identifying the main environmental issues and to start developing alternatives for improvement of rural drinking and irrigating water supplies.

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