

## **Problems of groundwater quality related to the urban environment in Greater Cairo**

**NAHED E. EL ARABI**

*Research Institute for Groundwater, National Water Research Center Building, El Kanater El Khairia, Egypt*

**Abstract** Greater Cairo is faced with increases in population and unplanned extensions in urbanization. This has not been followed by an equal expansion in water supply and sanitary drainage, thus resulting in poor environmental conditions. Cairo covers 300 km<sup>2</sup> with intensive and varied urban land uses and encompasses the oldest industrial areas of Egypt, such as Shubra-Mostorad and Helwan. In addition, new industrial communities are located in the western desert fringe of Greater Cairo with many industrial areas located in zones of highly vulnerable groundwater. Pollution sources of industrial origin threatening groundwater occur in a wide variety of both large and small industrial areas. Moreover the desert fringes of Cairo are being reclaimed by using sewage (waste) water for irrigation. The adverse environmental impacts of unplanned urban expansion and industrial and agricultural activities could lead to deterioration in groundwater quality. This has dictated quick interventions based on groundwater quality monitoring systems designed to detect pollution sources and their spatial extension. This paper presents groundwater quality indicators for domestic, agricultural and industrial pollution at representative sites within Greater Cairo.

### **INTRODUCTION**

The increase in population and subsequent unplanned urbanization in Greater Cairo has resulted in poor environmental conditions with groundwater resources being impacted by disposal resulting from agricultural, domestic and industrial activities. Within the current framework of Egyptian national environmental policy for water resource management, targets and standards are now defined for groundwater resources. The aim is to achieve an optimal and sustainable use of this precious resource in the framework of an overall integrated water resources management plan. The planning and management process continuously receives input from proper monitoring along with research on potential, vulnerability, pollution load and risk assessment.

Groundwater quality monitoring within Greater Cairo is carried out in selected areas based on land use and human activities along with groundwater vulnerability to pollution. The results of groundwater quality parameters are compared with the permissible level for a particular use to help indicate pollution sources and their spatial extension. This approach can help to define protection zones for water wells especially for those used for drinking purposes. In addition, the study recommends protective and preventative measures for local pollution sources in the region.

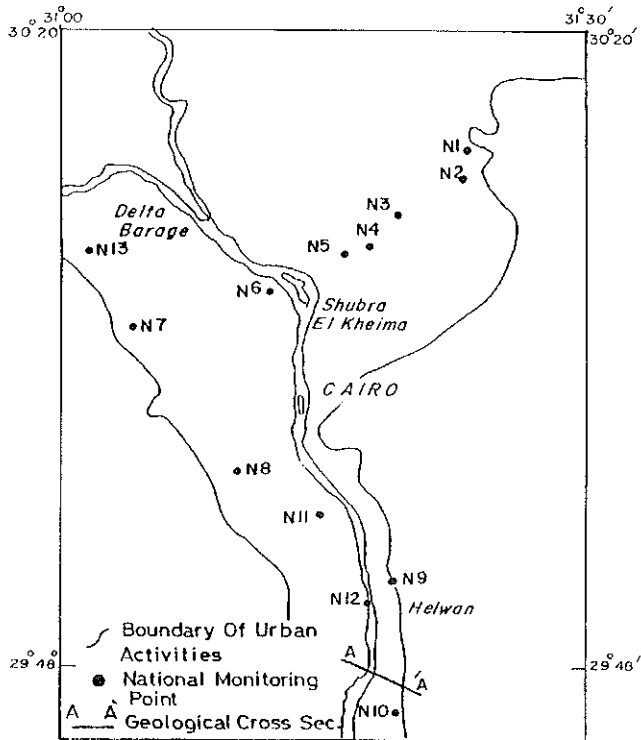


Fig. 1 Location map for the study area and monitoring points.

## PHYSICAL AND HYDROGEOLOGICAL SETTING

Cairo is situated along the River Nile. It lies between latitudes  $29^{\circ}40'$  and  $30^{\circ}12' N$  and between longitudes  $31^{\circ}00'$  and  $31^{\circ}40' E$  (Fig. 1) and is the most populated city in Africa. Urban land use covers about 60% of the total area, agricultural activities about 15%, and desert land some 25%. Industries and related activities are scattered all over the region and represent a further 1%.

The agricultural land is located in the north, west and east of the region, while the urban area is confined to the banks of the river (Fig. 2). The urban area is generally served with a piped sewerage system while the scattered rural areas and some unplanned settlements are either unserved or served with local networks or septic tanks. The main aquifer system consists of coarse massive sand and gravel intercalated by clay lenses, belonging to the late Pleistocene. The aquifer is covered by a layer of silty clay and/or fill deposits. This layer acts as a semipervious aquitard of thickness ranging from 5 m to 20 m and vanishing near the eastern and western edges of the flood plan. The aquifer thickness ranges from 20 m to 140 m. The areal extent of the aquifer is bounded to the east and west by limestone escarpments of Eocene and Cretaceous age (Fig. 3).

The aquifer is replenished through seepage from the river and irrigation canals, deep percolation from excess irrigation water and seepage from the water supply network. In unsewered regions the aquifer is recharged from sanitary trenches and pits

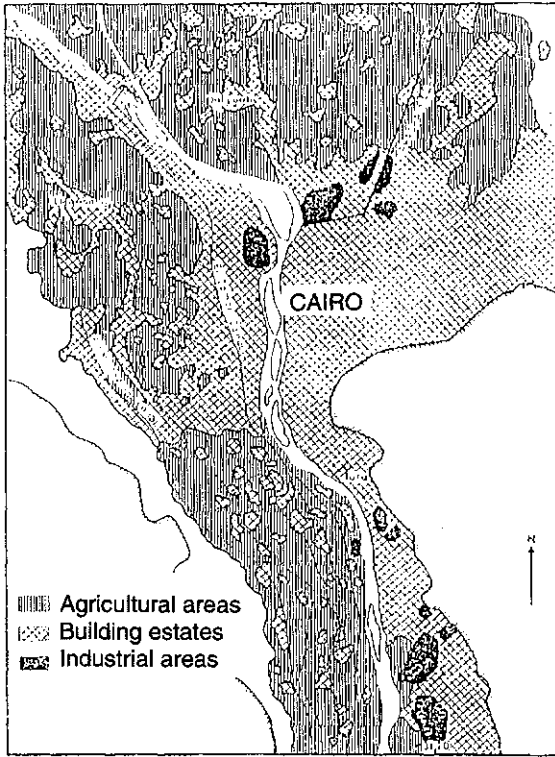


Fig. 2 Land-use map for the Greater Cairo region.

as well as by the leakage of palaeo-water from the deep aquifer system through major faults which bisect the southern portion of the study area (Helwan). On the other hand, discharge occurs as groundwater return flow to the river and by groundwater withdrawals.

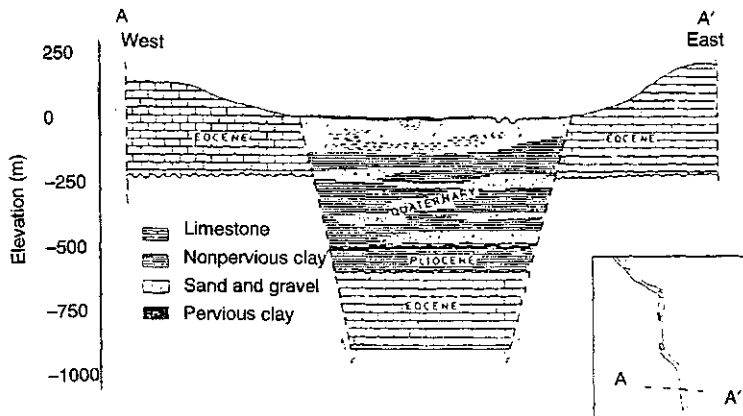


Fig. 3 Geological cross-section through the Greater Cairo region.

## GROUNDWATER QUALITY MONITORING

Recently, environmental protection of groundwater resources has become a key issue in resource planning as formulated in the National Environmental Action Plan. Available but scarce groundwater quality data however, already stress the urgent need for a quality-monitoring network. Protection measures should have high priority in areas where groundwater is vulnerable to pollution with restrictions on use and protection measures based on reliable data.

The design of the national groundwater quality-monitoring network is intended to distinguish characteristic groundwater quality monitoring areas in the Nile basin and Egyptian desert. This distinction has developed from a classification of aquifers, hydrogeochemical units, and salinization and pollution problems (pollution risk). The identification of homogeneous pollution units and pollution risks for each monitoring area are based on groundwater vulnerability to pollution and the pollution load (RIGW-IWACO, 1998).

### Groundwater vulnerability to pollution

The assessment of groundwater vulnerability to pollution is largely determined by the thickness of the top clay layer, depth to groundwater and rate of recharge. According to these parameters, groundwater vulnerability to pollution in the Greater Cairo region points to:

- most of the groundwater in the flood plain having a moderate to low vulnerability;
- high groundwater vulnerability areas existing on the fringes of the flood plain, where most of the agricultural lands are located with some scattered rural and industrial areas. Some of these agricultural lands are cultivated using wastewater, such as the Gabel al Asfar farm on the eastern fringes and Abu Rouash on the western fringes.

### Land use and pollution risk

Land use maps together with pollution sources are used to produce a pollution load map which is combined with the vulnerability map to classify qualitative pollution risk zones, as shown in Fig. 4. The pollution risk map is then used to select sub-monitoring areas for different types of land use pollution as shown in Fig. 5.

**Industrial pollution risk** About 120 industrial activities and gas filling stations occupy about 1% of the total Cairo land use and are diffusely located throughout the region (Platenburg *et al.*, 1997). The main industrial sites are Mustorod-Shubra in the north near to drinking water intakes and Helwan-El tabin in the south, as shown in Fig. 5.

**Agricultural pollution risk** Agricultural activities cover large areas on the western and eastern banks of the Nile and desert fringes of the region. The main two monitoring sites for assessment of agricultural pollution risk are El Gabal El Asfar and Abu Ruwash on the eastern and western fringes respectively. These two areas have been selected because irrigation is based on sewage water and they are located in zones

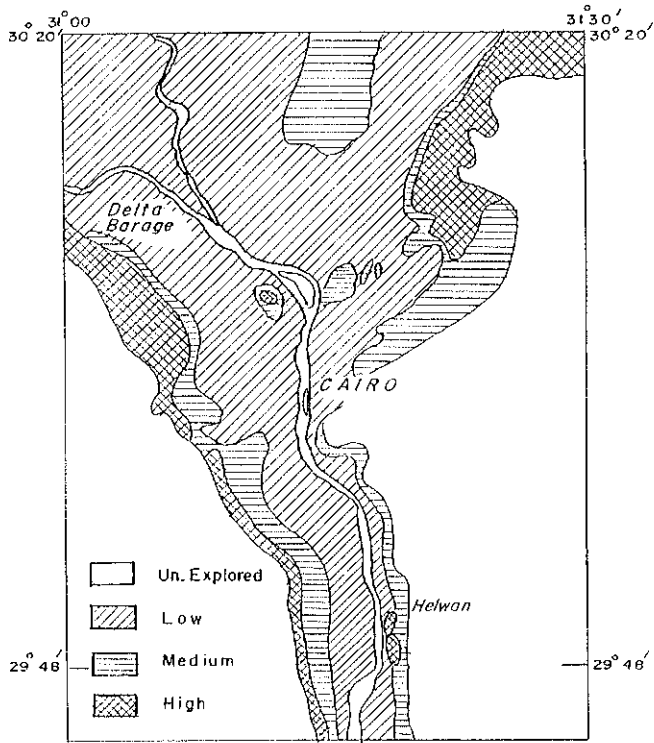


Fig. 4 Qualitative classification of pollution risk in Cairo.

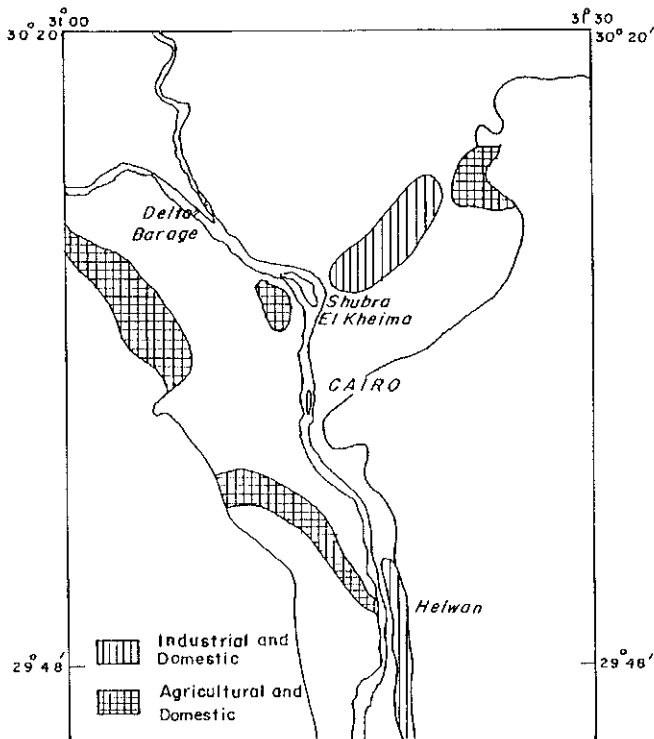


Fig. 5 Location of the monitoring areas in the Greater Cairo region.

of high groundwater vulnerability to pollution. The impacts of the sewage-based irrigation on groundwater have been assessed using a flow-solute model (El Arabi, 1996, 1997). The results of this study predicted the transport of solute (chloride as conservative parameter) to pumping wells after 30 years.

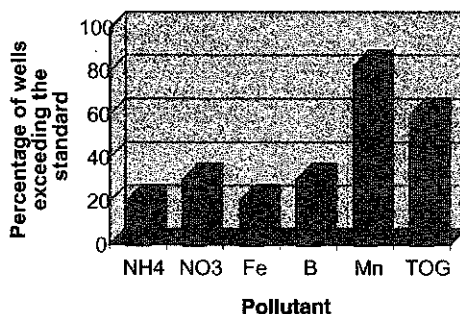
**Urban pollution risk** The major urban areas are confined to the banks of the river and are generally served with an old sewerage system. The remaining urban areas are represented by scattered and unplanned settlements which are either served or unserved with a local network or by septic tanks. Thus leakage from the old sewerage networks and the unserved rural settlements is considered to be one of the major environmental issues in Cairo.

## GROUNDWATER QUALITY AND POLLUTION INDICATORS

Since the main source of the Nile aquifer system recharge is Nile water, its chemical composition can be used to assess the groundwater degradation and pollution sources. Nile water is relatively fresh and of good quality (Table 1). Comparison of the chemical composition of Nile water and groundwater cations and anions recorded from the chemical analyses of the national groundwater quality monitoring survey, confirms the existence of degradation and pollution in the groundwater. The Egyptian standards for drinking water are based on groundwater use sustainability. Figure 6 shows the percentage of samples exceeding the standard.

**Table 1** The chemical composition of Nile water (Awad *et al.*, 1997).

pH	EC	TDS	Na	K	Mg	Ca	Cl	SO <sub>4</sub>	HCO <sub>3</sub>
8.1	147	230	19.1	6.24	11.3	25.6	21.3	9.6	145



**Fig. 6** Percentage of wells exceeding standards.

**Nitrate** Nitrate is an unambiguous indicator for domestic and agricultural pollution. The national monitoring programme shows high concentrations at many points in the selected priority monitoring areas for the assessment of agricultural and domestic pollution risk. Moreover the highest concentrations are found at well N9 in the industrial monitoring area (Hellwan) with the impacts of domestic pollution showing elsewhere (Fig. 7).

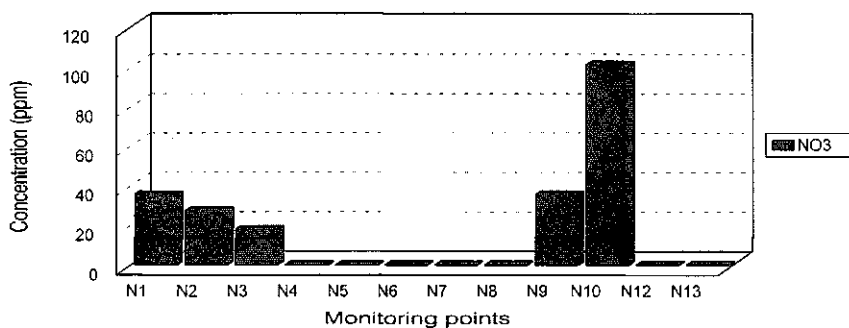


Fig. 7 Nitrate concentrations at monitoring points in Cairo.

**Sulphate** Sulphate has several sources. High concentrations could be caused by gypsum ( $\text{CaSO}_4$ ) dissolution, fertilizer and mixing with saline water (intrusion or seepage). High concentrations are detected at many points located in the industrial-domestic and agricultural-domestic monitoring areas. This indicates that the source is most probably the dissolution of gypsum (naturally present as well as added to soil), fertilizer and return flow. The highest sulphate concentration level occurs at well N9 in the Hellwan monitoring area where major faults and hot springs are common in this area of south Cairo.

**Boron** The natural sources of boron are saline water and evaporate deposits with non-natural sources being fertilizer and pesticides. Boron is found at many monitoring points for agricultural and industrial pollution such as N1 and N9 (Fig. 8, which also shows the occurrence of some heavy metals), with highest concentration levels being found in the Hellwan monitoring area where there is seepage of saline water through faults and hot springs. There is a clear relationship with salinity indicating that boron is mainly related to natural dissolution of salts.

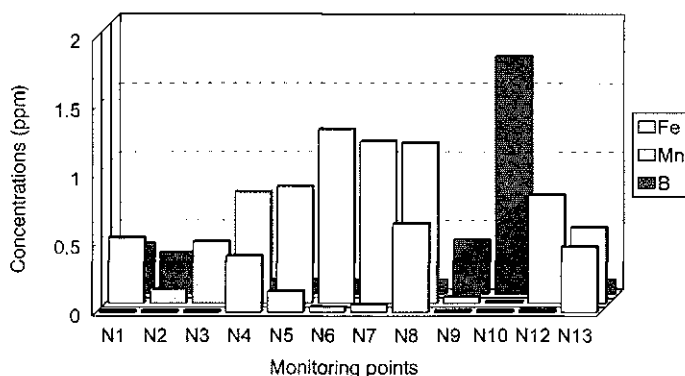


Fig. 8 Concentrations of some heavy metals at monitoring points in Cairo.

**Manganese** Manganese is present in clay minerals or as manganese hydroxides and is leached under anaerobic conditions. Analysis results indicate that high manganese concentrations are found in most of the wells compared with other water quality parameters which exceed the standard limit for drinking. Manganese

dissolution of aquifer sediment minerals seems to be the main pollution source (natural source) in the study area.

**Iron** Iron has the same source as manganese: iron hydroxides and clay minerals, and is also leached under anaerobic conditions and becomes precipitated as iron oxides or rust. The results of chemical analysis indicate the presence of iron in groundwater under the study area occurring as natural pollution and in some locations exceeds the standard limit for drinking water.

**Total oil and grease** TOG is one of the main industrial indicators and exceeds both the detection limit and the standard limit for drinking water.

## DISCUSSION

The evaluation of water quality showed that samples had one or more parameters exceeding their standards indicating that certain hydrochemical or pollution processes are governing the water quality:

- natural hydrochemical processes;
- reduction processes in groundwater (anaerobic, iron, manganese and ammonium);
- salt intrusion;
- leakage from brines;
- pollution hydrochemical processes;
- dissolution of minerals and salts (gypsum and halite);
- nitrification;
- return flow.

At wells N1 and N2 high concentrations of  $\text{NH}_4$ ,  $\text{NO}_3$ , phosphate, B, Mn and  $\text{SO}_4$  were observed with the first two parameters indicating that domestic pollution in this area took place due to re-use of sewage wastewater for irrigation. In the presence of bacteria and reducing conditions, nitrification processes take place but not all the ammonia is converted into nitrate. In addition, high concentrations of sulphate, boron and manganese reflect the effect of dissolution of some minerals in the Nile Delta soil as a natural source. Non-natural sources of sulphate, boron and manganese are fertilizers, pesticides and sewage irrigation water in this area. At wells N3, N4 and N5 in the industrial monitoring area, high concentrations of manganese, iron, sulphate and TOG are observed. The natural source of manganese and iron is the dissolution of clay minerals whilst non-natural sources are industrial and domestic pollution. At wells N7 and N8 in the agricultural-domestic monitoring areas, high concentrations of ammonia, iron, phosphate, sulphate and manganese occur reflecting the presence of pollution processes resulting from agricultural and domestic pollution sources.

At wells N9 and N10, high concentrations of  $\text{NO}_2$ ,  $\text{NO}_3$ , B, TOG and  $\text{SO}_4$  are observed. High concentrations of  $\text{NO}_2$  and  $\text{NO}_3$  with low concentrations of  $\text{NH}_4$  indicate the presence of nitrification processes at an advanced stage due to domestic pollution. High concentrations of sulphate and boron reflect the mixing of shallow groundwater with ascending water coming from deep aquifers along fault planes. The

hot sulphuric springs in this area intrude into salt groundwater as natural pollution processes in addition to the industrial pollution processes.

## CONCLUSIONS AND RECOMMENDATIONS

The results of the chemical analyses and the quality processes indicate the presence of various pollution sources in the Cairo region. Natural pollution sources originate from the dissolution of minerals in the clay layer and the aquifer deposits in addition to salt intrusion through faults and hot springs in the study area. Non-natural pollution sources are detected by concentrations of pollution indicators in the monitoring areas. The presence of different types of pollution indicators in the same location has confirmed the complexity of land use in the Cairo region and the negative impacts of the urban environment on groundwater quality.

Reducing processes take place in aquifers because of the presence of organic matter in the sediments and the recharging of sewage water. The high concentration of manganese clearly confirms this reduction. However, high concentrations of some parameters such as iron and manganese result from natural pollution sources and can be satisfactorily treated in water pumping stations. The excellence by many pollution parameters of the standards for drinking water has revealed the potential health hazards of using groundwater for domestic water supply in the Cairo region. The study recommends the design of local monitoring networks at pollution sites to detect the extension of pollution plumes. Vulnerability and pollution risk mapping could be used to determine protection zones for groundwater use.

## REFERENCES

- Awad, M. A., El Arabi, N. E. & Hamza, M. S. (1997) Use of solute chemistry and isotopes to identify sources of groundwater recharge in the Nile aquifer system, Upper Egypt. *Groundwat. J.* 35(2).
- El Arabi, N. E., Rashed, M. & Vermeulen, A. (1996) Environmental impacts of sewage water irrigation on groundwater. In: *Proc. Workshop on Managing Environmental Changes Due to Irrigation and Drainage* (ed. by C. A. Madramootoo & G. T. Dodds) (Proc. 16th ICID Congress on Irrigation and Drainage, September 1996, Cairo, Egypt), 102-114.
- El Arabi, N. E. & Fatma Attia (1997) Impacts of sewage-based irrigation on groundwater: an Egyptian case. In: *Water Management, Salinity and Pollution Control Towards Sustainable Irrigation in the Mediterranean Region* (Proc. Int. Conf. September 1997, Bari, Italy), 215-228. CIHEAM/MAI-B, Water Agronomico Mediterraneo Valenzano (Bari), Italy.
- Platenburg, R. J., Hoencamp, T. E. & El Arabi, N. E. (1997) Soil quality management at industrial sites: Dutch experiences relevant for Egyptian context. In: *Proc. Environment'97, First International Conference and Trade Fair on Environmental Management and Technologies*, (February 1997, Cairo, Egypt), vol. 2.
- RIGW-IWACO (1998) Identification of priority setting and selection of areas for monitoring groundwater quality. Environmental Management of Groundwater Resources Project Technical Report, January 1998, Cairo, Egypt.