Environ Geol (2008) 55:639–652
DOI 10.1007/s00254-007-1014-1

ORIGINAL ARTICLE

Groundwater of Egypt: "an environmental overview"

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Received: 11 April 2007 / Accepted: 20 August 2007 / Published online: 12 September 2007

Abstract Although Egypt has the great Nile River, which is the main supply of water, Egypt's water is limited to 55.5 billion m^3 per annum. Owing to the rapid growth of the population and the increasing consumption of water in agriculture, industry, domestic use, etc., it is expected that Egypt will rely to some extent on groundwater to develop the new projects such as Tushka in Upper Egypt and East Oweinat. Issues related to groundwater in Egypt are identified with the common geological features associated with formation of the aquifers and demonstrating the location of the main resources of groundwater, followed by the main objective of this paper, which is addressing the environmental issues related to groundwater in Egypt. Several studies have been reviewed and personal communication made with the authorities to introduce this work and provide an overview of the groundwater quality problems in Egypt with examples from different parts of the country.

Keywords Groundwater · Egypt · Environment · Pollution

Introduction

Groundwater is a vital resource and is used for many purposes, including public and domestic water supply systems, irrigation and livestock watering, and for industrial, commercial, mining and thermo-electric power production. Groundwater serves as the only reliable source of drinking and irrigation water in many localities. This vital resource is vulnerable to contamination, and is being increasingly threatened by an array of pollutants from landfills, soil treatment systems, septic tanks and subsurface disposal wells.

Although 75% of the earth's surface is covered by water, less than 1% is fresh water available for use. It has been estimated that approximately 96% of the world's available fresh water is stored in the earth as groundwater. It is noteworthy to mention that the groundwater represents more than 95% of the used fresh water.

Groundwater in Egypt

General outlines

Egypt has a semi-arid to extremely arid climate and displays the classical features of arid zone hydrology. One of these features is the availability of limited quantities of fresh water. Since ancient times the Nile has been the main source of fresh water to the country covering all water needs for Egypt's population, which inhabited the Nile Valley and the Delta. Human activities in the remaining 97% desert land remained confined to a few localities, where deep groundwater was available through springs and seepage zones (valleys, oases, and depressions).

Groundwater development in Egypt is not only confined to the Nile Valley and the Delta, but also extends to the desert areas where a large amount of non-renewable groundwater is stored.

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The hydrogeological framework of Egypt (Fig. 1; Table 1) comprises eight hydrogeological units (RIGW 1988, 1993):

1. Nile Valley and Delta aquifers,
2. Coastal aquifers,
3. Nubian Sandstone aquifer,
4. Moghra aquifer,
5. Tertiary aquifer,
6. Carbonate rocks complex aquifers,
7. Fissured basement complex aquifers and
8. Aquiclude rocks

The water-bearing rocks in Egypt are classified into the following two groups:

(a) Granular water-bearing rocks and
(b) Fissured and karstified water-bearing rocks (Table 1).

The following Table 2 summarizes the characteristics of the main aquifer systems of Egypt. Data are adopted from different sources, mainly, RIGW (1988, 1993), Abu Zeid and Rady (1992), Hefny (1992), RIGW/IWACO (1999), Shata (1982, 2001), Allam et al. (2002) and El Tahlawi (2004, 2006).

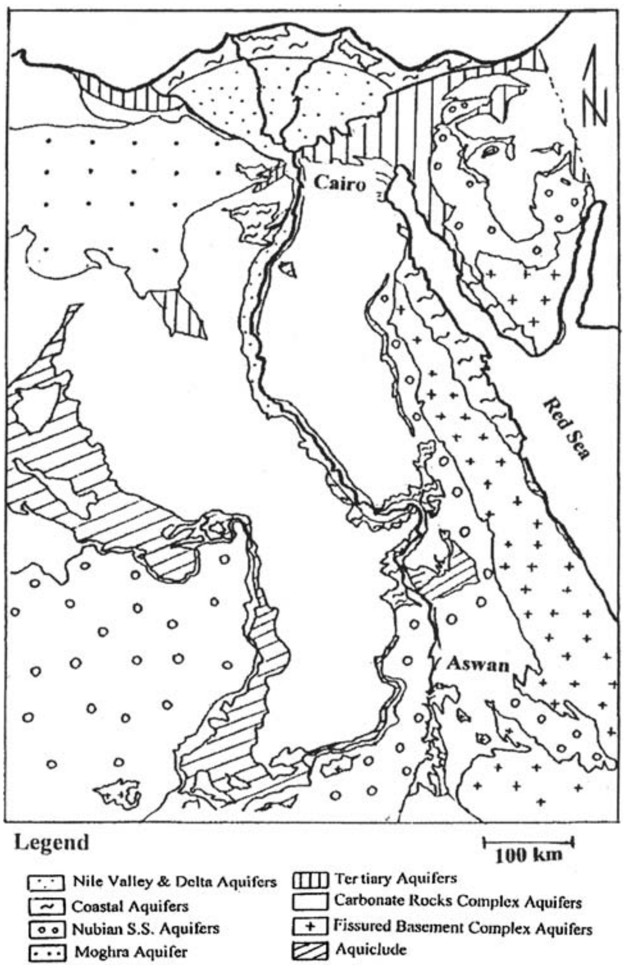


Fig. 1 Hydrogeological map of Egypt (simplified after RIGW 1988, 1993)

Granular water-bearing rocks

Nile Valley aquifer

This aquifer is in the Tertiary and Quaternary deposits. Its thickness is estimated as 300 m at Middle Egypt and decreases to the north towards Cairo and in the south direction up to Aswan (Fig. 2). Below this aquifer, there are clayey deposits that were formed during the Pliocene, which are impermeable and prevent the connection between this aquifer and the Nubian Sandstone aquifer. However, there could be a connection between the Quaternary deposits and the surrounding limestone. The water is mainly used for domestic purposes and irrigation; its salinity is less than 1,500 ppm.

The Nile Delta aquifers

In the Nile Delta basin four regional aquifers are present in addition to six sub-regional and local aquifers (Fig. 3). Table 3 represents the general features characterizing each aquifer.

The Nile Delta aquifer consists of the Pleistocene graded sand and gravel, changing to fine sand and clay to the north. In the floodplain of the Nile, the aquifer is semi-confined, as it is overlain by Holocene silt, clay and fine sand. In the northwestern part of the area, a calcareous loamy layer acts as a semi-confining zone outside the floodplain. The thickness of this zone ranges between 0 and 20 m. In the desert fringes, the semi-confined layer is missing and phreatic conditions prevail.

The thickness of the layers holding the groundwater are different from one place to another, however, its average thickness is 190 m, increasing gradually to the north till it reaches 350 m at Tanta. At the western part of the Delta the thickness of the layer holding water varies between 120 and 220 m, decreasing gradually towards the east.

The Nile Valley and Nile Delta aquifer are almost separated as the aquifer thickness is reduced to a few meters at Cairo.

The total thickness of the aquifer increases from Cairo northward to about 1,000 m along the Mediterranean coast. To the west the Quaternary aquifer is in hydraulic connection with the Moghra aquifer as indicated by the westward continuity of the piezometric gradient (Fig. 4). The Nile River is the main feeding supply to this aquifer. The quality and quantity of the southern part of the aquifer

Table 1 The main hydrogeological units in Egypt (RIGW 1988)

Lithology (rock type)	Unit	Recharge		Distribution	Productivity
		Surface	Sub-surface		
Granular rocks	(1) Nile Valley and delta	Continuous	Continuous	Extensive	High
	(2) Coastal aquifers	Occasional	Limited	Local	Moderate to high
	(3) Nubian Sandstone complex	None	Limited	Extensive	Moderate to high
	(4) Mohgra aquifer	Insignificant	Locally	Extensive	Low to moderate
	(5) Tertiary aquifers	Insignificant	Limited	Local	Low to moderate
Karstfied and fissured rocks	(6) Carbonates	None	Locally	Extensive	Moderate
	(7) Hard rocks	Insignificant	Limited	Local	Low
Clay or shale	Aquicludes	None	None	Generally local	None

Table 2 Characteristics of main aquifer system of Egypt

Name of aquifer	Type locality	Depth of top aquifer (m)	Saturated thickness (m)	Depth to water table (m)	Hydraulic conductivity (m/day)	Porosity (%)	Salinity (ppm)
Granular rocks							
Nile Valley and Delta aquifer	Nile Valley	0–20	10–200	0–5	50–70	25–30	<1,500
	Nile Delta (south)	0–20	100–500	0–5	50–100	25–30	<1,500
	Nile Delta (north)	20–100	500–1,000	0–2	<50	>30	>5,000
Coastal aquifers	Mediterranean	0	<5	±15	15–25	>30	1,000–6,000
	El-Qaa plain	50–100	60–80	50–70	5–10		600–2,500
	El-Arish aquifer	15–30	40–50	0–30	5–20		1,500–6,000
Nubian Sandstone	Western Desert						
	Kharga	50–200	500–700	0–30	2–4	20	<1,000
	Dakhla	200	500–1,000	0–20	6–7	20–25	<1,000
	Bahariya	150–300	1000–1,500	0–20	5–10	20–40	<1,000
	Farafra	200–500	1000–2,000	Flow	2–5	20–30	<1,000
	East Oweinat	10–20	100–300	20–30	10–20	20–30	<1,000
	Nile basin fringes						
	Qena area	100–250	500	Flow	1–2		2,000–2,500
	Laqeita area	100–500	200–400	Flow	1–3		1500–2,000
	Eastern Desert						
	Esh El Mallaha	0–30	>200	Flow			3,000–4,000
Nubian Sandstone	Sinai						
	Nakhla	1000	2,000	200			1,500–2,000
	Oyun Moussa	100–500	1,500	Flow			1,000–4,000
Mohgra aquifer	Natron/Qattara	0–200	500–900	100		20	1,000–1,2000
Fissured rocks							
Carbonates	Wadi Araba	0–100	500	Flow			1,000–1,2000
Hard rocks	South Sinai	0–50		+50			1,000–2,000

Depths are measured from ground surface

is much better than the northern part as its TDS does not exceed 1,000 ppm.

The aquifer is continuously recharged by infiltration of irrigation water. The permeability ranges between 35 and 75 m/day and it decreases near the coastline due to increase in clay content. The transmissivity ranges between less than 500 m^2/day at the edges in the desert fringe to more than 25,000 m^2/day in the apex of the Nile Delta. The characteristics of the northern portion of that system are considerably different. The aquifer becomes less productive, contains mainly brackish or saline water due to sea-water intrusion.

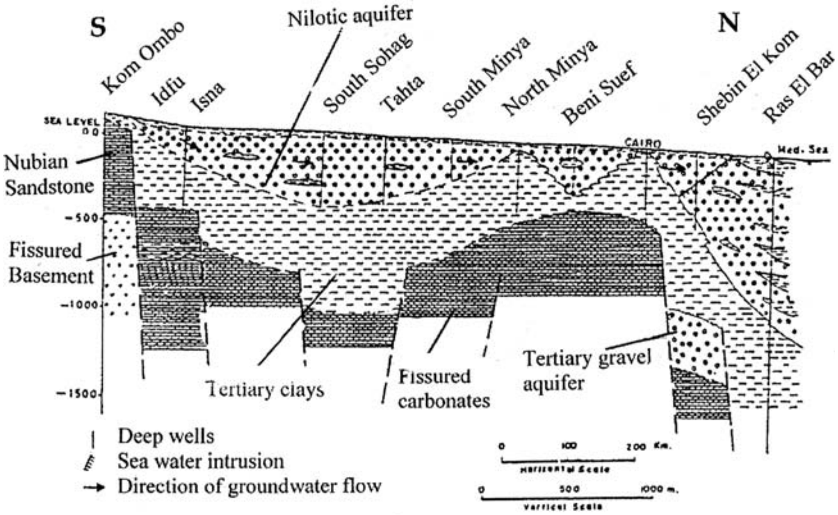


Fig. 2 Hydrogeological profile through the Nile Valley and Delta basins (after Hefny and Shata 2004)

El Moghra aquifer system

The Moghra aquifer consists of Lower Miocene fluviatile and fluviomarine coarse sand and gravel of the Moghra Formation. This system is west of the Cairo-Alexandria Desert road and covers a vast area of the Western Desert between the Nile Delta and the Qattara Depression. It has an average thickness of 300 m and is generally considered a non-renewable aquifer system. The current estimated annual extraction from this system is 200 million. The hydraulic gradients are very gentle and amount to less than 0.2 m/km.

The water in the Moghra aquifer is a mixture of fossil and renewable water. Discharge of the aquifer takes place through evaporation in the Qattara and Wadi El Natron depressions and through the lateral seepage into carbonate rocks in the western part of the Qattara Depression. The base of the aquifer slopes from ground level near Cairo to 1,000 m below mean sea level west of Alexandria. The saturated thickness is between 70 and 700 m.

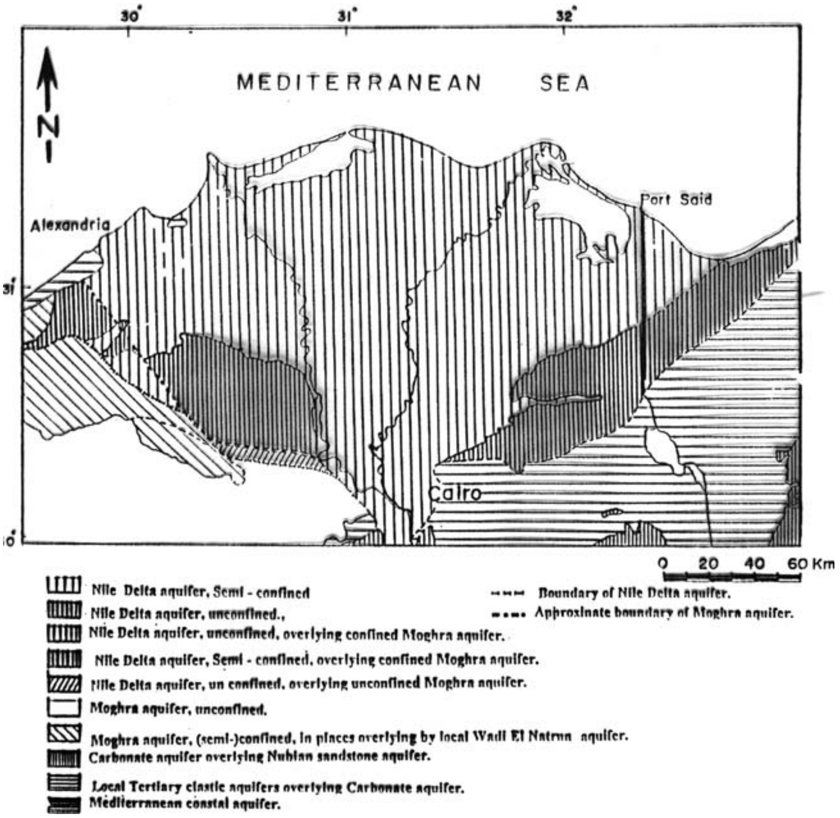


Fig. 3 Groundwater aquifers in the Nile Delta (after RIGW/IWACO 1990)

Table 3 Characteristics of the groundwater aquifers in the Nile Delta and its fringes (after RIGW 1988)

Aquifer	Age	Rock type	Extent	Location	Transmissivity (m^2/day)
Mediterranean coastal aquifer	Pleistocene	Granular	Local	West of Alexandria	500–1,500
Nile Delta aquifer	Pleistocene	Granular	Extensive	Nile Delta	500–5,000
Northwest Sinai aquifer	Pleistocene	Granular	Extensive	Western Sinai	<500
Wadi El Natron aquifer	Pliocene	Granular/clay	Local	Western Delta fringe	<500
Moghra aquifer	Miocene	Granular	Extensive	Northwest Desert	500–5,000
Cairo-Suez aquifer	Plio-Pleistocene/ Miocene/ Oligocene	Granular	Extensive	Cairo-Suez district	<500
Abu Zaabal volcanics	Oligocene	Fissured/volcanic	Local	South portion	<500
Upper carbonate aquifer	Middle Miocene	Fissured and karstified	Extensive	Almost the entire area	Largely unexplored
Lower carbonate aquifer	Upper Cretaceous	Fissured and karstified	Extensive	Almost the entire area	
Nubian Sandstone aquifer	Cretaceous to Paleozoic	Mixed granular and fissured	Extensive	Almost the entire area	Largely unexplored
Basement	Precambrian	Fissured/igneous	Extensive	Almost the entire area	Unexplored

Permeability ranges between 25 m/day east of Wadi El-Farig to less than 1 m/day in the Qattara area and near the coast. Transmissivity ranges between 500 and 5,000 m^2/day. The water balance of the Moghra aquifer is still subject to investigation, particularly in relation to the estimated and observed evaporation in the Qattara Depression and inflow of deep groundwater from the Nubian Sandstone.

The salinity of the water changes from less than 1,000 ppm in the east, i.e. close to the main recharging area, to more than 5,000 ppm in the west, i.e. close to the main discharging area. South of latitude 30°30′N, the aquifer is exposed, but not completely phreatic due to the intercalations of clay layers. North of this latitude it is confined by Pliocene deposits. The aquifer is underlain by

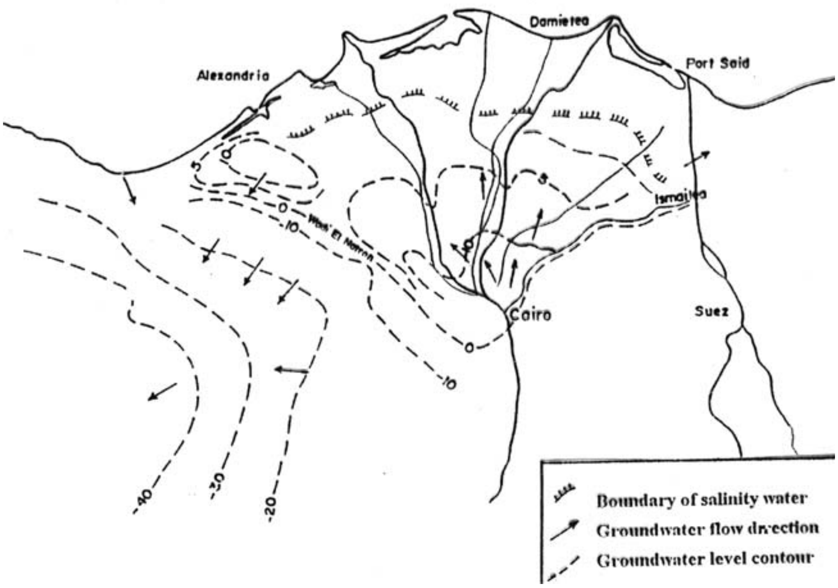


Fig. 4 Regional groundwater levels and trends in the Nile Delta and its fringes from hydrogeological map of Egypt (after RIGW/IWACO 1988)

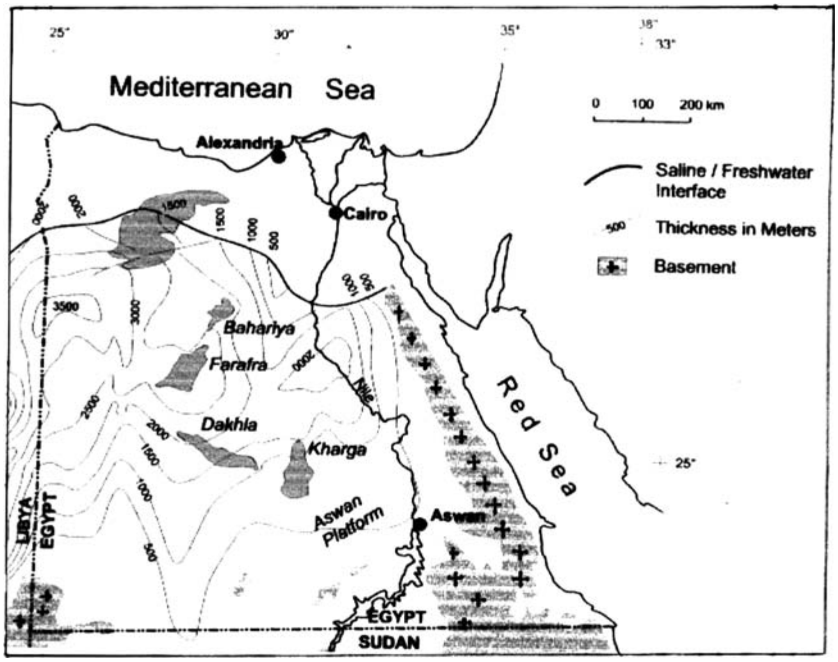


Fig. 5 Thickness of the Nubian aquifer system (after Thorweihe and Heinl 2002)

Oligocene basalt and shale. At the southern border it may be underlain by Oligocene sand.

Nubian Sandstone aquifers

The Nubian Sandstone aquifer system covers south-east Libya, Egypt, north-east Chad, north Sudan, and western Saudi Arabia with a total area of about two million kilometers. In the north and north–west, the pore volume of sediment is filled with saline water that entered the system either via an intrusion of Mediterranean Sea water from the north or groundwater that was not flushed out since the sedimentation of marine deposits (Thorweihe and Heinl 2002). This interface between fresh and saline water forms the system's border in the north and north–west and is considered spatially stable in its position although slow movement is conceivable (Fig. 5). The Nubian Sandstone aquifer system is, therefore, a broadly closed system.

Based on updated subsurface data, the calculated Nubian Sandstone aquifer system groundwater volume is in the order of 150,000 km^3, generally equal to the estimation given by Ambroggi (1966). This value corresponds to the Nile discharge of 1800 years.

There are three possible ways of groundwater recharge (Ambroggi 1966):

1. Regional groundwater influx from areas with modern groundwater recharge
2. Local infiltration through precipitation during wet periods in the past.
3. Post-High Dam construction seepage of Nile water.

In Egypt the Nubian Sandstone aquifer is divided into the following subsystems.

Nubian sandstone aquifer at the Western Desert The Western Desert Basin is exploited particularly in the New Valley area, where intensive deep drilling was carried out during the past five decades "more than 500 wells have been drilled to depths from 500 to 1,000 m" (Fig. 6). The Nubian Sandstone consists of alternating beds of sandstone and clay. The clay beds are laterally discontinuous and separate. The sandstone is separated into a multi-layered aquifer system, bounded below by impervious basement rocks. The Nubian Sandstone is occasionally overlain by impervious rocks and interbedded by clays. Groundwater flow in the Nubian Sandstone system in the Western Desert is generally towards the northeast with a gradient of the order of 0.5 m/km.

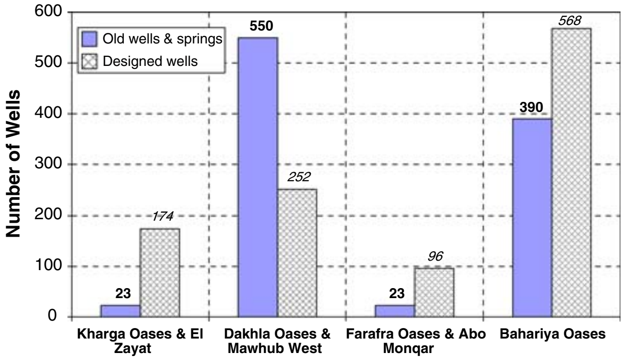


Fig. 6 Existing groundwater wells in the Western Desert of Egypt

The hydraulic parameters are determined in various parts of the New Valley: in Kharga, Dakhla, El Bahariya (El Bauity), El Farafra, and southward east of Oweinat area. Figures 6 and 7 summarize the groundwater availability and number of existing wells penetrating the Nubian Sandstone aquifer of the Western Desert Oases.

The salinity of the water in the Nubian Sandstone Basin changes horizontally and vertically. The salinity increases down slope of the hydraulic gradient from SW to NE and usually decreases with depth. At Kharga and Dakhla (Mut), the salinity decreases from 600 in the upper layers to 200 ppm in the lower layers. Most probably this is due to the long period of exploitation of the shallow aquifers causing an upward movement of the groundwater and eventually due to direct evaporation.

A similar condition is found in the fissured carbonate rocks overlying the Nubian Sandstone complex at Siwa Oasis in the North, where the salinity in the top Miocene layers is over 1,500 ppm and decreases to only 200 ppm in the Cretaceous and Eocene beds.

In the Nubian Sandstone complex, at Siwa Oasis and the Qattara Depression area, a normal salinity zonation is found, where fresh water (about 500 ppm) is reported above saline water (up to 100,000 ppm). There are no sharp lines of demarcation between water of different salinities. The regional salinity distribution shows increasing salinities towards the north from fresh water (TDS $< 1,000$ ppm) south of latitude 29° towards highly saline water in the north.

Groundwater investigations east of Oweinat proved the occurrence of two types of water, suitable for irrigation and domestic purposes. TDS ranges between 278 and 824 mg/l. (Werwer et al. 2000)

Nubian sandstone aquifer at the Nile Valley This aquifer extends from the north to the south up to Aswan. West of Cairo, groundwater has been found at a depth of one kilometer with high salinity. However, the hydrogeological information about this aquifer is insufficient. Not to mention, the springs of Helwan are mainly connected to this aquifer.

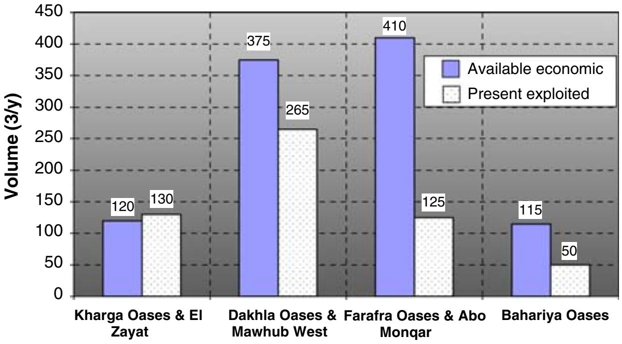


Fig. 7 Groundwater availability in the Western Desert, Egypt

Nubian sandstone aquifer at the Eastern Desert It appears in many zones on flowing state, e.g., at El Laqeita area, and east of Qena. The characteristics of this aquifer are different from one place to another.

At El Laqeita area a small number of wells penetrate this aquifer, where the groundwater is flowing freely and the piezometric level is up to 112 m above mean sea level MSL). The salinity varies in the Eastern Desert between 1,000 and 10,000 ppm.

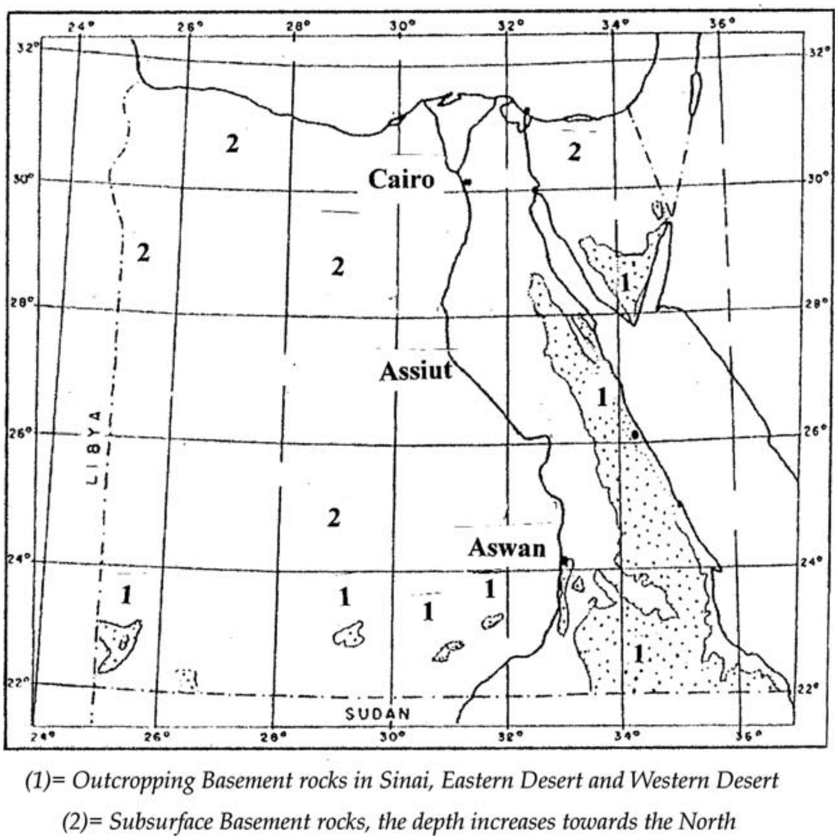
Nubian sandstone aquifer at Gulf of Suez This aquifer has been discovered by one of the petroleum companies. Its salinity is about 100,000 ppm. Its water originates from the watershed in Sinai and the Eastern Desert.

Nubian sandstone aquifer at Sinai In Sinai Peninsula the Nubian Sandstone complex is water-bearing and the reserve estimates are of the order of 100 billion m^3. The water is basically fossil water (Late Pleistocene), but it is recharged to a small extent from the uptake areas in Southern Sinai, where the rainfall rate is about 120 mm/year.

The regional flow pattern is in the northward direction. Sinai is bounded by two major rift valley basins and the local groundwater flow direction is towards these basins: westward in Western Sinai and eastward in the East. Consequently, springs are present near the Gulfs of Suez and Aqaba. In Central Sinai, the piezometric level is about 200 m above sea level and at the springs of Oyun Moussa (south of Suez) it is close to sea level. The salinity of the water in Central and Southern Sinai is of the order of 1,500 ppm, but it increases to more than 5,000 ppm in North and West Sinai.

Coastal aquifer systems

Mediterannean sea coast aquifer The Mediterranean littoral zone (about 10,000 km^2) is characterized by relatively high rainfall (up to 200 mm/year); local aquifer systems are present. These aquifers are represented by the oolitic limestone aquifer dominating the area to the west of the Nile Delta and by the complex fluviatile sandy gravels and the shallow marine calcareous limestone in North Sinai, near El Arish.



(1)= Outcropping Basement rocks in Sinai, Eastern Desert and Western Desert

(2)= Subsurface Basement rocks, the depth increases towards the North

Fig. 8 Distribution of basement rocks in Egypt (after Hefny and Shata 2004)

West of the Nile Delta the oolitic limestone aquifer has a thickness of 40 m. The fresh groundwater is recharged from winter rainfall and exists under phreatic conditions. It forms a thin layer (±1.0 m thick) floating on the saline water body resulting from sea water intrusion.

At El Arish in northern Sinai the aquifer also belongs to the afore-mentioned unit, it is differentiated into:

1. A top sandy aquifer, where the groundwater occurs at shallow depth from the surface (±2.0). The water is generally obtained by dredging open holes (locally known as *Thaimail*). This aquifer is recharged by local rainfall.
2. A middle fluviatile gravelly aquifer, having a thickness of about 30 m. The groundwater is under semi-confined conditions. The water-bearing zone is generally present at a depth of about 15 m from the surface and is capped by a clayey layer.
3. A lower calcareous sandstone aquifer (locally known as *Kurkar*) is of shallow marine origin, and has a wide geographical distribution in northeastern Sinai. This aquifer is 40 m thick and extends inland for a distance of about 15 km from the coast. This aquifer directly underlies the fluviatile gravelly aquifer and is in hydraulic contact with it. This aquifer, as well as the gravelly aquifer lying above are mainly recharged in the foot slope area of Sinai high land, by local rainfall, by runoff water and presumably also by the upward leakage from the high pressure water in the Nubian Sandstone aquifer system underlying the area. The salinity of the water varies between 3,000 and 5,000 ppm.

Red sea coast aquifers The Red Sea coastal aquifers, extending also into Sinai, comprise essentially the following:

- The Quaternary fluviatile aquifer is particularly developed at the deltaic areas of the main wadis, which cross the coastal plains. Within such deltaic areas the water is under phreatic conditions, nearly at sea level. Most of these aquifers are not prolific, except in the pocket to the south of Ras Banas (Bernice), southeastern desert, Red Sea Coast, where the annual recharge is relatively high.
- The Tertiary aquifers, particularly the Miocene and Oligo-Miocene sands are recharged by runoff water, by infiltration from the Quaternary aquifers and locally by upward leakage from deep-seated aquifers. The salinity is about 2,000–2,500 ppm.

Wadi El Qa'a, near El Tor in west Sinai, is a good representative of the Red Sea coastal aquifer systems. The aquifer has a thickness exceeding 100 m and is recharged from runoff water from the adjacent uplands. The water is under phreatic conditions at a depth of ±70 m from ground surface. Groundwater discharge takes place artificially through a number of wells drilled and also naturally through lateral seepages into Wadi El Qa'a itself. The salinity is about 1,500 ppm.

In addition to the phreatic water conditions in the vast region, high pressure water is locally recorded. This water is highly saline, with temperatures sometimes in excess of 30° and is recharged from deep-seated aquifers.

Fissured and karstified water-bearing rocks

Carbonate aquifer system

The fissured and karstified carbonate aquifer complex is the least explored and exploited in Egypt, although it occupies at least 50% of the total area of the country. It is characterized by several karst features in the Eastern and Western Deserts. The carbonate complex is generally divided into three horizons, namely:

- a lower horizon: Upper Cretaceous,
- a middle horizon: Lower and Middle Eocene, and
- an upper horizon: Middle Miocene

These three horizons are separated by two impervious clay media [Esna Shale (±100 m) and Daba Shale (>200 m)]. The carbonate rocks generally overlie the Nubian Sandstone complex. The water recharge to the aquifer depends essentially on the upward leakage from the underlying Nubian Sandstone aquifer and occasionally from local rainfall. The hydrogeology of the fissured limestone is not well understood. In Siwa Oasis, drillings show an upper fissured limestone complex, having a thickness of about 650 m (Upper Cretaceous to Middle Miocene) and lying unconformable on the Nubian Sandstone complex. The outcrop of the top portion of the fissured limestone (Middle Miocene) is dotted by at least 200 natural springs, having a total flow of about 200,000 m^3/day and salinity from 1,500 to 7,000 ppm. Test drilling in Siwa area points to the occurrence of water with a salinity of about 200 ppm in the underlying limestone, which belongs to the Eocene and the Cretaceous.

Fissured basement rock aquifer system

This aquifer is influenced by several factors, namely tectonic, morpho-tectonic and lithologic. The tectonic factors such as filled fractures, dykes, etc. may hinder the movement of groundwater. A good example is found in the Barramiya gold mine area, 100 km east of Idfu in the Eastern Desert, where faults and dykes affect greatly the movement of groundwater. Figure 8 shows the distribution of the outcropping and subsurface basement rocks.

The influence of the geologic contact between highly fractured and massive rocks and the different rock types is impressive. The fractures in the metavolcanic water-bearing rocks are detected in the southeastern desert of Egypt, where the groundwater occurs in free conditions.

Environmental issues related to groundwater

Water availability and water use in Egypt

The current water availability and water use in Egypt 2004 is given in Table 4. It is estimated that by year 2010 the total water use will approach 80 × 10^9 m^3/year, which is more than the actual water availability. The additional water is expected to be provided by the construction of the Jonglei canal in the Sudd swamps in Sudan (2 × 10^9 m^3), non-renewable groundwater (2–2.5 × 10^9 m^3), increasing use of agricultural drainage water (2–2.5 × 10^9 m^3), an increase in treated wastewater (1 × 10^9 m^3), and improved water management/irrigation efficiency (1 × 10^9 m^3).

Sources of groundwater pollution

(A) Oil and mining fields

1. Petroleum exploration and development.
2. Abandoned oil wells and test wells.
3. Buried pipelines and storage tanks.
4. Disposal of oil field brines.
5. Mining activities (including mine drainage and mine tailings.

(B) Water wells

1. Disposal, drainage and abandoned wells.
2. Over pumping.
3. Well construction.
4. River infiltration.
5. Sea water encroachment.

(C) Cultivated lands

1. Animal wastes.
2. Dray land farming.
3. Evapotranspiration from vegetation.

Table 4 The current water availability and use in Egypt (source: Ministry of Water Resources and Irrigation 2004)

	2004 billion m^3/year	2017 billion m^3/year
I. *Water resources*		
(a) Traditional water resources:		
1. Surface Nile water	55.50	55.50
2. Jonglei canal	–	2.00
3. Groundwater:	–	–
a. Valley and Delta (renewable)	6.10	8.40
b. Valley and Delta (non-renewable)	0.90	4.00
4. Rain and flash water	1.14	1.30
5. Desalination of sea water	0.06	0.10
Total of traditional reserves	63.70	71.30
(b) Non-traditional water resources:		
1. Reuse of agricultural drainage water	8	9.50
2. Reuse of treated drainage water	1	2.00
Total of non-traditional reserves	9	11.50
Total water reserves	71.70	82.80
(c) Others: Water available from improved water management, reuse in the industry, treated waste water and crop management, etc.	–	9.70
Total water reserves	71.70	92.50
II. *Water use*		
Agriculture	57.8	67.8
Industry	7.5	15.0
Domestic use	4.7	6.6
Fisheries	0.4	0.4
Navigation	0.2	0.2
Improvement of irrigation system	2.1	2.5
Total of water use	72.70	92.50

4. Feedlots.
5. Fertilizers and pesticides.
6. Irrigation return-flow.
7. Sewage treatment plant discharge.

(D) Urban areas

1. Urban and industrial landfills.
2. Surface impoundments.
3. Solid wastes.
4. Natural pollution.
5. Septic tanks and cesspools.

(E) Others

1. Lakes and spills.
2. Natural leaching.
3. Water from fault zones and volcanic origin.

Environmental impacts of groundwater in Egypt

The challenges to the sustainability of water resources in Egypt include salinity, water logging, and the decline in fresh water as a result of the continuous discharge of usually untreated domestic and industrial wastewater into the Nile. Agricultural drainage water affects the salinity of the main river downstream and in the delta. The quality of water in the river decreases gradually towards the delta and the coastal plains. Also likely to aggravate pollution is the use of chemical fertilizers, which has increased fourfold in the last two decades, partly in response to the Aswan High Dam's reduction of the flow of silt downstream.

The use of herbicides to control submerged weeds in canals and water hyacinths in drains (which, if unclear, can choke irrigation systems), has caused serious environmental hazards (Grwp 2004).

Although the deserts are characterized by a lack of sufficient water, even severe desert regions have usable amounts of groundwater—soften at significant depths, which have migrated long distances from recharge areas in the mountains. Water may also be transported from areas many kilometers away from the urban regions to supply the various needs of domestic, etc.

Pollution from seawater encroachment, as a result of excessive exploitation of the Nubian aquifer, is not possible as the whole section of the aquifer at the exploitation localities is fresh water. The other possibility is the intrusion of the highly saline water that occupies the northernmost part of the aquifer, to cause the movement of the boundary between the fresh water and the saline water to the south. Although this was safeguarded when computing the recommended exploitable water quantities for economical agriculture development, such intrusion if it occurs, would be in areas too far from the possible depression exploitation localities (Idris 2004).

Main environmental issues

Framing the main environmental issue in Egypt is the morphology of the country, which is characterized by the high plateaus that border the Nile valley. These are considered natural walls separating the Nile valley from the vast deserts. Historically, the population has always been concentrated along the river Nile because it has been the main source of fresh water.

However, this situation has resulted in the concentration of human settlements and economic activities on a limited strip of land, which has led to the generation and accumulation of all types of wastes. Table 5 summarizes the major environmental issues in Egypt.

Table 5 Summary of the environmental issues in Egypt (after Attia 1999)

1. Partial utilization of Egypt's territories	1.1 Nile valley morphology and type of boundaries 1.2 Aridity and poor distribution of water resources over country's area
2. Unbalanced population distribution and continuous immigration from rural to urban areas	2.1 Lack of regional plans and facilities/services to the rural community 2.2 Continuous decrease of job opportunities in the rural areas, especially in the farming sector
3. Lack of suitable potable water and sanitation in some regions, especially in the rural ones	3.1 The economic conditions of the country 3.2 Concentration of activities in the urban regions/governorates
4. Continuous decrease of per capita of water resources	4.1 Deterioration of water quality 4.2 Poor enforcement of water protection legislation 4.3 Increase of water-intensive cropping 4.4 Inefficient use of water on the farm level 4.5 Inefficient water distribution 4.6 Low efficiency of urban drinking water supply

Industrial wastewater A variety of industries are found in Greater Cairo. The major areas with high industrial concentration are in Helwan, south of Cairo, and Shubra El Kheima, in the north. Moreover, many small industries are spread throughout the city. The large factories are classified as shown in Table 6.

Table 6 Classification of main industries in Greater Cairo (after Attia 1999)

Type	Number	%
Chemical industries	23	18
Textile and spinning industries	27	21
Metal industries	7	6
Food industries	32	25
Engineering industries	29	23
Mining and refractors industries	9	7

These industries consume about 162 million m^3/year of water, and discharge about 130 million m^3/year. Till the year 1980, the majority of the industries discharged their wastewater into fresh water bodies, including the river Nile itself. Later, and up to the year 1998, irrespective of the number of environmental laws, factories were still discharging their effluent into fresh water bodies (Table 7). Since February 1998, the Nile became free of industrial outfalls, while the other water bodies are still awaiting the enforcement of law.

Present situation Extensive sampling has been done covering the main groundwater supplying areas in Egypt came to the following conclusions (Thorweihe and Heinl 2002):

A. High concentrations of sulphate and nitrate have been observed in the reclaimed in the fringes of the Nile basin. Salinity levels of the groundwater have increased under these areas, which may be partly caused by leaching of natural salts and partly by application of gypsum to the soil. This salinity front is moving towards the central parts of the Nile Valley and Delta.

B. The concentrations of nitrate are much lower than the fringes in the central parts of the Nile Delta and Valley. High concentrations of manganese, iron and

Table 7 Breakdown of industrial effluent by disposal mode (source: Egyptian Ministry of Water Supplies and Irrigation)

Effluent disposal mode	Discharge (million cm^3/year)	Total (%)
Sewers	55.5	43.5
Groundwater	6.5	5
Irrigation canals, including the Nile	24.5	19
Agricultural drains	21.0	16.5
Unidentified	20.0	16

sulphate are recorded, which be due to reduction and dissolution processes in the central parts of the Nile Delta and Valley.

C. In the Western Desert the quality standards are least exceeded and only iron shows high levels.

Vulnerability of groundwater to pollution in the Nile Delta Within the Nile Delta Region, the groundwater vulnerability to pollution is largely determined by the thickness of the clay layer, depth to the groundwater, rate of recharge and direction of natural vertical groundwater flow (Table 8).

Pollution problems in some selected areas

Rafah area, North Sinai The groundwater is endangered by agricultural activities, waste disposal, aquifer overexploitation, and seawater intrusion. The pollution risk is high since the water table is shallow and the aquifers are highly permeable and of poor buffering capacity (El Alfy et al. 2005). Due to excessive use of fertilizers and pesticides, the concentration of NO^{3-}, SO_4^{2-} and PO_4^{-2} are high. More than 71.2% of the aerial distribution of nitrate concentration is greater than 44.29 mg/l representing a serious problem. Dissolution and deposition of several minerals, evaporation of the groundwater, human impact on the aquifer, cation exchange, mixing between different waters and rainfall recharge are identified as the main factors affecting the groundwater.

Nile Delta, Dakahliya Governorate The water samples analyzed for iron in the Dakahliya Governorate was found suitable for drinking purposes except two samples in the middle of the area (Meet Ghamr), where they show values higher than the permissible limit of EMH (1995) and WHO (1984). The comparison between iron concentrations in drinking water and human blood shows a positive relationship, where the mean value of Fe is 3.076 and 0.149 mg/l for blood and groundwater samples, respectively. The mean value of Fe is 2.182 and 0.057 mg/l for blood and surface water samples, respectively (Zaghloul et al. 2005).

Sohag area, Upper Egypt Wastewater disposal has been suggested to be established in the low-land desert zone extending between the cultivated floodplain and the Eocene limestone plateau on both sides of Sohag city. It is aimed to use this wastewater in irrigating woody farmlands. Omer et al. show recently that using this desert zone for this purpose is very sensitive as it is extremely narrow and very close to the cultivated floodplain, reclaimed land, residential areas and surface water resources. Moreover the subsurface sediments in this zone (Pleistocene sand/gravel succession) constitute a significant part of the Quaternary aquifer of the Nile Valley. Omer et al. showed that no sufficient lands are available to expend the projected quantities of wastewater. Excess raw wastewater is accumulating on the ground surface forming large uncontrolled ponds. Such wastewater ponds generate major sources of environmental hazards causing disastrous health risks due to chemical, bacteriological pollution and water resources.

Table 8 Factors affecting the groundwater vulnerability in the Nile Delta (after Khater 2002)

Thickness of clay cap (m)	Vertical groundwater flow	Rate of recharge (mm/day)	Depth to groundwater from surface (m)	Groundwater vulnerability	Location
0	Downward	–	<5	High	Transmission zone between old and reclaimed land
0–2	Downward	>1	5–15	High	Transition zone
0	Downward	<1	>15	Moderate–high	Desert fringes
0–10	Downward	<1	<5	Moderate–low	Floodplain and partially transition zone
>10	Downward	0.25–1	<5	Low	Floodplain
0–10	Upward	<25	<5	Low	North Delta (Floodplain)

Bahariya oasis Bahariya oasis is a natural depression in the Western Desert, where the major iron resources of Egypt are located. A vast area of land suitable for land reclamation is available depending on groundwater. Recent studies proved that the groundwater quality of the pre-Cenomanian water-bearing part of the Nubian Sandstones sediments at Bahariya oasis is generally good and suitable for irrigation, industry, livestock and poultry, as well as building purposes (Serag El-Din 1999). However, it is not suitable for human consumption due to relatively high iron and manganese contents.

The deep groundwater temperature varies between 31 and 42° increasing with depth. The pH values are alkaline, ranging from 7.15 to 8.6; TDS ranges from 137 to 282. The aquifer salinity varies between 0.19 and 0.41 g/l. Generally, chloride and bicarbonate (+carbonate) ions are the dominant anions, whereas the sodium and magnesium ions are the dominant cations. Calcium values are consistently low, ranging from 3 to 13 ppm. Potassium remains constant between 11 and 16 ppm. Iron, although low compared with the major ionic species, does reach concentrations up to 2.5 ppm.

Groundwater at the New Valley: a case study

The Nubian aquifer system of the Western Desert is a part of a vast aquifer occupying south-east Libya, Egypt, north-east Chad, and north Sudan with a total area of about two million square kilometers.

The groundwater is the main water resource in the New Valley, where all the agriculture, industrial and domestic use depends upon it. In fact the groundwater aquifer in the New Valley is considered one of the largest aquifers in Arab Republic of Egypt where the Nubian sandstone is the main source of the aquifer and bearing the groundwater. The thickness of this aquifer is ±700, ±1,400, ±1,600 m in El Kharga, El Dakhla and El Farafra, respectively.

The water table at El Kharga and El Dakhla is about 60 and 30 m, respectively. The number of water wells drilled at the New Valley Governorate is 517 wells distributed as follows: El Kharga 175, El Dakhla 234 and El Farafra 108 wells.

Currently, the artesian wells (water is self-pumped) are present in El Farafra oasis and some wells at El Dakhla oasis. However, most of the wells at El Kharga oasis are working using hydraulic pumps. The rate of self-pumping water (artesian wells) varies between 4,000 and 8,000 m^3/day, but the rate of the hydraulic pumping is 200–300 m^3/h.

Is the groundwater renewable?

Many researchers and expertise have done several studies over the main aquifer at the New Valley. However, it must be assumed that even with regional groundwater inflow from present infiltration areas the groundwater in the Nubian Sandstone Aquifer is a fossil, i.e., it is a groundwater deposit that would be depleted through natural and artificial processes. For this reason, choice of development area and production rate must be planned carefully (Thorweihe and Heinl 2002).

Problems of groundwater contamination at the New Valley

The groundwater aquifer at the New Valley is considered as restrained aquifer i.e., the bed bearing water is found between two impermeable beds, where impermeable shelly beds are lying above the aquifer and granite beds lie beneath it. Thus, the nature of this aquifer is unique, so it is safe to say that the aquifer is isolated from all contamination sources. Additionally the depth of the aquifer is one of the main factors causing a limitation in water contamination.

Reviewing the water quality analysis of several groundwater samples, one can notice that there are several dissolved salts in the water, such as iron, magnesium, sodium, etc.). But the recorded levels of these parameters were almost within the maximum contamination limit (MCL) or can be treated easily using drinking water distillation stations, which are working perfectly for all purposes.

Other major environmental considerations for, which precise hydrologic data are needed include:

1. Protection against water logging of soils from irrigation practices.
2. Development of effective surface and subsurface drainage practices.
3. The impact of farming and pest control practices on the oases shallow groundwater.
4. Determination of the long-term development of the artesian water on the quality of the water from the aquifer systems in the Western Desert (LaMoreaux et al. 1985).

Main problems

- Periodical maintenance of the artesian wells.
- Fair distribution of the water panel to the users.
- Abusing of the water in some areas by planting some water-consuming types such as rise despite the restrictions laws.

Conclusions

The main conclusion related to the environmental issues in Egypt is that various environmental problems are encountered in Egypt due to the delay in providing environmental protection legislation and the poor enforcement of such legislation.

The most important problems and their causes are summarized as follows:

(A) Air pollution due to the emissions from factories and cars.
(B) Pollution of surface water and northern lakes due to the disposal of primary or non-treated domestic and industrial effluent.
(C) Pollution of the shallow groundwater for the same causes mentioned above and poor solid waste disposal.
(D) Increased drawdowns and salinity of groundwater on the desert fringes due to overexploitation.

Anther environmental issue in Egypt is the morphology of the country, which is characterized by the high plateaus that border the Nile Valley. These are considered natural walls separating the Nile Valley from the vast deserts. Historically, the population has always been concentrated along the river Nile. However, this situation has resulted in the concentration of human settlements and economic activities on a limited strip of land, which has added to the generation and accumulation of all types of wastes.

Acknowledgments The authors like to express their thanks to the Ministry of Irrigation and Water Resources authorities for supplying the up-to-date data on the water demands and use in the country. Sincere thanks are due to Engineer Hussein Idris, for supplying early exploration data.

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