

Chapter 2 Water Pollution and Riverbank Filtration for Water Supply Along River Nile, Egypt

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Abstract In a developing country such as Egypt, there are growing challenges for providing water supply of good quality. Committing to the Millennium Development Goals (MDG) by providing access to clean drinking water supply is an additional challenge. This is primarily attributed to treatment costs, especially when large quantities of water are treated. The two sources of potable water supply in Egypt are groundwater and surface water, either from the River Nile or from the main irrigation canals. In 2008, the total drinking water production in Egypt was about 7.5 billion m³/year, the contributions from the Nile and groundwater being about 60% and 40%, respectively. Nile water in Egypt is facing rising sources of pollution despite all the programs for pollution control. Discharging industrial and domestic wastewater, return drainage of irrigated water, and flash flood into the River Nile represent the major sources of pollution. There are also widespread problems of iron, manganese, nitrate, and fecal coliform bacteria in the groundwater used for drinking water supply. Riverbank filtration (RBF) is a water treatment technique that can improve surface water quality. Current and previous results of water quality produced from RBF have proven its potential to treat Nile water and to avoid quality problems associated with source water. This paper illustrates the benefits of using RBF, the ability to resolve a broad range of water quality problems in an economic manner and to provide clean and safe drinking for the residents of a desert country such as Egypt.

Keywords: Riverbank filtration, Egypt, Nile valley, groundwater, water supply, water quality, potable water, water pollution

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1. Introduction

Access to good quality and safe water, makes a tremendous difference to our quality of life. As we step into the twenty-first century, it is realized that the trend towards urbanization is posing ever-increasing challenges with respect to water supply. The rate of growth of population (~1.8%), especially in the urban areas, is far exceeding that of the rural areas in Egypt and most developing countries which put an increasing stress on treatment capacities in many cities. Statistics indicate that over one billion of the world population lack access to safe water, and nearly two billion lack safe sanitation worldwide. It is also reported that more than three million die every year from water-related diseases (UNICEF 2005). A growing number of water-related diseases such as diarrhea, schistosomiasis (bilharziasis), intestinal parasites, lymphatic filariasis, and trachoma are responsible for major health problems in the majority of rural and urban residents. One of the greatest challenges facing Egypt today is the growing number of rural and urban households who need access to basic infrastructure, mainly water supply and sewage. If lacking, this can have a significant adverse impact on human health, productivity and the quality of life (UNDP 2005).

During the last 2 decades, the Egyptian governments have invested massively in providing water supply and sewage networks to both rural and urban communities. Today, all Egyptian cities and more than 90% of villages are provided with water supply services. In the new Five-Year Plan (2007–2012), the Egyptian government planned to allocate more than 72 billion EGP to expand the water supply service to secure water access for all citizens. However, even with these unprecedented investments, 20% of Egyptian villages have inadequate potable water (IDSC 2009). Confronted with this challenge, the community is looking for innovative and cost-effective technologies for potable water supply (UNDP 2008). Great efforts are being made to increase water availability for the whole Egyptian population. These efforts, however, are not being felt by the users, neither in the suburban and rural areas, nor in the cores of the capital Cairo. The main reason for this is that the rate of population increase and the city's expansion outpaces these efforts.

The major problem of water supply in Egypt and other developing countries is not a lack of technology availability. Rather, it is due to the fact that stakeholders are largely unaware of the available alternatives and the complexity of the suitability of one technology over the other applicable in their situation. The major challenge is therefore to select an appropriate technology considering the multi faceted issues including technical feasibility, affordability, customs and practices, preferences, and available institutional support. The potential goal is, presenting no single and absolute solution, but offering a comparative analysis of various options, and encouraging the decision makers and communities to adopt the one that is best suited to their needs.

This paper highlights the qualitative and quantitative problems related to drinking water supply in Egypt, summarizes drinking water resources and their

pollution level, and investigates the feasibility of applying riverbank filtration (RBF) technique for water purification in the Nile valley of Egypt. Therefore, the main objective of the current study is to address the feasibility of RBF to tackle the water quality problems of drinking water supply in Egypt with a fraction of total cost (i.e., capital cost and O&M cost).

2. Methodology

The purpose of the current investigation is to present the economical, technical, and environmental benefits of using RBF for drinking water supply in the Nile valley. For this purpose, previous reported data and current measurements for Nile water and groundwater were conducted. The study is carried out in four steps. First, the pollution sources and extent of pollution in the River Nile and groundwater in Nile valley based on reported data were evaluated. Second, the quantitative and qualitative aspects of domestic water supply scheme in Nile valley were investigated. Third, section of Nile valley located between Qena and Assiut was investigated for RBF applicability to treat Nile water. In this part, additional measurements were made to supplement the available data. Measurements of flow hydraulics and alluvial sediments of River Nile were conducted. These measurements were conducted in the field or in the laboratory of New Naga-Hamadi Barrage. Physicochemical and microbiological quality analysis was performed on water samples. Temporal and spatial variations of quality parameters were monitored. These parameters include pH, TDS, BOD₅, hardness, chloride, iron, manganese, sulfate, orthophosphates, nitrate, ammonia, and bacteria. Quality measurements of samples were done according to the procedures laid down in the standard methods of the examination of water and wastewater (APHA 1998). Fourth, feasibility of using RBF technique to treat Nile water for water supply in Nile valley of Egypt was presented.

3. Drinking Water Sources and Pollution

Egypt can be classified as an arid climate with 95% of its area as desert. A narrow strip of fertile land exists along the main stem of River Nile and within a relatively small delta in the north. It became the base for economic and social life of one of the most distinguished ancient civilization where agriculture was the main human activity. The average rainfall is about 25.7 mm/year and the evapotranspiration rate ranges from about 0.7 mm/day in winter to about 15.7 mm/day in summer. The relative humidity ranges from 45% to 75% and the average daily temperature ranges from 13°C to 38°C. The total population of Egypt is about 77 million and increasing at a rate of about 1.8% annually (CAPMAS 2007).

The conventional water resources for drinking water supply in Egypt are limited to the River Nile and the groundwater in Nile valley, Nile delta, deserts and Sinai. Limited rainfall and flash floods are also available. The Nile is the main and almost the exclusive source of fresh water in Egypt. The country relies on the available water stored in Lake Nasser to meet needs within Egypt's annual share of water, which is fixed at 55.5 billion m³/year. Each resource has its limitations on use. These limitations relate to quantity, quality, location, and cost of development. Protecting this limited amount of fresh water is crucial to sustain the development of the nation (EEAA 1999).

Water quality problems of these sources vary depending on flow, pattern of use, population density, extent of industrialization, availability of sanitation systems and the social and economic conditions. Discharge of untreated, or partially treated, industrial and domestic wastewater, leaching of pesticides and residues of fertilizers and navigation are often factors that affect the quality of water. In general, ranking pollutants according to their severity to public health and the environment puts pathogenic microorganisms on the top. This is followed by biodegradable organic compounds which deplete dissolved oxygen, affecting water suitability for many purposes. This is followed by pesticide residues and heavy metals. However, little precise information is available to the magnitude of the problem (MWRI 2002). Furthermore, in Egypt there is no national monitoring program concerning the identification and determination of organic micropollutants in drinking water resources (Badawy 2009).

3.1. Pollution of River Nile

Egypt is one of the ten countries that share the 6,650 km long basin of River Nile. The last 1,600 km of it goes through Egypt from Aswan to Mediterranean Sea. Since 1968, Aswan High Dam (AHD) is used to regulate the flow of Nile and to provide multi-year storage. There are four main barrages, Esna, Nag-Hamada, Assiut, and Delta which control the flow and divert water into the main irrigation canals without lifting stations (Abdel-Dayem et al. 2007). Only River Nile and the main irrigation canals branching from it are used to supply drinking water in Nile valley and Nile delta (Figure 2.1).

Pollution load in the Nile system (River Nile, canals, and drains) has increased in the past few decades due to population increases, several new irrigated agriculture projects, new industrial projects and other activities along the River Nile. Consequently, quality of Nile water worsened dramatically in the past few years (Abdel-Satar 2005; Abdel-Dayem et al. 2007). It is anticipated that the dilution capacity of the River Nile system will diminish as the program to expand irrigated agriculture moves forward and the growth in industrial capacity increases the volume of pollutants discharged into the Nile (MWRI 2002). The major pollution sources of Nile and main canals are effluents from agricultural drains and treated

or partially treated industrial and municipal wastewaters, including oil and wastes from passenger and river boats. The most polluted part of Nile is the part located between Cairo and Mediterranean Sea within the two branches of Nile, Damietta and Rosetta (Abdo 2004; NAWQAM 1998, 2003).

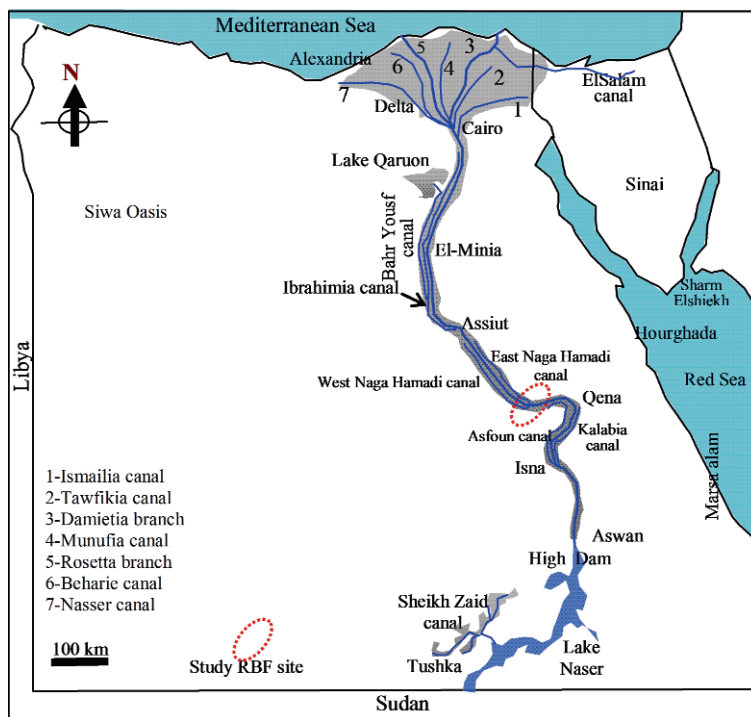


Figure 2.1. Map of Egypt with River Nile, main canals and study site, 2008.

Discharging the drainage water from drains into Nile, represent the primary source of Nile pollution. The volume of drainage water is about 12 billion m^3 /year, 25% of it is in upper Egypt and the rest in Nile delta. There are 76 drains discharging drainage water into Nile system with annual volume of about the half of the total drainage water (World Bank 2005). The part of Nile from Aswan to Delta Barrage receives discharges from 67 agricultural drains of which 43 are considered major drains. Previous reported measurements indicated that out of those 43 drains, only ten are complying with the Egyptian standards regulating the quality of drainage water allowed to be discharged into Nile systems (MWRI 2002). This drainage water contains dissolved salts washed from agricultural lands as well as residues of pesticides and fertilizers. Impact of this drainage water on Nile quality has been reported by several authors (Abdo 2004; Abdel-Dayem et al. 2007).

Industrial wastewater is considered the second of the main sources of Nile water pollution because of the toxic chemicals and organic loading in this wastewater. Egyptian industry uses about 7.8 billion m³/year of water, of which 4,050 million m³/year are discharged into the River Nile system. The River Nile supplies 65% of the industrial water needs and receives more than 57% of its effluents (MSEA 2007). There is an increasing trend in industrial consumption of water for new development activities. There are about 129 factories discharging their wastewater into the River Nile system. Effluent wastewater is often partially treated. In spite of all official efforts to prevent this pollution source, there are 34 factories still not complying with Egyptian regulation of water disposal into Nile systems (NBI 2005).

The third major source of pollution of River Nile is the effluent of municipal wastewater. There are about 239 wastewater treatment plants with an annual effluent of 4.5 billion m³, of which 1,300 million m³/year are discharged into River Nile system. Though the plants offer secondary level of treatment, the real treatment removal efficiency of these are lower than their design in many sites.

All aforementioned major pollution sources deteriorate Nile water. Indication of this pollution has been reported by chemical and microbiological quality measurements along many sections of the River Nile (MWRI 2002, 2003; MSEA 2005; NBI 2005). There are elevated levels of organic matter (measured as COD or BOD₅), heavy metals (Pb, Cr, Hg, and Cd), and fecal coliform. Sixteen organochlorine pesticides were detected in the drains and to less degree in canals, including total BHC and total DDT (El-Kabbany et al. 2000). These elevated values are higher than natural occurring and at some spots of Nile are higher than allowable limits for healthy water streams. Also, low levels of DO at many sections of River Nile were recorded (Ismail and Ramadan 1995; Mohamed et al. 1998; Wahab and Badawy 2004). The two branches of Nile, Rosetta Branch and Damietta Branch, downstream Delta Barrage, represent the worst quality of River Nile. Some quality parameters of Nile were reported by NBI (2005).

3.2. Pollution of Groundwater

The Nile system comprises the Valley and Delta regions, including Cairo. These are morphologic depressions filled with Pliocene and Quaternary sediments. The hydrogeological framework of Egypt comprises six main aquifer systems (Fadlelmawla et al. 1999). The aquifer of interest of this study is the Nile aquifer system that is assigned to the Quaternary and Late Tertiary, which occupies the Nile floodplain region, including Cairo, and the desert fringes. The width of the aquifer is about 20 km and bounded by the carbonates (Figure 2.2). Almost 90% of Egypt's population lives on the Nile aquifer (Shamrkh 1999).

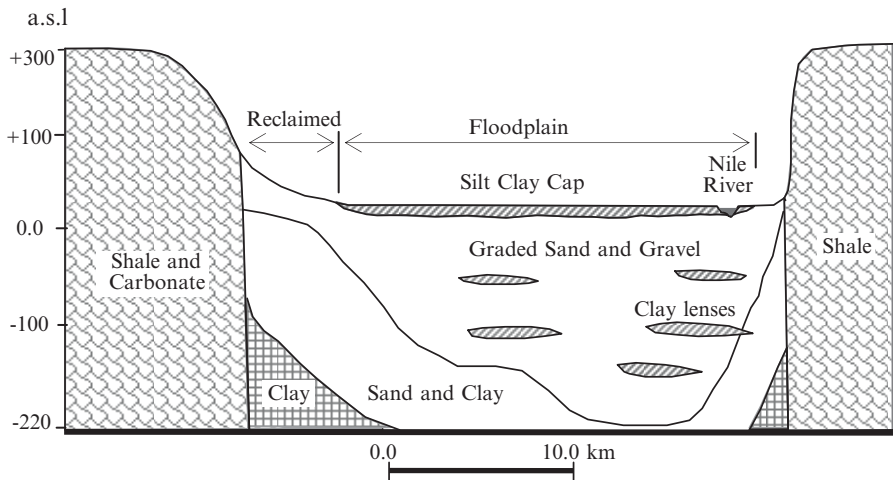


Figure 2.2. General hydrogeological cross section of Nile aquifer in Nile valley.

Nile aquifer consists of a thick layer of graded sand and gravel underlined by the Pliocene impermeable clays and covered by a silt-clay layer (5–20 m thickness) in its major part. The aquifer thickness varies from 350 m (at Sohag) to only a few meters (at Cairo and Aswan). North of Cairo, the aquifer thickness increases gradually until it reaches more than 800 m along the Mediterranean coastline. The transmissivity of the aquifer ranges on the higher side between 5,000 and 20,000 m^2/day (Shamrukh 1999; Ahmed 2009a). The main recharge source is the infiltration from the excess water application for agriculture, seepage from the irrigation canals and from sewerage system. Discharge from the aquifer is through seepage to the River Nile and groundwater extraction through wells. Thus, the main sources of pollution into Nile aquifer are agrochemicals, domestic wastewater, and natural dissolution of soil minerals such as iron and manganese.

Agrochemicals and concentrated salts are the main sources of groundwater for water supply. There have been extensive applications of chemical fertilizers (nitrogen, phosphorus, sulfur, and potassium) to enhance crop production after the construction of the High Aswan Dam (Shamrukh 1999). Elevated concentrations of nitrate and other agrochemicals such as sulfate and potassium are reported in many locations of the aquifer especially in Nile delta (Abdel-Dayem and Abdel-Ghani 1992; El-Fouly and Fawzi 1994; Awad et al. 1995; Shamrukh and Abdel-Lah 2004). In addition, measurements of elevated concentrations of pesticides in Nile aquifer were reported (Abdel-Dayem and Abdel-Ghani 1992). Furthermore, percolating water into the groundwater table contains concentrated salts due to evaporation of irrigation water and due to water use with high dissolved salts in reclaimed areas in eastern and western Nile floodplain (Soltan 1998).

Pollution from sewerage systems especially in rural areas is another source. In Egypt, water supply and sewage services are not implemented simultaneously. In the rural areas, where half of the population lives, 90% of the people have no access to sewer systems or wastewater treatment facilities (UNDP 2008). The “sewage room” is the most common disposal facility where its bottom has direct contact with the ambient groundwater. This method of local sewage disposal makes it a point source of pollution with pathogens and nitrate (Figure 2.3). Therefore, adverse water quality as a result of pathogen contamination occurs locally at a number of different locations. Sampling of shallow groundwater close to this septic room shows that the risks associated with pathogen contamination in such supplies is high (Abdel-Lah and Shamrukh 2001).

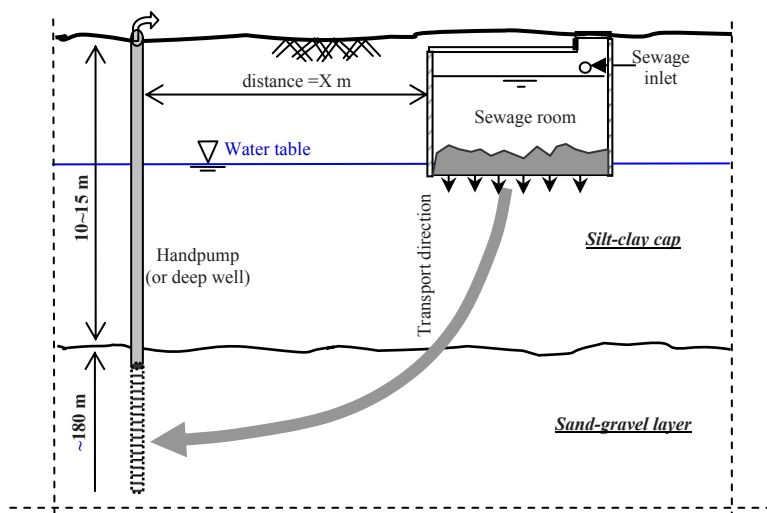


Figure 2.3. Schematic diagram shows the groundwater pollution from sewage room in Nile aquifer.

The last major source of groundwater pollution is the natural dissolution of soil minerals. The main attribute of these areas is high formation-inherited iron and manganese concentrations as a result of the highly reduced environment of the confined aquifer of the Nile basin. Therefore elevated contents of Fe and Mn in groundwater are reported at many locations by Ministry of Health (MoH 2009). Arsenic was also reported in few groundwater locations. In addition to those sources of pollution, other sources such as elevated TDS in desert fringes of Nile and salt water intrusion in coastline areas were reported (Zaghloul and Abdallah 1985).

Finally, it is clear that the main challenge for the sustainability of water resources is the control of water pollution. The Ministry of the Environment in Egypt is observing the enforcement of the legislation regarding the treatment of industrial and domestic wastewater. It is also advocating organic farming and limiting the use of chemical fertilizers and pesticides to reduce water pollution. In

addition, the present policy is to minimize the use of herbicides and to depend mainly on the mechanized control of submerged weeds and water hyacinths (MSEA 2005).

4. Situation of Drinking Water in Egypt

The municipal water supply in the urban and sub-urban areas in the valley and delta of Nile includes: (i) water treated from the Nile; (ii) a mixture of water treated from the Nile and groundwater; and (iii) groundwater alone. Almost all major towns setting at the banks of Nile system are supplied from Nile water through conventional treatment plants or compact units. Towns away from Nile and small villages located at the Nile banks are supplied from aquifer groundwater. The following treatment methods are commonly used:

- Conventional surface treatment plants to treat Nile water applying conventional treatment process: coagulation/flocculation with alum, sedimentation, filtration, and disinfection with chlorine gas
- Compact units to treat the water of main canals using the same processes applied in the conventional treatment plants but in compact design
- Direct groundwater pumping using deep wells (60–100 m) without any further treatment processes, not even disinfection
- Aeration units to treat groundwater rich in Fe and Mn followed by filtration and chlorine disinfection

In 2004, the Holding Company for Water and Wastewater (HCWW) and its affiliated 23 companies was established to take over the responsibility of operating the drinking water supply schemes all over Egypt. There are 153 large surface treatment plants, 615 compact surface treatment plants, 1,684 wells, and 21 desalination plants for producing water. Quality of produced water is monitored by Ministry of Health for compliance and by HCWW for operation and quality and quality control purposes.

4.1. Quantity of Supplied Water

Currently, total drinking water produced by HCWW is about 22 million m³/day. Drinking water reaches to about 97% of the population, however supply is intermittent, a few hours per day for 25% of the population. In summer of 2007, there was a water shortage due to limited capacity of water treatment plants. It is anticipated that this problem will be continue due to budget constraints to construct/expand treatment plants. It is difficult for the government with limited financial resources to provide enough quantity with rising demand and to keep the water in good quality. The price of consumed water, about \$0.06/m³ is less than its

actual cost as the government subsidizes the drinking water sector. Figure 2.4 shows the number of drinking water plants and water production in the last years. It is estimated that water demand will continue increasing by 2% per year as generated by rapid population growth, urbanization, and industrialization (CAPMAS 2008).

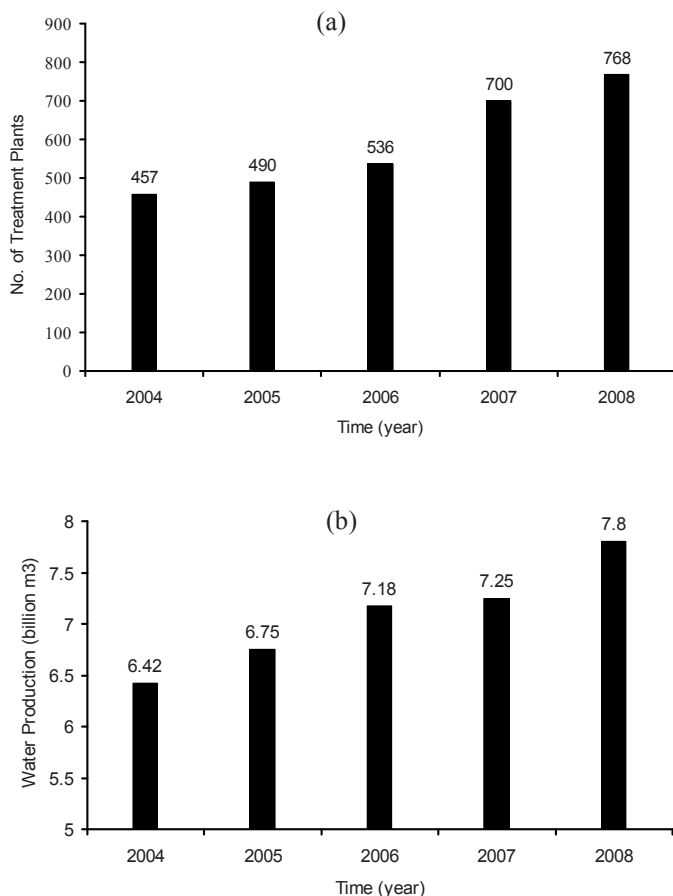


Figure 2.4. Recent development of water supply sector in Egypt (a) no. of treatment plants and (b) drinking water production.

4.2. Quality of Supplied Water

In Egypt, supply shortfalls exist in terms of quantity, physical, chemical and biological quality, and reliability. It is anticipated that the quality of drinking water will be the biggest challenge of water supply system in Egypt in the coming decades. Water-borne diseases from pathogens contamination is one of the biggest

public health concerns (UNDP 2005). Typhoid, paratyphoid, infectious hepatitis, and infant diarrhea are some endemic diseases indicating deterioration of water quality. According to a World Bank report (2005), the cost of diarrhea and mortality due, in large part, to water pollution was estimated at US\$800 million/year. Rural areas are often the most affected areas by those appreciable variations in water quality.

Quality of drinking water supplied from Nile using conventional treatment technology complies with Egyptian standards (Donia 2007; EHCW 2007). The normal water quality measurements carried out by Ministry of Health do not include pollutants of organic, microorganic or trace metals. As mentioned in previous sections, the pollution of Nile water is mainly chemical and biological. However, it is known that the conventional treatment processes does not have the ability to effectively remove dissolved materials such as pesticides, chlorinated organics, micropollutants and heavy metals. Very few research works have been carried out on such pollutants as these require extensive time and money. Elevated contents of heavy metals and pesticides in drinking water supplied from Nile have been reported (Mohamed et al. 1998; MWRI 2002). Therefore, it is imperative to carry out a precise and detailed investigation of the impact of Nile pollution on the quality of water obtained from it.

The presence of organic matter in the Nile is about 2–5 mg/L. The recommended total chlorine dose for disinfection in conventional normal or compact treatment units of Nile water is 5–8 mg/L. Chlorine is added to both the raw water (pre-chlorination) and the filtered water (post-chlorination). The applied chlorine dose is higher than what is actually needed for disinfection (Shamrukh and Abdel-Lah 2004). This higher dose is applied to maintain enough chlorine residual in order to prevent water quality deterioration in the distribution pipelines. Applying this high chlorine dose with dissolved organic matter is expected to form disinfection by-products (DBPs) formation, such as trihalomethanes (THMs) and haloacetic acids (HAAs). THMs are suspected carcinogens and/or mutagenic compounds (WHO 1996). A maximum contamination level of 100 µg/L is accepted by Egyptian standards. EI-Dib and Ali (1992, 1995) reported high concentrations of THMs in treated Nile water at Cairo. Measured concentrations of THM in winter and summer ranged 41.8–247.1, and 18.1–80.1 µg/L, respectively.

Elevated levels of chlorinated organics in Cairo drinking water have also been identified in one study (Smith 2009). These compounds have the effect of “chronic toxicity” which is usually characterized by long-term exposure to contaminants at relatively low concentrations. Adverse health symptoms may not appear for years but it may manifest later as cancerous tumors (Smith 2009). Polycyclic aromatic hydrocarbons (PAHs) measured at four locations were present in extremely high concentrations of 1,112.7–4,351.2 µg/L in raw Nile water but were not detected in treated water (Badawy and Emababy 2010).

Drinking water supplied from groundwater is also facing growing quality problems. A significant one is the high concentrations of Fe and Mn in many drinking wellfields. Table 2.1 shows the number of the villages declared by Ministry of

Housing and Utilities to have quality problems (Al-Ahram 9/28/2009). Treatment of groundwater polluted by Fe and Mn in Egypt is carried out using an aeration tower. A study carried out by Abdel-Lah et al. (2002) indicated that oxidation of Mn by aeration is not effective. Many health problems can be caused by elevated Fe and Mn in drinking water (WHO 1996).

TABLE 2.1. No. of villages with polluted drinking groundwater (mostly iron and manganese).

Governorate	No. of villages
Qena	4
Sohag	114
Assiut	168
Minia	31
Helwan	10
6th October	36
Menofia	51
AlGharbia	73
AlShargia	44

Problem of agrochemicals in groundwater is getting worse due to extensive application of chemical fertilizers and pesticides. Elevated concentrations of chemical fertilizers in drinking and irrigation wells have been reported (Shamrukh and Abdel-Lah 2004; Awad et al. 1995; El-Fouly and Fawzi 1994). In these studies, elevated concentrations higher than drinking water standards were reported for NO_3 , SO_4 , and K and up to 120, 530, and 45 mg/L, respectively. A recent study (Shamrukh 2010) indicated that nitrate pollution in drinking wells is increasing with time.

In addition to chemical fertilizers, elevated concentrations of pesticides and herbicides in groundwater wells were also reported (MWRI 2003). Concentrations higher than allowable limits were detected in few shallow wells. For instance, shallow groundwater in Delta was highly contaminated with organochlorine (OC) and organophosphorus (OP) residues such as BHC and DDT (Abd-Allah and Gaber 2004).

Bacterial contamination of drinking handpumps and municipal wells from leaching wastewater of sewage rooms is another problem. As shown in Figure 2.3, wastewater can easily move into handpumps and municipal wells due to the direct contact between sewage and ambient groundwater. Water quality from private handpumps that partially supply villages is not routinely sampled. However, occasional sampling shows that the risk associated with pathogen contamination in such supplies is high (Abdel-Lah and Shamrukh 2001). Their measurements indicated that drinking wells at depth of 60 m and close to sewage rooms by 40 m in rural areas were also at high risk of bacterial contamination. Drinking water associated with pathogenic pollution can cause a growing number of water-related diseases, especially in infants (WHO 1996).

5. Riverbank Filtration (RBF)

For more than 100 years, RBF has been used in Europe to supply drinking water to communities along the Rhine, Elbe, Danube, and Seine rivers. In Berlin, RBF contributes to about 70% of total drinking water demands. Potable water abstracted using RBF is about 50% in Slovak republic, 45% in Hungary, 16% in Germany and 5% in The Netherlands (Dash et al. 2008). In USA, RBF systems have also been supplying drinking water to several communities for nearly 50 years. In Europe, post-World War II when the rivers were significantly polluted with municipal and industrial effluents, RBF was the most efficient method of producing high quality drinking water (Ray et al. 2002). Recently, many countries around the world have started to evaluate RBF feasibilities for water treatment including India, South Korea, China and Jordan.

In RBF, which similar to some extent to slow-sand filtration, river water contaminants are attenuated from a combination of processes such as filtration, microbial degradation, sorption to sediments and aquifer sand, and dilution with background groundwater. According to previous published work by numerous researchers, RBF has proven its effectiveness in water treatment (Shamrukh and Abdel-Wahab 2008; Dash et al. 2008; Massmann et al. 2008; Weiss et al. 2003, 2005; Schmidt et al. 2003a, b; Hiscock and Grischek 2002; Tufenkji et al. 2002; Stuyfzand 1998; Doussan et al. 1997; Cosovic et al. 1996). Reported data indicated that RBF can effectively remove many water major pollutants and micropollutants including particulates, colloids, algae, organic and inorganic compounds, microcystins, pathogens and even heavy metals (Sontheimer 1980). Furthermore, bank filtration is able to attenuate concentration or temperature peaks and can provide protection against shock loads. Compared to traditional water treatment plants, RBF could have more advantages especially in improving the removal capacity and reducing the total cost. In addition, RBF reduces the concentrations of disinfection by-products due to its ability to remove organic matter. There is no waste generated from RBF which gives it an environmental advantage.

However in RBF, when the surface water is low in dissolved oxygen then conditions during underground passage will likely become anaerobic, which can cause iron and manganese to become soluble and therefore be drawn into the groundwater well (Hiscock and Grischek 2002). This can have the undesirable effect of degrading the water quality to unacceptable drinking water standards. In spite of that, under anoxic conditions, nitrates are reduced to nitrogen and thereby provide oxygen for organics removal and ammonia oxidation (Sontheimer 1980).

RBF is typically conducted in alluvial valley aquifers, which are complex hydrologic systems that exhibit both physical and geochemical heterogeneity. The performance of RBF systems depends upon well type and pumping rate, travel time of surface water into wells, source water quality, site hydrogeologic conditions, biogeochemical reactions in sediments and aquifer, and quality of ambient groundwater (Ray 2001).

6. RBF for Water Supply in Nile Valley

In Egypt, there is no designed RBF that has all the facilities to be investigated in depth. But there are few sites where the vertical wells are very close to Nile banks which can be considered RBF sites. One of the first studied such RBF sites is the wellfield of Sidfa city, which is south of Assiut city in upper Egypt (Abdel-Lah and and Shamrukh 2006). Sidfa RBF site includes seven vertical wells that are 70 m in depth and placed 50 m from the Nile bank. Results of Sidfa site indicated that Nile filtrate contributes about 70% of total wells production. The following sections illustrate that RBF that can be applied widely in Nile valley of Egypt.

6.1. Nile Water and RBF

In the current study, a section of Nile between Qena and Assiut was selected to evaluate the quality of Nile water and RBF applicability for water supply. Most measurements and sampling were done at Qena and Naga Hamadi barrage.

After constructing Aswan High Dam (AHD), the flow regime of Nile has been changed to dam-regulated flow. Figure 2.5 shows the discharge from AHD and level (i.e., stage) of River Nile at Qena. It is clear that the discharge in summer is double of winter. Also, discharge is minimum in December because of winter closure of irrigation systems and minimum gate openings of AHD. Lowest water level of Nile occurs during winter closure starting at the end of Dec and for 1 month long. Nile stage is almost consistent allover the year. The difference between water level in summer and winter is about 2.50 m.

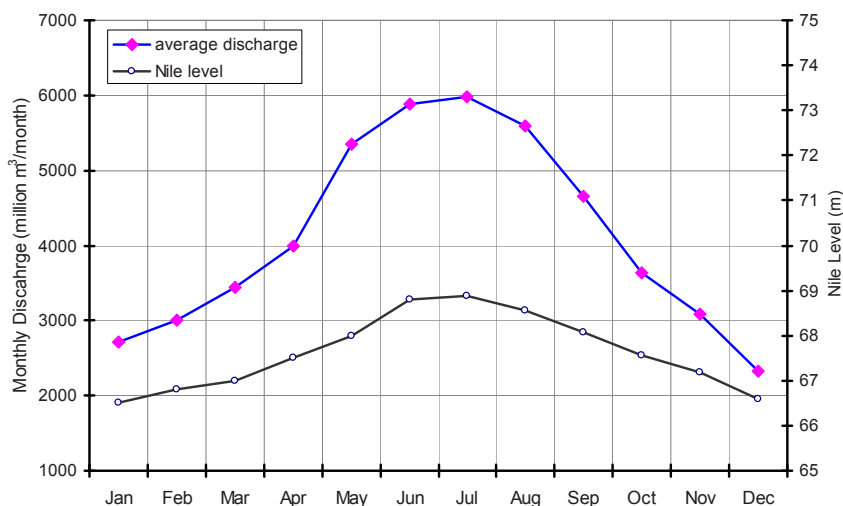


Figure 2.5. Average monthly discharge of Nile and water level, 2008.

The water quality parameters of Nile water at Naga Hamadi are shown in Figure 2.6. Temperature, turbidity, nitrate, DO and BOD₅ data are given for 3 months in 2009. In general, there are no significant variations of Nile quality between summer and winter. The suspended matter (i.e., turbidity) of the river is low compared to European and US rivers (Caldwell 2006). This low content of suspended solids is due to the sedimentation in Naser Lake, upstream of AHD. This could result in reducing the clogging of riverbed but the effect of low suspended solids on RBF performance needs a separate investigation. Dissolved oxygen of Nile water is good for RBF which is anticipated to make it aerobic and reduce the probability of iron and manganese mobilization in pumped water. Nitrate and BOD₅ can be considered as indication of Nile pollution from irrigation drains and industry. Nitrate and BOD₅ are low and illustrate that the Nile surface water is good at the studied section.

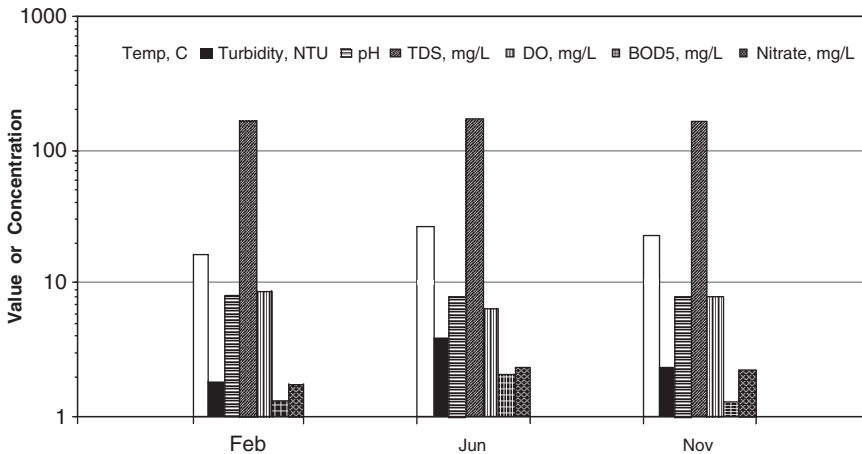


Figure 2.6. Some of quality parameters of the Nile at 10 km downstream Naga Hamadi barrage, 2008.

6.2. Nile — Aquifer Interaction

For RBF to work effectively, there should be a hydrogeologic connection between river and wells. Figure 2.7 shows the hydrogeologic cross section of Nile at new Naga Hamadi barrage. This section was drawn using the data of more than 30 boreholes made for the design of new Naga Hamadi barrage. The significant feature is that Nile cuts through the silt-clay cap forming a good hydraulic connection between the river and the main aquifer in absence of any low-permeable deposits below the riverbed. The estimated hydraulic conductance for the bed layer of River Nile ranges from 2 to 8 days. This will enhance the movement of bank filtrate

from Nile into any abstraction wells installed at the Nile banks. The general stratification of Nile aquifer system at Naga Hamadi area from top to bottom is:

- Quaternary
 - Holocene silt clay or clayey silt with fine sand
 - Pleistocene sand with gravel and broken stone fragments
 - Pleistocene lenses of silt and clay
 - Plio-Pleistocene deposits
- Tertiary
 - Pliocene clay
 - Paeleocene shale
 - Eocene limestone (also east and west of the floodplain)

In general, the water table is located in the silt-clay cap 2–3 m below the ground surface, which is higher than the Nile water surface in both summer and winter. The only exception is about 50 km upstream of the four Nile barrages due to back water curve. Therefore, Nile works as a drain for the Nile aquifer. For about 50 km upstream of any Nile barrage, the flow is from Nile into the aquifer (i.e., Nile recharges the aquifer). However, at new Naga Hamadi barrage, level of water table is 63.90 m (MSL) and Nile stage is 62.8 m, in summer. In addition, water table is higher than the piezometric surface of sand-gravel layer indicating that vertical recharge from silt-clay cap into the aquifer.

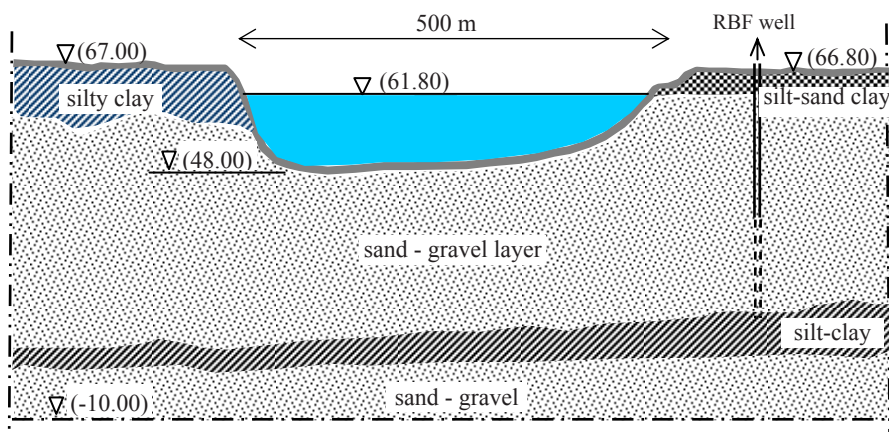


Figure 2.7. Hydrogeologic cross section at New Naga Hamadi Barrage and the studied RBF wells.

Particle size distribution of the main sand layer that form the main aquifer layer of Nile valley at Naga Hamadi barrage is shown in Figure 2.8. About 112 samples were used to draw the size distribution of this sand-gravel layer. Three significant sizes can be extracted from sieve analysis graph for each layer, they are effective

diameter (d_{10}), main diameter (d_{50}), and 60% passing diameter (d_{60}). Hydraulic conductivity from the current sieve analysis using d_{10} , d_{50} , and d_{60} and applying the empirical formulas of Hazen (1911) and Shepherd (1989) are given in Table 2.2. Other aquifer characteristics that could help in assessing the applicability of RBF in Nile valley taken from reported data are also given (Ahmed 2009b). It is clear that the hydraulic conductivity in the horizontal direction, K_h , for the main aquifer layer is very good and supporting water movement from the streambed and the banks into the pumping wells.

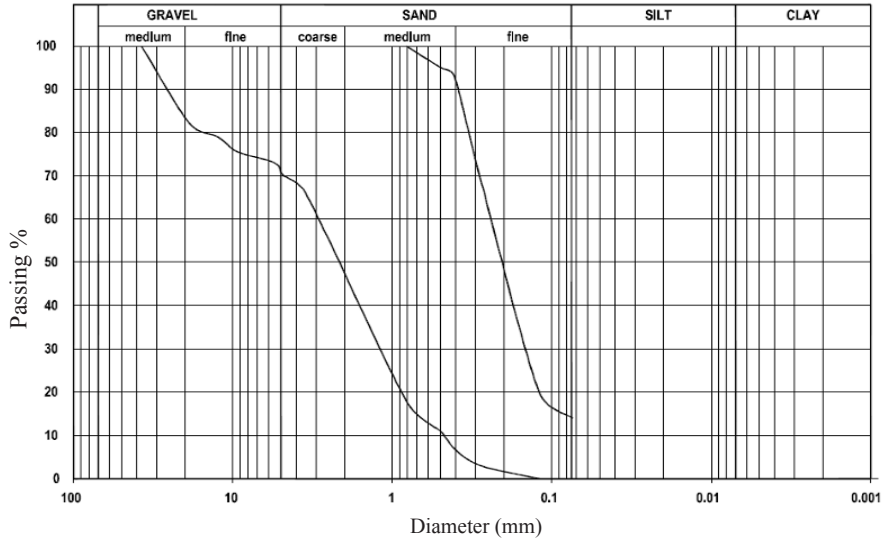


Figure 2.8. Particle size distribution of Pleistocene sand layer at the new Naga Hamadi Barrage.

TABLE 2.2. Hydrogeologic characteristics of the Nile aquifer at Naga Hamadi Barrage.

Aquifer layer	Silt-clay cap	Sand layer (Above 27.00 MSL)	Sand layer (Below 27.00 MSL)	Sand-gravel lenses	Clay lenses (At 15.00 MSL)
Thickness (m)	7–16	25–40	100–200	7–12	6–18
d_{10} (mm)	0.04	0.15–0.6	0.09–3.0	0.13–0.50	0.002
d_{50} (mm)	0.02–0.15	0.2–2.0	0.4–0.9	0.80–15.0	0.09
d_{60} (mm)	0.02–0.17	0.25–3.0	0.5–1.1	3.0–17.0	0.24
K_h (m/day) (Ahmed 2009)	0.1–0.3	40–120	40–120	40–120	na
K_v (m/day) (Ahmed 2009)	0.02–0.04	7–20	7–20	7–20	na
Hazen (1911)	–	20–260	10–80	30–310	Very low
Shepherd (1989)	–	15–300	35–110	75–330	Very low

na = not available

In addition, the ability of Nile aquifer sediments to adsorb cyanobacterial toxins supports the application of bank filtration. Zakaria et al. (2007) investigated the Nile sediments and reported that RBF can be used effectively in Nile valley of Egypt for removing these cyanobacterial toxins (microcystin) from drinking water.

6.3. RBF Wells at Naga Hamadi

There are two abstraction wells installed about 70 m away from the right bank of the River Nile and 50 m deep to supply potable water to the camp of new Naga Hamadi barrage (Figure 2.9). The supplied community is about 3,000 persons. Measurements of water quality from the abstraction wells in September 2009 were carried out. Collected samples were analyzed using Hach DR2000 spectrophotometer for physio-chemical measurements. Other meters for pH and TDS measurements were used. Instrument startup and analysis were carried out as detailed in the operating manual and each measurement was made in duplicate. Microbial measurements for pathogens were carried out at the laboratories of

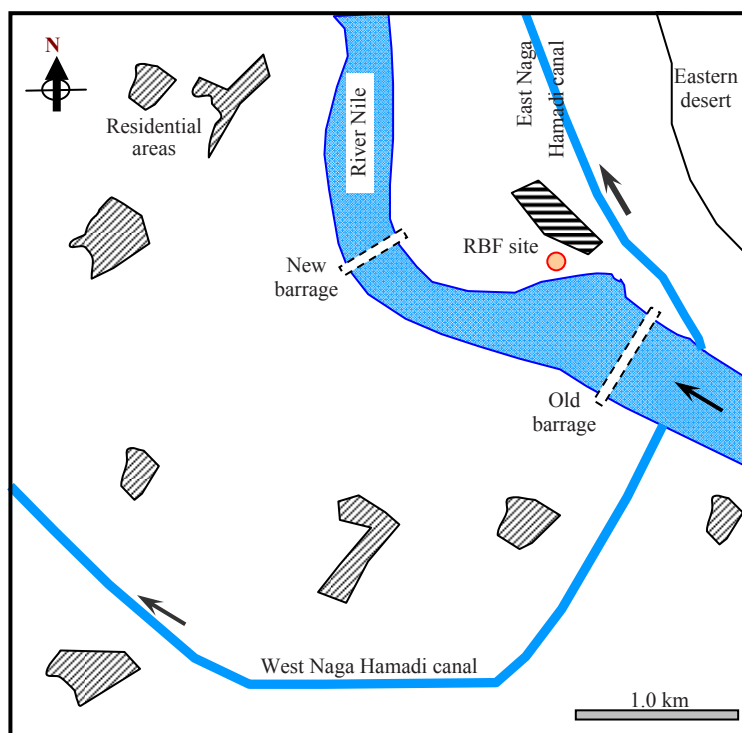


Figure 2.9. Location of RBF site at Naga Hamadi barrage, 500 km south to Cairo.

Ministry of Health in Egypt. The results of riverbank filtrates at the abstraction wells were compared with those of the River Nile water, and the ambient groundwater. Ambient groundwater was analyzed from a deep well located at 1 km from the current RBF site. The effectiveness of the RBF process is evaluated based on this comparison.

The RBF site at Naga Hamadi is the fourth RBF study site after Sidfa, AbuTieg, and ElMutia. All the three previous studied site are located on the western bank of Nile where the width of the floodplain is about 20 km. The quality of the ambient groundwater of the previous three RBF sites is different than the current investigated case. The most important feature of the current ambient groundwater is higher concentrations of almost all ions of concern. [Table 2.3](#) shows the water quality at the RBF site at Naga Hamadi.

TABLE 2.3. Water quality at the three locations of RBF site, Naga Hamadi barrage.

Parameter	Ambient GW	Nile water	RBF
Physicochemical			
pH	7.9	7.7	7.8
Turbidity (NTU)	0.3	4	0.2
TDS (mg/L)	622	168	320
Total Hardness (mg/L as CaCO ₃)	272	119	168
Major cations (mg/L)			
Ca ²⁺	58	26	39
Mg ²⁺	32	12	21
Na ⁺	57	22	38
Fe	0.2	0.15	0.16
Mn	0.6	0.07	0.09
Major anions (mg/L)			
Cl ⁻	42	19	27
SO ₄ ⁻	32	20	24
HCO ₃ ⁻	336	142	244
Nutrients (mg/L)			
NO ₃ ⁻	8	1.7	2.4
NH ₄ ⁻	nd	0.03	0.05
PO ₄ ⁻	1.8	0.5	1.0
Organic matter (mg/L)			
COD	nd	8.5	nd
BOD ₅	nd	2.7	nd
Bacteriological parameters			
Total coliform (fcu/100 mL)	0	1,100	0
Fecal coliform (fcu/100 mL)	0	290	0

nd = not determined

Results indicate that infiltrating water from Nile dilutes the ambient groundwater moving into the RBF wells. Results show that Nile pollutants were effectively removed through the RBF process as the pumped water meets the Egyptian standards. These results of RBF effectiveness are in agreement with the results of the previous two RBF studies in Nile valley (Abdalla and Shamrukh 2009; Shamrukh and Abdel-Wahab 2008). However, the ambient groundwater at this site has elevated values of most chemical species. Therefore, this should be considered when evaluating the RBF removal effectiveness of Nile water. This situation of ambient groundwater with higher constituents than adjacent surface water is similar to another RBF study reported in India (Dash et al. 2006, 2008).

Quality results indicated that distance and location of the RBF wells from Nile are the key parameters of the RBF performance. If the RBF wells are very close to Nile then the microbial removal will be reduced. On the other hand, if the RBF is far away from Nile then the problems of Fe and Mn as well as other contaminants will be detected. Organic carbon is consumed during biodegradation, mediated by microbial activities in presence of other compounds that are electron acceptors. Therefore, four zones can be defined according to the geochemical and transformation processes between Nile and RBF wells. Those four zones that influence the quality of bank filtrates from Nile are as follows (Wett et al. 2002):

1. Zone I: reduction of dissolved O_2 and NO_3
2. Zone II: reduction of Mn(IV) and Fe(III)
3. Zone III: reduction of Fe(III) and precipitation of $MnCO_3$
4. Zone IV: reduction of SO_4

In Nile aquifer, iron and manganese in drinking wells represent a major problem. To avoid the Fe and Mn dissolution and contamination, RBF wells should be installed within Zone I. Monika et al. (2009) proposed a quantitative approach which is called the *electron trapping capacity* (ETC). It is calculated using dissolved O_2 and NO_3 concentrations in bank filtrates. ETC represents the quantity of electrons that O_2 and NO_3 are capable of trapping as groundwater moves from oxidizing conditions to Mn and Fe reducing environment. The greater the ETC, the less reductive the conditions become and a lower probability of dissolution of manganese or iron oxyhydroxides exist. Therefore, ETC should not be lower than 0.2 mmol/L (Monika et al. 2009).

6.4. RBF Benefits and Scheme in Nile Valley

Current RBF results and previous work reported three RBF sites located in Nile valley improved the quality of drinking water production. In addition, most of the Egyptian towns are located within 10 km from River Nile which makes RBF physically and topographically suitable. The other advantages of using RBF among Egyptian water supply schemes are:

- Low capital and O&M costs
- Absence of or minimal addition of chemicals (i.e., coagulants)
- High rates of water-recovery
- Reducing or absence of disinfection by-products
- No sludge production or generation of hazardous waste stream
- Destruction, rather than sequestration or concentration of contaminants
- Simultaneous removal of multiple contaminants
- Protection against shock loads from flash floods and ship accidents in Nile
- Robustness over a wide range of operating conditions and water qualities

These attractive benefits of RBF have received the attention of decision makers in Egypt. The implementation of RBF application in Nile valley could be through the following three scenarios:

1. New installation of RBF vertical wells followed by online chlorine disinfection and elevated storage tank for new drinking water demands
2. Moving the current municipal wells with Fe and Mn or bacteriological problems closer to Nile
3. Stop the costly expansion of current surface treatment plants and integrate RBF wells that can be discharge water to the existing filtered water tank (i.e., Cl₂ contact tank)

7. Conclusion

This study illustrates that the River Nile and its aquifer as the main drinking water sources in Egypt is facing serious pollutant problems. River Nile receives considerable amounts of pollution from municipal and industrial effluents as well as agricultural drains. Problems of iron and manganese contaminations in the Nile aquifer are widespread. Fertilizers and septic rooms in the areas with no piped sewage system present another challenge to improving water quality of aquifers. There is an increasing demand for drinking water due the growing population. Conventional treatment plants used to treat Nile water are not capable of removing micropollutants in the River Nile. Riverbank filtration as natural treatment method could be the optimal solution to overcome Egyptian quantitative and qualitative challenges of drinking water. Previous research work and data of the present investigation shows that RBF can be an effective and economical means of drinking water production from Nile. Many of the large and small cities of Egypt are located along the banks of River Nile. RBF can be used as stand alone or as an alternative to direct Nile abstraction followed by conventional treatment process.

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