MONTHLY DRINKING WATER EFFICIENCY AT A RIVERBANK FILTRATION SITE AT EMBABA, CAIRO

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ABSTRACT

Increasing water demands by the agriculture, industrial, residential, and environmental activities decreasing the water supply due to climatic changes are increasing the water shortage in high stress regions and contaminating the water supplies. Riverbank filtration [RBF] is a green water supply that uses the porous media of the soil sand and gravel as a natural filter a pre-treatment step for drinking water production. It is a pre-treatment phase for drinking water production. For more than 100 years, RBF has been used in Europe, most notably along the Rhine, Elbe, and Danube Rivers, to produce drinking water. Although RBF is not commonly utilized in the United States, interest is increasing in using RBF as a low-cost complement or alternative to filtration systems to remove pathogens from water. RBF has proven to be invaluable in treating drinking-water sources in Europe. Studies have shown that RBF generally removes a substantial percentage of organic compounds found in raw river water including harmful pathogens such as Giardia, Cryptosporidium, and viruses. This study aims to model and investigate the RBF sharing (RBFS) in the site at Embaba, Cairo, Egypt by studying the effect of the monthly Nile river hydrograph on RBFS using MT3D and MODPATH. The study results showed that the RBFS reached 68.40% at the low Nile river hydrograph at stage 16m above mean sea level (amsl) at the month of December while the high hydrograph stage was 16.40m (amsl) and led to RBFS by 70.10% at the month of November. These results will be useful for the operation scenarios in the drinking water sites especially at the minimum months of the Nile River hydrograph where the RBFS is reduced to optimize the treatment costs for the high pollutant regions.

Keywords: Riverbank filtration, hydrograph, monthly, groundwater, travel time and modeling.

1 INTRODUCTION

Due to drought and population growth, the freshwater supplies are under a lot of stress. New resource water planning and management methods must be developed to avoid conflict escalation and stop environmental deterioration. The Middle East and North Africa regions are the most water-scarce places in the world due to the intense use water resources and decreasing precipitation **(Terink et al., 2013, Abd-Elaty et al., 2022a)**, this lead to causeg national water crises with low water levels and reservoir emptying **(Droogers et al., 2012**). The sustainability of potable water is a vital resource for maintaining global health, evaluating water quality indicators is an essential issue for integrated water resource management(**Abd-Elaty et al., 2019**).

Rising water temperatures and extreme climatic changes, such as floods and droughts are anticipated to affect water quality and exacerbate many types of water pollution from sediments, nutrients, dissolved organic carbon, pathogens, pesticides and salt, as well as adverse effects of thermal pollution on ecosystems and health **(Creed et al., 2018; El Shinawi et al., 2022a**). Global climate change may also relate to further changes and variability for groundwater quality and quantity may be impacted by dynamic changes and sea level rise **(Mujere and Moyce, 2018**). Unquestionably, the Intergovernmental Panel on Climate Change (IPCC) has encapsulated that type of reality. The evaluation of likely effects on water and its quality, as the most important and stable resource for human survival, has therefore become a key issue in this continuing period of global climate change (**Radhapyari et al., 2021; Abd-Elaty et al., 2022b**). About 18% 18% of the global population do not have access to safe drinking water (**UN, 2006, Pamela, 2011**). The distribution of the world health problems due to unsafe water is presented in **Figure 1a** (**Nature, 2000**). Also, about 90% of the world deaths are due to diarrhea in the developing world (**WHO, 2005; WHO, 2010**). **Figure** 1b shows the significant percentage of drinking water comes from RBF wells in European countries in 2018.

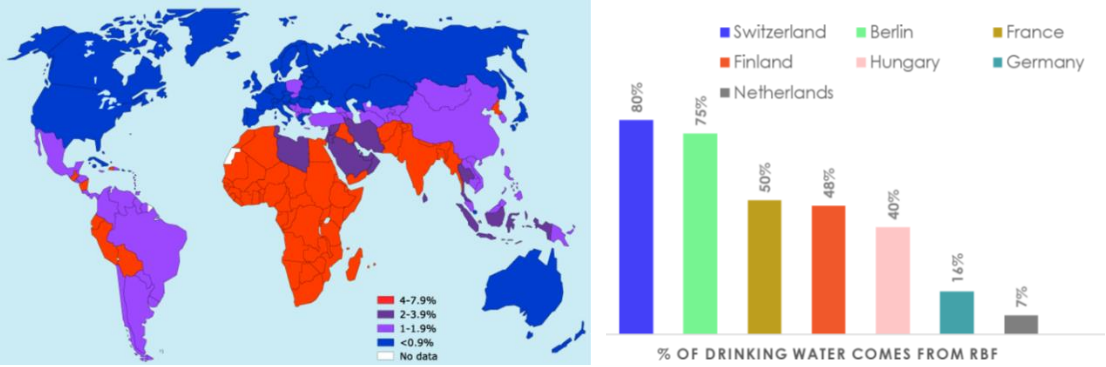

Figure 1. (a) Map of total disease burden caused by unsafe water by country in 2000 India is in the highest tier, with 4 to 7.9% of its total disease burden due to unsafe water (Nature, 2000) and (b) % of RBF in drinking water in Europe (UN-Habitat 2019)

United Nation identified 17 Sustainable Development Goals (SDGs) to achieve a better and more sustainable future for all, (see ***Figure 2a***). These goals address the global challenges including poverty, inequality, climate change, environmental degradation, peace, and justice. All governments are taking serious initiative to achieve and monitor these goals. Clean drinking water is addressed with goal number 6, ensuring access to clean water and sanitation. The ultimate objective of goal 6 to have access the clean water for all uses as presented in ***Figure 2b***. Clean drinking water is addressed with goal number 6, ensuring access to clean water and sanitation. The ultimate objective of goal 6 to have access the clean water for all uses as presented in ***Figure 2b***.

a)

b)

Figure 2. (a) Sustainable development goals, UN - SDG Portal, (2020), (https://ndla.no/subject:1:c8d6ed8b-d376-4c7b-b73a-3a1d48c3a357/topic:9e6c9f83-32a1-4cb4-977a-7a780c4948a3/topic:80fc34c3-f197-4e05-a2a8-49fea7278a32/resource:7b180d53-3f1a-4f56-9f54-8da1cdbfec96)

Egypt is one of the countries with a scarcity of freshwater. The Nile has long been the country's primary source of freshwater, meeting all of Egypt's water needs throughout the Nile Valley and Delta. The human activity is limited to a few settled localities where deep groundwater is available through springs and seepage zones, great challenges and specific risks are emerging in the lower Nile region for providing sustainable clean drinking water due to a lack of resources, water shortages, water resource management issues, and inadequate sanitation systems for citizens. Furthermore, additional water is required to ensure long-term irrigation **(Abd-Elaty et al., 2021a, El Shinawi et al., 2022b).**

RBF in Egypt aims to accomplish the strategic objectives of improving potable water production, including developing local and increasing the sustainability of freshwater with high quality at low cost and minimum waste product output. RBF can solve the issues that traditional treatment techniques in Egypt are now facing based on experiences from Europe and North America. Increased pollutant loads at the source, plant shutdowns due to shock loads from flash floods, accidents and spills of pollutants, seasonal algae blooms and accompanying toxins, and waste disposal at treatment plants are some of these issues (**Ghodeif et al., 2016; Abd-Elaty et al., 2021b**). The systems of RBF can remove pathogenic microorganisms, suspended solids, algae and their toxins, dissolved organic matter, ammonium, secondary disinfection precursors, etc. The effectiveness of removal is highly dependent on the river flow regime; Thus, RBF systems are also sensitive to climate change, mainly due to increased frequencies of extreme water levels, however, compared to surface and groundwater extraction and treatment, RBF is considered to be a more sustainable alternative and less sensitive to climate change (**Nagy-Kovács et al., 2018**).

This study is intended to identify and estimate the RBF sharing (RBFS) and the total water travel time from the river to the RBF wells using the solute transport model MT3D and MODPATH, considering the effects of the monthly changing in the river stages on RBF site at Embaba, Egypt.

2 METHOD AND MATERIALS

The current study includes the integration of numerical model to investigate the impact of changing in the river stages on RBF site at Embaba, Egypt.

2.1 Study Area

The study area is covers an area of about 4 km^2, it locates in the Giza Governorate of Egypt between latitudes 30°06´ N to 30° 07´N and longitudes 31° 12´ E to 31°13´E. This is the location of

Embaba's drinking water and sewage plant which serves a population of more than 8 million (**Capmas, 2020; Ghodeif et al., 2016; Abd-Elaty et al., 2021b**) as presented in **Figure 3**.

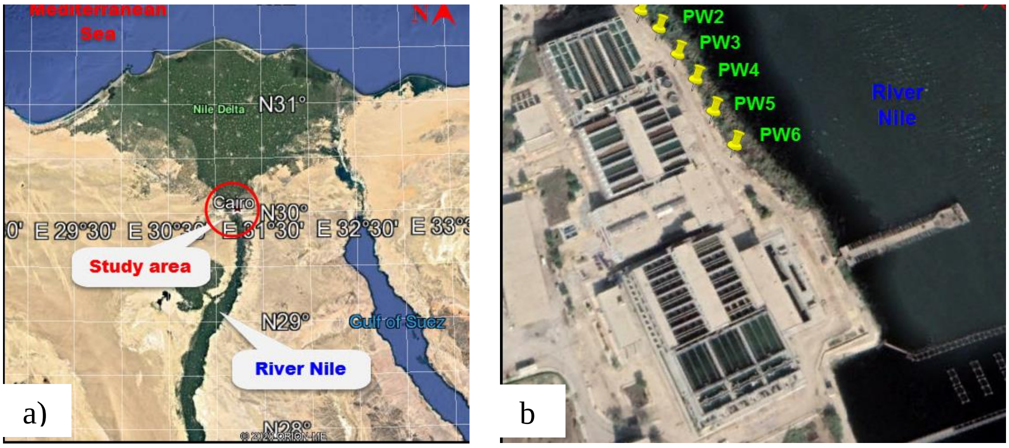

Figure 3. Study area for (a) Egypt map, (b) Embaba plant and RBF location

The study area's geomorphologic feature includes Al-Warraq Island to the east and the surrounding western branch of the Nile. The Nile River branch's east border has an average bed level of 8.8m above mean sea level (masl) and a width of 250m. The typical land levels range between 17m and 20m (masl), reaching 23m at the western boundary. The Nile River originates the delta barrages and feeds the groundwater reservoir in the study region, the flows direction typically in the north direction.

The flow conditions in the southern portion of the study area, on the left and right sides of the river, differ due to the presence of two side depressions, at the Giza pyramids to the west and the Marg to the east, as well as to the high rates of groundwater extraction at the Remayyah Golf Club and the Giza Pyramids site (**El-Arabi et al., 2013**). The climate of the Nile Delta is mild with a relative rise in temperature throughout the summer and average mean temperatures ranging from 12°C to 31°C in January and July, respectively. The rainfall is less than 40 mm per year, the humidity ranges from 45% to 84%, and the daily evaporation reaches 15 mm (**Abd-Elaty et al., 2021c**).

2.2 Contaminant Transport Model

The numerical model was used to investigate this system's possibility and simulate the RBF water quality for the current situation and different scenarios using MT3D code. The solute transport model and the partial differential equation (**Javandel et al., 1984**).

$$\frac{\partial[\theta C^k]}{\partial t} = \frac{\partial}{\partial x_i}\left[\theta D_u \frac{\partial c^k}{\partial x_j}\right] - \frac{\partial}{\partial x_i}[\theta V_i C^k] + q_s C_s^k + \sum R_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq1}$$

Where; C^k is the dissolved concentration of species k [ML^{-3}]; Θ is the porosity of the porous medium [-];t is time [T]; D_u is the hydrodynamic dispersion coefficient [$L^2 T^{-1}$]; V_i is the seepage or linear water velocity [LT^{-1}]; q_s is the volumetric flux of water per unit volume of aquifer [T^{-1}], and R_n is chemical reaction term [$ML^{-3}T^{-1}$].

2.2.1. Design of Groundwater Flow and Transport Simulation Model

The model domain covers a square area of 900 m^2 [300m length×300m width], in which it is divided into 60 columns and 60 rows with a square mesh size 6.25 m^2 [2.5 m×2.5m]as shown in **Figure 4**. The model depth is divided into six layers where the thickness of the first layer 5m which represents the clay cap while the other layers of the Quaternary aquifer with thickness about 42m. The boundary conditions were assigned using river package where the Nile River is assigned at the East-side with stage starts by 16.17m to 16.15 at the South. The Northern and the southern boundaries have No-flow boundaries. However, along the western model boundary; a general head boundary [GHB, Cauchy BC] represented the affected groundwater head was set to be 16.18 m [A.M.S.L.] at a distance of 150 m from the River Nile (**Figure4**).The aquifer hydraulic parameters including hydraulic conductivity [K], storage coefficient [S], specific storage [Ss] and effective porosity [ne] are presented in **Table 1**.

Table 1. Hydraulic parameters of the study area reported by (El-Atfy, 2007; Mabrouk et al., 2018).

Main hydraulic units	**Layer #**	**Hydraulic conductivity**		**Storage coefficient**	**Specific yield**	**Effective porosity**
		K_h	K_v	S	S_y	n_{eff}
		[[m/day^{-1}]	[m/day^{-1}]	[-]	[m^{-1}]	[-]
Clay	1	0.25	0.025	10^{-3}	0.1	0.40
Fine sand with lenses of clay	2,3	5-25	0.5-2.5	5×10^{-3}	0.15	0.35
Coarse sand	4,5,6	40-60	4-6	2.5×10^{-3}	0.2	0.25

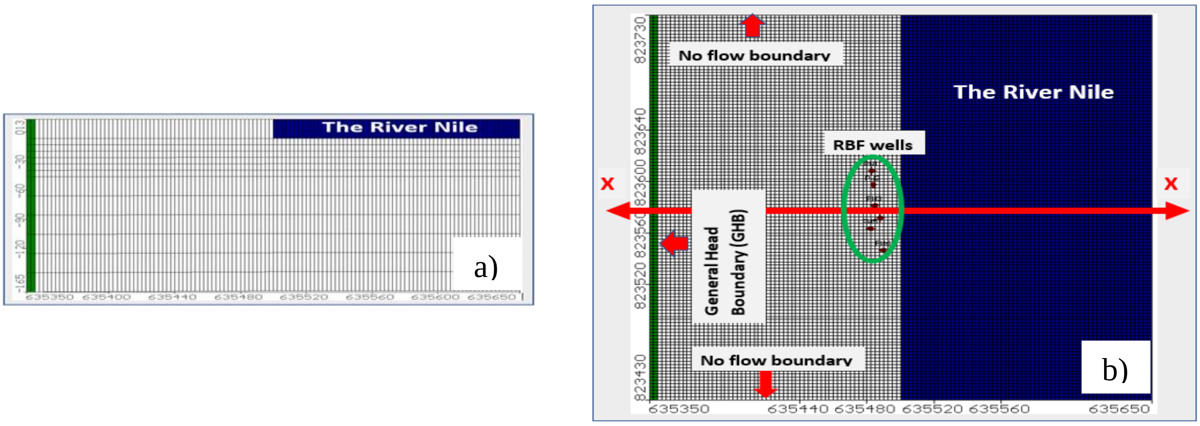

Figure 4. Study area digitizing and boundary **conditions for [a] section X- X and [b] aerial view**

2.2.3 Model Calibration

The model was calibrated using the collected from the Greater Cairo piezometric contour map. The steady-state flow model was calibrated by adjusting the aquifer hydraulic conductivity to match the model findings and the estimated head. The groundwater head is ranged between 13m to 15m also the TDS in the study area is ranged between 250p pm to 350 ppm at layer#2, **Figure 5a** and **3b** showing the distribution of salinity TDS in the Aerial view and vertical cross section respectively. The solute transport model was calibrated using the field data for TDS from (**Ghodeif et al., 2018**), The MT3D results give a good fit with the field and the observation wells.

The travel time for river particles was calculated for the transverse flow paths to redirect the trace and reverse trace particles simulated by MODPATH by assigning particles at a distance of 90 m from the pumping wells in the river using a forward tracking and the travel time reached 200 days.

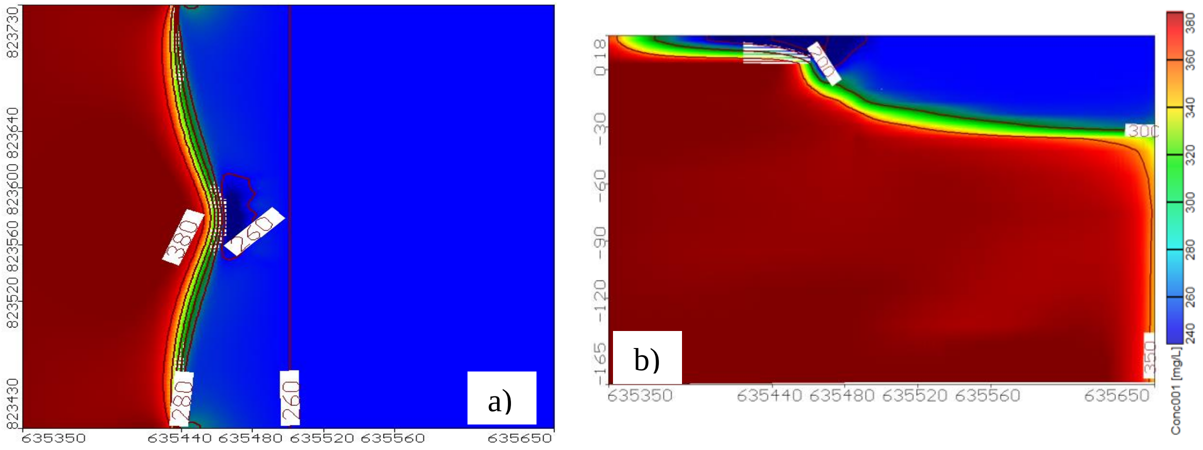

Figure 5. Model calibration results at base case for [a] Aerial view of TDS contamination and [b] Vertical cross section for distribution of TDS

4. RESULTS AND DISCUSSION

The model was developed to simulate the study area to assess the impact of changing the monthly river hydrograph on RBFS and the travel time of river particles. Data loggers were used to measuring water levels in the Nile River near Embaba from January, 2016 to December, 2016 (See **Figure 6**). According to water discharge downstream of the High Dam, the water levels range from 16m in December to 16.40m masl in November based on the recorded that was published by **(Ghodeif et al., (2016)**.

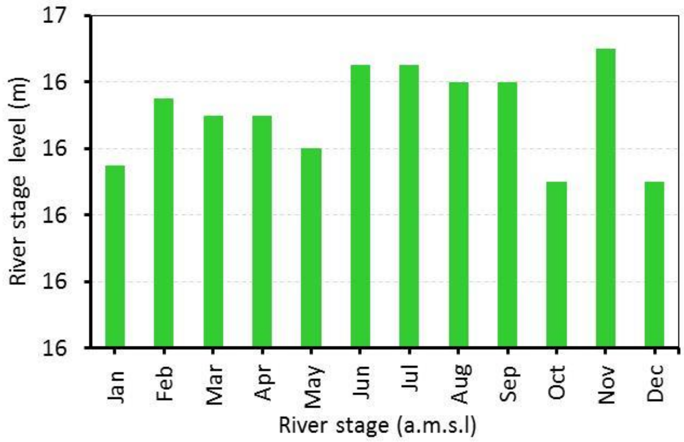

Figure 6. Month hydrograph of the Nile River at Embaba RBF site

4.1 Impact of river monthly hydrograph on RBFS

This case was studied the impact monthly river hydrograph on RBFS at Embaba RBF site. The percentage of bank filtrate in the pumped water was calculated with the following equation:

$$RBF_P\ \% = \frac{(TDS)_{GW}-(TDS)_{RBF}}{(TDS)_{GW}-(TDS)_{River}} \text{…………………………...…………………………} \text{Eq } (2)$$

The results revealed that lower Nile river water levels is occurs in the months of January, May, October and December to be 16.05m, 16.10m, 16m and 16m respectively, the caused a decrease in RBFS to 68.60%, 68.80%, 68.40%, and 68.40% respectively. The high values of RBFS was occurs at the months of February, March, April, June, July, August, September and November by 69.40%, 69.20%, 69.20%, 69.90%, 69.90%, 69.60%, 69.60% and 70.10% respectively (**Figure 7**). The maximum values of TDS in the study area for the river stage at 16m were done in December, while the minimum values were done at the river stage at 16.40m for September. Also, the high river stage levels are required to increase the system of RBF portion and sustainability.

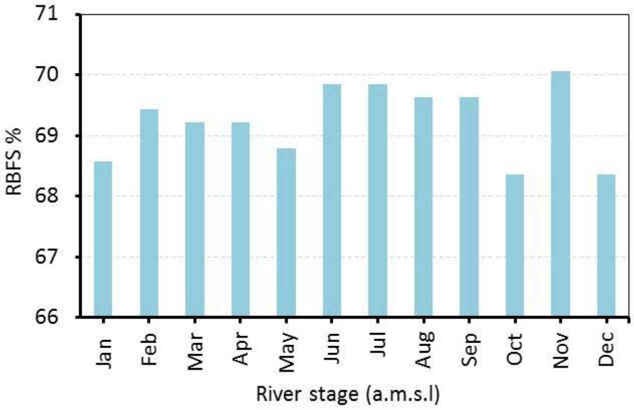

Figure 7. The relation between the month river stage and RBFS

Figure 8 illustrates the relationship between different river stages and particle travel time. The results show that this system is susceptible to the river stage, with the travel time reaching 202, 199, 200, 200, 201, 197, 197, 198, 198, 202, 197 and 202 day respectively from January to month of December respectively. This indicates that the river stage influences river particles' velocity and distance.

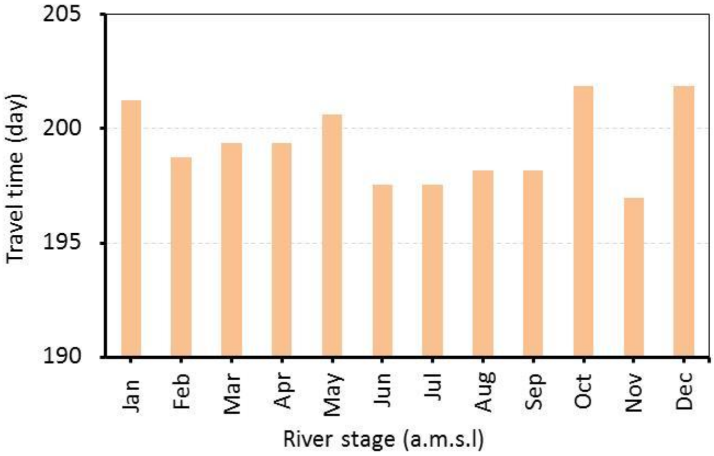

Figure 8. The relation between monthly river stage and particles travel time

SUMMARY AND CONCLUSION

RBF technology provides the drinking water from the bank of the rivers or streams and depends on the river the stage and the groundwater heads, so the quality of the water of rivers and aquifers is an essential factor. MT3D code was used in the current study and simulated the current study and the monthly changing of river stages at the RBF site, Embaba, Giza Governorate, Egypt. The RBF efficiency and the travel time of river particles were investigated. The simulation results indicated that the reduction in the river stage led to a reduction in RBFS to to 68.60%, 69.40%, 69.20%, 69.20%, 68.80%, 69.90%, 69.90%, 69.60%, 69.60%, 68.40%, 70.10% and 68.40% respectively while the travel time of river particles was increased to 202, 199, 200, 200, 201, 197, 197, 198, 198, 202, 197 and 202 day respectively. The operation of RBFS should be considered the effect of monthly river hydrograph on the system treatment and drinking water quality.

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