Environmental rethinking of wastewater drains to manage environmental pollution and alleviate water scarcity

Ismail Abd-Elaty¹ · Alban Kuriqi² · Abeer El Shahawy³

Received: 12 June 2021 / Accepted: 14 September 2021 / Published online: 27 September 2021
© The Author(s), under exclusive licence to Springer Nature B.V. 2021

Abstract

The conservation of water resources in developed countries has become an increasing concern. In integrated water resource management, water quality indicators are critical. The low groundwater quality quantitates mainly attributed to the absence of protection systems for polluted streams that collect and recycle the untreated wastewater. Egypt has a limited river network; thus, the supply of water resources remains inadequate to satisfy domestic demand. In this regard, high-quality groundwater is one of the main strategies for saving water supplies with water shortage problems. This paper investigates the critical issues of groundwater protection and environmental management of polluted streams, leading to overcoming water demand-about 18×10^3 km of polluted open streams with a discharge of 9.70 billion Cubic Metter (BCM). We have proposed proposals and policies for the safe use of groundwater and reuse of wastewater recycling for agriculture and other purposes. This study was carried out using the numerical model MODFLOW and MT3DMS—(Mass Transport 3-Dimension Multi-Species) to assess the Wastewater Treated Plant's (WWTP) best location and the critical path for using different lining materials of polluted streams to avoid groundwater contamination. The three contaminants are BOD, COD, and TDS. Five scenarios were applied for mitigating the impact of polluted water: (1) abstraction forcing, (2) installing the WWTP at the outlet of the main basin drain with and without a lining of main and sub-basin streams (base case), (3) lining of main and sub-main streams, (4) installing WWTP at the outlet of the sub-basin streams, and (5) lining of the sub-basin and installing WWTP at the outlet of the sub-basin. The results showed that the best location of WWTP in polluted streams is developed at the outlets of sub-basin with the treatment of main basin water and the lining of sub-basins streams. The contamination was reduced by 76.07, 76.38, and 75.67% for BOD, COD, and TDS, respectively, using Cascade Aeration Biofilter or Trickling Filter, Enhancing Solar water Disinfection [(CABFESD)/(CAT-FESD)] and High-Density Polyethylene lining. This method is highly effective and safe for groundwater and surface water environmental protection. This study could be managing the water poverty for polluted streams and groundwater in the Global South and satisfy the environmental issues to improve water quality and reduce the treatment and health cost in these regions.

✉ Alban Kuriqi
alban.kuriqi@tecnico.ulisboa.pt

Extended author information available on the last page of the article

Keyword Water poverty · Polluted streams · Groundwater · Contamination · MUDFLOW

Abbreviations

WWTP	Wastewater Treated Plant
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TDS	Total Dissolved Solids
SLR	Sea Level Rise
BCM	Billion Cubic Meter
RMS	Root Mean Square
VOCs	Volatile Organic Components
UV	Solar Ultraviolet
HDPE	High-Density Polyethylene
SWESD	Sedimentation Tank, Wetland, and Enhancing Solar Water Disinfection
EBABWWTP	Existing Bahr Al-Baqar Wastewater Treatment Plant
ESD	Enhancing Solar Water Disinfection
CABFESD	Cascade Aeration Biofilter Filter Enhancing Solar Water Disinfection
CATFESD	Cascade Aeration Trickling Filter Enhancing Solar Water Disinfection

1 Introduction

Water covers two-thirds of the Earth's surface, with salty seawater accounting for 97% of it. Only 3% of the water on our globe is fresh, with the remaining 2% trapped in ice caps and glaciers. (Tahir et al. 2020). The unfrozen water is mainly found in the soil, with only a small part above ground or air (Famiglietti 2014). Water demand in many places of the world already surpasses supply. As the world's population increases, the water demand grows (Barnes 2014; El-Rawy et al. 2020). Awareness of the global relevance of water conservation for ecosystem services has only recently evolved since over half the world's wetlands. Their essential environmental services have been destroyed in the twenty-first century (Mitsch and Gosselink 2000).

Freshwater environments rich in biodiversity are disappearing faster than marine and land habitats (Shiklomanov 2000). In the Middle East and North Africa, five percent of the world's population dwells. However, citizens of these countries have access to no more than 1% of global freshwater (Djuma et al. 2016). Most of the freshwater resources in Egypt are contained by the river Nile, i.e., 97% of freshwater resources (Strzepek and Yates 2000). Groundwater, rainfall, flash floods in the Delta, the western deserts, the Sinai, drainage and wastewater, and the Nile are Egypt's primary freshwater sources (El-Rawy et al. 2020). The current Nile flow rate relies on the available water in Lake Nasser to meet needs within the annual water share of Egypt, defined by an agreement struck with Sudan in 1959 at an annual rate of 55.50 trillion cubic meters (Abd Ellah 2020a). Egypt, an arid country at the mouth of the world's longest river, globally has a negative water balance. Its yearly supply of Nile water, precipitation along the Mediterranean Sea, and deep groundwater is around 57.7 BCM. Nearly 90% of the water from the Nile River is used for agriculture (Turhan 2021).

Water not collected by cultivated crops penetrates the soil and enters the drainage system. Drainage canals, also known as drains, run the river's length and discharge water into it. At certain spots, pumps pump water from the drainage network and feed it into the reuse

irrigation system. Many governments throughout the world have turned to unconventional energy sources. (Barnes 2014; Salem et al. 2020). Egyptians can consume a bigger quantity of water by reusing drainage water than those that flow onto the land, fall into the rain and are extracted annually from deep aquifers. However, there is an issue that as water goes through the soil and drainage system, salt and other pollutants are collected.

Therefore, drainage water differs from irrigation water in quality. So that both waters are mingled, at pumping plants or in the hands of farmers, Egypt moves its water (Allam et al. 2016; Barnes 2014). Groundwater exists in aquifers under the Western Desert, the Sinai, and the Nile River's Alluvium. In the shallow and deep aquifers, groundwater in Sinai exists. Other water resources include reuse of agricultural water drainage, residential water, and industrial wastewater, waste disposal of brackish groundwater, and/or seawater (El-Sadek 2010). Groundwater pollution is described as groundwater by human activities of undesirable substances (Peters and Meybeck 2000). The pollutants may originate from natural and anthropogenic sources (Oude Essink 2001; Ritter 2002). Seawater and brackish water are natural causes of soil water pollution. These natural sources can become severe contamination sources when human activities upset the natural environmental balance, such as the depletion of saltwater-intrusion aquifers, acid mine drainage from mineral resources, and excessive irrigation of hazardous chemicals (Meffe and de Bustamante 2014; Wagh et al. 2018). Groundwater pollution, however, differs from surface water contamination. It is invisible, and resource recovery is challenging at the current technological level (Kehrein et al. 2020). In addition, the harmful health effects of contaminated groundwater are persistent and difficult to detect (Yoshida et al. 2004). Once contaminated, cleanup is complex and expensive because groundwater flows in geological sub-surface and extended residential time (Giusti 2009; Li et al. 2021).

Natural treatment for contaminated soil water might take decades or even hundreds of years (Hashim et al. 2011). Since these substances disintegrate very slowly or not, they may endanger the underwater quality for drinking purposes forever (Hashim et al. 2011; Mitsch et al. 2014). At present, COVID-19 has caused a pandemic in every part of the Earth. COVID-19 is mainly transferred by respiratory gout from person to person (WHO 2020). Therefore, water polluted with this virus can also affect human health (Bhowmick et al. 2020; Lahrich et al. 2021).

Egypt's water quality concerns depend on flow, usage pattern, and population density among different water bodies. In addition, severe droughts resulting from climate change and increased protected farming make it difficult for agricultural water to be provided stably. Therefore, wastewater reuse for agriculture gains international interest as an alternative water supply. Wastewater treatment is suitable for agricultural water in many ways and is already widely employed worldwide (El-sayed 2020). The presence of Sea Level Rise (SLR) in the Nile delta, as well as the possibility of other human-induced stressors, such as the subsequent operation of the Grand Ethiopian Renaissance Dam (GERD), are threats that must be considered in order to ensure resilient agricultural practices in future scenarios (Abd-Elaty et al. 2019). Previous research shows that more than 10% of the world's population consumes wastewater-growing agricultural items (Gupta et al. 2009; Harmanescu et al. 2011). Agricultural wastewater reuse can be divided into two types: direct and indirect. Supplying irrigation water directly from the Wastewater Treatment Plant (WWTP) is known as direct wastewater reuse. Supplying irrigation water directly from the Wastewater Treatment Plant (WWTP) is known as direct wastewater reuse. (Jeong et al. 2016). The indirect reuse of wastewater is a method for collecting effluent from the WWTP or unprocessed wastewater downstream. The growth in WWTPs due to fast development enhances the indirect reuse of sewage by irrigation water. Drainage water from

irrigated areas is re-injected into the Nile Delta's distribution streams at various points. This reuse significantly improves the Delta's total water efficiency (Molle et al. 2016). Abd Ellah (2020b) showed that the reuse of agricultural drainage water in the Nile delta is 9.70 BCM. The reuse of domestic treated wastewater is 2.90 BCM. Salts accumulate in agricultural soil as a result of excessive usage. Drainage water seepage may contain harmful contaminants and chemical compounds that affect aquifers.

According to current protection scenarios in Egypt, polluted streams should be positioned in a low permeability layer to avoid water degradation (Abd-Elaty et al. 2019). By altering boundary conditions, erecting a cut-off wall, and employing linings for dirty drains. It demonstrates how polluted stream networks should be treated in future. Abd-Elhamid et al. (2019) conducted a numerical analysis to determine the efficacy of various lining materials in protecting groundwater from contaminated stream leakage. The findings showed that lowering the conductivities of liner materials lowered the contaminates spread. In the eastern Nile Delta of Egypt, Abd-Elaty et al. (2020) created simulation-based methods to reduce soil and groundwater contamination from fertilizers; the results revealed that installing a drainage network reduces groundwater and soil contamination.

Along with the Bahr El-Baqar drain system, the latter option can guard against nonpoint contamination. However, a more sustainable fertilizer application is required to safeguard the receptors located further downstream in the Nile Delta. The Impact of Lining Polluted Streams on Groundwater Quality: A Case Study of the Eastern Nile Delta Aquifer, Egypt, was studied by (Abd Ellah 2020a). The results showed that TDS values increased by 18.23 percent, 23.29%, and 19.24%, respectively, with increased abstraction rates of 15%, 34%, and 70%, due to population increases in 2010, 2025, and 2040.

Most of the information available on water use is imprecise. It is not based on field measures in agriculture in Egypt (Rutkowski et al. 2007). The water resource planning in Egypt confronts many issues, mainly due to a lack of funding and poor management. However, Egypt may have had too much water at once, which significantly hampered the need for a planning scheme because the emphasis on water resource planning is dependent on the scarcity of the resource. Egypt is anticipated to increase its water planning and management soon (Luo et al. 2020). Thus, this study highlights the future status of Egypt's water resources based on the existing state of managing water resources in terms of problems and opportunities and emphasizing the urgent need for water management strategies and policies (Hervás-Gámez and Delgado-Ramos 2020). This research examines drainage water reuse in Egypt and how people change water quality by acquiring the necessary water quantity.

This paper aims to manage the water scarcity in the arid region by implementing the best WWTP locations along the polluted streams and different lining materials of these polluted streams programs to protect the groundwater using a new proposal scenario and also improving the surface water quality for irrigation and minimizing the adverse hazards on environmental and citizen health. These scenarios are carried out for the current study area including, the first is increasing the abstraction rates by 60%, the second is installing the WWTP at the outlet of the main basin drain, the third is the lining of main and sub-basin drain, the fourth is installing the WWTP at the outlet of sub-basin drain, and the fifth is lining the sub-basin drain with installing WWTP at the outlet of sub-basin drain. Three treatments methods were considered using the first is Existing Bahr El-Baqar WWTP consists of a screen, coagulation, flocculation, lamella clarifiers, disk filters, ozonation chambers, and chlorine contact chambers (EBABWWTP), the second is proposed Sedimentation tank, Wetland and Enhancing Solar water Disinfection (SWESD), and the third is proposed Cascade Aeration, Biofilter or Trickling Filter, ESD [(CABFESD)/(CATFESD)].

2 Material and methods

2.1 Study area

The Mediterranean region is characterized by the significant development of coastal areas with a high concentration of water-intensive human activities, resulting in inadequately managed groundwater removal, emphasizing the phenomena of saltwater intrusion. The deterioration in groundwater quality is a big problem, particularly in locations, such as Salento, where a karst aquifer system is the most significant water source because of an inadequate external water supply (De Filippis et al. 2014; Stein et al. 2020).

Nile Delta aquifers are one of the greatest aquifers globally because of the size and thickness; various studies have been carried out with different extraction rate scenarios of the Nile Delta aquifer (Sherif et al. 2012). Due to the level of concentration of much of Egypt's infrastructure and development together with its low coastline and the reliance on the Nile Delta for the primary agriculture, coastal floods, and saltwater intrusions caused by anthropological rising seas, the Nile Delta and its narrow valley comprise 5.5% of the total area of Egypt (Darwish et al. 2013).

2.2 Study cases

Nile Delta is one of the largest deltas globally, surrounded by the North Mediterranean Sea, South Nile River, East Ismail Canal, and Western Nubaria Canal. It lies in the latitudes $30^{\circ} 00'$ and $31^{\circ} 45' N$ and lengths $29^{\circ} 30'$ and $32^{\circ} 30' E$, as illustrated in Fig. 1.

The Nile delta comprises flat, low-lying plains where the majority of the lands are farming. It is around 200 km from South to North, and the coastline is roughly 300 km in length and has over 25,000 km². It is believed to be one of the world's most densely populated farmland. In around 25 major towns and four brackish lagoons or lakes, it encompasses ten governorates. Nile Delta water systems are considered to be one of Egypt's most critical

Fig. 1 Main polluted streams (i.e., red lines) in the Nile Delta adapted after Fanack (2021)

water resources, essential for facing increased water requirements; they belong to the Quaternary age and consist of river marine deposits and deltaic deposits, and the aquifer is composed generally of unconsolidated sand and gravel, with occasionally clay-like lenses, which grow toward Northern Egypt (Darwish et al. 2013; Strzepek and Yates 2000). The Nile delta is a high-density populated area in the world. It suffers from water stress and contamination for surface and groundwater by agriculture drainage water, industrial and domestic wastewater.

This study is aimed at the most polluted stream in the Eastern Nile delta: the Bahr El-Baqar drain (main basin) and its tributaries (sub-basin). It releases around 3 billion cubic meters of water each year into Manzala Lake (Omran et al. 2012), which has a total length of 170 km (Taha et al. 2004). The Bahr El-Baqar drain gets its water from drainage sources: agricultural 58%, industrial 2%, and household and commercial 40% (Ghoubachi 2016).

2.3 Morphology and topography

Geomorphology represents the geological environment of the region. It has a significant impact on the type and extent of risks that affect the land use of the studied area, including the various rock and deposit types that constitute the various land and landforms of relief and extension (Zaid 2006). The new alluvial plains dominate the agricultural regions around the river channel and its branches. These lowlands cover most areas of the Nile Delta. Of the South, at El Qanater El Khayreya, the elevation in the terrain ranges from around 18 m Above Mean Sea Level (AMSL) at about 5 m (AMSL) near Tanta, with an average of 1 m/ 10 km in the northern direction (Abdelhady and Fürsich 2015).

2.4 Meteorological characterization

The Nile Delta is located in the arid zone belt of Northeast Africa and Southwest Asia. It is significantly affected by the Mediterranean climate, so this region can be considered semi-arid to arid climates in the South and Mediterranean climate along the coast (Rana and Katerji 2000).

Egypt lies in a semi-arid area. Its climate is characterized by warm, dry summers, moderate, and severely rainy winters. The Nile River is Egypt's primary and practically exclusive freshwater resource to meet the growing demands of agriculture, industry, and households. With over 95% of the population (i.e., 84 million in 2012) residing in the Nile Delta, any changes to the water supply due to climate change and the increasing population pressure represent a major risk for the country (Hendawy et al. 2019). The Sea Level Rise (SLR) also threatens towns and farming in the Delta of the Nile and the Red Sea. In addition, greater temperatures alone will evaporate more water, increase the need for water, produce more heat stress, exacerbate air pollution, and lead tourists away (Khedr 2019).

2.5 Geological characterization

The geologic areas for aquifers, comprising the Holocene and Pleistocene quaternary deposits and the tertiary deposits, encompass Pliocene, Miocene, Oligocene, Eocene, and the Paleocene sediments. The thickness of the quaternary watercraft varies from 100 m South to 1000 m along the Mediterranean Sea Coast near Cairo (El Sharawy and Nabawy 2018). The hydrological layers consist of sand and gravel (e.g., Pleistocene and Holocene)

with rare lenses of clay, which consider the major water-bearing formations (Sallam et al. 2018). The Quaternary base is a clay aquiclude of 4 m/km, approximately 30 times up to the ground surface slope (Abdalla and Mohamed 1999), as illustrated in Fig. 2.

The Quaternary reserves encompass the largest part of the eastern Delta of the Nile. They are predominantly developed in the northern part of the Nile. Quaternary deposits are represented by the Nile sediments, sometimes covered by a thin layer of windy sands. The sediments are varied sand, clay, and gravel proportions with lateral variance and varying thickness. Such sediments are not compliant in the older Tertiary rock units (Ghoubachi 2016). Holocene deposits in the Nile Delta area with a maximum thickness of approximately 77 m are extensively distributed, as Fig. 2 shows (Rizzini et al. 1978). The Nile River upstream of the Aswan High Dam has built an elaborate, open drainage system that transfers excess irrigation water into the Mediterranean and terminal lakes. The open drainage system was built around the end of the nineteenth century when the high-water Table and rising salt significantly harmed the ground. The system currently covers all farmed areas in the Nile Valley and Delta. There is approximately 16,686 km in length, 67% of which is found in the Delta, the remainder in Upper and Middle Egypt.

2.6 Coupled groundwater flow and solute transport model

The finite-difference model of MODFLOW, V4 (Xue et al. 2018), is applied in the current simulation. This code has numerous facilities for data preparation. The modular structure

Fig. 2 Longitudinal cross section showing the thickness and litho-facies variation of the Quaternary aquifer in Nile Delta adapted after El-Fayoumi (1968)

is easily modified, applied, data exchange in standard form, great flexibility in handling a wide range of complexity, extended worldwide experience, and continuous.

The partial-differential equation of groundwater flow used in Visual MODFLOW is:

$$\frac{\partial}{\partial x} \left(K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_{zz} \frac{\partial h}{\partial z} \right) + q = S_s \frac{\partial h}{\partial t} \quad (1)$$

The MT3DMS, a modular three-dimensional transport model, created by the USA Geological Survey (USGS) to model dissolved advection, dispersion, and chemical reactions, was used to simulate the solute transport model (Prommer et al. 2003). The differential equation for the solute transport model of MT3D is the following:

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x_i} \left(D_{ij} \frac{\partial C}{\partial x_j} \right) + \frac{\partial}{\partial x_i} (v_i C) + \frac{q_s}{\theta} (C_s) + \sum_{k=1}^N R_k \quad (2)$$

where K_{xx} , K_{yy} , and K_{zz} : aquifer conductivity (LT^{-1}), h : flow head (L), q : sources and/or sink of water (T^{-1}), S_s : specific storage (m^{-1}), t : time (T), C : groundwater concentration (ML^{-3}), D_{ij} : dispersion coefficient (L^2T^{-1}), V : seepage velocity (LT^{-1}), q_s : water flux of sources (positive) and sinks (harmful) (T^{-1}), C_s : sources or sinks concentration (ML^{-3}), θ : media porosity [dimensionless] and R_k is chemical reaction term ($ML^{-3} T^{-1}$).

2.7 Model geometry

The model domain is divided into 124 (row) $\times$ 116 (column) for active and inactive cells by square cell area dimension of 1 km². In contrast, the depth is divided into 11 layers. The domain depth varies and increases gradually from the North connected by the Mediterranean Sea with about 200 m near Cairo. The clay cap's average thickness varies from 20 m (South) to 50 m (North). This cap defined the Quaternary aquifer as a semi-confined aquifer. The Quaternary layers are represented in the main body of the aquifer. Two vertical sections are taken, the first from the East to the West (A-A) and the second from the North at coastal to the South (B-B) as shown in Figs. 3a and b.

2.8 Model boundary conditions and hydraulic parameters

The model hydrological setting was set using.

- (i) A constant head of zero along the Mediterranean shoreline above mean sea level (MSL) and ahead of 16.50 m at the South, which is represented the river Nile head,
- (ii) A river package varied from 16.15 m in the South to 0.50 m in the North to represent the east boundary; the west boundary was assigned by 14.50 in the South to 0.50 m in the North.
- (iii) A drain package for Bahr El-Baqar main basin and branches (Sub-basin) is ranged from head 12 m in the South to 0.25 m in the North.

Table 1 is presented the model hydraulic parameters, which were used as input data. Recharge to groundwater depends on rainfall, canal seepage, and excess water from the irrigation process, ranging between 0.05 and 1.10 mm/day. These values are based on the previous studies (El-Arabi 2007; Morsy 2009a; Sherif et al. 2012).

Fig. 3 Numerical model geometry and boundary condition **a** a realistic view, **b** section in the X direction from East to West, and **c** section in Y-direction from North to South in NDA

The well abstraction rates are variable and increased with the years; Mabrouk et al. (2013) indicated that the aquifer's abstraction rate increases by 0.10 BCM per year; the rate increased to 0.20 BCM per the year 2003 to 2010. The annual abstraction reached 3.50 BCM in 2003 and 7 BCM in 2016 (Molle et al. 2016). The total abstraction rate in the study area is 1702000 m³ per day (Morsy 2009b). The contaminant boundary conditions were assigned by constant concentration for three pollution sources, the first is BOD due to domestic Pollution by 82.50 ppm, the second is COD due to industrial Pollution by 112.50 ppm, and the third is TDS due to irrigation pollution by 2000 ppm, while the initial concentration was set by 0 ppm.

2.9 Model calibration

The Nile Delta Model (NDM) has been simulated using varied cell diameters to verify flow and solute transport sensitivity. Figure 4 depicts the head of groundwater

Table 1 Summary of hydraulic parameters used as input to the model

Hydraulic parameters		Value	Unit
Confined layer	Vertical hydraulic conductivity (K_v)	0.01–0.025	(m day ⁻¹)
	Horizontal hydraulic conductivity (K_h)	0.10–0.25	(m day ⁻¹)
	Specific storage (S_s)	10^{-7}	1/m
	Effective porosity (n_e)	40–50	%
	Total porosity (n_T)	50–55	%
Quaternary aquifer	Vertical hydraulic conductivity (K_v)	0.50–10	(m day ⁻¹)
	Horizontal hydraulic conductivity (K_h)	5–100	(m day ⁻¹)
	Specific storage (S_s)	5×10^{-3} –0.001	1/m
	Specific yield (S_y)	0.15–0.20	–
	Effective porosity (n_e)	20–30	%
	Total porosity (n_T)	25–40	%
	Longitudinal dispersivity (α_L)	250	m
	Transversal dispersivity (α_T)	25	m
	Diffusion coefficient (D^*)	10^{-4}	m ² day ⁻¹
	Storativity	0.01–0.001	–
	Ismailia canal	600–400	m ² day ⁻¹
Hydraulic conductance	Bahr El-Baqr drain	400–200	m ² day ⁻¹

with a grid size variation. The grid size of the model is split between 1000×1000 m, 500×500 m, and 250×250 m: indicating a low change in the groundwater head with the change of grid. In addition, for cell sizes 1000, 500, and 250 m, the percentages of contamination changes related to cell sizes were +1,19, +0,616, and –0,612%. These values suggest that for future cell dimensions of 333 m, the model is stable.

NDM calibration is a process that shows the difference between calculated values from the numerical model and the observed by observation well in the field (Fig. 5c).

Fig. 4 Sensitivity analysis results for grid size in NDM

Some 32 observation wells are distributed in the study area Fig. 5a. The groundwater flow model showed that the water levels are varied from 16.96 m in the South to zero in the North. The calibration was developed by trial and error to match the model and field results where the Root Mean Square (RMS) is 0.461 m. The residual head is ranged between -0.911 and -0.001 m, the residual mean 0.076 m, and the absolute mean residual is 0.413 m. Normalization root means square is 2.674%, as presented in Fig. 5b. The groundwater velocity and direction are shown in Fig. 5a from the high-head at the South near Cairo to the North's low, connected by the Mediterranean Sea. The water budget for the current model is estimated as presented in Table 2.

The constant head from the Mediterranean Sea and Elburulles lakes (at the North) is 0.11% ($2611.7 \text{ m}^3\text{day}^{-1}$) of the total inflow and 0.74% ($17,708 \text{ m}^3\text{day}^{-1}$) of the total outflow; the aquifer recharge is 85.31 of the total inflow ($2,035,000 \text{ m}^3\text{day}^{-1}$) which is the most parameters for the aquifer recharge, the leakage from the canals is 14.58 ($60,482 \text{ m}^3\text{day}^{-1}$) and 2.54% ($60,482 \text{ m}^3\text{day}^{-1}$) from the total inflow and outflow, respectively.

Fig. 5 Model results for **a** Aerial view of velocity direction, **b** Aerial view of groundwater head and **c** Calculated and observed groundwater head for Nile delta model

Table 2 Water balance parameters for the calibrated model

Parameter	Input		Output		Input–Output m ³ day ^{−1}
	m ³ day ^{−1}	%	m ³ day ^{−1}	%	
Constant head	2611.7	0.11	17,708	0.74	−15,096.3
Recharge	2,035,000	85.31	0	0.00	2,035,000
Canal leakage	347,920	14.58	60,482	2.54	287,438
Wells	0	0.00	1,702,000	71.35	−1,702,000
Drains	0	0.00	605,300	25.37	−605,300
Total	2,385,531.7	100	2,385,490	100	41.7

The wells and drain represent 71.35 (1,702,000 m³day^{−1}) and 25.37% (605,300 m³day^{−1}), respectively. The net between the total input and output flow is 41.7 m³day^{−1}. The solute transport model results for BOD, COD, and TDS are presented in Fig. 6. The concentration reached 2.40653×10^9 3.28165 $\times 10^9$ and 5.7686×10^{10} kg.

2.10 Treatment technologies and methods

The calibrated model was used to simulate three scenarios of groundwater contamination produced by the first is Traditional WWTP that consists of a screen, coagulation, flocculation, lamella clarifiers, disk filters, ozonation chambers, and chlorine contact chambers (EBABWWTP); the second is proposed Sedimentation tank, Wetland and Enhancing Solar water Disinfection (SWESD), and the third is proposed Cascade Aeration, Biofilter or Trickling Filter, Enhancing Solar water Disinfection [(CABFESD)/(CATFESD)] (See Table 3).

The proposed scenarios are carried out for the current study area including, the first is increasing the abstraction rates by 60%, the second is installing the WWTP at the outlet of the main basin drain, the third is the lining of main and sub-basin drain, the fourth is installing the WWTP at the outlet of sub-basin drain, and the fifth is lining the sub-basin drain with installing the WWTP as the outlet of sub-basin drain (Fig. 7).

(i) Sedimentation tank

The fundamental goal of sedimentation is to allow the separation in wastewater of solid and liquid phase fractions. Thus, it eliminates the quickly settled particles, primarily organic and floating substances, such as fats, oils, and fats (Gao and Stenstrom 2018).

(ii) Trickling filters

The filters known as biofilters consisted of an open structure packed with material that permits wastewater filtering. The media can be graded with natural stone, synthetic material randomly packaged, or synthetic material organized. The winding filter is an aerobic treatment method that uses a medium's microorganisms to extract organic materials from wastewater. Trickling filters enable a colony of microorganisms to absorb organic substances in Wastewater (Ahuja et al. 2014).

(iii) Wetlands

Wetlands are widely used for the treatment of wastewater as tertiary treatment. These could be natural systems for discharging a certain-quality effluent or even a built (human) Wetland (Hu et al. 2017). Essentially, wetlands are filters with the accumu-

Fig. 6 The actual view of contaminating distribution in the aquifer for **a** BOD, **b** COD, and **c** TDS

lation of sediments and nutrients. This rich nutrient material fosters plants such as bulrushes, grasses, shingles, water lilies, sedges, and trees to give food and places for many species. Some are entirely wetland-dependent; others utilize only part of their life cycle wetlands, such as nesting (Schenkova et al. 2018). Wetland systems clean water by filtering, settling, and decomposing microbes. Wetlands can also operate as sediments and organic debris filters and become a permanent sink for these chemicals

Table 3 Treatment parameters values

Case	Method	Parameters	Influent (ppm)	Effluent (ppm)
1	Traditional	BOD	82.50	30
		COD	112.5	50
		TDS	2000	1200
2	Sedimentation tank + Wetland + Solar Water Disinfection (SWESD)	BOD	82.50	9
		COD	112.5	11
		TDS	2000	1000
3	Cascade aeration + Sedimentation tank + (Bio Filter or Trickling Filter) + ESD [(CABFESD)/(CATFESD)]	BOD	82.50	4
		COD	112.5	5
		TDS	2000	100

Fig. 7 View for different scenarios for groundwater protection from polluted streams: **a** base case or installing WWTP I, **b** lining of main and sub-main streams and WWTP at the position I, **c** installing WWTP at position II, and **d** installing WWTP at position II and lining of the sub-basin

if buried in the substratum or released into the atmosphere (Gholipour et al. 2020). The mechanisms of wetlands play a part in carbon, nitrogen, and sulfur cycles by converting them into the atmosphere (Vymazal 2011).

(iv) Cascade aeration

Gravity aeration can be done using a simple weir, an inclined corrugated portion of the Sheet, or a stepped cascade. Stepped waterfalls have long been utilized to dissipate, aeration, or remove volatile organic components, especially dam spills

(Roy et al. 2020). The step-mounted cascade comprises steps that allow the water to flow as a thin film. When waterfalls, bubbles rise as the air draws in. There is gas exchange between the air and the water in these bubbles. Oxygen diffuses from air into the water and enhances the water's DO content (Liu and Mauter 2020). The dissolved nitrogen content could be reduced by using step cascades. In drinking water treatment, cascade aeration is used to reoxygenate and remove Volatile Organic Components (VOCs) such as methane and chlorine, dissolved iron and manganese, carbon dioxide, and hydrogen sulfide, and volatile oils' color and tastes (Moulick et al. 2010).

(v) Solar water disinfection (SODIS) + H_2O_2

Solar water disinfection (SODIS) is a simple, environmentally sustainable, cheap water treatment method that successfully eliminates fungus, viruses, and protozoa. Solar ultraviolet (UV) light can kill microorganisms by direct or indirect processes. H_2O_2 has been demonstrated to provide significant disinfection enhancement with SODIS. It is decomposed into water and oxygen after the disinfection process (Jin et al. 2020).

(vi) Lining

The second protection method for groundwater contamination is applied using the lining of polluted streams for the Bahr El-Baqar drain (main basin). It branches (sub-basin) using the low permeability of High-Density Polyethylene (HDPE) geomembrane. The material permeability of the lining is 8.64×10^{-10} m/day.

3 Results

3.1 impact of changing the hydrological force on GWQ

Over-pumping negatively impacts drinking and irrigation water from groundwater resources, as presented in Fig. 8.

This scenario is carried out by increasing the pumping rates by 60% due to increase population growth. The water resources sources are fixed or subjected to decrease by climate changes in arid and semi-arid rejoins. The well abstraction rates are increased from 1,702,019 to 2,553,029 $m^3 day^{-1}$; the results showed that over-pumping increases groundwater contamination to reach 2.93889×10^9 , 4.0076×10^9 , 7.12467×10^{10} kg for BOD, COD, and TDS, respectively.

3.2 Impact of WWTP location at the outlet of polluted streams

This scenario is carried out by installing the WWTP at the main basin drain (location I) outlet, as presented in Fig. 7. The results show that the groundwater is damaged along the polluted drain path. There is no protection for this essential source. Thus, the location of WWTP at the outlet of the main sub-basin has zero positive environmental effects for groundwater protection. Simultaneously, the treated wastewater is used in irrigation at the end of the basin region.

Fig. 8 Relationship between the aquifer salt mass and the contaminant sources for the hydrological force

3.3 Impact of lining method in stream's water quality

The relation between the aquifer salt mass and the contaminant sources for the lining of the main and sub-main polluted basin is presented in Fig. 9. The lining of the main basin drains, and the sub-basin drain using High-Density Polyethylene (HDPE) geomembrane is carried out. The permeability of the lining is assigned by 8.64×10^{10} m/day. The contamination reached 1.02853×10^9 , 1.40255×10^9 , and 2.49343×10^{10} kg for BOD, COD, and TSD, respectively.

3.4 Impact of WWTP location on GWQ

WWTP location is changed in this scenario to install at the sub-basin's outlet (location II), as presented in Fig. 7. The treated wastewater will be delivered in the main basin using the four methods of treatment be 30, 50, and 1200 ppm for BOD, COD, and TDS, respectively, for the first is Existing Bahr El-Baqar WWTP that consists of a screen, coagulation, flocculation, lamella clarifiers, disk filters, ozonation chambers, and chlorine contact chambers (EBABWWTP), the second method proposed Sedimentation tank, Wetland and Enhancing Solar water Disinfection (SWESD) is 9, 11, and 1000 ppm; also, the third is Cascade Aeration, Biofilter or Trickling Filter, ESD

Fig. 9 The relationship between the aquifer salt mass and the contaminant sources for the lining of polluted main and sub-main basins

$[(\text{CABFESD})/(\text{CATFESD})]$ of 4, 5, and 100. The contamination reached 1.73945×10^9 , 2.57968×10^9 , and 5.29693×10^{10} kg for BOD, also it is reached 1.25967×10^9 , 1.68867×10^9 , and 4.83999×10^{10} kg for COD, while it is reached 1.14547×10^9 , 1.55164×10^9 , and 2.78385×10^{10} kg for TDS, respectively (Fig. 10a).

3.5 Impact of lining method on GWQ

From the WWTP location at the sub-basin, as presented in the above scenario, the groundwater at the sub-basin is still damaged by the polluted drain. This scenario is proposed to apply the lining for the sub-basin drain using High-Density Polyethylene (HDPE) geomembrane. The current study is assigned by installing the lining of the sub-basin polluted drain; the permeability value is 8.64×10^{-10} m/day, while the WWTP concentration values are applied as presented in the previous section. The contamination reached 1.16737×10^9 , 1.79865×10^9 , and 3.90526×10^{10} kg for BOD, also it is reached 6.8972×10^8 , 9.11581×10^8 , and 3.45035×10^{10} kg for COD, while it is reached 5.75987×10^8 , 7.75102×10^8 , and 1.40325×10^{10} kg for TDS, respectively (Fig. 10b).

Fig. 10 Relationship between the aquifer salt mass and the contaminant sources for different WWTP locations at the polluted sub-main basin **a** without a lining of the sub-main basin and **b** lining of the sub-main basin

4 Discussion

From the previous scenarios, the total polluted streams lengths are 232 km at the current situation (base case) in which 107 km for the main basin and 125 km for the sub-main basin as presented in Fig. 7a; the second scenario showed that increasing the hydrological force by 60% lead to an increase the aquifer contamination by 22.12, 22.12, and 23.51% from the base case (Table 4). Moreover, construction of the WWPT at the outlet of the main basin (a position I) does not affect groundwater protection (0%), while the lining of polluted streams with a length of 232 km for main and sub-main basin will reduce the groundwater contamination by 57.26, 57.26, and 56.78%. Also, the construction of the WWTP at the outlet of the polluted sub-main basin will improve the water quality for the main basin with a length of 107 km. The groundwater contamination is reached 27.72, 21.39, and 8.18% using the EBABWWTP method, while using the SWESD method, the contamination reached 47.66, 48.54, and 16.10%. When the CABFESD method was implemented, the contamination reached 52.40, 52.72, and 51.74% for BOD, COD, and TDS. Moreover, the treatment of main basin water with a length of 107 km and lining the sub-main basin of 125 km improve the groundwater protection. Using the traditional method, the contamination reduction to 51.49, 45.19, and 32.30% reached 71.34, 72.22, and 40.19% using the SWESD method. In contrast, it reached 76.07, 76.38, and 75.67% using the CABFESD method for BOD, COD, and TDS, respectively (Table. 4). From these results, the best location for WWPT is the outlet of the sub-main basin, and the best treatment method is the CABFESD method for groundwater management.

4.1 Impact of WWTP location and lining method in stream's water quality

Regulations are needed to decrease hazards and optimize wastewater management, limiting the negative effect of wastewater use while supporting other advantages. The key objective for farmers is to raise their production by using wastewater as a rich nutrient and increasing their net return on agriculture. Present new and creative regulations influence wastewater management costs (Priya et al. 2021; Stentoft et al. 2021). Small-scale industries and corporations can apply effluent standards and fees to improve wastewater management. Policies and institutional structures could contribute to collecting cash to encourage wastewater savings and reuse. Maintain and invest in wastewater treatment plants and programs to improve wastewater utilization for different purposes.

The pursuit of sensible water management solutions will become more active if we identify wastewater resource potential, substantial economic development opportunities, and growth (Capodaglio 2017). The treatment of wastewater is a desirable method to mitigate the risk of agricultural, industrial, and urban by-products. Economic valuation indicators will be utilized to determine the value of direct and indirect wastewater use, which is directly linked to agricultural costs and benefits. The cost–benefit analysis follows direct/indirect components of wastewater discharge, agricultural practices, crop yield, policy, and socioeconomic conditions, maximizing agricultural wastewater reuse's direct and direct cost (Arena et al. 2020).

However, investors are reluctant to finance water infrastructure projects that need high costs and long periods of development (Ait-Mouheb et al. 2020). Expenditures of the wastewater treatment facility can be divided into public funding investment and maintenance costs. Wastewater should be treated to a quality suitable to end-users and farmers to

Table 4 Water balance parameters for the calibrated model

TWWP position	Protection Scenario	WWPT type	Polluted Stream lengths km	Salt mass (kg)*10 ⁹			Aquifer protection (%)		
				BOD	COD	TDS	BOD	COD	TDS
Base	–	–	232	2.41	3.28	57.69	–	–	–
Abstraction	–	–	232	2.94	4.01	71.25	+ 22.12	+ 22.12	+ 23.51
At the outlet of the main basin (I)	–	EBABWWTP	232	2.94	4.01	71.25	0	0	0
	–	SWESD	232	2.94	4.01	71.25	0	0	0
	–	CABFESD	232	2.94	4.01	71.25	0	0	0
	–	–	0	1.03	1.40	24.93	– 57.26	– 57.26	– 56.78
At out let of sub-main basin (II)	Lining MB + SMB	–	0	1.03	1.40	24.93	– 57.26	– 57.26	– 56.78
	Treatment MB	EBABWWTP	125	1.74	2.58	52.97	– 27.72	– 21.39	– 8.18
	–	SWESD	125	1.26	1.69	48.40	– 47.66	– 48.54	– 16.10
	–	CABFESD	125	1.15	1.55	27.84	– 52.40	– 52.72	– 51.74
Treatment MB + lining SMB	–	EBABWWTP	0	1.17	1.80	39.05	– 51.49	– 45.19	– 32.30
	–	SWESD	0	0.69	0.91	34.50	– 71.34	– 72.22	– 40.19
	–	CABFESD	0	0.58	0.78	14.03	– 76.07	– 76.38	– 75.67
	–	–	0	0.58	0.78	14.03	– 76.07	– 76.38	– 75.67

implement the wastewater reuse program. The cost–benefit relationship in wastewater reuse illustrates that private and public investments could benefit economically and socially.

In short, we found that the expanding population in emerging countries, such as India, has drastically increased urban wastewater. The reuse of wastewater has been a solution to the ongoing depletion of freshwater reserves. The method must include fertilizer recycling/reuse, lowering excessive nutrient stress on irrigated land, and enhancing agricultural yield. In the waste and water management industry, efficient and effective wastewater technology and management bestow the considerable co-benefits for sustainable development. Water recycling and reuse are designed to end the water cycle and allow for the sustainable reuse of the water resources available to tackle water security challenges (Djuma et al. 2016; Famiglietti 2014).

4.2 Risks of polluted stream's water recycling

There are several issues about health and environmental matters. Irrigation-induced rivers and rainfall runoff from irrigated areas may lead to eutrophication of surface water if not regulated. As salt levels are increased in recycled water, there is a risk of salination of the root zone (Hou et al. 2020).

(i) Impacts on irrigation, drinking water quality, and quantity

The impact of the recycled water quality depending on its use is relatively unknown. For example, difficulties with water quality can lead to real or imagined problems in agriculture, including concentrations of nutrients, salts, heavy metals when water is reused (Al-Saidi et al. 2021). In particular, reuse systems should contain a multi-barrier treatment framework consisting of advanced unit processes, particularly drinking applications. To be successful, they should incorporate resilience (i.e., the ability to adjust for upsets), redundancy (i.e., backup systems), and robustness (i.e., multi-contaminant properties) simultaneously. Treated wastewater is generally dumped into rivers and lakes, which are then used as potable water sources. Water demands have made the processing of wastewater flows a lucrative and readily available source of crude water. The recycled water is initially disinfected and filtered before discharge to the groundwater supply (Rizzi et al. 2020). Several biophysical impacts are associated with recycled water for different uses (Fernández et al. 2020). Higher concentrations of nitrate and organic nitrogen can affect soil quality over time. Salinity levels can affect less tolerant crops and contribute to saline groundwater. Several uses also retain the risk of human infection through physical contact and inhalation, which must also be managed (Harmanescu et al. 2011). Wastewater discharges may support receiving waters' health, especially inland waterways; wastewater may contribute to certain aspects of ecosystem function by supporting minimum flows (Hou et al. 2020).

(ii) Impacts on ecosystems

With the growing demand for freshwater in urban and agricultural areas, water systems have few choices to maintain their different ecohydrological requirements (Elliott et al. 2016; Harmanescu et al. 2011). Environmental uses for water reuse include constructing river and wetland habitats and increasing current water supplies to improve aquatic biota conditions. In addition to ecological benefits, there might also be economic benefits from such projects (for example, increased tourist, and storm protection) (Mainstone and Parr 2002). However, the ecological risk of

such proposed uses must be addressed to establish an acceptable environmental risk level concerning benefits (El-sayed 2020). The problems with irrigation salinity are typically aggravated by the sodium effect (Na^+) on the dispersion of soil colloids, resulting in a loss of soil structure. This phenomenon reduces salt drainage potential and speeds up salt build-up in the root zone. The dispersion of soil colloids is altered in irrigation water by the ratio of Na^+ to divalent cation calcium (Ca^{2+}) and magnesium (Mg^{2+}) (Wang et al. 2011).

(iii) Impacts on human's health

Microbial contamination is probably the most often discussed and investigated topic concerning recycled water irrigation. One reason is the possibility of greater human contamination than chemical compound contamination (Bhowmick et al. 2020; Li et al. 2021). Open-air irrigation can be contaminated by exposure to spray drift and hand-to-mouth exposure. Many researchers utilize Quantitative Microbial Risk Assessing (QMRA) model to evaluate the yearly risk of virus infection using raw vegetables irrigated with recycled water (Nauta 2000; Schijven et al. 2011; Zwietering and van Gerwen 2000).

5 Conclusions

This study used the MODFLOW model to simulate groundwater contamination and protection from polluted streams; the study was applied to Egypt's Nile Delta aquifer. It is hard to pollute from the main basin of Bahr El-Baqar drains. This research examines the location of WWTP on groundwater protection by installing the plant at the outlet of the polluted main basin and the outlet of the polluted sub-main basin. Moreover, the location was investigated using polluted main and sub-main basin lining at the two locations. Three treatment cases were considered, including the first is Existing Bahr El-Baqar WWTP that consists of a screen, coagulation, flocculation, lamella clarifiers, disk filters, ozonation chambers, and chlorine contact chambers (EBABWWTP), the second is the proposed Sedimentation tank, Wetland and Enhancing Solar water Disinfection (SWESD), and the third is proposed Cascade Aeration, Biofilter or Trickling Filter, ESD [(CABFESD)/(CATFESD)]. The solute transport model results reached 2.40653×10^9 , 3.28165×10^9 , and 5.7686×10^{10} kg at the base case. Simultaneously, it increased to 2.93889×10^9 , 4.0076×10^9 , and 7.12467×10^{10} kg for BOD, COD, and TDS, respectively, at over-pumping a negative environmental on drinking and irrigation water from groundwater resources. Moreover, the location of WWTP at the outlet of the main sub-basin has zero positive environmental effects for groundwater protection. Simultaneously, the treated wastewater is used in irrigation at the end of the basin region. In contrast, the main basin drain and the sub-basin drain lining using High-Density Polyethylene (HDPE) by 8.64×10^{-10} m/day decreased the contamination to 1.02853×10^9 , 1.40255×10^9 and 2.49343×10^{10} kg. The contamination reached 1.73945×10^9 , 2.57968×10^9 and 5.29693×10^{10} kg for BOD, also it is reached 1.25967×10^9 , 1.68867×10^9 and 4.83999×10^{10} kg for COD, while it is reached 1.14547×10^9 , 1.55164×10^9 and 2.78385×10^{10} kg for TDS, respectively, for installing the WWTP at the outlet of polluted sub-basin without lining of sub-basin while using the sub-basin lining decreased the contamination reached 1.16737×10^9 , 1.79865×10^9 and 3.90526×10^{10} kg for BOD, also it is reached 6.8972×10^8 , 9.11581×10^8 and 3.45035×10^{10} kg for COD, while it is reached 5.75987×10^8 , 7.75102×10^8 and 1.40325×10^{10} kg for TDS, respectively.

The results showed that increasing the hydrological force by 60% lead to an increase in the aquifer contamination by 22.12, 22.12, and 23.51% from the base case; also, the construction of the EBABWWTP at the outlet of the main basin (the position I) does not affect groundwater protection (0%), while the reduction in groundwater contamination by 57.26, 57.26, and 56.78% using the lining of polluted streams with a length of 232 km for the main and sub-main basin. Moreover, the reduction in groundwater contamination reached 27.72, 21.39, and 8.18% using the EBABWWTP method while using the SWESD method; the contamination reached 47.66, 48.54, and 16.10%, also using the CABFESD method the contamination reached 52.40, 52.72, and 51.74% for BOD, COD, and TDS, respectively, at the construction of the WWTP at the outlet of the polluted sub-main basin with a length of 107 km. Finally, treatment of main basin water with a length of 107 km and lining the sub-main basin of 125 km improves groundwater protection. Using the traditional method, the contamination reduction to 51.49, 45.19, and 32.30% reached 71.34, 72.22, and 40.19% using the SWESD method. It reached 76.07, 76.38, and 75.67% using the CABFESD method for BOD, COD, and TDS, respectively, which is considered the best solution for groundwater management in high-stress water regions. The current study recommended increasing the installing of WWTP and wastewater technology to improve the efficiency of wastewater reuse for quality and quantity in high water stress and populated area. Also, the environmental risks of the polluted streams for wastewater recycling on irrigation, drinking water, ecosystem, and human health should be applied in these arid and semi-arid regions to increase groundwater sustainability.

Acknowledgements The authors are grateful to Shakeel Ahmad Bhat and Martina Zelenakova for their contribution in improving the published version of this paper. Alban Kuriqi acknowledges the Portuguese Foundation for Science and Technology (FCT) support through PTDC/CTA-OHR/30561/2017 (WinTherface).

Authors contributions: I.A.-E., A.K., and A.E.S. contributed to conceptualization, methodology, investigation, formal analysis, data curation, visualization, writing—original draft, writing—review and editing. A.K. and A.E.S. contributed to writing—review and editing, resources. A.K. contributed to supervision.

Funding This study did not receive any funding.

Declarations

Conflicts of interest The authors declare no conflict of interest.

References

- Abd-Elaty I, Pugliese L, Zelenakova M, Mesaros P, Shinawi AE (2020) Simulation-based solutions reducing soil and groundwater contamination from fertilizers in arid and semi-arid regions: case study the eastern Nile delta. *Egypt Int J Environ Res Public Health* 17:9373
- Abd-Elaty I, Zelenakova M, Straface S, Vranayová Z, Abu-hashim M (2019) Integrated modelling for groundwater contamination from polluted streams using new protection process techniques. *Water* 11:2321
- Abd-Elhamid HF, Abdelaal GM, Abd-Elaty I, Said AM (2019) Efficiency of using different lining materials to protect groundwater from leakage of polluted streams. *J Water Supply Res Technol Aqua* 68:448–459. <https://doi.org/10.2166/aqua.2019.032>
- Abd Ellah RG (2020a) Physical properties of inland lakes and their interaction with global warming: a case study of Lake Nasser Egypt. *Egypt J Aquat Res* 46:103–115. <https://doi.org/10.1016/j.ejar.2020.05.004>
- Abd Ellah RG (2020b) Water resources in Egypt and their challenges, Lake Nasser case study. *Egypt J Aquat Res* 46:1–12. <https://doi.org/10.1016/j.ejar.2020.03.001>

- Abdalla HM, Mohamed FH (1999) Mineralogical and geochemical investigation of emerald and beryl mineralisation, Pan-African belt of Egypt: genetic and exploration aspects. *J Afr Earth Sc* 28:581–598. [https://doi.org/10.1016/S0899-5362\(99\)00033-0](https://doi.org/10.1016/S0899-5362(99)00033-0)
- Abdelhady AA, Fürsich FT (2015) Palaeobiogeography of the Bajocian-Oxfordian macrofauna of Gebel Maghara (North Sinai, Egypt): implications for eustasy and basin topography. *Palaeogeogr Palaeoclimatol Palaeoecol* 417:261–273. <https://doi.org/10.1016/j.palaeo.2014.10.042>
- Ahuja S, Larsen MC, Eimers JL, Patterson CL, Sengupta S, Schnoor JL (2014) Comprehensive water quality and purification. Elsevier, Amsterdam
- Ait-Mouheb N, Mayaux P-L, Mateo-Sagasta J, Hartani T, Molle B (2020) Chapter 5—Water reuse: a resource for Mediterranean agriculture. In: Zribi M, Brocca L, Trambly Y, Molle F (eds) Water resources in the mediterranean region. <https://doi.org/10.1016/B978-0-12-818086-0.00005-4>
- Al-Saidi M, Das P, Saadaoui I (2021) Circular economy in basic supply: framing the approach for the water and food sectors of the gulf cooperation council countries. *Sustain Prod Consump* 27:1273–1285. <https://doi.org/10.1016/j.spc.2021.03.004>
- Allam A, Tawfik A, Yoshimura C, Fleifle A (2016) Simulation-based optimization framework for reuse of agricultural drainage water in irrigation. *J Environ Manage* 172:82–96. <https://doi.org/10.1016/j.jenvman.2016.02.022>
- Arena C, Genco M, Mazzola MR (2020) Environmental benefits and economical sustainability of urban wastewater reuse for irrigation—a cost-benefit analysis of an existing reuse project in Puglia Italy. *Water* 12:2926
- Barnes J (2014) Mixing waters: the reuse of agricultural drainage water in Egypt. *Geoforum* 57:181–191. <https://doi.org/10.1016/j.geoforum.2012.11.019>
- Bhowmick GD, Dhar D, Nath D, Ghangrekar MM, Banerjee R, Das S, Chatterjee J (2020) Coronavirus disease 2019 (COVID-19) outbreak: some serious consequences with urban and rural water cycle. *NPJ Clean Water* 3:32. <https://doi.org/10.1038/s41545-020-0079-1>
- Capodaglio AG (2017) Integrated, decentralized wastewater management for resource recovery in rural and peri-urban areas. *Resources* 6:22
- Darwish K, Safaa M, Momou A, Saleh SA (2013) Egypt: land degradation issues with special reference to the impact of climate change. In: Heshmati GA, Squires VR (eds) Combating desertification in Asia, Africa and the middle East: Proven practices. Springer, Netherlands, pp 113–136. https://doi.org/10.1007/978-94-007-6652-5_6
- De Filippis G, Giudici M, Negri S, Margiotta S, Cattaneo L, Vassena C (2014) Numerical modeling of groundwater flow in the coastal aquifer system of Taranto (southern Italy). Paper presented at the EGU General Assembly Vienna, Austria, May 01, 2014
- Djuma H, Bruggeman A, Eliades M, Lange MA (2016) Non-conventional water resources research in semi-arid countries of the Middle East. *Desalin Water Treat* 57:2290–2303. <https://doi.org/10.1080/19443994.2014.984930>
- El-Arabi M (2007) Environmental impact of new settlements in groundwater in a region in the Nile Delta. M. Sc. Thesis, Fac. of Eng., Zagazig University
- El-Fayoumi I (1968) Geology of groundwater supplies in the Eastern region of the Nile Delta and its extension in the North Sinai. Cairo University
- El-Rawy M, Abdalla F, El Alfy M (2020) Water Resources in Egypt. In: Hamimi Z, El-Barkooky A, Martínez Frías J, Fritz H, Abd El-Rahman Y (eds) The geology of Egypt, Springer, Cham, pp 687–711. https://doi.org/10.1007/978-3-030-15265-9_18
- El-Sadek A (2010) Water desalination: an imperative measure for water security in Egypt. *Desalination* 250:876–884. <https://doi.org/10.1016/j.desal.2009.09.143>
- El-sayed MEA (2020) Nanoadsorbents for water and wastewater remediation. *Sci Total Environ* 739:139903. <https://doi.org/10.1016/j.scitotenv.2020.139903>
- El Sharawy MS, Nabawy BS (2018) The role of gamma-ray logs in deciphering geochemical and geological aspects of the Rudeis Formation, Gulf of Suez Egypt. *Arab J Geosci* 11:242. <https://doi.org/10.1007/s12517-018-3560-0>
- Elliott M, Mander L, Mazik K, Simenstad C, Valesini F, Whitfield A, Wolanski E (2016) Ecoengineering with ecohdrology: successes and failures in estuarine restoration. *Estuar Coast Shelf Sci* 176:12–35. <https://doi.org/10.1016/j.ecss.2016.04.003>
- Famiglietti JS (2014) The global groundwater crisis. *Nat Clim Chang* 4:945–948. <https://doi.org/10.1038/nclimate2425>
- Fanack (2021) Water Infrastructure in Egypt. https://water.fanack.com/egypt/water-infrastructure/#_ftn5.
- Fernández JE, Alcon F, Diaz-Espejo A, Hernandez-Santana V, Cuevas MV (2020) Water use indicators and economic analysis for on-farm irrigation decision: a case study of a super high density olive tree orchard. *Agric Water Manag* 237:106074. <https://doi.org/10.1016/j.agwat.2020.106074>

- Gao H, Stenstrom MK (2018) Evaluation of three turbulence models in predicting the steady state hydrodynamics of a secondary sedimentation tank. *Water Res* 143:445–456. <https://doi.org/10.1016/j.watres.2018.06.067>
- Gholipour A, Zahabi H, Stefanakis AI (2020) A novel pilot and full-scale constructed wetland study for glass industry wastewater treatment. *Chemosphere* 247:125966. <https://doi.org/10.1016/j.chemosphere.2020.125966>
- Ghoubachi SY (2016) Geology of groundwater occurrences of the Lower Cretaceous sandstone aquifer in East Central Sinai Egypt. *Acque Sotterranee Italian J Groundwater*. <https://doi.org/10.7343/as-2016-241>
- Giusti L (2009) A review of waste management practices and their impact on human health. *Waste Manage* 29:2227–2239. <https://doi.org/10.1016/j.wasman.2009.03.028>
- Gupta N, Khan DK, Santra SC (2009) Prevalence of intestinal helminth eggs on vegetables grown in wastewater-irrigated areas of Titagarh, West Bengal, India. *Food Control* 20:942–945. <https://doi.org/10.1016/j.foodcont.2009.02.003>
- Harmanescu M, Alda LM, Bordean DM, Gogoasa I, Gergen I (2011) Heavy metals health risk assessment for population via consumption of vegetables grown in old mining area; a case study: Banat County Romania. *Chem Central J* 5:64. <https://doi.org/10.1186/1752-153X-5-64>
- Hashim MA, Mukhopadhyay S, Sahu JN, Sengupta B (2011) Remediation technologies for heavy metal contaminated groundwater. *J Environ Manage* 92:2355–2388. <https://doi.org/10.1016/j.jenvman.2011.06.009>
- Hendawy E, Belal AA, Mohamed ES, Elfadaly A, Murgante B, Aldosari AA, Lasaponara R (2019) The prediction and assessment of the impacts of soil sealing on agricultural land in the North Nile Delta (Egypt) using satellite data and GIS modeling. *Sustainability* 11:4662
- Hervás-Gómez C, Delgado-Ramos F (2020) Cross-subsidies between water users in Spain: the Guadalquivir river basin case. *Water Resour Manage* 34:4577–4591. <https://doi.org/10.1007/s11269-020-02675-5>
- Hou C, Fu H, Liu X, Wen Y (2020) The effect of recycled water information disclosure on public acceptance of recycled water—Evidence from residents of Xi'an China. *Sustain Cities Soc* 61:102351. <https://doi.org/10.1016/j.scs.2020.102351>
- Hu S, Niu Z, Chen Y, Li L, Zhang H (2017) Global wetlands: potential distribution, wetland loss, and status. *Sci Total Environ* 586:319–327. <https://doi.org/10.1016/j.scitotenv.2017.02.001>
- Jeong H, Kim H, Jang T (2016) Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainable wastewater reuse in South Korea. *Water* 8:169
- Jin Y et al (2020) Enhancement of solar water disinfection using H₂O₂ generated in situ by electrochemical reduction. *Appl Catal B* 267:118730. <https://doi.org/10.1016/j.apcatb.2020.118730>
- Kehrein P, van Loosdrecht M, Osseweijer P, Garfi M, Dewulf J, Posada J, Technology, (2020) A critical review of resource recovery from municipal wastewater treatment plants—market supply potentials, technologies and bottlenecks. *Environ Sci Water Res* 6:877–910
- Khedr M (2019) Challenges and Issues in Water, Climate Change, and Food Security in Egypt. In: Negm AM (ed) *Conventional water resources and agriculture in Egypt*, Springer, Cham, pp 229–243. https://doi.org/10.1007/978_2017_67
- Lahrich S, Laghrib F, Farahi A, Bakasse M, Saqrane S, El Mhammedi MA (2021) Review on the contamination of wastewater by COVID-19 virus: Impact and treatment. *Sci Total Environ* 751:142325. <https://doi.org/10.1016/j.scitotenv.2020.142325>
- Li P, Karunanidhi D, Subramani T, Srinivasamoorthy K (2021) Sources and consequences of groundwater contamination. *Arch Environ Contam Toxicol* 80:1–10. <https://doi.org/10.1007/s00244-020-00805-z>
- Liu Y, Mauter MS (2020) Assessing the demand response capacity of US drinking water treatment plants. *Appl Energy* 267:114899. <https://doi.org/10.1016/j.apenergy.2020.114899>
- Luo P et al (2020) Historical assessment and future sustainability challenges of Egyptian water resources management. *J Clean Prod* 263:121154. <https://doi.org/10.1016/j.jclepro.2020.121154>
- Mabrouk MB, Jonoski A, Solomatine D, Uhlenbrook S (2013) A review of seawater intrusion in the Nile Delta groundwater system – the basis for assessing impacts due to climate changes and water resources development. *Hydrol Earth Syst Sci Discuss* 2013:10873–10911. <https://doi.org/10.5194/hessd-10-10873-2013>
- Mainstone CP, Parr W (2002) Phosphorus in rivers—ecology and management. *Sci Total Environ* 282–283:25–47. [https://doi.org/10.1016/S0048-9697\(01\)00937-8](https://doi.org/10.1016/S0048-9697(01)00937-8)
- Meffe R, de Bustamante I (2014) Emerging organic contaminants in surface water and groundwater: a first overview of the situation in Italy. *Sci Total Environ* 481:280–295. <https://doi.org/10.1016/j.scitotenv.2014.02.053>
- Mitsch WJ, Gosselink JG (2000) The value of wetlands: importance of scale and landscape setting. *Ecol Econ* 35:25–33. [https://doi.org/10.1016/S0921-8009\(00\)00165-8](https://doi.org/10.1016/S0921-8009(00)00165-8)

- Mitsch WJ, Zhang L, Waletzko E, Bernal B (2014) Validation of the ecosystem services of created wetlands: two decades of plant succession, nutrient retention, and carbon sequestration in experimental riverine marshes. *Ecol Eng* 72:11–24. <https://doi.org/10.1016/j.ecoleng.2014.09.108>
- Molle F, Gaafar I, El-Agha DE, Rap E (2016) Irrigation efficiency and the Nile Delta water balance. Egypt
- Morsy W (2009a) Environmental management to groundwater resources for Nile Delta region. Cairo University
- Morsy W (2009b) Environmental management to groundwater resources for Nile Delta region. Cairo University
- Moulick S, Tambada NV, Singh BK, Mal BC (2010) Aeration characteristics of a rectangular stepped cascade system. *Water Sci Technol* 61:415–420. <https://doi.org/10.2166/wst.2010.828>
- Nauta MJ (2000) Separation of uncertainty and variability in quantitative microbial risk assessment models. *Int J Food Microbiol* 57:9–18. [https://doi.org/10.1016/S0168-1605\(00\)00225-7](https://doi.org/10.1016/S0168-1605(00)00225-7)
- Omran E-SE, Abd El Razek AA, Management E (2012) Mapping and screening risk assessment of heavy metals concentrations in soils of the Bahr El-Baker Region Egypt. *J Soil Sci* 3:182–195
- Oude Essink GHP (2001) Improving fresh groundwater supply—problems and solutions. *Ocean Coast Manag* 44:429–449. [https://doi.org/10.1016/S0964-5691\(01\)00057-6](https://doi.org/10.1016/S0964-5691(01)00057-6)
- Peters NE, Meybeck M (2000) Water quality degradation effects on freshwater availability: impacts of human activities. *Water Int* 25:185–193. <https://doi.org/10.1080/02508060008686817>
- Priya AK, Pachaiappan R, Kumar PS, Jalil AA, Vo D-VN, Rajendran S (2021) The war using microbes: a sustainable approach for wastewater management. *Environ Pollut* 275:116598. <https://doi.org/10.1016/j.envpol.2021.116598>
- Prommer H, Barry DA, Zheng C (2003) MODFLOW/MT3DMS-based reactive multicomponent transport modeling. *Groundwater* 41:247–257. <https://doi.org/10.1111/j.1745-6584.2003.tb02588.x>
- Rana G, Katerji N (2000) Measurement and estimation of actual evapotranspiration in the field under Mediterranean climate: a review. *Eur J Agron* 13:125–153. [https://doi.org/10.1016/S1161-0301\(00\)00070-8](https://doi.org/10.1016/S1161-0301(00)00070-8)
- Ritter K (2002) Sources, pathways, and relative risks of contaminants in surface water and groundwater: a perspective prepared for the walkerton inquiry. *J Toxicol Environ Health A* 65:1–142. <https://doi.org/10.1080/15287390275338572>
- Rizzi V, Gubitosa J, Fini P, Romita R, Agostiano A, Nuzzo S, Cosma P (2020) Commercial bentonite clay as low-cost and recyclable “natural” adsorbent for the Carbendazim removal/recover from water: overview on the adsorption process and preliminary photodegradation considerations. *Colloids Surf, A* 602:125060. <https://doi.org/10.1016/j.colsurfa.2020.125060>
- Rizzini A, Vezzani F, Cococetta V, Milad G (1978) Stratigraphy and sedimentation of a neogene—quaternary section in the Nile Delta area (A.R.E.). *Mar Geol* 27:327–348. [https://doi.org/10.1016/0025-3227\(78\)90038-5](https://doi.org/10.1016/0025-3227(78)90038-5)
- Roy SM, Moulick S, Mukherjee CK (2020) Design characteristics of perforated pooled circular stepped cascade (PPCSC) aeration system. *Water Supply* 20:1692–1705. <https://doi.org/10.2166/ws.2020.078%JWaterSupply>
- Rutkowski T, Raschid-Sally L, Buechler S (2007) Wastewater irrigation in the developing world—Two case studies from the Kathmandu Valley in Nepal. *Agric Water Manag* 88:83–91. <https://doi.org/10.1016/j.agwat.2006.08.012>
- Salem HS, Yihdego Y, Muhammed HH (2020) The status of freshwater and reused treated wastewater for agricultural irrigation in the occupied palestinian territories. *J Water Health* 19:120–158. <https://doi.org/10.2166/wh.2020.216>
- Sallam ES, Abd El-Aal AK, Fedorov YA, Bobrysheva OR, Ruban DA (2018) Geological heritage as a new kind of natural resource in the Siwa Oasis, Egypt: the first assessment, comparison to the Russian South, and sustainable development issues. *J Afr Earth Sc* 144:151–160. <https://doi.org/10.1016/j.jafrearsci.2018.04.008>
- Schenkova J, Bílková M, Polášková V, Horsák M, Schläghamerský J (2018) Variation of Clitellata (Annelida) assemblages related to water saturation in groundwater-dependent wetlands. *Hydrobiologia* 823:49–65. <https://doi.org/10.1007/s10750-018-3695-8>
- Schijven JF, Teunis PFM, Rutjes SA, Bouwknegt M, de Roda Husman AM (2011) QMRAspot: a tool for quantitative microbial risk assessment from surface water to potable water. *Water Res* 45:5564–5576. <https://doi.org/10.1016/j.watres.2011.08.024>
- Sherif M, Sefelnasr A, Javadi A (2012) Incorporating the concept of equivalent freshwater head in successive horizontal simulations of seawater intrusion in the Nile Delta aquifer Egypt. *J Hydrol* 464:465:186–198. <https://doi.org/10.1016/j.jhydrol.2012.07.007>
- Shiklomanov IA (2000) Appraisal and assessment of world water resources. *Water Int* 25:11–32. <https://doi.org/10.1080/02508060008686794>

- Stein S, Sola F, Yechieli Y, Shalev E, Sivan O, Kasher R, Vallejos A (2020) The effects of long-term saline groundwater pumping for desalination on the fresh–saline water interface: field observations and numerical modeling. *Sci Total Environ* 732:139249. <https://doi.org/10.1016/j.scitotenv.2020.139249>
- Stentoft PA, Munk-Nielsen T, Møller JK, Madsen H, Valverde-Pérez B, Mikkelsen PS, Vezzaro L (2021) Prioritize effluent quality, operational costs or global warming?—Using predictive control of wastewater aeration for flexible management of objectives in WRRFs. *Water Res* 196:116960. <https://doi.org/10.1016/j.watres.2021.116960>
- Strzepek KM, Yates DN (2000) Responses and thresholds of the Egyptian economy to climate change impacts on the water resources of the Nile River. *Clim Change* 46:339–356. <https://doi.org/10.1023/A:1005603411569>
- Taha A, El-Mahmoudi A, El-Haddad I (2004) Pollution sources and related environmental impacts in the new communities southeast Nile Delta Egypt. *Emirates J Eng Res* 9:35–49
- Tahir F, Baloch AAB, Ali H (2020) Resilience of Desalination Plants for Sustainable Water Supply in Middle East. In: Khaiteh PA, Erechchoukova MG (eds) *Sustainability perspectives: science, policy and practice: a global view of theories, policies and practice in sustainable development*. Springer, Cham, pp 303–329. https://doi.org/10.1007/978-3-030-19550-2_15
- Turhan Y (2021) The hydro-political dilemma in Africa water geopolitics: the case of the Nile river basin. *Afr Security Rev* 30:66–85. <https://doi.org/10.1080/10246029.2020.1844775>
- Vymazal J (2011) Constructed wetlands for wastewater treatment: five decades of experience. *Environ Sci Technol* 45:61–69. <https://doi.org/10.1021/es101403q>
- Wagh VM, Panaskar DB, Mukate SV, Gaikwad SK, Muley AA, Varade AM (2018) Health risk assessment of heavy metal contamination in groundwater of Kadava River Basin, Nashik, India. *Model Earth Syst Environ* 4:969–980. <https://doi.org/10.1007/s40808-018-0496-z>
- Wang W-J et al (2011) Addition of HPMA affects seed germination, plant growth and properties of heavy saline-alkali soil in northeastern China: comparison with other agents and determination of the mechanism. *Plant Soil* 339:177–191. <https://doi.org/10.1007/s11104-010-0565-1>
- WHO (2020) Modes of transmission of virus causing COVID-19: implications for IPC precaution recommendations: scientific brief, 27 March 2020. World Health Organization
- Xue S, Liu Y, Liu S, Li W, Wu Y, Pei Y (2018) Numerical simulation for groundwater distribution after mining in Zhuanlongwan mining area based on visual MODFLOW. *Environ Earth Sci* 77:400. <https://doi.org/10.1007/s12665-018-7575-3>
- Yoshida T, Yamauchi H, Fan Sun G (2004) Chronic health effects in people exposed to arsenic via the drinking water: dose–response relationships in review. *Toxicol Appl Pharmacol* 198:243–252. <https://doi.org/10.1016/j.taap.2003.10.022>
- Zaid S (2006) Geo-environmental study of eastern Nile Delta, Egypt. PhD thesis. Faculty of Science, Zagazig University, Egypt, p 339
- Zwietering MH, van Gerwen SJC (2000) Sensitivity analysis in quantitative microbial risk assessment. *Int J Food Microbiol* 58:213–221. [https://doi.org/10.1016/S0168-1605\(00\)00275-0](https://doi.org/10.1016/S0168-1605(00)00275-0)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Ismail Abd-Elaty¹ · Alban Kuriqi² · Abeer El Shahawy³

Ismail Abd-Elaty
Eng_abdelaty2006@yahoo.com

Abeer El Shahawy
abeer_shahawi@eng.suez.edu.eg

¹ Department of Water and Water Structures Engineering, Faculty of Engineering, Zagazig University, Zagazig 44519, Egypt

² CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisbon, Portugal

- ³ Department of Civil Engineering, Faculty of Engineering, Suez Canal University, PO Box 41522, Ismailia, Egypt