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Enhanced efficiency of water purification plant by combined riverbank filtration water

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Abstract: Water shortages occur due to several factors, with drought being one of the biggest drivers. Another major environmental issue related to the contamination of freshwater systems worldwide is thousands of micropollutants, although they generally occur at low concentration levels. The provision of safe drinking water to the population in rural developing nations remains a problem, in particular when surface water and shallow wells or non-watertight headworks wells serve as sources of drinking water. Dramatically changing raw water qualities, floods and high rainfall events anthropogenic pollution, lack of electricity supply in developing regions demand new and adapted solutions for treatment and rendering water safe for distribution. Our study aimes to find another source of water supply using riverbank filtration (RBF). The RBF is a water treatment method that removes water from rivers by pumping wells into a nearby alluvial aquifer. Several physical, chemical, and biological processes that occur underground improve the quality of surface water and eliminate the need for traditional potable water treatment. Additional treatment techniques in this process include biological degradation, sorption, and filtration. Physical, chemical, and microbiological variables were used to assess the effectiveness of the RBF system in Upper Egypt. Our study proposes a workable water treatment strategy that replaces RBF treatment or pretreatment technique for high-quality Nile water to eliminate or reduce surface water pollutants without the use of chlorine.

Keywords: riverbank filtration, water purification, water quality, water supply

INTRODUCTION

Riverbank filtration (RBF) is a natural alternative technique for water supply applications that involves the removal or degradation of surface water contaminants as the infiltrating water travels from the river to the pumping wells. In many cases, the produced water is far superior to the original surface water. In some cases, the RBF technique may be used instead of standard surface water treatments to remove or reduce pollutants in surface water. The RBF employs natural soil as a filtration medium, making it a simple and natural procedure (Abdellatif *et al.*, 2022). Turbidity, chemicals, pesticides, industrial contaminants, organic debris, and other pollutants are reduced or removed as surface water passes through the aquifer medium during the RBF process. RBF has an advantage over traditional water resource development options in that it improves water quality through percolation. Physical, chemical, and biological interactions in the riverbed zone modify and filter components of infiltration water during the percolation process. Furthermore, RBF can completely utilise both surface water and groundwater, assuring enough sustainable water supplies (Matusiak *et al*., 2021). Although most chemicals are present in trace amounts, one of the most urgent environmental concerns facing humanity today is the contamination of freshwater systems with hundreds of micropollutants (Jenny *et al*., 2020). The growing need for safe drinking water has generated worldwide interest in natural surface water treatment techniques, including riverbank filtration (Handl *et al*., 2023). Decision-makers favour RBF as a surface water alternative due to the high cost of water treatment and public concerns (Maliva, 2020; Rossetto *et al*., 2020).

The RBF offers two extra benefits. The first is concerned with how aquifer flow mitigates concentration peaks generated by unintentional pollution releases. In the winter, when air temperatures are low, filtered water is typically warmer than surface water, while in the summer it is colder. The second step is to manage temperature changes in river water. The tiniest temperature difference increases the quality of the bank filtrate and subsequent processing (Ren *et al*., 2020). Surface water recharges the aquifer as production wells draw water from it, and subterranean sediments act as a natural filter, eliminating impurities and generating water of higher quality than the original source water (Patil *et al*., 2020). The RBF successfully eliminates most contaminants present in surface water, including particles, bacteria, viruses, parasites, micropollutants (such as chelating agents, herbicides, amines, medications, and endocrine disruptors), organic and inorganic substances, and particles. The RBF has been demonstrated to eliminate heavy metals including chromium and arsenic by 90%. Metals can be mobilised by it (Osman *et al*., 2022).

Even though the quality of the filtrated water produced by RBF systems varies depending on river conditions, well-designed systems can serve as a pretreatment for high-quality water. Furthermore, the system mitigates river shock loads and can balance concentration or temperature peaks. Egypt is now grappling with economic challenges as well as worries over the quality of its natural groundwater supply wells and surface Nile water treatment facilities. The RBF technology may be able to address these cost and quality concerns. The water quality of Lake Nasser, as well as the volume of water discharged, have a considerable influence on the Nile's water quality. Although the Nile's overall water quality is suitable for generating drinking water via conventional treatment, inadvertent (oil) spills and flash floods are common, interfering with the functioning of water treatment plants (Yehia *et al*., 2017). The overuse of pesticides and fertilisers in agriculture also adds to Nile River water contamination (Hassanain *et al*., 2021).

This study investigated the RBF facility in Upper Egypt, on the Nile's eastern bank. Our study has introduced a hybrid system combining the RBF and conventional systems used in water purification plants to assess the demonstrated effectiveness of the RBF technique in removing or degrading surface water contaminants from the Nile River in the study area. This method allows treated water that exits the filter to be delivered to the distribution system after a quick post-chlorination, allowing it to be presented as a complete treatment system. The efficacy of these water-production schemes was determined by analysing and interpreting water quality in relation to several specific characteristics, such as bacteriological parameters, iron, manganese, and calcium.

MATERIALS AND METHODS

SAMPLING PROCEDURE

The Nedda water treatment plant (WTP) is our investigated location, which is situated in Sohag, Upper Egypt. In the Nedda WTP site, monitoring of the water quality was done. Our research includes using riverbank filtration (RBF) to dilute the Nile water for a surface water facility in Upper Egypt. The sampling sites were monitored for 12 months, from May 2022 to May 2023. The three sampling sites include the Nile, which is replenished surface water, RBF water, which is natural groundwater in the background, and a blend of Nile water and RBF water in a mixing facility. Ten different factors were measured to determine the production of 70% Nile water, which generates 540 $dm^3 \cdot s^{-1}$, 30% bank water, which produces 240 $dm^3 \cdot s^{-1}$, and WTP, which produces 800 $dm^3 \cdot s^{-1}$ of drinkable water.

We compared the plant production results using water from May 2022 to May 2023 after incorporating the Nile and bank water into the reservoir to favour plant production for the same period the previous year. During that time, the WTP plant was completely reliant on Nile water as a source of water. Nile water samples were collected from a depth of 1 m near the RBF facilities. Natural background groundwater samples were collected from pumping well sites at least 0.5 km away from the Nile bank. The sampling process began at 9:00 a.m. on a regular basis and lasted approximately two to three hours to complete water sampling at five sites covering the study segment. The sampling process began at 9:00 a.m. on a regular basis and lasted approximately two to three hours to complete water sampling at five sites covering the study segment. Surface water samples were collected (1 m) using nonmetallic water samplers and stored in the dark until they arrived at the laboratory. Samplers were quickly delivered to the laboratory (Nedda WTP, Sohag Drinking Water Company), where all analyses and investigations were carried out.

SAMPLE ANALYSES

Analyses of the physical and chemical properties of water samples were performed in accordance with standard water examination methods. The electric conductivity (*EC*) was determined using a YSI model 33 S.C.T. meter. The CORNING (Cole-Parmer model Checkmate 90) conductivity dissolved oxygen meter was used to determine total dissolved solids (*TDS*). The method described in APHA was used to determine ammonia-N. Dissolved oxygen (*DO*) and *TDS* are the parameters that are used (APHA, 1926). Quality parameters of physical (turbidity, *TDS*, *EC*, and *DO*), chemical (iron, manganese, and ammonia), and microbiological characteristics (total plate count at 35°C, total coliform and faecal coliform) were obtained. A comparison of produced water from Nile water with RBF mix in water treatment plant with effluent quality of water production in the previous year from May 2022 to May 2023 when WTP depended on Nile water source only was done. Using a Hach DR2000 spectrophotometer, the materials were evaluated for physico-chemical data. Several meters were used to take *TDS* readings. Each measurement was performed twice, the equipment was turned on, and analysis was performed in accordance with the operating manual (APHA, 2000). Egypt's Ministry of Health and

Population's laboratories performed microbiological assessments for illnesses. Microbiological parameters were performed using standard plate counts (SPC) and the most probable number (MPN·100 cm^{-3}) procedures (APHA, 2000). The effectiveness of the RBF process is assessed based on this comparison and compliance with drinking water laws. At abstraction wells, the results of riverbank filtration and river water were compared. The water quality at the Nedda RBF facility was monitored three times. Three sampling points were observed. The three sample locations include Nile at the WTP intake as replenished surface water, processed water generated from traditional Nedda WTPs in the final storage tank, and manufacturing water straight from RBF's four abstraction vertical wells. Water sampling from the river and wells was carried out according to Egyptian rules and regulations. The river Nile was sampled daily for important parameters including pH, *EC*, turbidity, and microbiological parameters, and weekly for other parameters like significant ions. Every operational well was tested on a regular (at least weekly) basis from its sampling tap. Every operating well's sample tap was frequently (at least weekly) inspected. Table 1 summarises the analytical methods for finding the discussed parameters. Water analysis was carried out by many laboratories (local company labs and central labs) (Abdel-Gawad, 2007).

The findings of riverbank filtrates at abstraction wells were compared to those of river water, and the effectiveness of the RBF process was assessed using this comparison and compliance with drinking water requirements.

Table 1. Parameters and analytical methods, according to the standard methods for examination of water and wastewater acc. to APHA (1926) and APHA, AWWA and WEF (2017)

Parameter	Abbreviation	Unit	Method / equipment / method No.
Physical parameters			
Electric conductivity	*EC*	S·cm^{-1}	laboratory method / WTW cond. meter, 2–55 / conductivity (2510)
Turbidity	turb	NTU	nephelometric method / turbidimeter (Hach), 2–12 / turbidity (2130)
Chemical parameters			
Potential of hydrogen	pH	–	electrometric method / ThermoScientific (Orion 3 STAR), 4–95 / pH (4500–H^+)
Alkalinity	Alk	mg·dm^{-1}	titrimetric method, 2–36 / alkalinity (2320)
Total organic carbon	TOC		C. persulfate–ultraviolet or heated-persulfate oxidation method, 5–29 / TOC (5310)
Total hardness	$CaCO_3$		EDTA titrimetric method, 3–69
Ammonium	NH_4^+		phenate method, 4–114 / ammonium (4500–NH_3)
Chloride	Cl^-		argentometric method, 4–75 / chloride (4500–Cl^-)
Sulphate	SO_4^{2-}		turbidimetric method, 4–197 / sulphate (4500–SO_4^{2-})
Nitrate	NO_3^-		ultraviolet spectrophotometric method / Cecil 2041 UV/VIS, 4–126 / nitrate (4500-NO_3^-)
Iron	Fe		phenanthroline method / Cecil 2041 UV/VIS, 3–79 / iron (3500-Fe)
Manganese	Mn		persulfate method / cecil 2041 UV/VIS, 3–87 / manganese (3500–Mn)
Microbiological parameters			
Heterotrophic plate count 35°C	HPC 35°C	HPC·cm^{-3}	B-Pour Plate Method, 9–53 / HPC (9215)
Total coliform count	TCC	TCC·(100 $cm^3)^{-1}$	B-D, endo agar method, 9–81 for drinking water, MTFT 9221 B-C-E for intake water / MFT (9222)
Faecal coliform count	FCC	FCC·(100 $cm^3)^{-1}$	membrane filter procedure for coliform group D, thermotolerant (faecal) coliforms / MFT (9222)
Biological parameters			
Total algae count	TAC	cells·cm^{-3}	plankton (10200) / C, E and F, 10–11, 10–15, 10–17

Source: own elaboration.

RESULTS

High levels of nutrients can be found in the water of the Nile, with El-Nasria having the greatest quantities of phosphates (0.46 mg·dm^{-3}), nitrates (0.63 mg·dm^{-3}), ammonia (2.83 mg·dm^{-3}), total nitrogen (3.48 mg·dm^{-3}), sulphates (62.57 mg·dm^{-3}), and silicates (3.50 mg·dm^{-3}) (Ali *et al.*, 2014). There is little doubt that this is impacted by the water quality at the El-Nasria pumping water treatment plant WTP. Dissolved oxygen (*DO*) and hydrogen ion concentration (pH) both indicated a noticeably downward trend at this site. The conductivity electrical (*EC*) of the Nile water was significantly impacted by the maximum amount of total dissolved solids (*TDS*), sulphate chlorides, and other conductible solids.

A comparison of the effluent quality of Nile water indicated as a monthly fluctuation from May 2021 to May 2022 is summarised in our study. Physical parameters presented in Table 2 were used to compare the quality of Nile water in 2021 and 2022 based on parameters of turbidity (as shown in Tab. 2) and *DO* (as shown in Tab. 3). In terms of turbidity, there was a nonsignificant slight elevation in September, January and February (in 2021–2022) while in the other months, there was a nonsignificant slight decrease. Additionally, *TDS* and *EC* showed a slight elevation in 2021 compared to 2022.

From May 2021 to April 2022, there was no statistically significant difference in either turbidity or *DO* (p values = 0.2 and 0.93, significance at $p \leq 0.05$, respectively). *EC* and *TDS* differ significantly (p value = 0.001), as shown in Table 2. During the two-year study, the parameters for iron, manganese, and ammonia quality as shown in Table 2 indicated an undetectable level.

The microbiological traits (total plate count (*TPC*) at 35°C, total and faecal coliform (*TCC*, *FCC*)) in Table 3 indicated values of <1. In terms of *DO* level (Tab. 3), 2021 and 2022 have nonsignificant almost equal values ($p \leq 0.05$).

As demonstrated in Table 4, which examined physical and chemical quality assessments (turbidity, *TDS*, and *EC*), iron, manganese, and ammonia (NH_3) were examined. The dilution significantly improved the quality of the water produced. Our study compared monthly fluctuations in Nile and RBF water from May 2022 to April 2023. In Table 4, a comparison of the quality of raw RBF and Nile water from May 2022 to April 2023 can be observed. According to our analysis, there was a discernible decline in turbidity between Nile and RBF water reaching zero value in autumn season.

Additionally, the *TDS* and *EC* (Tab. 4) both significantly rose in RBF water more than in Nile water, almost reaching a maximum level in the summer season. Iron, manganese, and ammonia all show considerable increases in chemical quality parameters (Tabs. 4 and 5) in RBF more than in Nile water.

According to recent research, RBF water has higher NO_3^-, Mn, Fe, and SO_4^{2-} concentrations than Nile water. This could be due to mixing with nearby groundwater containing higher concentrations of these chemicals. According to the most recent measurements, 70% of infiltrated Nile water has the greatest impact on RBF at 30 m from the river. The Nile water has been mixed with the natural background groundwater.

Table 2. Physical (turbidity, total dissolved solids (*TDS*) and electrical conductivity (*EC*)) and chemical (iron, manganese and ammonia) quality parameters expressed as monthly variations from May to April (2021 and 2022)

Month	Turbidity (NTU)		*TDS* (mg·dm^{-3})		*EC* (S·cm^{-1})		Iron (mg·dm^{-3})		Manganese (mg·dm^{-3})		Ammonia (mg·dm^{-3})	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
May	0.62	0.61	230	207	359	323	UDL	UDL	UDL	UDL	UDL	UDL
June	0.63	0.72	250	204	390	318	UDL	UDL	UDL	UDL	UDL	UDL
July	0.77	0.65	230	195	359	305	UDL	UDL	UDL	UDL	UDL	UDL
August	0.64	0.69	210	193	328	301	UDL	UDL	UDL	UDL	UDL	UDL
September	0.79	0.73	210	201	328	314	UDL	UDL	UDL	UDL	UDL	UDL
October	0.57	0.70	204	201	318	314	UDL	UDL	UDL	UDL	UDL	UDL
November	0.57	0.74	230	204	359	318	UDL	UDL	UDL	UDL	UDL	UDL
December	0.54	0.73	241	227	376	354	UDL	UDL	UDL	UDL	UDL	UDL
January	0.69	0.74	245	228	382	320	UDL	UDL	UDL	UDL	UDL	UDL
February	0.78	0.70	230	220	359	324	UDL	UDL	UDL	UDL	UDL	UDL
March	0.70	0.72	250	219	390	316	UDL	UDL	UDL	UDL	UDL	UDL
April	0.64	0.72	251	211	392	342	UDL	UDL	UDL	UDL	UDL	UDL
p value significance at $p \leq 0.05$	0.2		0.003		0.003		–		–		–	

Explanation: UDL = undetected level.
Source: own study.

Table 3. Quality parameters of dissolved oxygen (*DO*) and microbiological characteristics (total plate count (*TPC*) at 35°C, total coliform (*TCC*) and faecal coliform (*FCC*)) expressed as monthly variations from May to April (2021 and 2022)

Month	*TPC* CFU·(100 cm^3)$^{-1}$		*TCC* TCC·(100 cm^3)$^{-1}$		*FCC* FCC·(100 cm^3)$^{-1}$		*DO* (mg·dm^{-3})	
	2021	2022	2021	2022	2021	2022	2021	2022
May	<1	<1	<1	<1	<1	<1	9.5	10.5
June	<1	<1	<1	<1	<1	<1	9.8	9.3
July	<1	<1	<1	<1	<1	<1	10.0	9.4
August	<1	<1	<1	<1	<1	<1	10.5	9.2
September	<1	<1	<1	<1	<1	<1	9.7	10.0
October	<1	<1	<1	<1	<1	<1	9.2	9.0
November	<1	<1	<1	<1	<1	<1	9.5	10.3
December	<1	<1	<1	<1	<1	<1	9.0	9.7
January	<1	<1	<1	<1	<1	<1	9.3	10.0
February	<1	<1	<1	<1	<1	<1	9.5	10.2
March	<1	<1	<1	<1	<1	<1	9.1	10.5
April	<1	<1	<1	<1	<1	<1	10.0	11.0
p value significance at $p \leq 0.05$	–	–	–	–	–	–	0.93	

Source: own study.

Table 4. Comparison between Nile and riverbank filtration (RBF) water according to physical (turbidity, total dissolved solids (*TDS*) and electric conductivity (*EC*)) and chemical (iron, manganese and ammonia) quality parameters of expressed as monthly variations from May 2022 to April 2023

Month	Turbidity (NTU)		*TDS* (mg·dm^{-3})		*EC* (S·cm^{-1})		Iron		Manganese		Ammonia	
							mg·dm^{-3}					
	Nile	RBF	Nile	RBF	Nile	RBF	Nile	RBF	Nile	RBF	Nile	RBF
May	3.75	0.89	186	610	295	953	0.13	0.23	0.16	0.52	0.021	0.35
June	3.60	0.79	185	601	291	940	0.14	0.21	0.12	0.30	0.025	0.21
July	3.65	0.66	192	587	296	917	0.13	0.20	0.10	0.40	0.039	0.42
August	3.58	0.61	182	539	289	842	0.15	0.143	0.11	0.34	0.038	0.30
September	3.85	0.57	187	547	290	854	0.11	0.13	0.09	0.43	0.035	0.39
October	3.70	0	195	543	305	848	0.13	0.15	0.085	0.37	0.035	0.31
November	4.00	0	206	581	312	908	0.13	0.16	0.11	0.51	0.027	0.31
December	4.11	0	213	529	334	826	0.11	0.14	0.13	0.31	0.033	0.23
January	4.82	0.72	234	530	365	856	0.10	0.15	0.11	0.30	0.030	0.21
February	4.31	0.63	214	564	334	816	0.07	0.10	0.15	0.28	0.035	0.18
March	3.93	0.52	208	602	325	861	0.08	0.18	0.12	0.32	0.021	0.20
April	4.31	0.61	209	557	326	891	0.12	0.01	0.08	0.16	0.020	0.23
p value significance at $p \leq 0.05$	≤0.001		≤0.001		≤0.001		≤0.001		≤0.001		≤0.001	

Source: own study.

The quality of *DO* and microbiological parameters (*TPC* at 35°C, *TCC*, and *FCC*) were assessed monthly from May 2022 to April 2023. There is a comparison between Nile and RBF water provided in Table 5. In Table 3, *DO* (Tab. 5) and the microbiological characteristics of Nile water and RBF raw water during the period of May 2022 to April 2023 were provided. Total plate count at 35°C in the Nile water showed a significant increase in March and April compared to the RBF. In contrast, in RBF water there was a noticeable decrease of *TPC* at 35°C almost reaching zero.

Table 5. Comparison between Nile water and RBF water according to quality parameters of dissolved oxygen (*DO*) and microbiological characteristics (total plate count (*TPC*) at 35°C, total coliform (*TCC*) and faecal coliform (*FCC*)) expressed as monthly variations from May 2022 to April 2023

Month	*TPC* CFU·(100 cm^3)$^{-1}$		*TCC* TCC·(100 cm^3)$^{-1}$		*FCC* FCC·(100 cm^3)$^{-1}$		*DO* (mg·dm^{-3})	
	Nile	RBF	Nile	RBF	Nile	RBF	Nile	RBF
May	880	20	1300	0	180	0	8.1	5.4
June	2500	21	1400	0	680	0	8.2	5.6
July	1600	18	780	0	450	0	8.1	5.5
August	2000	0	800	0	700	0	8.0	5.0
September	2200	0	450	0	200	0	8.2	4.9
October	1800	0	1100	0	490	0	7.0	5.8
November	400	0	450	0	180	0	8.1	5.6
December	2200	0	1200	0	680	0	7.9	5.5
January	800	0	330	0	230	0	7.7	5.0
February	660	0	230	0	130	0	8.2	4.85
March	3400	0	270	0	220	0	8.1	5.9
April	3400	0	270	0	220	0	7.8	4.9
p value significance at $p \leq 0.05$	≤0.001		≤0.001		≤0.001		≤0.001	

Source: own study.

Total coliform levels in the Nile water showed a significant increase in May and June compared to RBF water. In contrast, there was an enhancement in the decrease of total coliform in RBF water, which almost reached zero.

Faecal coliform levels in the Nile water showed a significant elevation of their level in August, October and December in comparison to RBF water that had an enhancement in the decrease of faecal coliform which almost reached zero.

These results revealed a considerable decline in the *TPC* at 35°C (Tab. 5), total coliform (which reached zero), and faecal coliform (which reached zero). The physicochemical and microbiological properties of the produced water exceed those required for safe drinking water. The findings support the use of RBF treatment technology for water supply in the Nile Valley.

DISCUSSION

Fundamental objectives include ensuring that everyone has access to secure and healthy water as well as promoting sustainable water use. Water quality is a difficult subject to determine because it is the factor that determines whether water is polluted. The most important source of freshwater for human life is rivers (Ali *et al.*, 2014). High levels of nutrients can be found in the water of the Nile, with El-Nasria having the greatest quantities of phosphates (0.46 mg·dm^{-3}), nitrates (0.63 mg·dm^{-3}), ammonia (2.83 mg·dm^{-3}), total nitrogen (3.48 mg·dm^{-3}), sulphates (62.57 mg·dm^{-3}), and silicates (3.50 mg·dm^{-3}) (Ali *et al.*, 2014). There is little doubt that this is impacted by the water quality at the El-Nasria pumping WTP. Dissolved oxygen (*DO*) and hydrogen ion concentration (pH) both indicated a noticeably downward trend at this site. The conductivity (*EC*) of the Nile water was significantly impacted by the maximum amount of total dissolved solids (*TDS*), sulphate chlorides, and other conductible salts. Because of the presence of carbonates and bicarbonates, the nearby Nile water in Mansoura City tends to be on the alkaline side of the pH scale. The amount of CO_2 released by the nitrification process occurring within the system at times of maximum nutrients and phytoplankton levels was discovered to control pH and alkalinity changes (Ali *et al.*, 2014).

An effective and reasonably priced natural alternative method for water supply applications is riverbank filtration (RBF), which comprises the removal or degradation of surface water contaminants as the infiltrating water passes from the river/ lake to the pumping wells. Physical, chemical, and biological mechanisms work together to remove or degrade pollutants. Along the Rhine, Elbe, and Danube rivers, RBF has been used for the public and industrial water supply in Europe for more than a century (Shamrukh and Abdel-Wahab, 2008). The RBF is an appropriate technique for use in Colombia's highly turbid and polluted surface rivers due to its ability to remove a variety of contaminants associated with the influence of the rivers' heavily suspended sediment loads. Most dissolved and suspended contaminants are eliminated due to cake formation on the riverbed and aquifer restriction caused by suspended sediments. Furthermore, high-quality water can be drawn from the abstraction wells, requiring only a few additional steps in the purification process to make it drinkable. Except for turbidity and bacteria, the quality of the Nile water and RBF water meets general drinking water regulations. Furthermore, there are some differences in Nile water quality when compared to natural groundwater (Osman *et al.*, 2022). The RBF may compete with traditional pesticide removal methods such as ozone, UV light, and granular-activated carbon in highly contaminated waterways. The costs of producing O_3, UV, H_2O_2, and Cl_2 vary when using a standard process that includes the steps coagulation, sedimentation, filtration, activated carbon filtration, and disinfection, as well as when using a different train that includes the steps of RBF, aeration, filtration, activated carbon filtration, and disinfection. The use of RBF saves money on chemical dosing, sludge control, and filter backwashing. According to Sharma and Amy (2009), switching from a traditional WTP to a process that uses an RBF system could result in a 50% reduction in operational costs. Furthermore, the sedimentation process can be skipped, and advanced pathogen eradication is no longer required.

According to Egyptian standards or WHO recommendations, Nedda WTP evaluated quality indicators of produced water are below allowed levels for drinking purposes (WHO, 2005). However, the results show that the RBF water is a mixture of Nile water and natural groundwater in the background. On its way to the production bank wells, Nile water frequently undergoes significant chemical and biogeochemical transformation.

The focus of our investigation is a full-scale RBF water production facility in Upper Egypt's Nile Valley. Our research focused on analysing the mixture created at a WTP in upper Egypt by combining RBF and Nile water. Water's physical, chemical, and microbiological properties could be assessed. Turbidity, total dissolved solids (*TDS*), *EC*, dissolved oxygen (*DO*), and total dissolved oxygen were among these characteristics.

Water produced at the WTP utilising RBF and Nile water is compared to the effluent quality of the year before, from May 2022 to April 2023, when the WTP exclusively used Nile water. Surface and natural groundwater for the research plant, as well as chemical and bacteriological water quality standards, have all shown how effective the RBF technique is at supplying Upper Egypt with potable water. The term *TDS* refers to the measurement of dissolved or suspended particles in water. From May to April, there was no statistically significant difference in either turbidity or *DO* (p values = 0.2 and 0.93, respectively). *EC* and *TDS* differed significantly (p value = 0.001). Iron, manganese, and ammonia quality parameters indicated an undetectable limit during the two years of study. While the microbiological traits (*TPC* at 35°C, total and faecal coliform) indicated values of 1. We found that the presence of dissolved iron and manganese in the bank filtrate can worsen fouling of ultrafiltration membranes, which is in line with the findings of Haas *et al.* (2019). Inline electrolysis can oxidise dissolved iron and manganese, which can then be filtered out. Without pre-treatment, such as flocculation, the membranes performed exceptionally well in treating bank filtrate by removing turbidity and germs at a flux of 60 $dm^3 \cdot m^{-2} \cdot h^{-1}$ (Q = 20.8 $m^3 \cdot h^{-1}$) with an energy usage of 0.18 $kWh \cdot m^{-3}$.

The *TDS*, which measures the amount of material dissolved in water or/and sediment suspended in water, revealed relatively minor changes in the Nile sampling section. Conductivity, which measures a water's ability to carry an electrical current, is related to water cleanliness. Iron is the next most used heavy metal. The RBF's ability to eliminate turbidity and pathogens has been amply demonstrated at all sites. It's also worth noting that there was a decrease in colony-forming units of heterotrophic plate count (HPC). According to a previous study, RBF technology and the slow sand filtering process have many similarities. For instance, the turbidity in water caused by RBF has been reduced by more than 95%. The RBF process successfully reduced *TDS*, alkalinity, and hardness as well as turbidity. These RBF effectiveness results are similar to those from published studies (Shamrukh and Abdel-Wahab, 2008). The Nedda WTP background groundwater has elevated levels for most chemical components, nevertheless. It is also unclear what treatment procedures the RBF factory performs to remove pollutants. In many places throughout the world, research in the past has shown that RBF considerably reduces river pollution. Redox processes mediated by bacteria are responsible for the most important chemical changes (Hiscock and Grischek, 2002). In general, boundary conditions specific to the location are required for microbial (metabolism and degradation) processes, as well as both electron donors and acceptors. In the Nedda WTP, microorganisms can use *DO*, NO_3^-, Mn, Fe, and SO_4^{2-} in that sequence as electron acceptors. Organic substances that enter water and organic substances that exist in solid phases can both serve as electron donors. According to recent research, RBF water has higher NO_3^-, Mn, Fe, and SO_4^{2-} concentrations than Nile water. This could be due to mixing with nearby groundwater containing higher concentrations of these chemicals. According to the most recent measurements, 70% of infiltrated Nile water has the greatest impact on RBF at 30 meters from the river. The Nile water has been mixed with the natural background groundwater. The dilution significantly improved the quality of the water produced.

From May 2022 through April 2023, our study compared monthly fluctuations in the quality assessments of Nile and RBF raw water. This study included physical and chemical quality assessments (turbidity, *TDS*, and *EC*), iron, manganese, and ammonia. According to our analysis, there was a discernible decline in turbidity between Nile and RBF raw water. Additionally, both the *TDS* and *EC* significantly rose. Iron, manganese, and ammonia all show considerable increases in chemical quality measurements. Quality assessments were conducted monthly from May 2022 to April 2023, measuring *DO* and microbiological parameters, including total plate count at 35°C, total coliform, and faecal coliform. During the period of May 2022 to April 2023, *DO* (Tab. 5) and the microbiological characteristics of Nile water and RBF raw water were provided. These results revealed a considerable decline in the *TPC* at 35°C, total coliform (which reached zero), and faecal coliform (which reached zero). The physicochemical and microbiological properties of the produced water exceed those required for safe drinking water. The findings support the use of RBF treatment technology for water supply in the Nile Valley.

According to Ali *et al.* (2014) study, El-Nasria experienced increases in *TDS* between April 2011 (318.0 mg·dm^{-3}) and June 2011 (524.0 mg·dm^{-3}). Electrical conductivity (*EC*) followed a similar pattern, with high values in both months (821.0 and 1330.0 S·cm^{-1}). This explains the high correlations (r = 0.99) between *TDS* and *EC*, as well as other salt-related measures. The water at El Nasria was characterised by bacterial thick patches and undetectable *DO* levels due to maceration processes in nearby settlements, according to Ali *et al.* (2014) study of the lowest water quality. Because a greater proportion of the groundwater on the landside is rich in Fe and Mn, Fe and Mn concentrations are slightly higher at the Almaragha location. Unsurprisingly, temperature had a significant impact on the amount of *DO* throughout the sampling year (2011–2012), with minimum levels during warm months and gradual rises with decreasing temperature (Ali *et al.*, 2014). Compared to river water, ammonium concentrations are rising, yet they frequently remain below the 0.5 mg·dm^{-3} limit. It is crucial to evaluate the added chlorine dosage for disinfection since ammonium and chlorine react. Although ammonium may be released by organic-rich riverbed sediments, it can also be regulated by accelerating penetration by increasing abstraction rates. In RBF well water, no coliforms or faecal coliforms were found (Gupta, Sunita and Saharan, 2009). Because of the High Aswan Dam, the turbidity of the Nile remains consistently low and stable throughout the year. Also modest levels of NO_3^-, PO_4, Cl, Fe, and Mn are present, as well as significant levels of SO_4^{2-} and *TDS*. Approximately 4.5 and 8.5 mg·dm^{-3} of *DO* and organic matter, respectively, are present in the Nile. It is envisaged that oxygen and organic matter will act as electron donors and acceptors during RBF treatment methods. After investigation, it was discovered that the MPN·(100 cm^3)$^{-1}$ for both total coliform and faecal coliform, or specific count plate, in Nedda WTP was within the limits for drinking water. The microbial eradication may have been hampered by the filtration processes and the effects of the RBF system's travel time. This result aligns with other results from earlier investigations (Shamrukh and Abdel-Wahab, 2011). Ammonia levels, for example, were generally low at all sites except El-Nasria. This could be due to organics in residential sewage and fertiliser runoff. According to statistical research, ammonia has significant positive correlations with a few pollution-related variables, including total nitrogen (*TN*) (r = 74), sulphate (r = 0.66), *EC* (r = 0.64), *TDS* (r = 0.62), dissolved reactive phosphorus (*DRP*) (r = 0.56), and total phosphorus (r = 0.55). These statistically significant associations revealed the interaction of sewage outflow and agricultural runoff at this location. The *TDS* and *EC* values had a strong positive correlation (r = 0.99) because the latter is the functional property affected by *TDS* levels and the conductibility effect of those salts. According to El-Sherbini *et al.* (1997), insufficient *DO* may result in unfavourable environmental conditions in which aerobic bacteria are replaced by anaerobic bacteria, degrading water quality and producing unpleasant odours from the generation of gases (H_2S, NH_3, and CH_4). According to El-Gamel and Shafik (1985), a lack of *DO* may also indicate a high organic matter and nutrient load. According to El-Naggar *et al.* (1997) and Ali *et al.* (2014), *DO* correlated negatively with sulphate (r = −0.66), *DRP* (r = −0.60), temperature (r = −0.58), ammonia (r = −0.56), *TDS* (r = −0.53), *EC* (r = −0.52), and nitrate (r = −0.50). The results of the bank filtrate were compared to the natural results of groundwater and previously published Nile water results. The RBF's chemical and microbiological quality indicators are within acceptable drinking water ranges. Furthermore, bank filtration improves ambient groundwater quality while purifying Nile water in the study area. The results of this large RBF facility revealed the Nile Valley's success with riverbank filtration as a treatment approach at one-fourth the cost of conventional surface treatment plants (Hamdan, Sensoy and Mansour, 2013). More studies are required to quantify quality characteristics along the path from the Nile to the producing wells to obtain a comprehensive picture of RBF in the Nile valley. It's critical to comprehend how the treatment processes affect how Nile water seeps into RBF wells. The actions of people, communities, and governments at all levels of administration to conserve and manage water resources in a way that supports our health will be largely responsible for future water quality on a local, regional, and global scale. The most crucial factors in establishing the kind, calibre, and condition of water are its physicochemical properties, whether fresh, brackish, or salty. The integration of ecological concerns might be amply proven using metrics like the WQI. To summarise, when constructing an RBF system, a balance between the water quality and the production capacity must be sought. There is a necessary trade-off between being able to supply large flows and having superior water quality in the abstraction wells; longer residence times may lead to higher removal efficiencies. The greater the trip distance, the lower the system's extraction capacity, and the bigger the percentage of groundwater extracted from the aquifer's storage (Covatti, Grischek, Burghardt, 2022). The infiltration rate and residence time of the pollutants must be high enough at the river-aquifer interface to deliver the necessary water quantity and quality, respectively, for an RBF system to be sustainable. The results of our study were in line with those of Zhai *et al.* (2022), who showed that one alternative to RBF in the one-step reverse osmosis (OSRO) concept for supplying drinking water from locally available resources is artificial bank filtration (ABF). The ABF is an artificial recharge system that uses a sand filtration system. To make it even more eco-friendly and renewable, the OSRO idea might potentially be used in conjunction with wind power. We suggest a decentralised water system for water reclamation and reuse that is based on OSRO. For technically efficient, economically viable, resource-reusable, ecologically relevant, and economically viable drinking water, future water treatment should focus on hybrid systems combining natural and manmade components.

CONCLUSIONS

The Nile water contains a lot of nutrients. El-Nasria pumping water treatment plant (WTP) has the highest concentrations of phosphates (0.46 mg·dm^{-3}), nitrates (0.63 mg·dm^{-3}), ammonia (2.83 mg·dm^{-3}), total nitrogen (3.48 mg·dm^{-3}), sulphates (62.57 mg·dm^{-3}), and silicates (3.50 mg·dm^{-3}). These levels are likely affected by the water quality at the El-Nasria pumping WTP. A clear trend toward decreasing hydrogen ion concentration (pH) and dissolved oxygen (*DO*) was observed at this location. Upper limits for total dissolved solids (*TDS*), sulphate chlorides, and other conductible salts had a substantial effect on the electrical conductivity (*EC*) of Nile water. Our study concludes with a comparison of the effluent quality of Nile water, as evidenced by monthly fluctuations from May 2021 to May 2022. Based on turbidity and dissolved oxygen readings, when comparing the months of May 2021 and April 2022, turbidity and dissolved oxygen levels did not change much. The relationship between electrical conductivity and total dissolved solids is very different. The two-year investigation found no detectable levels for iron, manganese, and ammonia in the quality parameters. The microbiological features, which include total and faecal coliform bacteria, total plate count at 35°C, and others, all displayed values of 1. A comparison of RBF and Nile water revealed that the former had greater quantities of NO_3^-, Mn, Fe, and SO_4^{2-} than the latter. The possibility that this is a result of chemical contamination from adjacent groundwater is being considered. The latest data shows that at 30 m from the river, 70% of the infiltrated Nile water has the largest effect on RBF. A combination of the Nile water and the naturally occurring groundwater has been made. The diluted water was far better than the original. Our investigation analysed Nile and RBF raw data as monthly changes from May 2022 to April 2023. Iron, manganese, and ammonia were tested, as shown in Table 4, which displays physical and chemical quality assessments (turbidity, total dissolved solids, and electric conductivity). From what we can see, the turbidity of the raw Nile and RBF waters was far lower. Further, there was a marked increase in electric conductivity and total dissolved solids. Measuring chemical quality, ammonia, iron, and manganese all exhibit significant increases. A comparison between Nile water and RBF was shown according to quality assessments of dissolved oxygen and microbiological parameters (total plate count at 35°C, total coliform, and faecal coliform) that were expressed as monthly changes from May 2022 to April 2023. All coliforms, total coliform, and faecal coliforms decreased significantly to zero at 35°C, according to these findings. This water is unsuitable for human consumption since it lacks the necessary physicochemical and microbiological qualities. Using RBF treatment technology to purify the Nile Valley's water supply is backed by the results.

AUTHOR CONTRIBUTIONS

1st Author (contribution – 40%): data collection, manuscript preparation. 2nd Author (contribution – 15%): study design, data interpretation. 3rd Author (contribution – 15%): study design, statistical analysis. 4th Author (contribution – 30%): study design, literature search, statistical analysis.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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