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The efficiency of bank filtration to remove chemical pollutants in Egypt: field and batch studies

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Abstract

Bank filtration (BF) is a low-cost water treatment technology in which surface water contaminants are removed through the biochemical and physical process taking place during the filtration process. This study aimed to assess the effectiveness of this technique to produce high drinking water quality in Egypt. In this study, field-works was conducted, and samples were collected from the River Nile and the bank filtrate wells at Al-Edwah, El Menyia Governorate. The samples were analyzed and the chemical pollutants (e.g., pesticides, pharmaceuticals, inorganic) were determined. Moreover, batch studies were conducted to get insight on the mechanical removal of the organic contaminants and to assess the impact of temperature (15, 25, 30 ºC) and redox condition (oxic, anoxic) conditions on the removal. The results revealed that bank filtration can remove the inorganic pollutants such as nitrate and nitrite efficiently. However, its effectiveness to remove organic pollutants is highly dependent on the temperature; higher removal was obtained at a higher temperature. To conclude, bank filtration is an effective technique to remove chemical contaminants and to produce high water quality, and it is highly recommended to extend the usage of this technique in Egypt.
Keyword: bank filtration, Egypt, organic and inorganic pollutants.

1. Introduction

As the World's growing population puts greater demands on the available supply of high-quality drinking water, several advanced treatment technologies have been developed and applied by water utilities to treat waters of degraded quality (Hiscock et al., 2002). These technologies include adsorption, ion exchange, membrane filtration, soil aquifer treatment, and advanced oxidation. Notwithstanding the effectiveness of these technologies, there are challenges for their widespread applications in developing countries. This is primarily attributed to cost (especially for treating large quantities). In this context, an old method called riverbank filtration (RBF) is returning and evolving as an inexpensive and a sustainable approach to improving the quality of surface waters (Blanford et al., 2010). This treatment technique is currently being used in Europe along the Rhine, Danube, Elbe, and Seine rivers (Ray et al., 2002). Along the Rhine, there is one of the first RBF plants in Dusseldorf, Germany, to supply drinking water to a population of about 600,000. For more than 100 years, RBF has been used in Europe for public and industrial water supply along Rhine, Elbe, and Danube rivers (Tufenkji et al., 2002).

Riverbank filtration (RBF) is an efficient and low-cost natural alternative technology for water supply application in which surface water contaminants are removed or degraded as the infiltrating water moves from the river/lake to the pumping wells. The removal or degradation of contaminants is a combination of physicochemical and biological processes. RBF is a process by which water for drinking and industrial use is produced by placing wells sufficiently close to riverbanks (Boving et al., 2014). The same principal also applies in the case of lakes. In RBF, pumping wells located adjacent to a body of surface water (river, lake) may, over time, withdraw enough water from the flow system to reverse flow gradients and induce water from the surface source (Eckert et al., 2006). This is much like the reactive barriers currently being used to remediate the contaminated groundwater. Abstraction wells are commonly placed in close proximity to riverbanks and lakes to take advantage of this induced infiltration thereby maximizing the water-supply potential of the area.

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Because RBF is a natural process, it wins support from consumers who want safe, but not highly treated, potable and industrial water supplies.

Riverbank filtration is typically conducted in alluvial valley aquifers, which are complex hydrologic systems that exhibit both physical and geochemical heterogeneity. During RBF, which is similar to slow-sand filtration, the impurities of river water are attenuated through combination treatment processes (KamalOuda Ghodeif, 2011). The performance of RBF systems depends upon well type and pumping rate, travel time of surface water to wells, site hydrogeology conditions, source water quality, biogeochemical reactions in sediments and aquifer, and quality of background groundwater (K. Ghodeif et al., 2016). The processes involved in bank filtration maybe physical, biological, and chemical (Grischek et al., 2003). Physical processes such as (a) hydrodynamic including advection, dispersion, and diffusion, and (b) mechanical including filtration i.e. trapping of particles in pore spaces. Physicochemical processes, such as sorption, precipitation, complexation, ion exchange, coagulation, and redox reactions (Grischek et al., 2003).

Biological processes such as degradation of organic matter for metabolic needs and mineralization of secondary substrates. Mechanical filtration leads to the removal of suspended material, including hydrophobic organic substances adsorbed on suspended solids. In the riverbed and at the beginning of the groundwater flow path, aerobic conditions are frequently found and a relatively high microbial activity that can lead to mineralization or transformation of degradable organics (Sharma et al., 2009). Biodegradation, principally within the first few meters of infiltration, is the primary removal process for dissolved organic carbon (Drewes et al., 2003; Grischek et al., 2003). Adsorption of metals can have a finite lifetime before breakthrough or desorption occurs (Abdelrady et al., 2018). The degree of adsorption varies depending on the nature of the compounds and the kind of solid material present. In general, contact with a large surface area and long flow paths between the river and the wells increase the extent of adsorption (Abdelrady et al., 2019).

Currently, in Egypt there are economic and quality problems with both surface treatment plants of Nile water and supply wells from natural groundwater. Using RBF technology has the potential to overcome those economic and quality problems. The main goal of current work is to evaluate the proven effectiveness of RBF technique in removing particulates, dissolved solids, and microbial pathogens from one of the World's largest rivers, the Nile River and investigate the effect of soil type (morphology) on the efficiency of RBF (adsorption, biodegradation and fates of pollutants).

1.1. Study area

Al-Edwah town which is one of the principal cities of El Menia Governorate, South of Egypt. The town located at the east of River Nile and the study wells (Well 1, 2 and 3) were used as the alternative source of drinking water. The well 1 far from the Nile about 10 m and the Well 2 about 200 m and the third well (well 3) about 500 m.

2. Methodology

2.1. Field study

The water samples collected from the river Nile at Al-Edwah, El Menyia Governorate and Wells (1, 2 and 3), the collected samples were submitted to Reference laboratory of HCWW, Cairo for bench scale treatment and subsequent analysis (physical, chemical, biological and microbiological analysis).

2.2. Batch study

Batch reactors were used to get an understanding of how the temperature can affect the efficiency removal of micro-organics (Barbieri et al., 2012; Maeng, 2010). Batch reactors used in this experiment consisted of twenty-four one-liter glass bottles; (twenty under aerobic and four under anoxic conditions). The bottles were filled by 150 grams of washed and dry silica sand with 0.8 mm to 1.2 mm size and 7 days hydraulic residence time (HRT) was used. They were fed with 800 ml of Sharoka Canal (Cairo, Egypt) with DOC ranges between 3.6 and 5.4 ppm. The reactors were acclimated for 3 months inside incubators with different temperatures (15, 25, 30°C) until the difference between three successive DOC removals is less than 1. After that, the reactors were injected with selected pesticides (Lindane Endrin, Aldrin, Hexachlorobenzene) at an initial concentration of 5 µg/l. Another series of batch reactor had been performed by injecting sodium azide (20mM) (Maeng et al., 2010) into the reactors to suppress the biological activity and quantifying the role of adsorption in the removal process.

2.3. Analytical methods

Samples were taken from the study area, in different periods during 2018, were subjected to analysis of some physico-chemical parameters before and after treatment. The collected water samples were refrigerated at 4oC for subsequence laboratory tests. The pH and temperature were measured using pH meter (HI-9125 Handheld pH/mV Meter) fitted with pH electrode and temperature probe. The EC was measured using an analytical Electrical Conductivity unit –sension EC5, Hach Company, USA. COD, and inorganic parameters were determined by the open reflux method according to SMWW. The pesticides analysis was performed according the EPA Method 508 using gas chromatography as described before; a macro extraction technique with dichloromethane and the substituted solvent was hexane. The pharmaceuticals pesticides analysis was performed according the EPA Method 531.1 (17, 28) with HPLC (Agilent 1100, USA) equipped with a fluorescent detector, auto sampler and HPLC column C8 (25 cm 2.5 mm 5.0 µm).

2.4. Data Analysis

The removal of the chemical pollutants during the batch study was calculated as a percentage difference between the initial concentration and the effluent concentration. The average (n=3) of concentration of pollutants was calculated and presented.

3. Results and discussion

3.1. Raw and bank filtrate quality

Water-quality changes in the Nile River (with time and discharge) and in wells (with time) were determined from Nile River samples near the Independence well field and

from wells 1, 2 and 3, (Table 1), (Figure 1,2). Many seasonal water-quality changes in the Nile River are related to changes in discharge.

The results showed that a decreased in temperature by 5-7ºC during the filtration process. The temperature was decreased from 27.5 to 21 ºC approximately in summer and from 12 to 9.4 ºC in winter at Al-Edwah (El- Minea governorate), this infer to the high capacity of bank filtration technique to reduce the temperature and to act as a barrier to the changes of temperature. So, it can be concluded that bank filtration is a promising technique toward the climate change effects in Egypt.

Likewise, the turbidity was decreased by tenfold its value in the raw water, the turbidity was decreased from an average of 2.5 NTU to 0.25 NTU approximately. Which is considered as an indicator to the high effectiveness of bank filtration technique to remove the suspended solids, colloids and micro-organisms during the filtration process.

However, a slight change in the pH and dissolved oxygen concentration was observed between the raw water and the drilled bank filtration wells. The pH had been increased slightly from 8 to 8.2, which might attribute to the dissolution of some carbonate minerals which is very common in the Nile river banks. In contrast, the dissolved oxygen was decreased by 2 mg/L during the passage of the water into the pumped wells. The decreasing is mainly ascribed to the biological activity on the soil and the degradation of organic matter. Maeng, et al. (2010) illustrated that 50% of the removal of dissolved organic matter process is taking place at the first 50 cm of the filtration process.

The total dissolved solids showed an increasing trend during the filtration process. The total dissolved solids were increased from 210 mg/L to 280 mg/L approximately during the passage of the water toward the bank filtrate well. This was accompanied by an increasing in the conductivity by 10-20%. The main reason for this increasing is the dissolution of metals and ions and its migration to the infiltrate water.

Table (1): Physical characteristics of water from Nile river and from RBF wells at Bani Amer (Al-Edwah) water treatment plant (No. of Samples: 5)

Parameters	Nile River		Well 1		Well 2		Well 3	
	Range	Aver.	Range	Aver.	Range	Aver.	Range	Aver.
Temperature (C°)	12-27.4	18.3	9-20.5	16.1	9.7-25.2	17.1	10-27.5	17.7
pH	7.9-8.2	8.0	8.0-8.2	8.1	8.1-8.3	8.1	8.0-8.2	8.1
DO (mg/L)	7.3-9.8	8.3	6.2-7.2	6.7	6.3-7.4	6.8	6.1-7.6	6.9
Conductivity (µS/cm)	312-377	348	342-398	376	355-403	386	468-510	482
TDS (mg/L)	188-227	209	206-239	226	214-242	232	281-308	291
Color (Pt/Co)	45-80	18.3	5-10	7.5	5-20	12.7	5-25	14.6
Turbidity (NTU)	2-8.4	8.3	0.2-0.23	0.21	0.2-0.24	0.22	0.2-0.28	0.24

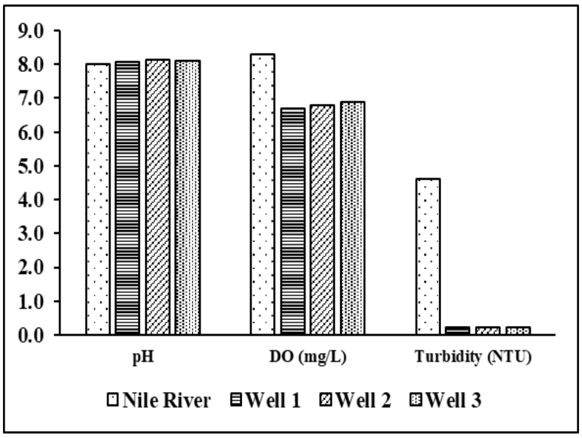

Fig (1). Average values of pH, Dissolved Oxygen and Turbidity of water from Nile river and RBF wells at Bani Amer water treatment plant.

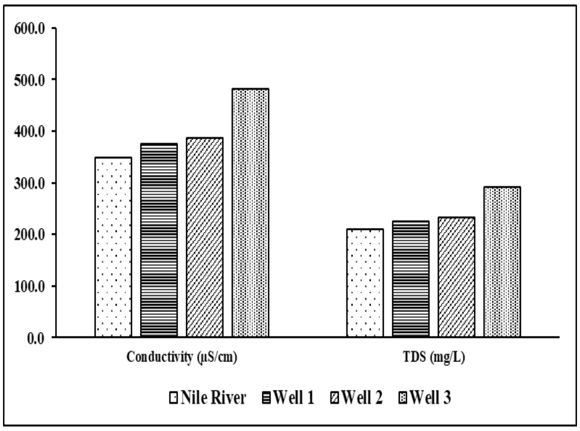

Fig (2). Average values of Conductivity and TDS of water from Nile river and RBF wells at Bani Amer water treatment plant.

3.2. Removal of inorganic chemical parameters

Water-quality changes in the Nile River (with time and discharge) and in wells (with time) were determined from Nile River samples near the independence well field and

from wells 1, 2 and 3, (Table 2), (Figure 3). Many seasonal water-quality changes in the Nile River are related to changes in discharge.

The organic matter in terms of COD and BOD was decreased by 50-60% for the first two wells near to the surface water system and increased suddenly at the third far well. The decreasing trend was appeared in the beginning of infiltration process due to the highly ability of filtration area to remove the organic pollutants through adsorption and biodegradation process. These processes have a high impact at the first meter of infiltration. Maeng (2010) illustrated that 50% removal of dissolved organic matter takes place at the first few meters of infiltration process. The removal percentage is highly dependent on the concentration of biodegradable matter and the biological activity associated to the sand. This indicates that bank filtration technique has a high capability to remove various pollutants and it is highly effectiveness under arid climate conditions.

Table (2) Chemical characteristics of water from Nile river and from RBF wells at Bani Amer (Al-Edwah) water treatment plant (No. of Samples: 5)

Parameters	Nile River		Well 1		Well 2		Well 3	
	Range	Aver.	Range	Aver.	Range	Aver.	Range	Aver.
COD (mg O_2/L)	5.2-9.4	6.2	0.82-1.4	0.93	1.1-2.2	1.7	3.2-7.4	4.8
BOD (mg O_2/L)	3.4-7.1	5.1	0.2-0.8	0.51	0.3-1.2	0.66	2.1-5.2	3.2
TSS (mg/L)	1.8-5.5	4.2	0.1-0.2	0.2	0.1-0.2	0.2	0.1-0.2	0.2
Alkalinity (mg/L, $CaCO_3$)	128-154	138	138-166	146	144-172	156	148-186	162
T. Hardness (mg/L, $CaCO_3$)	128-172	144	144-178	162	152-182	172	160-188	180
Ca. Hardness (mg/L, $CaCO_3$)	84-96	88	80-98	92	84-98	94	86-102	96
Mg. Hardness (mg/L, $CaCO_3$)	44-76	56	58-86	70	66-86	78	72-88	84
Sodium (mg/L)	21-33	27.2	28-39	35.6	31-43	38.1	36-49	42.4
Nitrate (mg/L, NO_3)	0.4-1.4	0.8	< 0.1	< 0.1	< 0.1	< 0.1	0.1-0.21	0.17
Nitrite (mg/L, NO_2)	< 0.1-0.11	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ammonium (mg/L, NH_4)	< 0.005-0.1	0.06	0.1-0.25	0.18	0.1-0.4	0.25	0.1-0.55	0.35
Phosphate (mg/L, PO_4)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Oil & Grease	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0
Fluoride (mg/L)	0.13-0.31	0.18	0.34-0.46	0.37	0.34-0.54	0.42	0.42-0.89	0.63

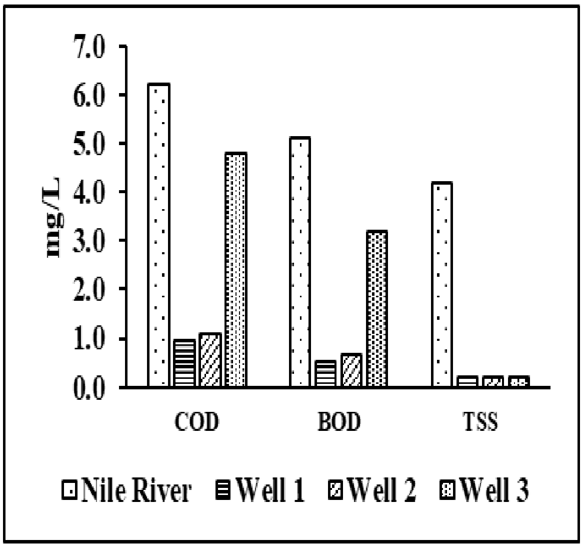

Fig (3). Average values of COD and BOD of water from Nile river and RBF wells at Bani Amer water treatment plant.

3.3. Removal of micro-organics

The results (Figure 4) revealed that bank filtration has a high ability to remove Pharmaceuticals during the filtration process. The removal of the tested pharmaceuticals exceeds 80% at all the bank filtration wells. This is in agreement with Maeng et al. (2010)

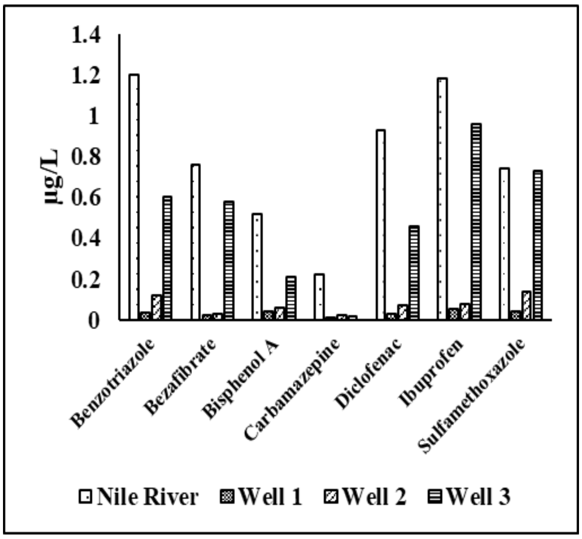

Fig (4). Average values of Pharmaceutical residues of water from Nile river and RBF wells at Bani Amer water treatment plant.

study which pointed out that bank filtration could remove the pharmaceutical through adsorption and biodegradation process taking place during the subsurface filtration process. However, Bertelkamp et al. (2014) illustrated that bank filtration is not an optimize technique to remove Carbamazepine and Ibuprofen that have higher hydrophobic and aromatic characteristics and a post treatment process may be needed. The higher removal of these organic compounds in this study is mainly attributed to the temperature. The air temperature in this study area in summer ranges between 35-45 ºC that might enhance the adsorption characteristics of the micro-organic compounds. Moreover, it promotes the biological activity associated to the sand and thus augmenting the biodegradation rate of the compounds

The same trend was observed for chlorinated pesticides, the values of most chlorinated pesticides were blow the analysis detection limit (<0.01 µg/l) and the detected values were heptachlor in Nile river and Endrine in both River Nile and Well No. 3 and Methoxychlor in both Nile and well No.3, all observations of chlorinated pesticides were blow the permissible limits.

To ensure these finding and get better understanding about the behaviour of micro-organics compounds during the filtration process. The results (Figure 5 and 6) illustrated that:

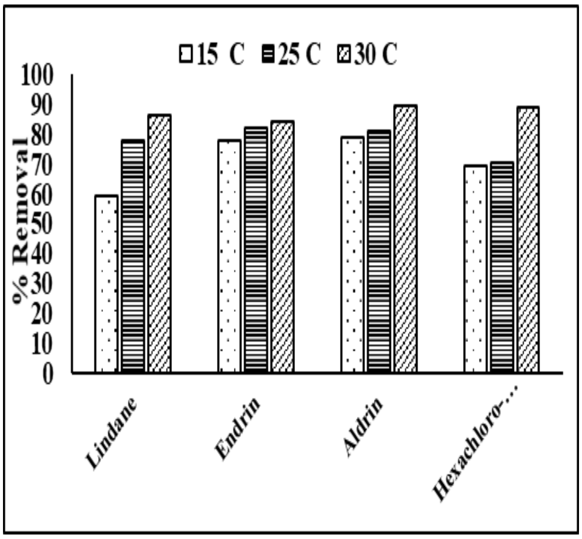

Figure (5): effect of temperature (15, 25,30 ºC) on pesticides compounds removal (batch study).

•Adsorption is the main mechanism to remove these pollutants during the bank filtration process
•Increasing the clay contents in the filtration media leads to increase the removal efficiency as the biological activity related to the soil increased and so the biodegradation rate is higher
•Oxic condition is the favourable conditions to remove organic pesticides compounds during the filtration process
•Temperature has an influential role in the removal of pesticides with favourable removal at high temperature Adsorption play a main role in the removal of hydrophobic compounds with low solubility characters. However, biodegradation is the dominated mechanism in the removal of hydrophilic compounds with high solubility and contain amino groups.

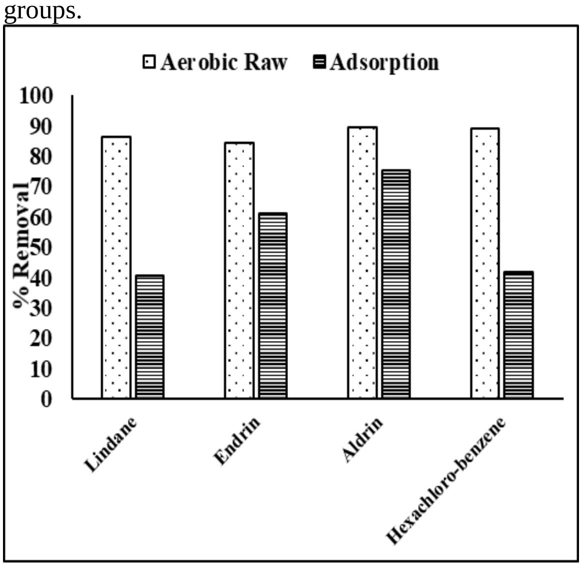

Figure (6) effect of Sodium Azide at aerobic condition on pesticides compounds removal (batch study).

4. Conclusion

Riverbank filtration is a promising technology for a secure supply of clean water. It is a widespread water management operation where bank sediments are used as a pre-treatment option for substantively reducing the quantity of many common microbial and chemical contaminants. This technique had been experienced for many hundred years in Europe and North America, However, its application in developing countries is still rare.

This research revealed that bank filtration is applicable in Egypt and has a high ability to remove the pollutants. A field study was conducted at Minia governate to evaluate the effectiveness of this technique under these hot climate weather. Bank filtration exhibited high efficacy to remove the inorganic pollutants during the filtration process. Ammonia was removed totally during the filtration process. Adsorption and biodegradation are the main mechanisms to remove these pollutants during the filtration process. Bank filtration also exhibited high efficiency to remove micro-organic pollutants during the filtration process. Laboratory- batch study was performed to verify these findings and to assess the impact of environmental conditions such as temperature, redox conditions and raw water organic composition on the removal of these pollutants. It was observed that temperature enhance the removal of these pollutants as it promotes the microbial growth and increase the adsorption efficiency of these pollutants. Aerobic conditions are preferred to remove these pollutants during the filtration process. Moreover, it was found that adsorption is the dominate mechanism for removing these pollutants during the filtration. Therefore, the characteristics of soil might affect the removal of these pollutants and this needs to be investigated.

It can be concluded that bank filtration is a promising technique to remove the chemical and biological pollutants and to provide high-grade drinking water quality at low cost. The efficiency of this technique is enhanced in hot climate countries such as Egypt.

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7. Arabic Abstract

ترشيح الطبيعى (BF) هو تقنية معالجة مياه منخفضة التكلفة يتم فيها إزالة ملوثات المياه السطحية من خلال العملية الكيميائية الحيوية والفيزيائية التي تحدث أثناء عملية الترشيح. هدفت هذه الدراسة إلى تقييم فعالية هذه التقنية لإنتاج مياه شرب ذات جودة عالية في مصر. أجريت في هذه الدراسة أعمال ميدانية وجمعت عينات من آبار ترشيح نهر النيل والبنك في العدوة بمحافظة المنيا. تم تحليل العينات وتحديد الملوثات الكيميائية (مثل مبيدات الآفات والمستحضرات الصيدلانية وغير العضوية). علاوة على ذلك ، تم إجراء دراسات على دفعات للحصول على نظرة ثاقبة حول الإزالة الميكانيكية للملوثات العضوية ولتقييم تأثير درجة الحرارة (15 ، 25 ، 30 درجة مئوية) وحالة الأكسدة (الأكسدة ، نقص الأكسجين) على الإزالة. أظهرت النتائج أن ترشيح البنك يمكن أن يزيل الملوثات غير العضوية مثل النترات والنتريت بكفاءة. ومع ذلك ، فإن فعاليتها في إزالة الملوثات العضوية تعتمد بشكل كبير على درجة الحرارة ؛ تم الحصول على إزالة أعلى عند درجة حرارة أعلى. في الختام ، يعتبر الترشيح البنكي تقنية فعالة لإزالة الملوثات الكيميائية وإنتاج مياه ذات جودة عالية ، ويوصى بشدة بتوسيع استخدام هذه التقنية في مصر.