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The reclamation of municipal effluent for irrigation by a pilot-scale advanced treatment plant

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ABSTRACT

This study concerns about the reclamation of municipal effluent for agricultural irrigation by the application of a pilot-scale advanced treatment plant capable of rapid sand filter and disinfection. The rapid sand filter significantly reduced suspended solids and turbidity. Average reductions in these parameters 76 and 62%, respectively, were achieved. The percentage removals of chemical oxygen demand and biological oxygen demand by the rapid sand filter were 32 and 55%, respectively. The amounts of heavy metals in the rapid sand filter effluent were below the national and international standards. The pilot-scale advanced treatment plant eliminated almost the 100% of fecal coliforms. Hence, the treatment costs of the pilot-scale advanced treatment plant were calculated approximately US \$0.063 /m^3. These results showed that the pilot-scale advanced treatment plant provided a low-cost water source which can be used for agricultural irrigation.

Keywords: Advanced treatment; Agricultural irrigation; Municipal effluent; Reclamation

1. Introduction

Approximately 70% of global water use, including all the water diverted from rivers and pumped from the underground reservoirs, is applied to agricultural irrigation [1]. New approaches invariably lead to the reclamation and the reuse of the wastewater that is increasingly being generated as a result of rapid population growth and the related development. Activities associated with development include agriculture and industrial production [2,3]. Highly treated wastewater effluents from municipal wastewater treatment plants (WWTPs) are, therefore, now increasingly being considered as a reliable source of water supply [4].

Major among the motivational factors for wastewater reclamation/reuse are (1) opportunities to augment limited primary water sources; (2) prevention of excessive diversion of water from alternative uses, including the natural environment; (3) possibilities to manage *in situ* water sources; (4) minimization of infrastructure costs, including total treatment and discharge costs; (5) reduction and elimination of discharges of wastewater (treated or untreated) into receiving environment; and

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(6) scope to overcome political, community, and institutional constraints [2].

The major concerns associated with water reuse are the health risks caused by pathogens, organics and heavy metals, and esthetics related to public acceptance. To satisfy these concerns, tertiary filtration is used to (1) remove residual suspended solids (SS) found in the secondary effluents that may interfere with subsequent disinfection and lower the efficiency of the irrigation system; (2) reduce the concentration of organic matter that can react with chlorine; and (3) improve the aesthetic quality of the reclaimed wastewater by reducing its SS/turbidity [5]. When more efficient elimination of microorganisms is needed, tertiary filtration could be carried out before disinfection to improve the disinfection efficiency [6].

Various technologies have been used for wastewater filtration. The most commonly used filter media are incompressible materials such as sand or anthracite with a fixed porosity between 35 and 50%. In terms of cost efficiency, rapid sand filtration remains the cheapest and most reliable application for meeting the reuse criteria for secondary effluent [7]. To date, chlorination is the most widely used means to inactivate pathogenic microorganisms in water and wastewater, and it is the principal method for preventing waterborne infectious diseases throughout the world. However, several studies have reported that the effectiveness of the chlorination process is reduced by turbidity, SS, and by the presence of nitrogen-containing materials, such as NH_3 and NO_2 [8].

Hamoda et al. [5] studied the combination of sand filtration and chlorination for producing reclaimed wastewater for agriculture in three different WWTPs in Kuwait. The tertiary-treated effluent satisfied the requirements for its use in landscape irrigation. Lubello et al. [9] revealed that a pilot plant consisting of a two-step pressure filter system with a multilayer sand, and anthracite medium and disinfection with peracetic acid (PAA) and ultraviolet (UV) for the reuse of secondary municipal wastewater achieved a mean reduction of 89% in SS. The value of two total coliforms MPN/100 mL that is legally set for unrestricted irrigation was consistently satisfied. Kuo et al. [10] evaluated tertiary filtration and disinfection systems for upgrading high-purity oxygen-activated sludge plant effluent. Sand filters were capable of consistently meeting the State of California's effluent turbidity limit, and the 2.2 MPN/100 mL coliform standard could be met.

This study is based on the reclamation of municipal effluent for agricultural irrigation by means of the pilot-scale advanced treatment plant capable of rapid sand filter and disinfection. The efficiencies of the treatment units were evaluated by the determination of turbidity, SS, organic matter, fecal coliform (FC), and heavy metals removal and the quality of the pilot-scale advanced treatment plant effluent was compared with national and international standards for unrestricted agricultural irrigation water.

2. Materials and methods

2.1. Characteristics of the municipal effluent and the pilot-scale advanced treatment plant

The pilot-scale advanced treatment plant was used for the reclamation of the municipal effluent produced by a municipal WWTP located at Bursa in northwestern Turkey. The WWTP consists of screens, grit removal, screw pumps, a selector tank, anaerobic biophosphorus tanks, aeration tanks, a secondary sedimentation tank, and sludge dewatering units, and the WWTP treats, approximately, 160,000 m^3/day [11]. The municipal effluent of the WWTP was used to carry out the experimental work. The pilot-scale advanced treatment plant was located at the municipal WWTP. The municipal effluent characteristics are shown in Table 1.

Grab samples for physical, chemical, and microbial analysis were collected from the municipal effluent and the pilot-scale advanced treatment plant (twice a month). Sixteen effluent samples were collected over an eight-month period (from March 2011 to October 2011).

The municipal effluent and the pilot-scale advanced treatment plant effluents were evaluated for pH, conductivity, SS, turbidity, organic as well as inorganic pollutant parameters, and bacteriological quality. Because of the seasonal variation in the municipal wastewater and weather conditions, the extent of reduction of pollutant parameters (especially FC) in the municipal effluent demonstrated in Table 1 can also vary extensively. The quality of the municipal effluent must be improved to be reused for agricultural irrigation. The pilot-scale advanced treatment plant was designed to treat the municipal effluent for the additional removal of SS, turbidity, and organic and inorganic residual pollutants to provide the disinfection of the municipal effluent and to eliminate variability in the municipal effluent. The advanced treatment based on rapid sand filtration and disinfection was tested by the 0.18 m^3/h pilot-scale advanced treatment plant. The municipal effluent of the WWTP was supplied to the pilot-scale advanced treatment plant. This system was run 30 h per week. Pilot plant was taken into operation on Monday every week.

Table 1
Characterization of the municipal effluent and treated effluent after the rapid sand filter

Parameter	Unit	The municipal effluent	Treated effluent characterization after the rapid sand filter
pH	–	7.76 ± 0.16	7.68 ± 0.09
Turbidity	NTU	3.1 ± 0.5	1.19 ± 0.15
SS	mg/L	6.42 ± 2.09	1.55 ± 0.84
Conductivity	μS/cm	908 ± 14	911 ± 13
COD	mg/L	29 ± 3.66	19.86 ± 2.60
BOD	mg/L	9.56 ± 1.50	4.33 ± 0.49
NH_3	mg/L	0.56 ± 0.14	**0.56** ± 0.07
NO_3^-	mg/L	2.36 ± 0.87	3.47 ± 1.46
PO_4^{2-}	mg/L	0.65 ± 0.58	**0.65** ± 0.14
SO_4^{2-}	mg/L	90.13 ± 4.88	**90.04** ± 8.20
Ca^{2+}	mg/L	64.84 ± 5.35	65.2 ± 6.46
Mg^{2+}	mg/L	13.10 ± 0.47	13.56 ± 0.44
Na^+	mg/L	101.91 ± 2.94	100.94 ± 3.74
SAR	–	3.01 ± 0.42	3.25 ± 0.55
Zn	μg/L	146.35 ± 57.1	69.82 ± 14.75
Mn	μg/L	27.07 ± 3.64	25.35 ± 9.37
Cu	μg/L	15.89 ± 9.88	11.08 ± 5.33
Pb	μg/L	74.157 ± 66.63	23.48 ± 4.85
Fe	μg/L	437.54 ± 127.50	195.31 ± 43.39
Ni	μg/L	28.52 ± 37.71	12.80 ± 7.46
Al	μg/L	156.38 ± 80.95	114.69 ± 61.05
Cr	μg/L	6.32 ± 1.31	3.02 ± 1.21
FC	MPN 100/mL	$1.6 \times 10^5 \pm 1.9 \times 10^4$	$1.4 \times 10^5 \pm 9.8 \times 10^4$

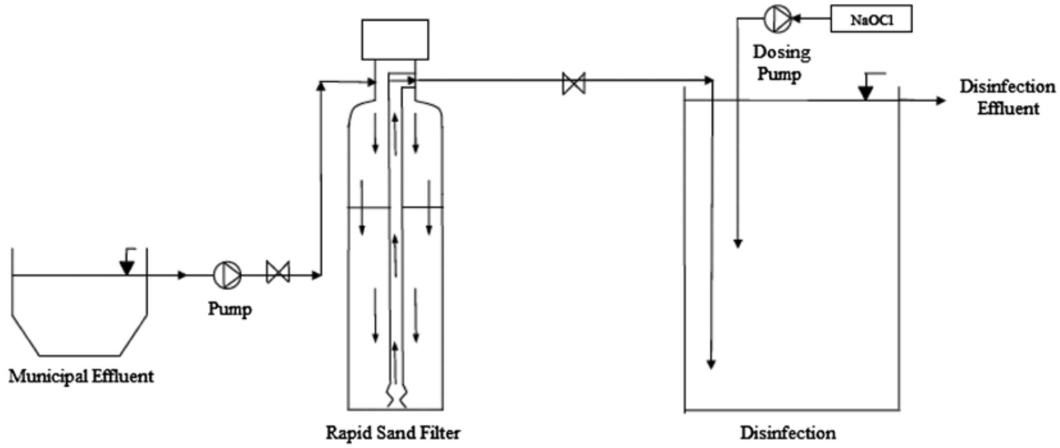

Fig. 1. The flowchart of the pilot-scale advanced treatment plant.

Samples were collected following the turbidity removal efficiency of filtration unit. Prior to disinfection, the municipal effluent was subjected to the rapid sand filter. The flowchart of the pilot-scale advanced treatment plant is illustrated in Fig. 1.

2.2. *Rapid sand filter*

Filtration was provided by a multilayer gravity-driven cylindrical rapid sand filter composed of two layers: anthracite (0.8–1.8 mm diameter) and quartz (1–3, 3–5, and 5–8 mm diameter). The rapid sand filter had a diameter of 21.2 cm and a height of 90 cm, containing (from top down) 26 cm of anthracite (diameter 0.8–1.8 mm) followed by 9 cm of 1–3 mm quartz, 10 cm of 3–5 mm quartz, and 10 cm of 5–8 mm quartz. A 35 cm void space was left at the top to facilitate aeration of the system.

The municipal effluents were fed into the top inlet of the rapid sand filter and were evenly distributed downward through the distribution laterals. In the filtration zone, the municipal effluent flowed from top to bottom throughout the sand bed and entered the distributor as treated filtrate. The treated water flowed up through the center tube to the filter outlet.

The rapid sand filter was operated to provide an average filtration rate of 6 m^3/m^2h. Backwashing of the filter was carried out for two hours weekly using the pressure of urban network water and the flux of backwash was applied as 15 m^3/m^2h. Sodium hypochlorite (NaOCl) was supplied after the rapid sand filter to ensure effective disinfection of the rapid sand filter effluent.

2.3. Disinfection studies

Laboratory-scale disinfectant optimization experiments were performed using jar test apparatus. NaOCl (15% available chlorine) and PAA (40%) were used as disinfectants for the disinfectant optimization experiments in batch operation. The filtered water was obtained by rapid sand filtration of the municipal effluent through. The filtered water was placed in 1 L beakers with disinfectant at 1, 2, and 3 mg/L dosages. The solutions were subsequently stirred at 30 rpm for 30 min. The paddles were withdrawn, and samples were collected and analyzed for FC. Laboratory-scale disinfectant optimization experiments were carried out to determine the type of disinfectant and the concentration of disinfectant for the pilot-scale advanced treatment plant startup.

2.4. Analytical procedure

The municipal effluent and treated wastewater samples that were collected at the outlet of the rapid sand filter and disinfection unit were evaluated for pH, conductivity, SS, turbidity, organic as well as inorganic pollutant parameters, and bacteriological quality. Conductivity and pH were measured using a conductivity/total dissolved solids (TDS) meter and a pH-meter using the HACH HQ40d multimeter (HACH Co, Loveland, CO, USA), respectively. SS were analyzed according to Standard Methods [12]. For biological oxygen demand (BOD) analysis, the manometric method was employed with the aid of a HACH BOD Track II instrument operated at 20°C for five days. A HACH DR5000 UV–vis spectrophotometer (CO, USA) was used to determine phosphate (PO_4^{2-}), nitrate (NO_3^-), chemical oxygen demand (COD), ammonia (NH_3), sulfate (SO_4^{2-}), and chlorine residuals. Turbidity was measured using a HACH 2100P turbidity meter.

The sodium adsorption rate (SAR) is one of the most important criteria for selecting irrigation water. The SAR value was used to indicate the degree of harmfulness of the water in terms of sodium (or similar alkali). The SAR values for each stage were calculated by Eq. (1) [13], where the concentrations are reported in meq/L.

$$\mathrm{SAR} = \frac{\mathrm{Na}^+}{\sqrt{\frac{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+})}{2}}} \tag{1}$$

The Ca^{2+}, Mg^{2+}, and Na^+ ions and the metal concentrations in digested samples were analyzed using ICP-AES. The targeted metals were Zn, Mn, Cu, Pb, Fe, Ni, Al, and Cr. The blanks, standard calibration solutions and digested samples were put into the tubes of an automatic sampler and were read using the instrument. The standard calibration solutions employed in the analyses were at concentrations of 0.05, 0.1, 0.25, 0.5, and 1 mg/L for the metals and at concentrations of 0.2, 0.1, 0.05, 0.025, and 0.01 mg/L for the ions. If the sample concentration was higher than the calibration range, the calibration solution concentrations were raised to 1, 2, 5, and 10 mg/L. The blanks were prepared by adding concentrated 5% HNO_3 to ultrapure water produced from a Milli-Q system (Millipore Co.).

Quality control analyses were performed with certified liquid samples (multielement standard, catalog number 900-Q30-002, lot number SC0019251, SCP Science, Lasalle, Quebec) to ensure that the measurement apparatus conformed to accepted standards. Quantification limits were as follows: 3 μg/L for Pb; 5 μg/L for Cr, Cu, Mn, and Zn; 20 μg/L for Ni; 100 μg/L for Fe; and 200 μg/L for Al. Certified liquid samples were used to check the analytical accuracy, which ranged between 1 and 10%.

For bacteriological analysis, water samples were collected in sterile glass bottles (100 mL) and analyzed immediately after collection. The determination of the bacteriological quality of the water was based on the measurement of FC, because FC is not only a fecal contamination indicator but also has high numbers in conventional wastewater effluent [6]. The analysis of FC was implemented according to Standard Methods [12].

3. Results and discussion

The samples from pilot-scale advanced treatment plant effluents were analyzed, and the results were used to determine the performance of the rapid sand filter in improving the quality of the municipal effluent and the efficiency of disinfection.

3.1. Efficiency of rapid sand filter

Approximately $0.18\,m^3/h$ of municipal effluent was introduced to the rapid sand filter section of the pilot-scale advanced treatment plant. Table 1 summarizes the results obtained for the analysis of the municipal and rapid sand filter effluents for physical, chemical, and bacteriological parameters.

Table 1 shows that the municipal effluent characteristics have large deviations for some parameters. Variability in municipal effluent quality may arise from a problem caused by diurnal or seasonal variations in the influent wastewater flow and characteristics. The municipal effluent characteristics exhibited more variability than those of the rapid sand filter effluent for the parameters analyzed. Therefore, filtration may be regarded as a supplementary polishing step for the production of a constant quality effluent which is not affected by the performance of the activated sludge unit and by the eventual variation in secondary effluent quality [4].

Rapid sand filter played an important role in removing pollution parameters from the municipal effluent. According to Table 1, the rapid sand filter achieved a significant reduction of SS. A mean reduction of 76% was observed. This removal efficiency represented an SS removal efficiency of 70% corresponding to the relatively high turbidity removal attained by [5], after the sand filtration of secondary municipal wastewater for reuse. According to [14], for the typical dual media pressurized filters, a 67–75% mean reduction could be expected when turbidity in the influent is lower than 2.9 NTU. A lower SS elimination efficiency (approximately 50%) has been observed by Illueca et al. [15], when applying a treatment alternative consisting of settling plus sand filtration and UV radiation for the agricultural reuse of reclaimed secondary wastewater.

Turbidity was reduced from 3.1 to 1.2 NTU (mean values). This diminution corresponded to 62% removal efficiency from the munipical effluent. This removal was consistent with the 60% reduction of municipal effluent turbidity after filtration found by De Koning and Van Nieuwenhuijen [16]. Petala et al. [17] observed, approximately, 45% turbidity removal from secondary municipal effluent after sand filtration. Lower turbidity reduction capacities (approximately 15%) have been observed by Jimenez et al. [18], during the sand filtration of a primary treated effluent containing a high solid and organic content.

The removal of pollutants using rapid sand filtration is primarily due to the straining mechanism of the sand grains [19]. The percentage removal of COD and BOD through the rapid sand filter was 32 and 55%, respectively. This removal of organic matter was attributed to the remarkable removal of SS. A similar COD and BOD removal capacity of 38 and 54%, respectively, was obtained by Hamoda et al. [5] after the sand filtration of secondary municipal wastewater for reuse. Lower COD and BOD removal efficiencies (13 and 38%, respectively) were attained by Sekaran et al. [19] after sand filtration of an anaerobic-treated effluent. However, as shown in Table 1, a small increase in the amount of NO_3^- was observed. Sekaran et al. [19] were not able to achieve the removal of NO_3^- after the sand filtration of an anaerobically treated effluent. National standards [20] have been developed for metals and trace elements according to international guidelines, such as those from the US EPA [21]. As shown in Table 1, the concentrations of heavy metals in the municipal effluent were low, and the amounts of heavy metals in the rapid sand filter effluent were much lower than in the municipal effluent. Consequently, the average rapid sand filter effluent values meet agricultural irrigation standards according to both national and international guidelines. With respect to the removal efficiency of the rapid sand filter for heavy metals, the most effective and remarkable removals were obtained for Pb (68%), Fe (55%), Ni (55%), Zn (52%), and Cr (52%). Lower removals were observed for Cu (30%), Al (27%), and Mn (6%). The removal of heavy metals and other substances can be attributed exclusively to the filtration of filterable matter. Filtration in the traditional sense is meant to remove SS. In WWTP effluent, these solids contain mainly organic pollutants and insoluble complexes of metals [22]. Dissolved organic matter and sludge flocs are defined as weak acids which are able to form complexes with heavy metal ions. The removal of heavy metals has often been attributed to the possibility of filterable organic material that appears as weakly acidic compounds [23,24].

As shown in Table 1, conventional wastewater treatment reduces the numbers of enteric microbes, but reductions resulting from the treatment processes can vary extensively, and wastewater effluents can still contain high numbers of FC. Conventional treatment processes removed the enteric microorganisms quite efficiently, but high numbers of fecal indicator bacteria survived the treatment processes and were discharged to the receiving natural waters [6]. The reduction of FC through the rapid sand filter was 13% with a large deviation. This deviation has arisen from the variability of the amount of FC in the munipical effluent. The quality of effluent obtained from the sand filter is, therefore, dependent on the quality of the influent that is treated [15].

3.2. Disinfection process

The results of the laboratory-scale disinfection studies are shown in Table 2. The removal efficiencies of disinfectants were investigated for FC because of a criterion for FC is present in the national guidelines.

As shown in Table 2, disinfection of rapid sand filter effluents with 1–3 mg/L of PAA and NaOCl after 30 min of contact time achieved a significant removal of FC from the municipal effluent. The FC removal efficiencies at 2–3 mg/L NaOCl dosages were similar. There is a little difference in the removal efficiencies for 2–3 mg/L PAA dosages. As shown in Table 2, the removal efficiencies of different disinfectants were similar. Because NaOCl is much less expensive than PAA, NaOCl disinfectant was used in the pilot-scale advanced treatment plant study. Additionally, free chlorine concentrations with different NaOCl doses are shown in Table 3. The optimum NaOCl dosage was determined to be 2 mg/L for the disinfection unit of the pilot-scale advanced treatment plant based on the EPA free chlorine limits.

The removal efficiencies of rapid sand filter and disinfection units and the characterization of disinfection unit effluent obtained from the pilot-scale advanced treatment plant were compared with national and international standards for agricultural irrigation water, as shown in Table 4.

Table 4 demonstrates that the values of the pilot-scale advanced treatment plant effluent (the disinfection unit effluent) are consistent with the stated parameters of the national irrigation guideline Class A [20], Class B [20], and [21], standards for irrigation.

As shown in Table 4, the disinfection unit effluent meets the Class B national irrigation guidelines [20], easily. Class B encompasses the irrigation of commercial crops such as orchard and vineyard crops, the irrigation of fodder crops and pastures, and irrigation areas with limited public access. Class A of the national irrigation guidelines includes the surface or the spray irrigation of any food crop, including crops eaten raw, and landscape irrigation in areas of public access such as parks. The rapid sand filter used in this pilot-scale study is the filtration unit suggested in these guidelines as the tertiary treatment. The turbidity of the municipal effluent was reduced from 3.1 to 1.19 NTU with the rapid sand filter. The recommended amount of turbidity (<2 NTU) was obtained prior to disinfection, as stated in Table 4. The combination of rapid sand filter and disinfection units made the values of turbidity and SS of the municipal effluent suitable for Class A of the national irrigation guidelines. The average value of FC from the disinfection effluent was determined to be 7.67 MPN/100 mL. Although this value was higher than 0 MPN/100 mL, the average values of FC did not exceed 14 MPN/100 mL as stated in the Class A guidelines for any of the samples. Conductivity was higher than the value suggested for the criteria of the I class (<700) for irrigation water. Because of this higher

Table 2
Removal efficiencies for FC in disinfection treatments of effluents after rapid sand filter with different doses of NaOCl and PAA

Parameter	Disinfectants					
	NaOCl (mg/L)			PAA (mg/L)		
	1	2	3	1	2	3
FC (%)	97.86	99.99	99.99	93.47	99.92	99.94

Table 3
Free chlorine concentrations with different NaOCl doses

Parameter	The municipal effluent	The rapid sand filter effluent	NaOCl (mg/L)		
			1	2	3
Free chlorine (mg/L)	0.03 ± 0.01	0.04 ± 0.01	0.09 ± 0.02	0.42 ± 0.11	0.97 ± 0.28

Table 4
Removal efficiencies after each treatment step and the characterization of disinfection unit effluent compared to the applicable agricultural irrigation guidelines

Parameter	Unit	Rapid sand filter removal (%)	Disinfection removal (%)	Disinfection unit effluent	National guideline class A (WPCR, 2010)	National guideline class B (WPCR, 2010)	US EPA, 2004
pH	–	–	–	7.8 ± 0.09	6–9	6–9	–
Turbidity	NTU	62	–	1.22 ± 0.19	<2[a]	–	2
SS	mg/L	76	25	1.16 ± 0.33	<5[b]	<30	5[b]
Conductivity	μS/cm	−0.3	−2	934 ± 13.5	<700[c]	–	–
COD	mg/L	32	10	17.98 ± 2.29	–	–	–
BOD	mg/L	55	20	3.47 ± 0.26	<20	<30	10
NO_3^-	mg/L	47	11	3.1 ± 1.18	–	–	–
PO_4^{2-}	mg/L	**0**	18	**0.53** ± 0.05	–	–	–
SO_4^{2-}	mg/L	**0**	11	**80.13** ± 7.61	–	–	–
SAR	–	–	–	5.29 ± 0.83	–	–	–
Chlorine residual	mg/L	–	–	0.42 ± 0.15	>1[d,e]	>1[d,e]	1
FC	MPN/100 mL	13	99.9	7.67 ± 0.58	0/100[f,g]	<200/100[f,h]	–

[a]The recommended amount of turbidity must be accomplished prior to disinfection. Not to exceed 5 NTU at all times.
[b]If SS are used instead of turbidity.
[c]States in the chemical quality criteria of irrigation guidelines.
[d]Characterizes the value after thirty-minute of contact time.
[e]The value of chlorine residual in the treated wastewater distribution system (at the last application point) must be over 0.5 mg/L.
[f]Characterizes seven-daily mean values.
[g]The value of FC must not exceed 14 MPN/100 mL.
[h]The value of FC must not exceed 800 MPN/100 mL.

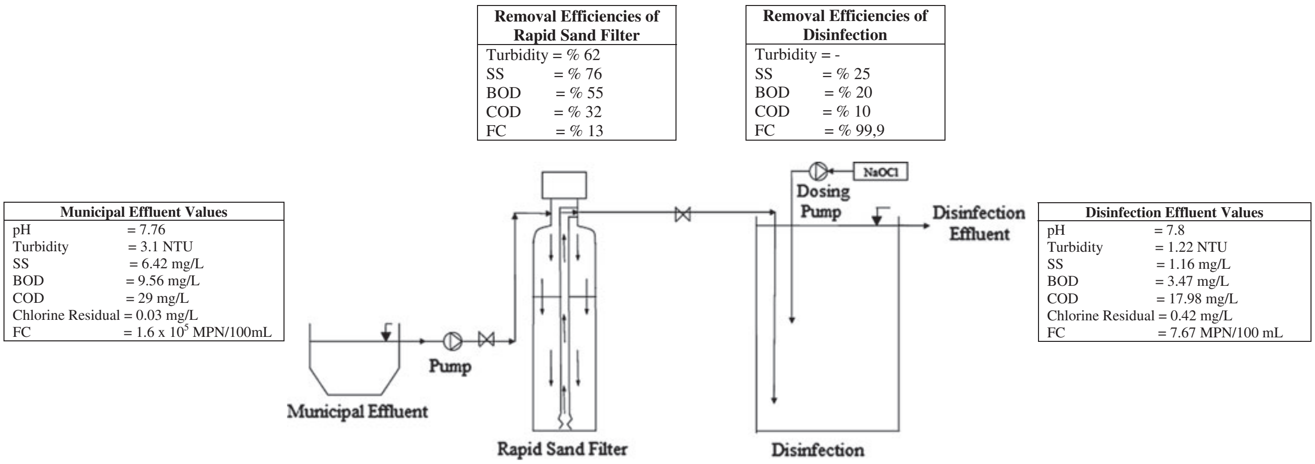

Fig. 2. Removal efficiencies in each treatment step and the values of the municipal effluent and the disinfection unit effluent.

conductivity, disinfection effluent has complied with the II Class (700–3,000) of the national guidelines with respect to conductivity. The SAR value of the disinfection effluent is at a level which can affect the irrigation of over-sensitive plants such as avocado, according to the guidelines. Salinity collectively indicates salts in the water and is measured in the form of TDS. Because the amount of TDS in the disinfection effluent is 598 mg/L, this effluent can easily be utilized for the irrigation of sensitive plants such as beans, carrots, and oranges as stated in the national guidelines. Furthermore, the disinfection effluent has conformed to the guidelines in terms of the heavy metals, as shown in Table 1. Removal efficiencies in each treatment step and the values of the municipal effluent and the disinfection unit effluent were shown in Fig. 2.

For unrestricted irrigation (that is, for uses that include crops likely to be eaten uncooked), the WHO guideline is 1,000 FC bacteria/100 mL [21]. The combination of rapid sand filter and disinfection of municipal effluent apparently achieve the WHO guidelines.

Üstün et al. [25], investigated the tertiary treatment plant including coagulation–flocculation–disinfection for the reuse of secondary municipal effluent for irrigation. The highest removal efficiencies for SS, COD, turbidity, and FC were determined to be 64, 39, 81%, and 4 log reduction, respectively. Tertiary treated effluent was demonstrated to be a source of viable water for irrigation.

Illueca et al. [15] applied an alternative treatment consisting of settling, sand filtration, and UV irradiation for the agricultural reuse of reclaimed secondary wastewater. This combination provided 99.8% removal efficiency for FC and was suitable for the reduction of the FC of secondary effluent to the WHO recommendations for agricultural reuse.

Liberti and Notarnicola [26] studied the combination of settling, sand filtration, and disinfection with PAA for producing reclaimed wastewater for agricultural usage at a West Bari (Italy) sewage treatment plant. The disinfected effluent complied with the Italian standards for wastewater reuse in agriculture for the pH, SS, BOD, COD, and SAR parameters. This study revealed that filtration to an SS concentration of $\leqslant$10 mg/L was necessary to improve the PAA disinfection rate.

3.3. Cost estimation

Cost estimation is an important aspect of wastewater treatment. The overall costs are represented by the sum of the capital, operation, and maintenance costs. For a fullscale system, these costs depend strongly on the nature and the concentrations of the pollutants, the flow rate of the effluent, and the configuration of the reactor [27]. An estimation of costs has been made in this section for the operating costs of the treatment processes used for the advanced treatment. The operating cost of the pilot-scale advanced treatment plant included the cost of power for the operation of each treatment process, the corresponding pumping requirements, and the consumable expenses. Energy consumption comprises pumping of municipal effluent to the rapid sand filter column and disinfectant pumping. Consumables include the cost for the NaOCl used for disinfection and the cost of clean water for backwashing of the rapid sand filter. Backwashing of the filter was carried out weekly. The pilot-scale advanced treatment plant was run 30 h per week.

Table 5
Operating costs for the pilot-scale advanced treatment plant

Reagents	Basis	Unit cost ($)	Treatment cost ($/m^3)
NaOCl (15%)	L	0.39	0.00546
Electricity	kW/h	0.13	0.018
Clean water cost for backwashing	L	1.5	0.04
Total treatment cost[a]	($/m^3)		0.063

[a]Cost of labor and sludge disposal not included.

Estimated operational costs are presented in Table 5. The treatment cost of the pilot-scale advanced treatment plant was approximately US $0.063 /m^3.

As shown in Table 5, pilot-scale advanced treatment plant effluent supplied a low-cost water source. In terms of value for money, rapid sand filtration remains the cheapest and most reliable application for meeting the reuse criteria of secondary effluents [28]. Pilot-scale advanced treatment plant effluent can be used for irrigation of crops which are eaten raw and landscape irrigation where there is public access, such as parks, by checking continuously. Furthermore, this advanced degree-treated effluent has a sufficient water source quality to meet the need for agricultural irrigation water, especially in the arid summer seasons when water is scarce.

4. Conclusions

The pilot-scale advanced treatment plant, including rapid sand filter and disinfection, was investigated for the reclamation of municipal WWTP effluent for irrigation. The municipal effluent and advanced degree-treated wastewater samples collected at the outlet of the rapid sand filter and disinfection unit were evaluated for some physical, chemical, biological, and microbiological pollutant parameters. Based on the experimental results, the following conclusions can be drawn:

- The municipal effluent of WWTP meets the direct discharge standards in Turkey, but this effluent does not conform to the applicable agricultural irrigation guidelines. The performance of rapid sand filter for improving the quality of municipal effluent and the efficiency of disinfection was investigated.
- The rapid sand filter played an important role in removing pollution from the municipal effluent. The removal of pollutants by sand filter is primarily a result of the straining mechanism of the sand grains. The rapid sand filter produced a significant reduction of SS and turbidity. A mean reduction of 76 and 62% was achieved for SS and turbidity, respectively. The percentage removal of COD and BOD through the rapid sand filter was 32 and 55%, respectively. This removal of organic matter was attributed to the remarkable removal of SS.
- Regarding the removal efficiencies of the rapid sand filter for heavy metals the most effective and remarkable removals were observed for Pb (68%), Fe (55%), Ni (55%), Zn (52%) and Cr (52%). The removal of heavy metals was often attributed to the removal of SS containing mainly organic pollutants and insoluble complexes of metals and possibly filterable organic material, which appears as weakly acidic compounds.
- In the pilot-scale advanced treatment plant, 2 mg/L of NaOCl was added to the rapid sand filter effluent. After the disinfection unit, 99.9% removal efficiency for FC was achieved, and the FC level in the municipal effluent was reduced to the WHO recommendations for agricultural reuse.
- The average values of advanced degree-treated municipal effluent are consistent with the US EPA standards for irrigation.
- The combination of rapid sand filter and disinfection has made the values of turbidity and SS in municipal effluent suitable for Class A of the national irrigation guidelines. FC and conductivity were higher than the national irrigation water guidelines. The average value of FC in the disinfection effluent was determined to be 7.67 MPN/100 mL. Although this value was higher than 0 MPN/100 mL, the average values of FC did not exceed the level of 14 MPN/100 mL, as stated in Class A for any samples.
- Rapid sand filter has produced a cheap water source which meets the reuse criteria for municipal effluent. Sand filters does not create the problem of chemical sludge formation. Because of these considerations, reuse of advanced degree-treated municipal effluent for agricultural irrigation is an economical and environmentally friendly option for the development of water resources in Turkey.

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