Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.21398

89 (2017) 118–126
September

Influence of sand filter in wastewater treatment (a case study in Gaza City, Gaza Strip wastewater treatment plant)

Yasser El-Nahhal[a,*], Omran El-Dahdouh[a], Husam Al-Najar[a,b]

[a]*Faculty of Science, Islamic University Gaza, Palestinian Authority, emails: y_el_nahhal@hotmail.com (Y. El-Nahhal), nabila.dahdouh@hotmail.com (O. El-Dahdouh), halnajar@iugaza.edu.ps (H. Al-Najar)*
[b]*Faculty of Engineering, Islamic University Gaza, Palestinian Authority*

Received 29 June 2017; Accepted 28 August 2017

ABSTRACT

Scarcity of water resources increases the pressure to develop methods for wastewater treatments. In this study, modifications of sand filter were made by installing vertical devices with different length to change the conditions inside the sand filter; consequently, the produced water may be suitable for reuse. We assessed the performance of modified sand filters cultivated with and without reed plant in changing the flow rate, removing biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), removal of ammonia, total Kjeldahl nitrogen (TKN), removal of nitrate, total suspended solids (TSS), and fecal coliforms (FC). Two types of sand filters were used in this study: one sand filter was planted with reed bed and the second without reed bed. Results showed that modified sand filters had the ability to reduce the flow rate nearly 10 times lower than regular sand filter (horizontal flow). Moreover, removal of BOD_5, COD, nitrogen compound, TSS, and FC was also significant. An interesting outcome of the study is that sand filter removed 52% of BOD_5, 32% of COD, 39% of TKN, 35% of NH_4 as result of NH_3 conversion to NO_3, 93% of FC, and 71% of TSS. It is evident that modified filters have higher efficiency in removing pollutants from wastewater. It can be concluded that application of sand filters will significantly improve the quality of treated wastewater. The study revalued that increasing retention time in the sand filters considerably increased the removal efficiency.

Keywords: Wastewater; Sand filter; Reed bed; Biochemical oxygen demand; Chemical oxygen demand; Total suspended solids; Fecal coliforms; Total Kjeldahl nitrogen; TKN

1. Introduction

Wastewater is classified into three classes: domestic, industrial, and hospital wastewater [1,2], and their reuse is categorized into four groups according to their biological properties [3,4]: Group A, has high quality, no restriction for irrigation, biochemical oxygen demand (BOD) value below 20, total suspended solids (TSS) value below 30, and FC below 200; Group B, good quality, similar as above except FC value five times higher than Group A; Group C, has higher BOD and TSS values than Group B, strictly controlled irrigation, medium quality; and Group D, bad quality and extremely restricted. So far, reuse of treated wastewater has two advantages: one is improving the environment quality and second is conserving water resources.

Wastewater collection in developed country occurred through pipelines connected to the treatment plants, which usually consist of primary treatment ponds (settling ponds, precipitation ponds), secondary treatment ponds (oxidation ponds) and tertiary treatment ponds (co-angulation, bioremediation, and/or reverse osmosis units).

For our case study, there are four wastewater treatment plants operating in the Gaza Strip: Beit Lahia wastewater treatment plant in the north, Gaza wastewater treatment plant in the Gaza city, Khan Younis, and Rafah wastewater treatment plant in the south. These plants are overloaded as the actual flow far exceeds the capacity of the plant. So far, wastewater treatment plants receive around 115,000 m^3/d in Gaza Strip [5], with a quality far away from Palestinian Standards [6].

---

* Corresponding author.

1944-3994/1944-3986 © 2017 Desalination Publications. All rights reserved.

Treatment of wastewater includes several methods such as constructed wetlands [7–9], bioreactors combined with ultraviolet radiation disinfection [10], photochemical and electrochemical oxidation [11,12], and sand filters [13,14]. Filtration of wastewater may be a suitable option for treatments which is defined in this manuscript as an interaction between a suspension and a filtering material; pollutants are removed from the solution when they are attached to the media or to previously captured particles.

Several attempts have been studied for wastewater treatment, including slow sand filter [15,16], sand filter followed by granular activated carbon [17], combination of sand, marble chips, and wetland plant *Typha latifolia* is in constructed wetlands [18], sand filter with reed plants [19,20], zeolite biological aerated filters [21], and filtration by a population of *Daphnia magna* [22].

The above mentioned attempts were costly, need trained manpower, specified for removal of certain pollutants and/or specified for certain wastewater (gray water, dairy product wastewater, or industrial wastewater). In the present study, we designed a sand filter with some modifications that enable chaining conditions inside the sand filter so that the retention time is increased, consequently, the treatment process may become better than the regular sand filter. As a result, the treated wastewater could be used for agricultural irrigation. So far, treated wastewater has advantages in agricultural production. For instance previous studies [23,24] showed the ability of treated wastewater to increase the agricultural products and to change the soil properties. Furthermore, El-Nahhal et al. [25] revealed the importance of application of sewage sludge to increase plant growth. In the way around El-Nahhal et al. [24] reported that application of sewage sludge may increase hydrophobicity of soil.

2. Materials and methods

2.1. Site description

Components of wastewater treatment plant are shown in detail by EL-Dahdouh [26]. The wastewater treatment plant of Gaza City is located on an elevated location to the south of the city with a total area of 130,000 m^2. It was constructed in 1977 as a two-pond treatment system and enlarged in 1986 with additional two ponds. Part of this enlargement includes reuse facilities, consisting of three large recharge basins, a booster pumping stations, a 5,000 m^3 storage tank, a distribution piping system, and an overflow pipeline to the Wadi Gaza. Additional development including establishing two trickling filters and four anaerobic ponds were made during the periods of 1996–2006.

2.2. Experimental layout

The experiment includes sand filter cultivated with reed plants (R) and sand filter without cultivation (S). The five units are fed from one central header of inlet channel through inlet gates. At the bottom of the filters a herringbone drain is installed to collect the filtered water. This drain is made of UPVC pipes with a diameter of 6″, the slope of the filters is 1–2 and the filter close to vertical. The lining of a filter is impervious, durable, and able to resist penetration by macrophyte roots.

2.3. Sand filter design

Materials of sand with different grains (0.015–0.35 mm) and gravels with size (1–7 cm) were purchased from Pioneer Company, Texas, USA.

Reed plants were collected from Wadi Gaza and from Gaza wastewater treatment plant. Polyvinyl chloride (PVC) sheets (0.2 mm thickness) were purchased from Pioneer Company, Texas, USA. Table 1 provides details on the engineering structure of sand filter. The sand filter was backed with different grain size starting from larger size (5–7 cm) in the bottom of the sand filter up to fine particles (0.015–0.035 cm) in the top, more details of a cross section of a sand filter is presented in Table 1. For the reed bed filters, the top 20 cm of sand was basted by reed [27].

Moreover, Fig. 1 shows the arrangements of different layers in sand filter.

2.4. Operating and conditioning the sand filter

The sand filter was operated at the normal conditions, inlet at zero level (horizontal layout). Changing the levels was operated by installing a perpendicular device with levels of 30, 50, 70, and/or 90 cm above the ground. These levels change the retention time of wastewater inside the sand filter, consequently changing the quality of wastewater to be obtained. More details are demonstrated in Fig. 1.

2.5. Measuring the infiltration rate

Following the procedure previously described by Nichols et al. [28], the infiltration rate (IR) was calculated by measuring the amount of water infiltrated through the surface area of the sand filter during 24 h, as shown in Eq. (1):

$$\mathrm{IR} = \frac{Q}{A} \tag{1}$$

where Q is the quantity of water (m^3) and A is the surface area (m^2).

At the beginning, the first reading of the water level was taken, and then every 3 h during 24 h and finally the IR to each reading was calculated below:

$$\mathrm{IR} = \frac{\mathrm{HR} \times 1000}{\text{Surface area}} \ \mathrm{m^3/m^2/d}$$

where IR is the infiltration rate and HR is the hydraulic rate.

Table 1
Construction of sand filter

Depth (cm)	Layer	Diameter (cm)
0–10	Gravel	5–7
10–30	Gravel	3–5
30–50	Gravel	1–3
50–60	Gravel	1
60–70	Gravel	Less than 1
70–160	Sand	0.5–0.35 mm

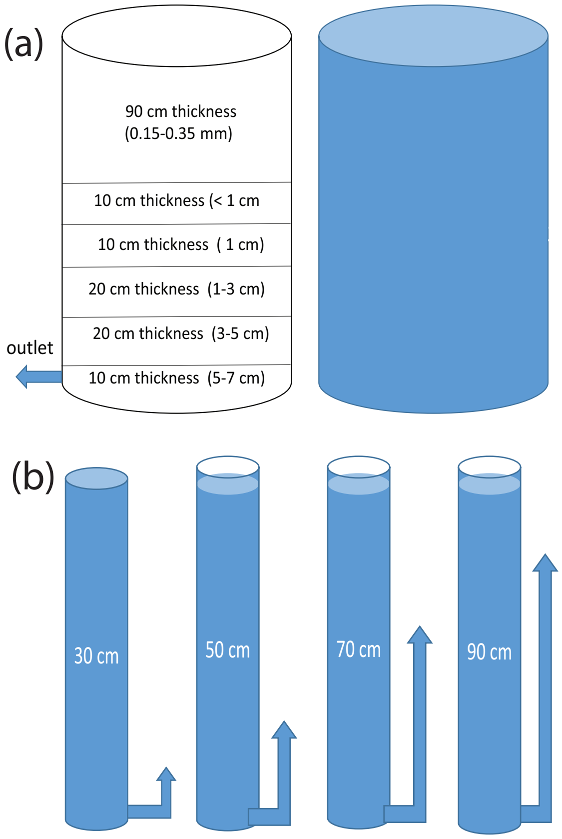

Fig. 1. Sand filter structural design (A) and side modifications (B). Numbers indicate length of column for the vertical flow.

2.6. Sample collection

Eight samples were collected from the system each week. In total 64 samples were collected during the experimental period. The samples were collected after 1 h of running sand filter and transferred to clean, sterile plastic bottles with 2 L capacity and kept in ice box. The samples were brought to the laboratory at Islamic University Gaza for the needed analysis. Sampling program started on 3/8/2013 and ended on 26/10/2013. Samples were collected from R0, R30, R50, R70, S0, S30, S50, and S70, where R0, R30, R50, and R70 are planted slow sand filter at 0, 30, 50, and 70 cm level, respectively, and S0, S30, S50, and S70 are unplanted slow sand filter at 0, 30, 50, and 70 cm level, respectively. Samples were collected on Friday 27/12/2014 during 24 h each 3 h increment. The physical and chemical characterization of the raw wastewater samples are as follows: the color was dark black, and turbid; BOD value of 500 mg/L, chemical oxygen demand (COD) value of 1,020 mg/L, and TSS value of 550 mg/L.

2.7. Influence of wastewater on the growth of reed plants

A reed bed was planted with a reed (*Phragmites australis*) on 20/05/2013 at pacing of 50–70 cm between centers and the other bed was left unplanted. Treated water was applied to the beds immediately after the reeds were planted in the first 40 d; the reeds were irrigated by treated water twice a week for each bed 70 m^3. Some of the reeds became brown but regained their green color after 1 week. The growth of the reeds was monitored for 7 months; the average growth rate of the reeds was about 30 cm/month; after 7 months the reeds attained an average height of 2 m. Effect of wastewater on reed growth was evaluated by visual rating as described in previous study [29–31].

Visual rating is a method used to evaluate plant growth by two independent experts without using measuring tools. They depend on their eyes.

In winter time (from November till February), parts of the plants became brown but they did not dry out completely even in December and January.

2.8. Determination of biochemical oxygen demand

BOD was measured using OxiTop according to the procedure described in previous study [24]. The samples were discharged into OxiTop bottles followed by placing a magnetic stirring rod. Rubber quiver was inserted in the neck of the bottle.

Three sodium hydroxide tablets were placed into the rubber quiver with a tweezers. OxiTop bottle was directly tightly closed and pressed on S and M buttons simultaneously for 2 s until the display shows zero reading. The bottles were placed in the stirring tray and incubated for 5 d at 20°C. Readings of stored values were collected after 5 d. Percentage of removal was calculated according to Eq. (2) [32] with a slight modification:

$$\%\ \text{BOD removal} = \frac{100 \times \left(\text{BOD}_i - \text{BOD}_f\right)}{\text{BOD}_i} \tag{2}$$

where BOD$_i$ and BOD$_f$ are the values before and after treatments, respectively.

2.9. Determination of chemical oxygen demand

The COD is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant [24].

The closed dichromate reflux method (colorimetric method) was used to determine COD. 2 mL of the sample is refluxed in strongly acid solution vessel. After digestion in COD reactor at 160°C for 2 h, oxygen consumed is measured against standard at 620 nm with a spectrophotometer. Using Eq. (2) with a slight modifications enables the calculation of percentage of COD removal.

2.10. Ammonia

Ammonia in wastewater was determined according to Kjeldahl methods without digestion in this procedure. Distillation method was used followed by titration step to determine the concentration of ammonia. NaOH solution was added to wastewater sample and ammonia distilled into a solution of boric acid. The ammonia in the distillate was determined titrimetrically with standard HCl [33]. Using Eq. (2) with a slight modifications enables the calculation of percentage of ammonia removal.

2.11. Total Kjeldahl nitrogen

The total Kjeldahl nitrogen (TKN) method is based on the wet oxidation of nitrogen using sulfuric acid and digestion catalyst. In the presence of H_2SO_4, potassium sulfate (K_2SO_4), and copper sulfate ($CuSO_4$) – catalyst, organic nitrogen and ammonia were converted to ammonium. After addition of base, organic nitrogen and ammonium were converted to ammonia, which is distilled from alkaline medium and absorbed by boric acid. The ammonium was finally determined by titration against standard hydrochloric acid [24]. Using Eq. (2) with a slight modifications enables the calculation of percentage of TKN removal.

2.12. Nitrate

As previously reported [24], NO_3 concentration in wastewater was determined according to salicylic acid method. In this method, 5 g salicylic acid was dissolved in 100 mL H_2SO_4. Then 1 mL of the solution was transferred to each test tubes containing 1 mL of standard solution or unknown concentration. The tubes were left for 20 min reaction time. Then 18 mL NaOH 6 N is added to the tubes to neutralize H_2SO_4. Then a yellow color of para nitro salicylic acid is developed. The color in the standard solutions and unknown samples was measured at 420 nm. The linear relationship between the optical description and concentration was used to determine the NO_3 concentration in the unknown samples. Using Eq. (2) with a slight modifications enables the calculation of percentage of NO_3 removal.

2.13. Suspended solids

The method previously described in [33] is used for determining the total suspended solids. A well-mixed sample is filtered through a weighed standard glass fiber filter and the residue retained on the filter is dried to a constant weight at 103°C to 105°C. The increase in weight of the filter represents the total suspended solids. If the suspended material clogs the filter and prolongs filtration, it may be necessary to increase the diameter of the filter or decrease the sample volume. To obtain an estimate of total suspended solids, calculate the difference between total dissolved solids and total solids. Using Eq. (2) with a slight modifications enables the calculation of percentage of TSS removal.

2.14. Statistical analysis

We calculated average and standard deviation of 64 samples. Differences among treatments were detected by T-test. *P*-value and error bar for both reed beds and unplanted slow sand filter were determined and presented.

3. Results and discussion

3.1. Sand filter design, conditioning, and operation

The presented data in Fig. 1 clearly show the construction of sand filter and its modifications that enable changes inside the filter. It is observed that the top layer of the filter filled with fine sand and the sand size was gradually increased to reach the largest sand size in the bottom of the filter. This data indicates that the void volume increased from the top to the bottom of the sand filter indicating increasing of hydraulic conductivity. Moreover, the installation of side tubes to the filter with different lengths (0–70 cm) (Fig. 1(B)) enables increasing the retention time of wastewater inside the sand filter, consequently, enhancing the biodegradation and removal of pollutants. This is in accords with Torrens et al. [34] who stated that satisfactory pollutant removal depended upon type of sand, sand size distribution, and quality of effluent. Moreover, the designed planted and unplanted slow sand filters are filters with different pore size from the top to the bottom of the filter. They have the same structure except the absence of reed plants in the sand filter.

The average results for both systems (sand planted and unplanted slow sand filter) outlet were taken for different levels/depths (0, 30, 50, and 70 cm). Conditioning of sand filter was performed by allowing low quantity of wastewater to flow over the surfaces of sand filter and reed beds to make a soil saturation in the top 20 cm. Ensuring complete wetting and saturation of the surface indicate conditioning of the filter. Then operating of the filter was controlled at normal flow by installing the vertical devices (Fig. 1(B)) to change the flow rate according to the experimental design.

3.2. Measurement of infiltration rate and influence of side modification

The IRs in sand filter and reed beds for a 3-month period are shown in Table 2. Before the side modification of the filters (0–70 cm perpendicular Fig. 1(B)), IR was 12 $m^3/m^2/d$. After modifications, the IRs reduced to 1.93 and 1.95 $m^3/m^2/d$ on 29/7/2013. The values tend to decrease and reached 0.96 and 1.1 $m^3/m^2/d$ for slow sand filter and reed beds, respectively, on 25/10/2013. It is obvious that the reduction rate of the infiltration reached 12.5 and 10.9 times lower than the initial flow rate for reed beds and sand filter, respectively.

Table 2
Infiltration rate during the experimental period for both systems

Date	Rate ($m^3/m^2/d$)	
	Reed	Slow
21/7/2013	2.5	2.5
23/7/2013	2.59	2.59
25/7/2013	1.26	1.76
29/7/2013	1.93	1.95
1/8/2013	1.72	1.63
3/8/2013	1.68	1.59
4/9/2013	2.04	1.44
9/9/2013	1.5	1.08
15/9/2013	1.3	1
17/9/2013	1.32	1.05
23/9/3013	1.42	0.95
24/9/2014	1.22	0.9
29/9/2013	1.1	1.02
24/10/2013	1.06	1.1
25/10/2013	0.96	1.1

These reductions in the flow rates maintained the wastewater longer time in sand filter and reed beds, enhancing the biodegradation and removal process of pollutants as shown by the presented results below.

Regressing the values of flow rates vs. time shows values of R^2 in the range of 0.726–0.93. This suggests a strong positive association between flow rate reduction and time. The explanation of these results is that void volume decreased due to participation of suspended organic materials resulting in smaller size of voids that further reduce the flow rate. Moreover, this process may create anaerobic condition that result in degradation of pollutants. Furthermore, high percentage of pollution removal may be expected.

3.3. *Influence of wastewater on the growth of reed plants*

Reed plants grow rapidly in the reed bed due to irrigation with wastewater; this indicates the ability of the reed plant to survive under hard conditions. Visual rating of reed growth indicates fast growth and reproduction of new generation. These results agree with previous reports [4,20] that revealed that reed plants can survive, grow rapidly, and be a good option of biological treatment of wastewater.

3.4. *Removal efficiency of BOD_5*

Removal percentage of BOD_5 is shown in Fig. 2. It can be seen that both systems, planted and unplanted slow sand filter, were able to remove more than 50% of BOD_5 in all periods except September. This indicated the efficiency of both systems to remove BOD_5. So far, the trend of BOD_5 removal is similar to TSS (Fig. 7). This indicates that removal of TSS is associated with BOD_5 removal by sand filters. However, the low % removal of BOD_5 by both systems probably due to solubility of organic carbon in wastewater which may give energy to bacteria to be able to survive in the anaerobic system such as sand filter, in accords with previous report [24]. However, the initial BOD value was 90 mg/L whereas the final BOD values were 43 and 42 mg/L for S1 and R1-system, respectively.

Moreover, comparisons between reed and sand systems to remove BOD indicate no significant difference as *P*-value was above 0.05. This indicates that reed system has the same ability of sand filter in removing BOD_5.

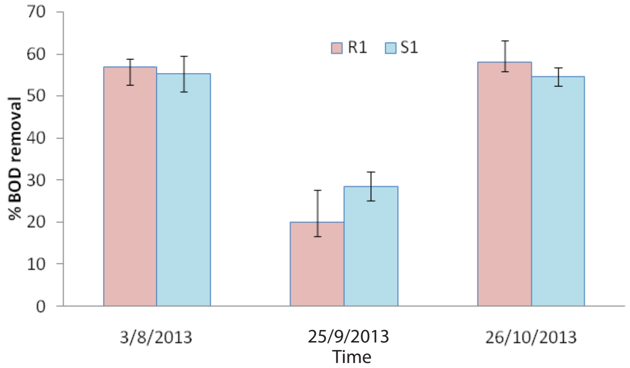

Fig. 2. BOD_5 removal efficiency with time for planted and unplanted slow sand filter. Error bars indicate standard deviation.

3.5. *Removal of COD*

Removal of COD by both systems is shown in Fig. 3. It can be seen that low COD fraction (less than 35%) was removed in the 1st period (03/08/2013) or in 2nd period (25/09/2013). A little increase was observed in the 3rd period (26/10/2013).

However, the initial COD value was 215 mg/L whereas the final COD values were 154 and 137 mg/L for S1 and R1-system, respectively.

Furthermore, the data in Fig. 3 show the ability of R1 and S1-systems to remove COD. It can be seen that R1-system is more efficient than S1-system in removing COD in most periods. The explanation of these results is that R1-system is able to remove BOD in more efficient way than S1-system. Since both values are interrelated. This is probably due to chemical change that may take place in R-system due to growth of reed plant.

Moreover, COD removal depended on physical and biological process and the amount of dissolved oxygen in wastewater. This is in agreement with El-Nahhal et al. [24] since removal behavior in COD is related to the removal of BOD_5 and TSS and this is considered to be part of COD. Statistical analysis of COD removal in the 3rd periods did not discriminate significant difference *P*-values are above 0.05.

3.6. *Removal of ammonia*

Removal of ammonia by both systems is shown in Fig. 4. Regardless of the high value of standard deviation, removal of NH_3 is similar to the case of TKN. The explanation of these results is similar to that of TKN (Fig. 5). Moreover, it can be seen that anaerobic conditions are created by increasing time from 03/08/2013 to 26/10/2014. This condition enhances the reduction of NO_3 to NH_3 then to N_2 accordingly more removal was obtained, at the periods mentioned above. Moreover, increasing the retention time of treated waste water (TWW) in the station increasing the anaerobic conditions which may result in reduction of inorganic nitrogen to ammonia. So far, increasing the anaerobic conditions may enhance the biodegradation of organic molecules and enhance removal of pollutants [35]. Significant differences are also obtained in the 3rd period of analysis similar to that of TKN. Eq. (3) shows the reduction stage and removal of nitrate under a nonaerobic condition.

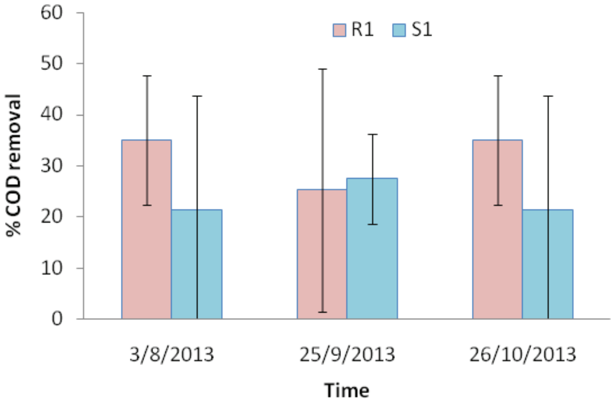

Fig. 3. COD mean removal efficiency and time relationship for planted and unplanted slow sand filters. Error bars indicate standard deviation.

$$2\,NO_3^- + 10\,e^- + 10\,H^+ \rightarrow NH_4 \rightarrow N_2 + 2\,OH^- + 4\,H_2O \qquad (3)$$

3.7. Removal of total Kjeldahl nitrogen

Removal of TKN is presented in Fig. 5. However, the initial TKN value was 69 mg/L whereas the final TKN values were 38 and 47 mg/L for S1 and R1-system, respectively.

Regardless of the large value of standard deviation, it is obvious that (Reeds), R-system was able to remove considerable fraction of TKN. However, in the 1st period (3/08/2013), R-system removed about 50% TKN, followed by sharp reduction in 2nd and 3rd periods. Moreover S-system showed considerable increase in TKN removal. The explanation of these results is that in R-system, the activity of plant roots may change the metabolic pathways of organic nitrogen compounds, besides the fact that nitrifying bacteria became less active in the acidic media around plant roots. Moreover, the ability of sand filter to remove TKN emerges from the fact that nitrifying bacteria may become active in nearly alternative media as shown in sand filter. Reed bed worked to transfer oxygen from the atmosphere to root zone which may lead to changing condition of slow sand filters and increase nitrogen conversion. Our results agree with previous reports [36–38] that demonstrated the activity of cyanobacteria to remove acetochlor (organic nitrogen) from water and soil systems.

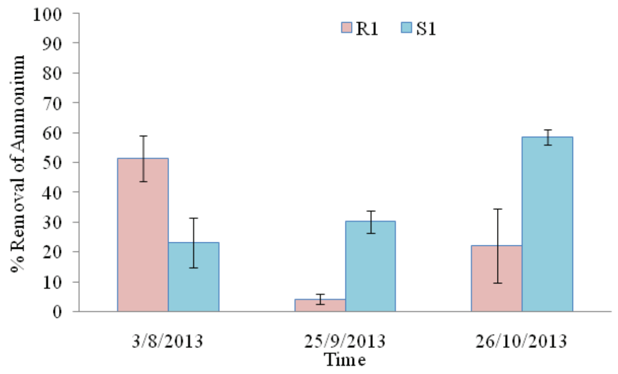

Fig. 4. Removal efficiency of ammonia by both systems.

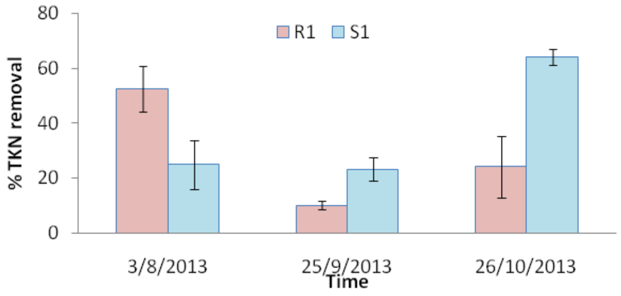

Fig. 5. TKN mean removal efficiency and time relationship for planted and unplanted slow sand filters. Statistical analysis show significant differences with the 3rd period of TKN removal as shown low *P*-value (0.001).

More supports to our explanation come from Safi et al. [38] who demonstrated partial activity of cyanobacteria to remove diuron from water and soil systems.

3.8. Removal of nitrate

Removal of nitrate is shown in Fig. 6. It can be seen that both systems demonstrate to increased NO_3 in effluent water from sands and this is due to conversion of NH_4 to NO_3 through sand filter (nitrification process). Plants absorb nitrate as nutrient to growth, and there is increasing concentration with time. Our results agree with previous reports [39,40]. Since concentration of NO_3 in inlet sand filter was very low, less than 1 mg/L, due to partial conversion of NH_4 to NO_3 led to its increased concentrations in outlet.

3.9. Removal of TSS

Removal Efficiency of TSS by both systems is shown in Fig. 7. It can be seen that % removal by both systems (R and S) are high in 03/08/2013, slightly decreased in September. This fluctuation may be due to the variation in temperature, relative humidity, and rate of evaporation that affect the microbial activity.

However, the initial TSS value was 80 mg/L whereas the final BOD values were 23 and 23 mg/L for S1 and R1-system, respectively.

However, the results presented in Fig. 7 clearly explain the relationship between planted and unplanted slow sand filter and time. It can be suggested that the primary removal mechanisms of TSS are physical filtration and sedimentation. Infiltration systems provide filtration of run off but the percentage removal of solids depends on other variable, particle size, and the size of the pore opening between soil particles [41].

Our results demonstrated that sand and reed system were able to remove high fraction of TSS. This is probably due to adsorption or sieving properties.

The low error bar of our results indicates the homogeneity for different outlet level and this agree with previous reports [41,42]. Moreover, statistical analysis indicated no significant difference in first period (03/08/2013) and third

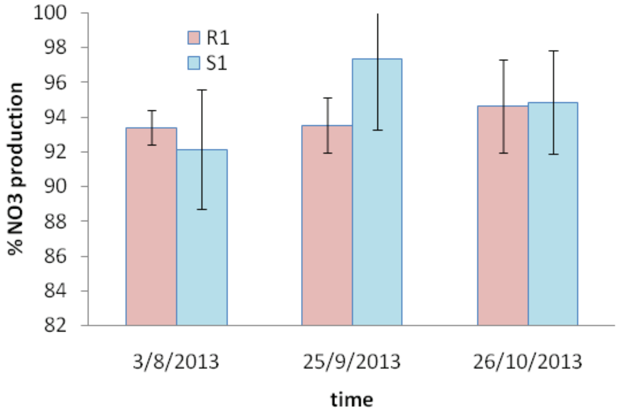

Fig. 6. NO_3 mean increasing efficiency and time relationship for planted and unplanted slow sand filters. Error bars indicate standard deviation.

period (26/10/2013) as *P*-value was above 0.05 and significant difference in the second period (25/09/2013) as *P*-value was below 0.05.

3.10. Removal of fecal coliforms

Removal of FC is shown in Fig. 8. It can be seen that both systems, planted and unplanted slow sand filters, were able to remove nearly 100% of FC in the 1st and 3rd periods. A little reduction was observed in 2nd period (25/09/2013). However, the initial FC value was 3 × 10^4 cell/L whereas the final FC values were 2.1 × 10^3 and 2.5 × 10^3 cell/L for S1 and R1-systems, respectively.

However, the data in Fig. 4 clearly demonstrate the efficiency of both systems to remove FC. These results are in accord with previous reports [15,16] that demonstrated the efficiency of high sand filter (1.5–2 m height) to remove FC from TWW. Since mechanism of FC removal is mainly a biological process, accordingly both systems tend to have the ability to remove FC with different mechanisms (aerobic and/or nonaerobic).

Comparison of our results with those in the literature by Zipf et al. [17], and Matikka and Heinonen-Tanski [43] are shown in Table 3. Comparing the BOD and COD values with similar systems [17] and [43] indicates high efficiency of our system to reduce the values of BOD and COD compared with Zipf et al. [17] who used sand filter combined with granular activated carbon. Moreover, the system of Matikka and Heinonen-Tanski [43] showed more satisfactory value of BOD than ours, probably due to differences in measurement. Furthermore, our system proved more satisfactory reduction in FC content than the systems of Zipf et al. [17], which showed higher value. In addition, percentage removal of TKN by the system of Matikka and Heinonen-Tanski [43] is nearly half (0.55) the value obtained by our system. Moreover, the nitrate concentration increased 16.3 times higher than the original by the systems of Matikka and Heinonen-Tanski [43], whereas our system increased the nitrate concentration 18.18 times. This indicates the efficiency of our system. On the other hand, the system of Matikka and Heinonen-Tanski [43] showed more efficiency than our system in NH_3 removal. Nevertheless, it can be concluded that the presented work is encouraging and its application elsewhere will save water for the life in the planet Earth.

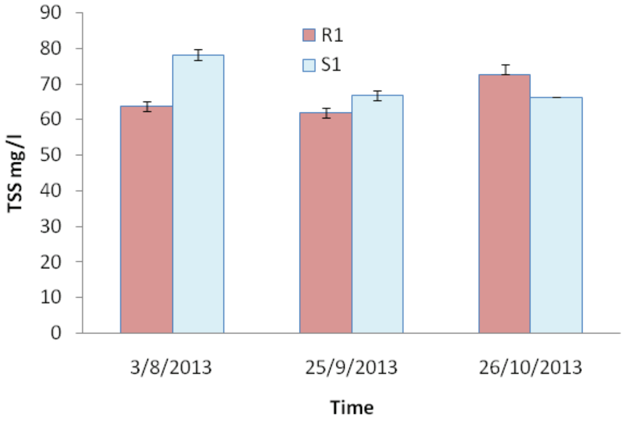

Fig. 7. TSS removal efficiency with time relationship for planted and unplanted slow sand filter. Error bars indicate standard deviation. *P*-values indicate significant differences between R and S-systems only on the period of 25/09/2013.

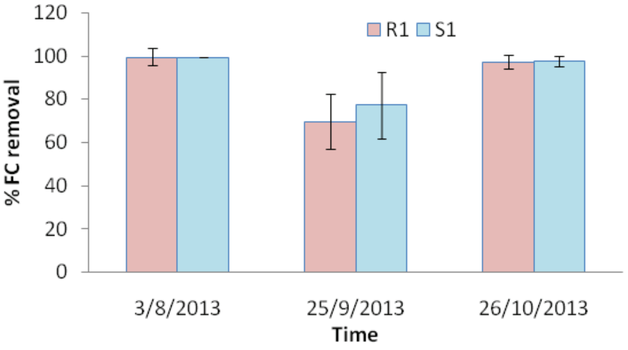

Fig. 8. FC mean removal efficiency and time relationship for planted and unplanted slow sand filters. Statistical analysis showed significant differences between the 1st period and the other two periods as indicated by low *P*-value (0.0001).

Table 3
Comparison between our results and some of those in the literature. Numbers indicate averaged values and values between brackets indicate percentage

Parameter	This study		Zipf et al. [17]		Matikka and Heinonen-Tanski [43]
	Before treatment	After treatment R-system	Sand filter	Sand filter with granular activated carbon	Sand filter with biotite
TSS	80	23	–	–	–
BOD_5 (mg/l)	90	42 (53.3 %)	81	46	1.3 ± 2.0 (98.8%)
COD (mg/L)	215	137 (36.28%)	295	221	–
FC colon/100 mL	3 × 10^6	2.5E + 5	7.27E + 5	9.21E + 5	–
TKN (N mg/L)	69	47 (31.88%)	–	–	48.6 ± 10.8 (17.4%)
NH_3-N (mg/L)	54	39 (27.77%)	–	–	4.9 ± 11.1 (91.3)
NO_3 (mg/L)	0.44	8 (18.18 times increase)	–	–	(16.3 times increase)

4. Conclusions

The constructed modified sand filter and reed systems show the ability to reduce the IR from high value (12 $m^3/m^2/d$) to lower values (0.96 and 1.1 $m^3/m^2/d$). These modifications increased the retention time of wastewater inside the filters. The modified filters showed interesting ability to remove BOD, COD, ammonia, TKN, NO_3, TSS, and FC.

An outcome of the study is that kinetic removal of TSS, BOD, COD, and FC remains in high level during 24 h. It is still not obvious to us to recommend the product water for agriculture irrigation. The results of sand filters in improving the quality of wastewater are promising and enabling agricultural reuse.

It can be concluded that both systems (sand filter and reed bed) in comparison with the work in the literature are very effective in reducing most pollutants.

A comparison between our results and Palestinian standards indicates that both systems (reed bed and slow sand filter) reduced the values of TSS, BOD, COD, TKN, and NH_4 below the initial values and that of Palestinian Standards whereas the values of FC values remain above the standards.

Acknowledgments

Prof. Dr El-Nahhal would like to thank AVH Foundation, Germany. Engineer EL-Dahdouh would like to thank Middle East Desalination Research Center (MEDRC) for partial financial support.

References

[1] M.E. Kotti, A. Parisis, A. Vlessidis, N.P. Evmiridis, Pattern recognition techniques for the classification of wastewater samples based on their UV-absorption spectra and their fractions after applying MW-fractionation techniques, Desalination, 213 (2007) 297–310.

[2] C.M. Tsoumanis, D.L. Giokas, A.G. Vlessidis, Monitoring and classification of wastewater quality using supervised pattern recognition techniques and deterministic resolution of molecular absorption spectra based on multiwavelength UV spectra deconvolution, Talanta, 82 (2010) 575–581.

[3] B. Capra, B. Scicolone, Emitter and filter tests for wastewater reuse by drip irrigation, Agric. Water Manage., 68 (2004) 135–149.

[4] A.M.J. Alobaidy, M.A. Al-Sameraiy, A.J. Kadhem, A. Majeed, Evaluation of treated municipal wastewater quality for irrigation, J. Environ. Prot., 1 (2010) 216–225.

[5] CMWU, Status of Wastewater in Gaza Strip: Coastal Municipalities Water Utility, Gaza, Palestine, 2012.

[6] PMOE, Palestinian Standard for Waste Water Treatment. Annual Report, Article # PS 742-2003, Gaza, Palestine, 2003.

[7] S. Saumya, S. Akansha, J. Rinaldo, A.M. Jayasri, K. Suthindhiran, Construction and evaluation of prototype subsurface flow wetland planted with *Heliconia angusta* for the treatment of synthetic greywater, J. Clean. Prod., 91 (2015) 235–240.

[8] J. Laaffat, N. Ouazzani, L. Mandia, The evaluation of potential purification of a horizontal subsurface flow constructed wetland treating greywater in semi-arid environment, Process Saf. Environ. Prot., 95 (2015) 86–92.

[9] C. Ramprasad, L. Philip, Surfactants and personal care products removal in pilot scale horizontal and vertical flow constructed wetlands while treating greywater, Chem. Eng. J., 284 (2016) 458–468.

[10] E. Friedler, Y. Gilboa, Performance of UV disinfection and the microbial quality of greywater effluent along a reuse system for toilet flushing, Sci. Total Environ., 408 (2010) 2109–2117.

[11] L. Lopez, C.B. Panther, W.T. Turney, Contaminant effects on the photooxidation of greywater over titania film catalysts, J. Water Process Eng., 7 (2015) 46–53.

[12] A.K. Vakil, K.M. Sharma, A. Bhatia, A.A. Kazmi, S. Sarkar, Characterization of greywater in an Indian middle-class household and investigation of physicochemical treatment using electrocoagulation, Sep. Purif. Technol., 130 (2014) 160–166.

[13] M. Pratap, S. Clark, R. Pitt, U. Khambhammettu, C. Roenning, D. Treese, C.Y.S. Siu, Runoff Polishing by Natural Media Filtration: Up Flow vs. Downflow, Pennsylvania Storm Water Management Symposium, October, Villanova Urban Stormwater Partnership, Villanova, PA, 2007, pp. 17–18.

[14] Z. Khan, R. Farooqi, Roughing filtration as an effective pretreatment system for high turbidity water, Water Sci. Technol., 64 (2011) 27–64.

[15] K. Langenbach, P. Kuschk, H. Horn, M. Kästner, Slow sand filtration of secondary clarifier effluent for wastewater reuse, Environ. Sci. Technol., 43 (2009) 5896–5901.

[16] E. Lee, R.L. Oki, Slow sand filters effectively reduce Phytophthora after a pathogen switch from Fusarium and a simulated pump failure, Water Res., 47 (2013) 9–47.

[17] S.M. Zipf, G.I. Pinheiro, G.M. Conegero, Simplified greywater treatment systems: slow filters of sand and slate waste followed by granular activated carbon, J. Environ. Manage., 176 (2016) 119–127.

[18] R. Kadaverugu, P.R. Shingare, K. Raghunathan, A.A. Juwarkar, R.P. Thawale, K.S. Singh, The role of sand, marble chips and *Typha latifolia* in domestic wastewater treatment – a column study on constructed wetlands, Environ. Technol., 37 (2016) 2508–2515.

[19] I. Blumberg, Reed Bed Treatment Systems – A Concept of Ecological Engineering, Ecotechnologies International Gänsemarkt, 10 – D-37120 Bovenden, Germany, 2003.

[20] S. Nielsen, E. Peruzzi, C. Macci, S. Doni, G. Masciandar, Stabilisation and mineralisation of sludge in reed bed systems after 10–20 years of operation, Water Sci. Technol., 69 (2014) 539–545.

[21] S. Shi, Y. Qu, Q. Ma, X. Zhang, J. Zhou, F. Ma, Performance and microbial community dynamics in bioaugmented aerated filter reactor treating with coking wastewater, Bioresour. Technol., 190 (2015) 159–166.

[22] T. Serra, J. Colomer, C. Pau, M. Marín, L. Sala, Tertiary treatment for wastewater reuse based on the *Daphnia magna* filtration – comparison with conventional tertiary treatments, Water Sci. Technol., 70 (2014) 705–711.

[23] Y. El-Nahhal, M. Safi, K. Tubail, J. Safi, Effect of treated wastewater irrigation on plant growth and soil properties in Gaza Strip Palestine, Am. J. Plant Sci., 4 (2013) 1736–1743.

[24] I. El-Nahhal, H. Al-Najar, Y. El-Nahhal, Cations and anions in sewage sludge from Gaza waste water treatment plant, Am. J Anal. Chem., 5 (2014) 655–665.

[25] I. El-Nahhal, H. Al-Najar, Y. El-Nahhal, Physicochemical properties of sewage sludge from Gaza, Int. J. Geosci., 5 (2014) 586–594.

[26] O. EL-Dahdouh, Performance Evaluation of Sand Filter in Improvement of Effluent Wastewater from Gaza Wastewater Treatment Plant, MSc Thesis, The Islamic University - Gaza, Palestine, 2014.

[27] PWA, Palestinian Water Authority, Annual Report, 2013.

[28] W.B. Nichols, T. Lucke, C. Dierkes, Comparing two methods of determining infiltration rates of permeable interlocking concrete pavers peter, Water, 6 (2014) 2353–2366.

[29] Y. El-Nahhal, S. Nir, T. Polubesova, L. Margulies, B. Rubin, Organo-clay Formulations of Alachlor: Reduced Leaching and Improved Efficacy, Proc. Brighton Crop Protection Conference UK, Weeds, Vol. 1, 1997, pp. 21–26.

[30] Y. El-Nahhal, S. Nir, T. Polubesova, L. Margulies, B. Rubin, Leaching, phytotoxicity and weed control of new formulations of alachlor. J. Agric. Food Chem. 46 (1998) 3305–3313.

[31] Y. El-Nahhal, S. Nir, T. Polubesova, L. Margulies, B. Rubin, Movement of metolachlor in soil: effect of organo-clay formulation, Pestic. Sci., 55 (1999) 857–864.

[32] Y. El-Nahhal, N. EL-dahdouh, N. Hamdona, A. Alshanti, Toxicological data of some antibiotics and pesticides to fish, mosquitoes, cyanobacterial mats and to plants, Data Brief, 6 (2016) 871–880.

[33] APHA, Water Works Association, Water Environmental Federation, American Public Health Association, 21th Edition, 2005.

[34] A. Torrens, P. Molle, C. Boutin, M. Salgot, Impact of design and operation variables on the performance of vertical-flow constructed wetlands and intermittent sand filters treating pond effluent, Water Res., 43 (2009) 1851–1858.

[35] Y. El-Nahhal, S. El-Hams, Effects of bromacil, malathion and thiabendazole on cyanobacteria mat growth, Int. J. Appl. Sci. Res. Rev., 4 (2017) 1.

[36] A.M. Abed, N.M. Safi, J. Köster, D. Beer, Y. El-Nahhal, J. Rullkötter, F. Garcia-Pichel, Microbial diversity of a heavily polluted microbial mat and its community changes following degradation of petroleum compounds, Appl. Environ. Microbiol., 68 (2002) 1674–1683.

[37] Y. El-Nahhal, Y. Awad, J. Safi, Bioremediation of acetochlor in soil and water systems by cyanobacterial mat, Int. J. Geosci., 4 (2013) 880–890.

[38] J. Safi, Y. Awad, Y. El-Nahhal, Bioremediation of diuron in soil and by cyanobacterial mat. Am. J. Plant Sci., 5 (2014) 1081–1089.

[39] Y. El-Nahhal, Contamination of Groundwater with Heavy Metals in Gaza, Proc. 10th International Water Technology Conference, Alexandria, Egypt, 23–25 March, 2006, pp. 1139–1150.

[40] Y. El-Nahhal, J. Safi, Removal of Pesticide Residues from Water by Organo-bentonites, Proc. 12th International Water Technology Conference. Alexandria, Egypt, 27–30 March, 2008, pp. 1711–1724.

[41] P. Weiss, G. Lefevre, J. Gulliver, Contamination of Soil and Groundwater Due to Storm Water Infiltration Practices, 2008, http://www.pca.state.mn.us/index.php/view-document.html?gid=7732.

[42] S. Heinze, Y. Chen, Y. El-Nahhal, Y. Hadar, R. Jung, J. Safi, M. Safi, J. Tarchitzky, B. Marschner, Small scale stratification of microbial activity parameters in Mediterranean soils under freshwater and treated wastewater irrigation, Soil Biol. Biochem., 70 (2014) 193–204.

[43] V. Matikka, H. Heinonen-Tanski, Reduction of phosphorus, nitrogen and microorganisms in pilot scale sand filter beds containing biotite, treating primary wastewater, Environ. Technol., 37 (2016) 46–54.