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Greywater treatment for irrigation purposes using pottery scraps and aerated moving bed biofilm reactor

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ABSTRACT

Decentralized greywater treatment systems can reduce the demand of freshwater and potentially solve freshwater scarcity. Pottery scraps are nondegradable byproducts produced from pottery manufacturing process and cause environmental problems. Greywater from three houses was subjected for treatment using pottery scraps column unit (PSCU) followed by moving bed biofilm reactor (MBBR) then disinfected using hydrogen peroxide with the aim of producing effluent that meets Egyptian reuse guidelines for agriculture. Average values of basic wastewater parameters were calculated for 30-d operation. PSCU showed very good removal efficiencies of 69.6% and 86.3% for total suspended solids (TSS) and turbidity, respectively, and moderate removal efficiencies for total coliform (51.3%) and *Escherichia coli* (44.0%), while no considerable removal efficiency of organic matters in terms of biological oxygen demand (BOD_5) and chemical oxygen demand (COD). Aerated MBBR increased the overall removal efficiencies of turbidity (93.6%), TSS (97.8%), BOD_5 (95.1%), and COD (95.0%). Hydrogen peroxide disinfection at dose of 1.5 mL/L/h removed more than 99.0% of total coliform and *E. coli* and prevented bacterial regrowth in effluent after 2 d of storage. The system effluent meets local guidelines for restricted and unrestricted irrigation. The evaluated system was found simple, easily operated and maintained, and eco-friendly.

Keywords: Greywater treatment; Industrial byproducts reuse; MBBR; Pottery scraps; Wastewater reuse

1. Introduction

To satisfy society water demands, water resources are subject to increased pressure. This increased pressure leads to water scarcity especially in arid and semi-arid countries [1]. In Egypt, the quantity of available water passed the scarcity threshold (1,000 m^3/cap/y) in the 1990s. Because of population growth, climatic changes, and increased urbanization, searching for new water resources becomes a national target in Egypt and all over the world. Reuse of domestic wastewater after suitable treatment is considered as an important solution for water scarcity. Wastewater generates from a household can be divided to blackwater and greywater. Blackwater is the wastewater that generates from toilet flushing, while wastewater generates from showers, kitchen sinks, lavatories, dishwashers, and washing machines is defined as greywater. Greywater is considered as a suitable source of water for non-potable uses because it contains low levels of pollutants compared with domestic sewage [2].

Living standards, cultural and social traditions, the number of house residents and their age distribution, quality

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of freshwater supply, etc. are the main factors affecting the characteristics of greywater. Greywater contains suspended solids, organics, surfactants (from detergents and shampoos), and high levels of chemicals such as sodium, phosphorus, and nitrogen [3]. Greywater contains low concentrations of organic matters, nutrients, and pathogens in comparison with blackwater. Greywater represents about 50%–80% substantial fraction of the total produced wastewater in a household but contains about 30% organic fraction and 9%–20% of the nutrients [4,5].

In developing countries, both greywater and blackwater are collected together through conventional collection systems of domestic wastewater and discharged into the sewer system. Because of the global shortage of freshwater resources, treatment and reuse of greywater receive much attention of researchers [2]. On-site separation and treatment of greywater have many benefits such as (i) reduction of freshwater consumption in a household and related reduction of cost for treatment and supply of drinking water, (ii) reduction in the collected quantity of blackwater which reduce the cost of treatment at the sewage treatment plant [6]. Treated greywater can be reused for specific purposes such as garden irrigation, toilet flushing, and car washing [3].

Various greywater treatment technologies (physical, chemical, and biological) are studied and implemented. Physical treatment technologies include coarse filtration and/or membrane-based processes coupled with disinfection [7]. Chemical treatment technologies include chemical coagulation, electrocoagulation, and photocatalysis [6,8]. Biological treatment technologies include biological aerated filters, rotating biological contactors, and aerated bioreactors [9,10].

Many of these technologies when applied singly are not effective for greywater treatment to reach the reuse permissible limits and criteria. A combination of two or more processes is necessary for better treatment of greywater. Also, the choice of suitable disinfectant is necessary because some disinfectants such as chlorine produce harmful and carcinogenic byproducts [10,11]. Biological treatment methods that depend on suspended biomass such as activated sludge which proved high removal efficiencies of organic matters from wastewater have some limitations because these methods produce large quantities of sludge and require settling tanks, large reactors, and biomass recycling. In order to avoid such limitations, biological treatment methods that depend on biofilm technology such as trickling filters, granular media biofilters, rotating biological contractors, moving bed biofilms, etc. are widely studied and applied [12].

In Egypt, pottery manufacture is an ancient industry (7,000 years ago). Pottery is made from burning clay at high temperatures (500°C–1,000°C). In Egypt, pots and containers made of pottery were used many years ago (still used in some villages) as a natural water purification technique. Pottery scraps (PSs) are the broken pieces occurred during the whole pottery manufacturing process. PS is not a recyclable material and has some environmental problems as PS is accumulated in roads nearby the manufacturing places. Also, the large dumped volumes of PS decrease the lifetime of sanitary landfill. PSs are characterized with the red color due to the presence of iron oxide [13].

A novel type of biological wastewater treatment called moving bed biofilm reactor (MBBR) has been developed in Norway by the late 1980s [14]. MBBR depends on the ability of microorganisms to form biofilms [15]. MBBR systems have been widely used for the treatment of different types of wastewater in both pilot studies and in full-scale plants [16,17]. MBBR is typically filled with plastic biocarriers on which biomass is attached and circulate inside the reactor using mechanical stirring or aeration. MBBR has some advantages including the capacity of treatment of different types of municipal and industrial wastewater, the cope ability with high loading conditions and the avoidance of excess sludge formation [18,19].

In this study, a pilot-scale system was established for the treatment of natural greywater. The system composed of pottery scraps column unit (PSCU) containing PS with different sizes followed by aerated MBBR tank and finally a storage tank supplemented with a disinfection process using hydrogen peroxide (H_2O_2). The main objective of this study is to treat natural greywater for reuse in restricted irrigation according to the Egyptian guidelines of wastewater reuse in irrigation.

2. Material and methods

2.1. Natural greywater

For the collection of natural greywater, sewerage systems of three different houses (three, four, and six persons each) were modified through separation of the toilet flush (blackwater) away from other wastewater sources (greywater), that is, showers, kitchens, and laundries. The average daily volume of collected raw greywater was 120 L. Greywater from each house was collected in 200-L plastic container and continuously mixed. Collection tank was refilled every day before the next cycle of greywater collection.

2.2. Greywater characterization

Characterization of raw and treated greywater was carried out through measuring some physicochemical and bacteriological parameters. These parameters were biological oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), pH, turbidity, total coliform, and *Escherichia coli*. All these parameters were measured according to the standard methods for examination of water and wastewater [20].

2.3. PSs column unit

PSs were collected from Al-Fakharain village, Al-Fustat area, Cairo, Egypt. Scraps were crushed manually to produce three different sizes of scrapes (large, medium, and fine). The crushed PSs were placed in a polyethylene plastic column (40 cm diameter and 1 m length) from the bottom to the top according to scrapes size (Fig. 1). Fine-sized (6–8 mm) scrapes layer was placed at the bottom of the column for 30 cm height followed by the medium-sized (50–70 mm) layer for 30 cm height then finally the large-sized (130–150 mm) layer was placed on the top for 30 cm height. A stainless steel net with pore size 20 mm used to separate between top and medium layers, while another net with pore size 3 mm was placed under the bottom layer. Two sets of PSs layers were used alternately. Every 48 h, the first set was replaced with the second set then the first set was air dried for 48 h and reused again instead of the second set. The three PSs layers were replaced every 2 d with new layers to prevent clogging.

2.4. MBBR setup

An MBBR plastic tank with a volume capacity of 200 L and working volume of 180 L was established. Inside the MBBR tank, cylindrical polyethylene plastic biomass carriers ($d = 50$ mm, $h = 30$ mm) with a specific area of 431.5 m^2/m^3 were used. MBBR was operated 2 weeks before the experiment using domestic wastewater to allow the formation of biofilm onto polyethylene plastic carriers. The required oxygen for aeration was supplemented into the MBBR tank using an aerator at a constant rate of 2.5 L/min.

2.5. Storage and disinfection tank

A storage tank with a capacity of 200 L was established. Disinfection process was carried out using hydrogen peroxide (H_2O_2) through a dosing pump. H_2O_2 dose was adjusted at 1.5 mL/L/h. The maximum storage period of treated greywater was 2 d.

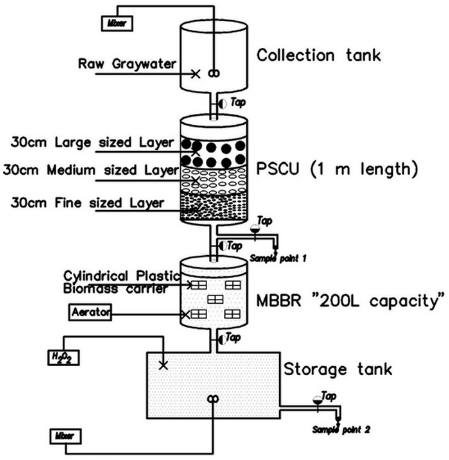

Fig. 1. Schematic diagram of the treatment system.

2.6. Experimental setup

Fig. 1 describes the treatment process train. The greywater was fed (flow rate = 7 L/h) from the collection tank into the PSCU containing three different sized PSs. After passing through the PSCU, greywater moved into the MBBR with a 24-h hydraulic retention time (HRT). Finally, the treated greywater was collected in a storage tank and disinfected using H_2O_2 (50% concentration). Four samples (sample every 6 h) after the PSCU (sampling point 1) were collected. Also, at the end of the daily operation, one sample was collected after MBBR from the storage tank (sampling point 2). The daily results were recorded, and average values were calculated after 30 d system operation. The second cycle began after emptying the collection tank and refilling with the new collected greywater. The organic loading rate was 6.79 Kg COD/L/d.

3. Results and discussion

3.1. Characterization of greywater

The characteristics of raw greywater are represented in Table 1. Some physicochemical and bacterial parameters were used to express the quality of raw greywater. In this study, pH of raw greywater ranged from neutral to slightly alkaline (7.1–7.9). Couto et al. [1] observed the same pH values near 7 in raw natural greywater. However, Travis et al. [21] reported low pH values of untreated greywater ranged from 5.7 (bath) to 7.3 (kitchen) in Israel. Washing machines are usually the main source of alkaline pH in greywater due to the presence of soaps and detergents [22].

Referring to turbidity, the average value was 58.5 NTU in raw greywater which was much lower than turbidity values reported by Saidi et al. [23]. Chrispim and Nolasco [24] mentioned that turbidity was higher in greywater collected from showers than in greywater collected from other sources such as lavatories, washing machine, and sinks. It was clear that raw greywater contains high concentrations

Table 1
Characteristics of raw natural greywater ($n = 30$) vs. Egyptian guidelines for wastewater reuse in agriculture

Parameters	Unit	Effluent greywater			Egyptian guidelines grades[a]		
		Minimum	Maximum	Average ± standard deviation	A	B	C
pH	–	7.1	7.9	7.4 ± 0.12	–	–	–
Turbidity	NTU	51.5	64.0	58.5 ± 3.42	–	–	–
BOD_5	mgO_2/l	312	396	373 ± 25.4	<20	<50	<250
COD	mg/L	615	748	728 ± 34.8	–	–	–
TSS	mg/L	374	512	484.5 ± 4.42	<20	<60	<400
Total coliform	cfu/100 mL	3.6×10^3	2.5×10^4	$7.4 \times 10^3 \pm 1.1 \times 10^3$	–	–	–
Escherichia coli	cfu/100 mL	2.4×10^3	3.9×10^3	$2.1 \times 10^3 \pm 1.6 \times 10^3$	<1,000	<5,000	Unspecified

[a] Egyptian code for reuse of treated wastewater in agriculture, [25].
A, Plants and trees grown at hotels, touristic villages, feed crops, and trees producing fruits.
B, Nursery plants, fiber crops, and roses.
C, Wood trees and industrial oil crops.

of suspended matters measured by either TSS or turbidity. TSS average concentration (484.5 mg/L) was higher than those reported by some researchers (15–116 mg/L, Smith and Bani-Melhem [26]; and 50–165 mg/L, Abdel-Shafy et al. [27]), while it was comparable with reported average concentrations of 288–788 mg/L by Vakil et al. [6]. Laundry greywater is the main source of high values of TSS which arise from washing clothes using detergents.

Moreover, raw greywater showed high concentrations of organic matter fraction expressed as COD and BOD_5 which derives primarily from laundry and dishwashing detergents. The obtained results in Table 1 showed that greywater had a relatively high average concentration of COD (728 mg/L) compared with other studies. Hernández et al. [28] reported a greywater COD concentration of 420 mg/L in Germany. Also, in Netherlands, Nolde [29] measured COD concentration of 450 mg/L in raw greywater. In Egypt, Abdel-Shafy et al. [27] reported low concentrations of COD in raw greywater with maximum value of 526 mg/L. However, Smith and Bani-Melhem [26] reported a wide range of COD concentrations (381–843 mg/L) during monthly survey (summer 2009–autumn 2010) of raw greywater in Egypt. The increase in COD concentrations might indicate the presence of anions (chloride) used in disinfectants and cations such as sodium used in soaps [30]. Similarly, BOD_5 average concentration of greywater (373 mgO_2/L) was higher than reported average concentrations of 298.6 mgO_2/L [27] and 191 mgO_2/L [26]. High concentrations of BOD_5 are attributed to the presence of kitchen greywater which contains food residues [31].

Average counts of both total coliforms and *E. coli* in greywater were less than those reported by some previous studies in Egypt [12,26]. In contrast, other researchers reported higher counts of total coliform and *E. coli* in greywater than measured counts in this study. Teh et al. [10] studied raw greywater collected from lavatories and showers and they reported total coliform and *E. coli* counts of 1.1×10^8 cfu/mL and 4.5×10^5 cfu/mL, respectively. Also, Chrispim and Nolasco [24] reported high concentrations of total coliform (7.6×10^6 cfu/mL) and *E. coli* (5.0×10^4 cfu/mL) in raw greywater collected from lavatories and showers. The variation in total coliform and *E. coli* counts is affected by some factors such as family makeup because some studies have found lower counts of total coliform and *E. coli* in greywater produced in houses occupied by only adults than those occupied by adults with young children [32]. High values of physicochemical and bacterial parameters during the study may be attributed to the presence of three different sources (three houses) of greywater that widely vary in composition from household to other which depend on some factors such as personal habits, lifestyle of residents, and the different types of used products at home [33].

Generally, raw greywater showed higher average values of physicochemical and bacterial parameters than the permissible limits of treated wastewater reuse in irrigation purposes according to the Egyptian guidelines [34,41].

3.2. Treatment performance of PSCU

The results in Table 2 summarize the average values of physicochemical and bacterial parameters after using the treatment system continuously for 30 d. The removal efficiency (*R*%) after the PSCU was calculated to study the effect of PSs on the quality of greywater and the treatment process. It was clear that there is no considerable effect of PSs on the removal of organic matter in greywater. The removal efficiencies were 9.91% and 6.04% for BOD_5 and COD, respectively. This effect may be attributed to the continuous flow of greywater through PSCU and replacement of PSs every 2 d which in turn negatively affect biofilm formation process (i.e., formation of thin biofilm) and subsequently the biodegradation of organic matters. Nevertheless, PSs can act as microbial carriers due to their numerous internal pores and rough surface, thus by increasing the contact time, biofilm attaching would reinforce the removal of organic matters. Stoodley et al. [35] demonstrated that biofilm development process is slow and often require several days to reach structural maturity. Furthermore, the biofilm formation depends mainly on the production of an extracellular matrix [36–38]. This matrix consists generally of 97% water, 2%–5% microbial cells, 3%–6% extracellular polymeric substances (EPS) and ions [39]. EPS is a constructive agent and plays a principal role in biofilm formation as a structural component [38]. Thin biofilms are composed of less EPS compared with cells [40].

In contrast, the removal effect of PSs was clear in case of turbidity (86.3%), TSS (69.6%), total coliform (51.3%), and *E. coli* (44.0%). This effect can be explained as the PSs layers are considered as natural filter media, which adsorbs suspended particles and bacteria present in the greywater. Also, the highly porous nature of PSs increases the filtration surface area. The extent of adsorption has a proportional relationship with the specific surface area of the adsorbent.

Table 2
Treatment efficiencies of PSCU and MBBR (30-d operation)

Greywater parameter	Unit	Average ± standard deviation			
		After PSCU	R (%)	After MBBR	Overall R (%)
pH	–	7.1 ± 0.16	–	7.0 ± 0.1	–
Turbidity	NTU	8.0 ± 1.19	86.3	3.7 ± 1.05	93.6
BOD_5	mgO_2/L	336 ± 13.6	9.91	18.0 ± 3.13	95.1
COD	mg/L	684 ± 25.4	6.04	36.3 ± 2.79	95.0
TSS	mg/L	147 ± 1.79	69.6	10.6 ± 2.72	97.8
Total coliform	cfu/100 mL	3,600 ± 210	51.3	14.0 ± 5.0	99.8
Escherichia coli	cfu/100 mL	1,175 ± 13	44.0	9.0 ± 3.0	99.5

The specific surface area is the portion of the total surface area that is available for adsorption [41,42]. Thus, the more porous and more finely divided adsorbent is the greater adsorption capability [43].

Industrial activities produce large amounts of solid wastes as byproducts such as fly ash, sludge, and red mud which can be used as adsorbents for removal of pollutants from water and wastewater [44]. Gu et al. [45] revealed the ability of novel porous bricks for the removal of phosphate and ammonium from water into the fine pores present in bricks which maintain highly specific surface areas and increase the adsorption capability.

The chemical structure of PSs may affect the bacterial removal process because PSs are composed mainly of some metal oxides such as iron oxide (Fe_2O_3), silicon oxide (SiO_2), sodium oxide (Na_2O), and aluminum oxide (Al_2O_3) [46]. Many researchers have reported the bactericidal effect of these metals on bacteria such as *E. coli, Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Vibrio cholera* [47–49]. Nemade et al. [50] studied the removal of total coliform from drinking water using single-pass constructed soil filter which achieved excellent removal efficiency since coliform counts decreased from 10^5 to 5 cells/100 mL after 10-h retention time.

Zipf et al. [7] used slat waste as a filter medium for greywater treatment in Brazil and reported average removal efficiencies regarding COD, BOD, turbidity, total coliform, and thermotolerant coliform were 21%, 17%, 21%, 61%, and 49%, respectively.

3.3. Treatment performance of MBBR

Wastewater treatment using biofilm systems such as MBBR has many advantages compared with suspended growth systems. These advantages include low-space requirements, operational flexibility, increased biomass residence time, reduced HRT, high active biomass concentration, flexibility to changes in the environment, as well as slower microbial growth rate resulting in lower sludge production [51–53]. Biofilm systems also permit enhanced control of reaction rates and population dynamics [54].

The key components necessary for MBBR performance are biofilm formation, type, and characteristics of biofilm carriers, and aeration system [55]. Inside MBBR, biofilms grow on biofilm carriers which move around the aerator [56–58]. The movement of biofilm carriers inside the reactor can be carried out using hydraulic, mechanical, or aeration systems [59]. Biofilms growth depends mainly on the presence of microbes themselves and a substrate. The absence of microbes and/or substrate can cause failure of biofilm development. In addition, the presence of water is important for biofilm development because the availability of nutrients and bacterial motility will be reduced if there is not enough water. Water is also necessary to keep bacterial osmotic pressure [60]. There are some factors affecting biofilm formation in MBBR including the presence of nutrients, velocity, type of distribution system materials, pressure, and HRT [61,62]. In addition, the composition, specific surface area, shape, and size and porosity of biofilm carriers play an important role in biofilm attachment and in the performance and removal efficiency of MBBR [63].

Recently, biofilm carriers such as polyethylene plastics, granular activated carbon, polyvinyl alcohol gels, sand and diatomaceous earth, polyurethane sponges, and polymer foam pads have been introduced to the MBBR process [64,65]. Polyethylene plastic carriers can achieve a high removal efficiency of up to 94.96% for COD and 99.07% for BOD_5 due to the presence of pores on the outside surface of the carrier which protect from biofilm loss and encourage biofilm growth, forming active biofilm layers outside and inside the carrier for effective treatment [55,66].

The removal efficiency of MBBR after 30 d operation was calculated and summarized in Table 2. A daily sample was collected after 24 h operation. The removal efficiency of BOD_5 (95.1%) and COD (95.0%) was on average excellence which indicates that most of the organic matters present in greywater were degraded. Compared with a previous study that evaluated an MBBR for single household greywater treatment [67], the MBBR used in this study had higher removal efficiencies of BOD_5 and COD; while in case of turbidity and TSS, the same removal efficiencies were reported. Similarly, Chrispim and Nolasco [24] evaluated MBBR for synthetic greywater treatment at a university campus in Brazil and reported low removal efficiencies of turbidity (66%), TSS (87.07%), BOD_5 (59%), and COD (70%).

The variation in removal of organic matters depends mainly on some factors such as the type and concentration of organic matter, bacterial load, and presence of microbial inhibitors or toxic substances such as chlorine-containing cleaning agents in greywater [68]. The removal efficiency of BOD_5 and COD increased significantly from the first day to the last day (Day 30). This increase may result from the microbial adaptation and growth on the polyethylene plastic biomass carriers which finally stabilizes the degradation process and increases the performance [67]. The high residence time of biomass onto the carriers, which could allow a wide range of microbial biodiversity through the protection of slow-growing microorganisms from washout, increased the removal efficiency of organic matters [15]. The large variety of microbial species included in biofilm, whereas all of them contribute to each other's metabolic needs [69].

Regarding to physical impurities such as turbidity and TSS, MBBR showed the removal percentage of 93.6% and 97.8% for turbidity and TSS, respectively. Chrispim and Nolasco [24] obtained low-removal percentage of turbidity (66%) and TSS (87.07%) using MBBR for synthetic greywater treatment. Despite absence of membrane in our study, Leyva-Díaz et al. [70] reported similar concentrations of TSS in the municipal wastewater effluent using aerobic MBBR-membrane bioreactor with a removal efficiency of >94.0%.

In this study, the presence of PSCU as a primary treatment unit was responsible for most of turbidity and TSS removal efficiencies (Table 2). Colic et al. [71] developed a hybrid centrifugal-dissolved air flotation system, which they termed gas-energy mixing (GEM) system, as an advanced pretreatment to increase the treatment efficiency of MBBR for high-strength candy manufacturing wastewater in Mexico. TSS concentration decreased from (influent) 1,300 to 50 mg/L and to 25 mg/L after GEM and MBBR, respectively.

In terms of bacterial quality, hydrogen peroxide (H_2O_2) was injected as a disinfectant at constant dose of 1.5 mL/L/h. Table 2 showed that the PSCU has a moderate effect on total coliform (51.3%) and *E. coli* (44.0%) removal efficiencies. As a biological aerobic treatment method, MBBR is expected

Table 3
Average values of treated effluent versus Egyptian guidelines for wastewater reuse in irrigation [33]

Parameter	Unit	Treated effluent	Egyptian guideline	
			Unrestricted irrigation	Restricted irrigation
TSS	mg/L	10.6	20	40
COD	mg/L	36.3	40	80
Fecal coliform (*E. coli*)	cfu/100 mL	9.0	100	1,000

to have little removal effect on total coliform and *E. coli* in greywater. The aerobic biological treatment methods reduce the solids and organic matter present in greywater without having any bactericidal or bacteriostatic effects [10]. On the other hand, more than 99.0% removal efficiency of both total coliform and *E. coli* was achieved using hydrogen peroxide (H_2O_2) as a disinfectant.

H_2O_2 has a cell-destruction power which can be explained by the oxidation of intracellular components due to the active forms of oxidants (hydrogen peroxide decomposition products) such as perhydroxyl ($HO_2^•$) and hydroxyl ($OH^•$) radicals. These radicals have lethal and sublethal effects on the bacterial intracellular molecules and genome, leading to growth delay, physiological alterations, and disturbances in the ionic control of cell membrane which in turn cause bacterial cell death [10,72]. Also, Teh et al. [10] used H_2O_2 as a disinfectant for treated greywater using aerobic digestion. They reported the excellent capability of H_2O_2 as a disinfectant against total coliform and *E. coli*. In addition, they reported that H_2O_2 prevent the regrowth of total coliforms even after 3 d of storage with a recommended 1 mL/L H_2O_2 dose to prevent bacterial regrowth during storage of treated greywater.

In this study, the maximum storage period of treated greywater was 2 d. Storage of greywater is an important aspect in greywater reuse systems [10]. Continuous greywater treatment systems require storage units due to the sporadic nature of greywater flows and reuse demands [73]. During the study period, total coliform and *E. coli* could not be detected in treated samples during Day 2 of storage, an immense reduction compared with bacterial counts detected in samples analyzed at the end of the first day storage. Thus, it could be concluded that disinfection with hydrogen peroxide requires a much longer contact time [74].

3.4. Reuse of treated greywater in irrigation purposes

As previously mentioned, greywater accounts for 50%–80% of the total wastewater produced in household with low concentrations of organic matter, nutrients, and pathogens. Therefore, it makes sense to reuse treated greywater for irrigation, washing, infiltration, and other non-potable applications [75]. Table 3 summarizes the average values of treated greywater effluent from Table 2 in comparison with the Egyptian guidelines for wastewater reuse in irrigation. It was clear that our treatment system produces effluent, particularly as pertains to TSS, COD, and *E. coli*, which satisfies the Egyptian guidelines for both restricted and unrestricted irrigation. Similar results were observed by Smith and Bani-Melhem [26] because they found that treated greywater using submerged membrane bioreactor met the local Egyptian guidelines for restricted irrigation.

A wide variety of biological treatment technologies have been used or are being developed for greywater treatment and reuse, including fluidized-bed reactor + UV disinfection [76], sedimentation + rotating biological reactor (RBC) + UV disinfection [76], screen + RBC + sand filtration + chlorination [9], MBR [77,78], and upflow anaerobic sludge blanket reactor [79]. Jefferson et al. [80] suggested that advanced biological processes which combine bioreactor such as MBBR are likely to be the most suitable technology for greywater recycling.

4. Conclusions

From the obtained results in this study, it can be concluded as follows:

PSs which are nondegradable byproducts causing environmental problems could be reused as a natural filter medium in greywater treatment process because it showed great ability in removal of turbidity and TSS, and moderate removal of total coliform and *E. coli*. The using of PS as a primary treatment step improved the treatment performance of MBBR by improving the quality of raw greywater. MBBR proved high performance in removal of organic matters in terms of BOD_5 and COD present in greywater. Effluent disinfection with H_2O_2 had some benefits compared with other disinfectants such as chlorine because H_2O_2 is safer, cheap, and no formation of dangerous disinfection byproduct compounds. H_2O_2 showed excellent bacterial removal efficiency and prevents the bacterial regrowth in stored treated greywater. The treated effluent met the Egyptian guidelines for both restricted and unrestricted irrigation purposes regarding to TSS, COD, and *E. coli*. The application of such decentralized systems for greywater treatment is better studied for implementation in new housing developments to reduce sewage networks, wastewater treatment costs and operation, also for better utilization of water resources. The treatment cost was cost-effective as the main cost was for the installation stage (tanks and column) while the operation cost was cheap.

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