Household greywater treatment methods using natural materials and their hybrid system

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ABSTRACT

Discharge of household greywater into water bodies can lead to an increase in contamination levels in terms of the reduction in dissolved oxygen resources and rapid bacterial growth. Therefore, the quality of greywater has to be improved before the disposal process. The present review aimed to present a hybrid treatment system for the greywater generated from households. The hybrid system comprised a primary stage (a natural filtration unit) with a bioreactor system as the secondary treatment combined with microalgae for greywater treatment, as well as the natural flocculation process. The review discussed the efficiency of each stage in the removal of elements and nutrients. The hybrid system reviewed here represented an effective solution for the remediation of household greywater.

Key words | flocculation, microbiological aspects, natural filtration, nutrient, phycoremediation, removal

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INTRODUCTION

The speedy growth of humans and their activities alongside the scarcity of freshwater resources in arid and semi-arid countries have seriously contributed to water pollution. In Jordan, the present water scarcity is a prominent issue for the country, due to their growing population over the previous decade. The water availability per capita reducing to 198 m^3/capita/year from the standard of 1,000 m^3/capita/year has been frequently used to show the conditions for water shortage (Najib 2005). This has given disruption to economic activities that mostly depend on water. The increased population has also resulted in the domestic wastewater load into water bodies. The high cost of the sewerage network and sewage treatment plant has been identified as the main constraint to expanding wastewater services to small communities. As a result, domestic wastewater from houses is discharged, untreated, into the drainage and contributes to the phosphorus, nitrogen, biochemical oxygen demand (BOD) and others entering into the water bodies.

Wastewater originating from households is divided into greywater and black water, based on its composition. Greywater is wastewater discharged from showers, bathtubs, washing machines and kitchen sinks, while black water is toilet wastewater (Paulo *et al.* 2013; Wurochekke *et al.* 2014). In some places, kitchen greywater is considered as black water (Oron *et al.* 2014). However, there is much controversy on this issue as in some countries like Malaysia, greywater is toilet wastewater only. The greywater discussed in this article included both kitchen and bathroom discharges that came from the same point. The range of pollutants included BOD_5 47–466 mg/L, chemical oxygen demand (COD) 100–700 mg/L, total suspended solids (TSS) 25–183 mg/L, total nitrogen (TN) 1.7–34.3 mg/L and total phosphorus (TP) 0.11–22.8 mg/L (Li *et al.* 2009).

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In some countries the kitchen and bathroom wastewater are separated, therefore the TN and TP contents in the bathroom wastewater are low. However, countries like Malaysia consider both kitchen and bathroom wastewater as greywater, hence the TN content can be up to 10–38 mg/L and TP 3–20 mg/L (Mohamed *et al.* 2013b). Similarly, a study conducted by Wurochekke *et al.* (2014) revealed that the concentration of ammonium was 3.83 mg/L in household greywater.

Domestic wastewater contains high concentrations of fecal indicator organisms, which range from 10^6 to 10^8 CFU/100 mL (Wilén *et al.* 2012). In terms of pathogenic organisms in the greywater, the concerns associated with the disposal of these wastes into the environment and natural water bodies lie in the ability of pathogens to survive and persist for a long time (Efaq *et al.* 2015). Pathogenic microorganisms have several mechanisms to survive in a stressed environment. For example, some bacteria such as *Bacillus* spp. and most fungi have a high potential to produce spores that might tolerate an unfavourable environment for many years. Another mechanism is presented among non-spore forming bacteria, which is the ability to change to a viable but-non-culturable status. In this case, the cells minimize the metabolic activity to the minimum level, and thus can survive for a long period in the absence of good conditions for growth (Al-Gheethi *et al.* 2015a).

The organic and inorganic constitutents in the greywater disposed of into natural water bodies might lead to a rise in BOD_5, resulting in the depletion of oxygen levels required for the various types of living organisms supported by the estuary (Reinheimer 1992). The eutrophication is a phenomenon occurring due to high levels of nutrients (TN and TP) in the water bodies. This situation has a negative effect on the survival of aquatic organisms (Mcelwee *et al.* 2006; Marcos & Carlos 2007). The high concentrations of TSS in the discarded greywater reduce light penetration and increase water turbidity, or cloudiness of water. Oil and grease in the greywater that contained kitchen wastewater lead to increased odour and undesirable appearances. Besides, they are hazardous pollutants for aquatic environments due to the consumption of dissolved oxygen (DO) that is necessary for the forms of life in water (Jameel & Olanrewaju 2011; Saroj & Mukund 2011).

Greywater is another source of water, and the quantities of greywater generated in developing countries are more than those reported in developed countries. In the UK, the quantities of greywater and sewage produced are equal; in contrast, greywater represents 70–80% of domestic wastewater in Jordan and Oman. This might be due to the nature of living, environmental conditions such as weather, climate and standard of living, social habits and water usage pattern and time (Prathapar *et al.* 2005; Jamrah *et al.* 2008; Efaq *et al.* 2016). Furthermore, the quantities of household greywater in Middle East countries are discretionary, because the greywater is combined with the sewage. Therefore, accurate information about the quantities of greywater in those countries is unavailable. Among the Middle East countries, Israel and Jordan are the best in the treatment and disinfection of greywater, which is reused for irrigation purposes. On the contrary, the latest country in this field is Yemen. However, Yemen is the first country to reuse wastewater for irrigation due to the absence of an alternative resource of water. In comparison, in developed countries, sewage and greywater are segregated from the source and they are treated separately. Besides that, the treated greywater contributes significantly to the irrigation of gardening and public parks (Matos *et al.* 2014). However, in the Middle East countries, there is no segregation between greywater and black water. Countries like Malaysia most often discharge household greywater, and this occurs in village houses from baths and kitchens openly together in the environment. Consequently, the practice affects aquatic habitats, environmental aesthetics, plants and soil due to heavy metal concentrations beyond the acceptable limits (Ali *et al.* 2013).

The removal of organics and nutrients from greywater is an essential means of averting eutrophication and algal blooms. Therefore, greywater ought to be given proper treatment prior to discharge into water bodies. The present review aimed to present a hybrid system consisting of three stages including filter media, a microalgae phycoremediation process and a flocculation process, to be used for the treatment of greywater resulting from village houses in developing countries. The hybrid system is proposed based on previous studies that investigated the efficiency of each stage in an individual work (Mohamed *et al.* 2013c, 2016; Wurochekke *et al.* 2014).

SELECTION OF TREATMENT TECHNOLOGY FOR GREYWATER

There are numerous methods for greywater treatment (GWT), differing in their characteristics, forms, pollution loadings and treatment procedure. The selection of the suitable technology depends on the quantities of greywater, organic contents, final application and standards acceptance. The treatment processes included preliminary, primary and secondary processes. However, there is no established design for GWT globally, except for in a few countries like Australia and America, and it is basically designed in relation to the greywater source, quality and quantity, site condition and reuse alternatives (Edwin *et al.* 2014). Moreover, the accepted fact is that greywater should be treated with an eco-friendly technology and without chemical additives or toxic by-products. Some authors indicated that the greywater might be subjected to a storage period before the treatment process; however, a storage period should be conducted for a short time to prevent microbial growth (Harju 2010).

Filtration and disinfection methods are mainly used in physical/chemical GWT systems, while aeration and membrane bioreactors (MBRs) are biological treatment methods. The majority of treatment methods seen universally are sequence batch reactors, MBRs and biologically aerated filters which may have high potential to produce higher greywater quality than that generated from the traditional processes such as the primary and secondary processes. However, the energy consumption and capital cost of these methods are high (Allen *et al.* 2010). Therefore, they are not appropriate techniques for low and middle income or developing countries. In Germany, high water bills and water saving actions led to a complicated GWT system that included active aeration (Shaikh & Zubayed 2013).

Numerous systems are in operation for the removal of nutrients from greywater, although these are expensive and generate elevated amounts of thick, soft mud (Alejandro *et al.* 2010). A natural treatment system using primary settling with cascaded water flow, aeration, agitation and filtration had been used and was less expensive (Bhausaheb *et al.* 2010; Saroj & Mukund 2011). Moreover, microalgae have been reported as another potential biological treatment for use in removing wastewater nutrients (Li *et al.* 2010a; Jianhua *et al.* 2012; Wu *et al.* 2012). If applied properly, benefits could be driven from greywater reuse, including domestic freshwater savings, reduce pollution to water bodies and a contribution to household income savings.

In arid areas of the USA, Australia, India and the Middle East countries, simple GWT systems are commonly used for irrigation and lawn crops (Mohamed *et al.* 2013a). Therefore, in treating greywater, there is a basic challenge that depends on its inconsistent nature such as the type of domestic product preference and the tradition of the inhabitants (Mohamed *et al.* 2013b). The system used should be designed to have the potential to work at a small scale without the need to use advanced technology. Taking the maintenance aspect of the system into account as well, depending on the maintenance, the biodegradability of the influent substances will have to be watched for clogging. For long term maintenance, it might be expected that biomass needs to be withdrawn from the bioreactor periodically. Filtration with natural materials followed by a phycoremediation process with microalgae can be used to meet the standard limits required for reuse in irrigation.

THE TREND FOR DOMESTIC GWT METHODS

GWT technologies involve the combination of preliminary (physical), primary (chemical) and secondary (biological) systems. These technologies are emphasized because these processes are low cost, no skilled personnel are required, they are easy to handle and have high treatment efficiency. In this section, the role at each stage of the hybrid treatment system (Figure 1) will be discussed in terms of nutrient reduction and improvement of the treated greywater quality.

Natural filtration unit

The primary treatment for greywater mainly removes pathogens and suspended solids (SS). The system was found to improve turbidity and contribute to the reduction of total

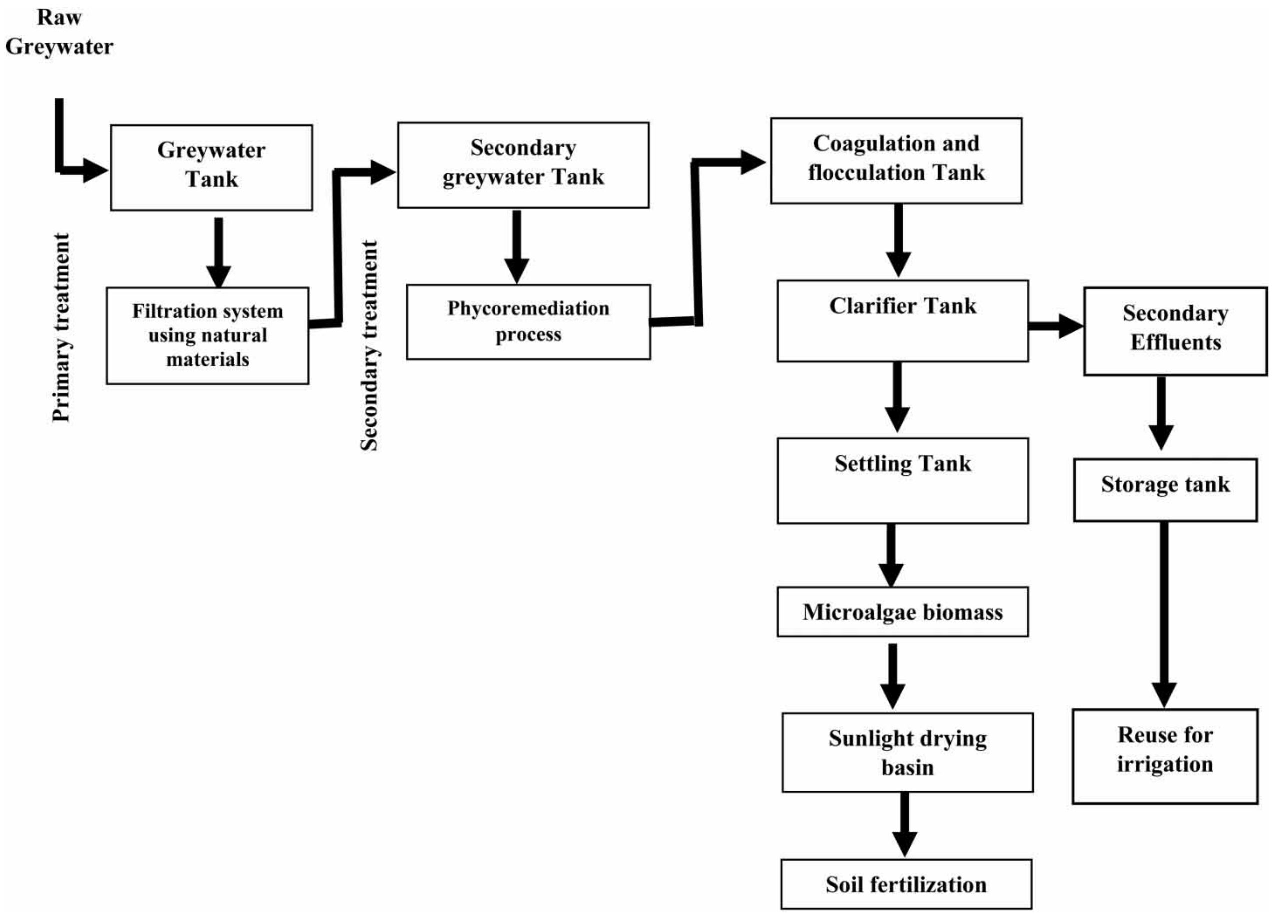

Figure 1 | Hybrid system for treatment of household greywater.

and fecal coliforms (FC), COD, BOD, phosphorus (P), nitrogen (N), TSS, aluminium (Al) and zinc (Zn) (Mohamed *et al.* 2014, 2016). The primary treatment mostly consisted of coarse sand and soil filtration, where the coarse filter alone has a limited effect on the removal of the pollutants present in the greywater, hence it is usually combined with soil filtration and is called the hybrid treatment process.

Several types of natural materials such as sand beds, fine particles, coarse size brick beds, charcoal beds, ceramics, clamshell, limestone, wooden sawdust beds and beds of coconut shell cover have been combined to design a filter bed in the filtration unit (Lalander *et al.* 2013; Mohamed *et al.* 2014). The utilization of natural materials as a filtration unit, such as in constructed wetlands, have exhibited high efficiency for removing pollutants, as well as being inexpensive and simple to operate (Siracusa & La Rosa 2006). Mohamed *et al.* (2014) found that a filtration system consisting of peat, charcoal and gravel was effective for the treatment of greywater. The filtration system consisted of bark and activated charcoal, which also exhibited efficiency in reducing BOD_5 and TP by more than 90% (Lalander *et al.* 2013).

Table 1 compares the different low cost treatment schemes on greywater from different sources, including several households (Gross *et al.* 2006), mosques (Mohamed & Ali 2012), residential quarters (Nnaji *et al.* 2013), village houses and house kitchen wastewaters (Mohamed *et al.* 2013a). The main components that are removed by using the primary treatment system are BOD, COD, and TSS, with efficiency ranges of 37–98, 74–90.8 and 40–95%, respectively (Gross *et al.* 2006; Sahar *et al.* 2012). In a review by Al-Jayyousi (2003), a simple GWT system consisting of a sand filtration unit reduced SS and BOD by 40 and 74%, respectively.

Table 1 | Review of primary treatment systems for greywater from different sources

Location	GWT system	Greywater sources	Pollutant removal	Advantages	References
Nsukka, Nigeria	Gravity system by sedimentation unit, sand & gravel filtration unit, receiving unit, adsorption unit, storage unit	Residential quarters	BOD (85.68%) COD (57.09%) TSS (70.74%) FC (100%)	Can decrease health hazards from handling this treatment system	Nnaji et al. (2013)
Madaba Governorate, Jordan	Filter media: • Wetland bed • Volcanic Tuff (volcanic ash) • White gravel	Al-Faisalia, Al-Areash and Jraineh village houses	BOD (73%) COD (65%) TSS (84%) FC (15.67%)	Achieves significant local water saving and no effect on soil and plants	Mohammed et al. (2013a, 2013b, 2013c)
Cairo, Egypt	Combine chemical system by: • Coarse & surge tank • Sand filter with reeds	Mosque, shower bathroom of housing building and sinks of the bathroom	BOD (71%) COD (67%) SS (87%) Turbidity (90%) TC (100%)	Can be used for multiple occupancy building	Mohamed & Ali (2012)
USA	Vertical flow constructed wetland used: • Peat moss • Lime pebbles	Several households	COD (90%) TSS (95%) *E. coli* (100%)	Used for small scale decentralized filter systems and presence of non-enteric pathogens Often more economical than centralized sewer systems in rural areas	Gross et al. (2006)
Tafileh, Jordan	Separation and automatic greywater system (automatic back washing sand filter)	Houses and institutional buildings	TSS (40%) BOD (74%)	Greywater is used in groundwater recharge, landscaping, and plant growth	Al-Jayyousi (2003)
Sweden	• Pine bark • Activated carbon • Foam • Sand filters	Laboratory (column experiment)	BOD, COD, TN, TP (98, 74, 19 and 97% respectively) BOD, COD, TN, TP (97, 94, 98 and 91% respectively) BOD, COD, TN, TP (37, 37, 13 and 36% respectively) BOD, COD, TN, TP (75, 72, 5 and 78% respectively)	The effluent is used for irrigation, as it can replace chemical fertilizer	Sahar et al. (2012)
Malaysia	Gravel, peat, charcoal and sand filter media	House kitchen wastewater	BOD_5 40%, COD_{tot} 37%, SS 72%, NH_4^+-N 87% and pH 6.6–6.7	Peat media can serve as a sustainable, effective and inexpensive alternative for the filtration of kitchen greywater.	Mohamed et al. (2013a, 2013b)
Australia	Land and water greywater system with dual sponge filter	House (laundry & bathroom)	BOD 24–200 mg/L, COD 35–739 mg/L, TSS 78.33–163 mg/L, TP 3–20 mg/L		

Greywater from kitchens contained much higher concentrations of organic substances, nitrogen, oil and grease, and detergents from the dishwashing processes. Mohamed et al. (2013c) showed that the efficiency of the treatment system, which consisted of gravel, sand, peat and charcoal as treatment media to remove nutrients and organics in kitchen greywater, was 72% for SS, 37% for COD_{tot}, 40% for BOD_5, and 87% for NH_4^+-N. This signified that peat soil can also be among the potential materials used for the removal of pollutants. Hence, kitchen greywater can be treated with peat media. Furthermore, according to Table 1, TN removal varies from 5 to 98%, while phosphorus removal is observed in the range of 36–99.9%.

Francis et al. (2011) investigated a five-barrel GWT system consisting of five recycled polyethylene plastic barrels linked by polyvinyl chloride (PVC) pipes. The treatment system was connected with an ordinary sieve as a pre-treatment for the greywater. Rock alum (aluminium sulphate) was added to the greywater, then disinfection with sodium hypochlorite was carried out before reuse. The treated greywater system met the WHO guidelines for irrigation. The designed GWT system was found to reduce total and FC, as well as *Salmonella* sp. in greywater in order to be appropriate for subsurface irrigation.

Sahar et al. (2012) studied the efficiency of activated charcoal, pine bark, sand filters and polyurethane foam for the reduction of contaminants from artificial greywater in a laboratory column experiment. Pine bark and activated charcoal filters showed high efficiency for reducing BOD_5 by 98 and 97% and methylene blue active substances by 99 and 99%, as well as TP by 97 and 91%, respectively. The efficiency recorded in that study might be related to the absorption process associated with the presence of a high percentage of sodium chloride (NaCl) and uranin (93%) traces in the pine bark filter. The study gives an indication that activated charcoal and pine bark might be effective to produce treated greywater suitable for irrigation purposes. Besides, the study demonstrated that the pine bark filters might be more useful for the effluent, which would be used for irrigation, as they preserved and restored the use of chemical fertilizer due to their high concentration of nitrogen.

Nnaji et al. (2013) reported on the sand filter treatment method. The study revealed a significant removal of organic, physical and microbial pollutants such as BOD_5 with 85.68%, COD 57.09%, TSS 70.74% and FC by 99.99%, respectively.

The chemical composition of steel slag, clamshell and limestone used in the natural filtration system exhibited an efficiency for the removal of pollutants from greywater. Clamshell and limestone contain an alkaline agent (CaO) which played an important role in neutralizing or partially neutralizing acidity, as well as in the adsorption process of suspended solids. Steel slag that contained CaO, Fe_2O_3 and SiO_2 at different percentages increased the removal efficiency of TSS (Bird & Drizo 2010). These filtrations might also contribute to the reduction of TP and nitrogen during the filtration of wastewater, and might be used to improve secondary effluent quality (Zhang et al. 2015).

Clamshells are made of aragonite, a form of calcium carbonate ($CaCO_3$); thus, it has the potential to remove BOD_5 efficiently. In addition to providing removal, sand filtration removes the BOD_5 contained in the suspended particles (Libhaber & Jaramillo 2012). In a previous study performed by Park (2009) and Luo et al. (2013), a treatment system using oyster shell removed BOD_5 by 89.3% and 85.02%, respectively. This was because oyster shell is rich in calcium oxide, which exhibited high biosorption efficiency. In the present study, the filtration system was designed with multilayers to increase the removal efficiency of COD and BOD_5. Liu et al. (2010) also reported that the two-layer filter was more efficient for the removal of COD_5 than the single layer (85 vs. 76%). Liu et al. (2010) showed that the filtration system of wastewater using oyster shell reduced COD by 85.1%. The application of sand and clamshell filtration reduced turbidity by 90 and 89.9%, respectively (Park 2009; Mohamed et al. 2014).

Niwagaba et al. (2014) investigated the treatment of greywater by a multi-media filter that consisted of gravel, charcoal, and geotextile. It was noted that the filtration system reduced TSS by 85.2%. The reductions in COD and BOD_5 were 90.8 and 96.1%, respectively. Lalander et al. (2013) found that a filtration system consisting of bark and activated charcoal removed BOD_5 by more than 90%. In contrast, Mohamed et al. (2014) studied the efficiency of a natural filtration system that consisted of two-stage filter media, with pre-treatment (gravel and sand) and peat based (peat, charcoal and gravel) for the treatment of household greywater. However, the reduction of TSS, BOD_5 and COD was 81, 54, and 52%, indicating that the gravel and charcoal were not the main factors that affected the efficiency of the filtration system.

The study carried out by Mohamed *et al.* (2013c) on a natural filtration system for greywater indicated that the quality of the treated wastewater complied with the limits of the Malaysian Standard (Standard B). The treated greywater using a septic tank followed by an intermittent sand filter in Jordan met the Jordanian Standards JS (893/2006) for reclaimed wastewater reuse for restricted irrigation (Assayed *et al.* 2010). However, EQA 1974 has more strength standards, and these wastes do not meet the EQA 1974 standard A. Moreover, using a treatment system consisting of primary and secondary treatment might produce a high quality of greywater.

Phycoremediation process

Secondary treatment is a process that aims to produce high quality greywater by removing phosphorus, nitrates and heavy metals. Several biological methods such as the anaerobic sludge blanket (UASB), MBR and much more were applied to treat greywater (Merz *et al.* 2007; Lucıa *et al.* 2010; Lai *et al.* 2014). The treatment process consisted of an aerobic/anaerobic biological treatment unit, flocculation and ultrafiltration, which was more efficient in removing pollutants (Huang *et al.* 2011; Melo-Guimarães *et al.* 2013). However, it had high capital, operations and maintenance costs. Thus, it is not suitable in rural areas and for individual usage in village houses (Nakajima *et al.* 1999). The biological methods had the ability to achieve excellent removal efficiencies. Gunes *et al.* (2012) investigated a free water surface flow-constructed wetland (FWS-CW) with a three-compartment septic system for the treatment of greywater. As a hybrid system, the TSS, BOD, COD, TN and TP declined to 31 mg/L (86%), 30 mg/L (91%), 61 mg/L (91%), 18 mg/L (57%) and 4.3 mg/L (43%), respectively. Moreover, if the system worked independently, poor performance of the septic system in terms of TSS and nutrient removal was observed. As such, a constructed wetland was considered as one of the eco-friendly and financially acceptable GWT systems. Tarcio *et al.* (2012) reported on the constructed wetlands of a single household using natural materials and wetland plants (*Cyperus giganteus* and *Hymenachne grumosa*) that achieved an excellent removal efficiency for COD and nutrients in the greywater from each wetland.

On the other hand, alternative technologies such as the phycoremediation process represent a green technique for the treatment of greywater and reduction of pollutants. Microalgae have a high capacity to assimilate nutrients. Domestic greywater is a suitable medium for algal growth due to the high content of carbon, nitrogen and phosphorus, as well as trace elements necessary for their growth. The most important nutrients with respect to greywater are nitrogen and phosphorus. These nutrients may be present in concentrations ranging between 20 and 40 mg/L for TN and 50 and 70 mg/L for TP. Phosphorus in untreated greywater resulted from the soap and detergents used by house occupants, while nitrogen can be from blood in meat that is washed in the kitchen sink, and nitrate from nappies washed in the bathroom (Donner *et al.* 2010; Maimon *et al.* 2010). Bio-treatment with microalgae is a very acceptable method because of their photosynthetic capabilities, changing solar energy into biomass yields and embracing the phosphorus and nitrogen contents that inflict eutrophication (Abdel-Raouf *et al.* 2012).

Nowadays, GWT technology from microalgae is potentially forethought as a practicable technique. Since uptake is the major means of removing nutrients by microalgae, the colony of microalgal growth squarely influences the nutrient removal rate. Greywater can contain nutrients such as TP, TN from detergents and total organic carbon that can benefit algal growth (Park *et al.* 2011; Sara *et al.* 2013). Meanwhile, nitrogen and phosphorus could be concurrently consumed by microalgae, which take them out efficiently, barely if the N/P fraction in greywater is within the appropriate capacity, which ranges between 3.6 and 19.4 mg nitrogen/L and between 0.6 and 27.3 mg phosphorus/L (Mohamed *et al.* 2013b). Therefore, nutrients in greywater are essential to microalgal growth during the phycoremediation process.

Microalgae have the potential to survive in a stressed environment. Therefore, they represents a good source for biomass (Li *et al.* 2010a, 2010b; Yanan *et al.* 2013; Bala *et al.* 2016). The utilization of greywater as a production media for microalgae biomass leads to a reduction in the nitrogen and phosphate content (Singh & Gu 2010; Li et al. 2010b; Teresa et al. 2010). The microalgae biomass can be used as feedstock for many industries, such as food and feeds, and pharmaceuticals (Spolaore et al. 2006; Harun et al. 2010).

Microalgae have a high potential for removing organic/inorganic substances and nutrients from greywater, which make them more attractive in treating greywater for reuse (Li et al. 2010a). Microalgae remove greywater contaminants basically by the uptake of nutrients into algal cells (Aslan & Kapdan 2006; Garcia et al. 2006). The most widely used and studied species of microalgae for the reduction of nitrogen and phosphorus removals are *Chlorella* sp., *Scenedesmus* sp. and *Spirulina* sp. (Sriram & Seenivasan 2012; Panneerselvam et al. 2013). As a pioneering technology, 'green technology' microalgae acquire some advantages in the removal of contaminants that include: low cost because of adequate solar energy, no extra organic carbon additive as in the biological nitrification-denitrification process, immediate uptake of CO_2 for cell growth, the release of oxygen into water bodies as effluent, prevention of issues of handling sludge and the high prospect and financially viable harvested algal biomass (for fertilizer, biofuel, feedstock etc.). Therefore, microalgae are considered or measured as a hopeful alternative for GWT and its algal biomass as fertilizers in the future. The efficiency of microalgae for the reduction of nitrogen and phosphorus is presented in Table 2 due to their high capabilities for treating a wide range of wastewater. Thus, they have the potential to treat greywater as low strain wastewater.

In the study of Gokulan et al. (2013), nitrogen (0.31 mg/L) and phosphorus (2.16 mg/L) content were reduced significantly after screening, grit removal and using *Botryococcus braunii* microalgae as a treatment medium. Jing (2009) used a twin layer system with two green microalgae, *C. vulgaris* and *S. rubescens*, to remove nitrogen and phosphorus from wastewater in Germany. Both nitrogen and phosphorus were removed, by 96 and 84%, respectively.

From the literature review by Kim et al. (2007), data signified the highest nutrient concentration was from fermented swine urine. The concentrations of TN reached 662.4 mg/L and TP of 120 mg/L from animal wastewater. By using *Scenedesmus* spp. microalgae as agents in the removal of nutrients, after treatment TN was reduced to

Table 2 | Reduction of TN and TP by using microalgae in treating different types of wastewater

		Characteristics		Removal efficiency of microalgae species (%)			
		Raw water (mg/L)			% removal		
Type of wastewater	**Treatment**	**Nitrogen**	**Phosphorus**	**Species**	**Nitrogen**	**Phosphorus**	**References**
Animal wastewater	Pilot plant scheme for the swine urine fermentation process. The swine urine remains in the aeration (*Scenedesmus* spp.)	662.4 ± 39	120 ± 12	*Scenedesmus* spp.	87	83.2	Kim et al. (2007) Korea
Secondary wastewater from municipal	Investigated using a novel method of algal cell immobilization, the twin-layer system (*C. vulgaris and S. rubescens*)	6.2	3	*C. vulgaris and S. rubescens*	96 ± 2	84 ± 2	Jing et al. (2009) Germany
Wastewater	The *Scenedesmus* sp. were cultivated in a growth medium to remove TN and TP	10	0.5	*Scenedesmus* sp.	> 99	> 99	Li et al. (2010a) China
Piggery wastewater	Six microalgae species were used to treat piggery wastewater (Focus of microalgae on *Scenedesmus obliquus*)	53	7.1	*Scenedesmus obliquus*	58	24	Abou-Shanab et al. (2013) Korea
College hostel greywater	*Botryococcus Braunii* algae were grown in the laboratory to treat greywater	14.21	9.61	*Botryococcus Braunii*	97.82	77.52	Gokulan et al. (2013) India

86.4 mg/L (87%) and TP was decreased to 20.2 mg/L (83.2%) from the levels observed in raw water samples. Consequently, the majority of TN and TP in wastewater were removed by this treatment.

In a study by Abou-Shanab *et al.* (2013), piggery wastewater could boost microalgae species growth from separate water bodies. After 20 days' cultivation of six microalgae species: *Caulerpa mexicana, Micractinium reisseri, C. vulgaris, Neonycteris pusilla, S. obliquus* and *Ourococcus multisporus*, in wastewater, the TN and phosphorus levels dropped significantly from 53 to 22 mg/L and 7.1 to 5.4 mg/L, respectively, for 14 days of cultivation with *S. obliquus* solely. The removal percentages of nitrogen (58%) and phosphorus (24%) were achieved by 15 days of cultivation (Abou-Shanab *et al.* 2013). Moreover, Li *et al.* (2010b) studied animal wastewater using freshwater *Scenedesmus* spp. microalgae to assess nutrient uptake and lipid accumulation under different growth conditions. In another study of institutional buildings (a men's hostel), *B. braunii* microalgae were used for GWT. The treatment achieved 97.82 and 77.52% nitrogen and phosphorus removal, respectively.

The quality of treated wastewaters using different microalgae met the discharge limits for the Jordanian standard for reuse in agriculture. The maximum allowable concentrations for cooked vegetables allowed 30 mg/L of BOD_5, 100, 50, 30, 45 and 30 mg/L of COD, TSS, nitrate, TN and TP, respectively. Thus, the literature studies in this review are in accord with these limits. However, TN from the study of Kim *et al.* (2007) using *Scenedesmus* sp. was slightly higher than this limit of 86.4 mg/L compared to the allowable limit of 45 mg/L. This could occur due to some environmental factors that contributed to the microalgae's ability to absorb this nutrient.

The efficiency of the phycoremediation process to remove heavy metals from wastewater has been reported (Nacorda *et al.* 2007; Olguín & Sánchez-Galván 2012; Dixit & Singh 2013). Microalgae play an important role in the biosorption of heavy metals from wastewater due to the presence of numerous functional groups such as amino and phosphate, amido, sulphhydryl, carboxyl, and hydroxyls in the microalgae cells, which contribute to the biosorption of heavy metals (Rao & Prabhakara 2011). Microalgae offer advantages over other microorganisms in terms of cultivation and growth during the phycoremediation process. Therefore, they have the potential to provide significant improvements in dealing with the world-wide problems of metal pollution (Wilde & Benemann 1993).

One of the most important points in the phycoremediation process is the source of the microalgae species. Microalgae species obtained from fresh water might be inappropriate to be used for the phycoremediation of greywater. The laboratories' observations indicated that most microalgae obtained from freshwater failed to survive and grow in the greywater. This may be due to the differences in the composition of freshwater and greywater.

Based on the aforementioned, it appears that many microalgae have a high efficiency to reduce nitrogen and phosphorous from greywater during the phycoremediation process. Therefore, by the combination of natural filtration as a primary treatment, which could reduce the physicochemical characteristics, and the phycoremediation process as a secondary treatment, the quality of final effluents would be safer to be reused for irrigation purposes.

Coagulation and flocculation processes

The coagulation and flocculation processes are a critical step in the treatment of wastewater. Both processes contribute significantly to the reduction of turbidity, COD, BOD and TSS (Mohamed *et al.* 2014; Al-Gheethi *et al.* 2015b). Moreover, these processes are also used for the harvesting of microalgal biomass by the charge dispersion mechanism, which takes place between the negative charge of functional groups on the walls of microalgal cells such as carboxyl, hydroxyl, phosphate, amine, and amide groups and positive charged flocculants, and leads to the flocculation of microalgal biomass (Harun *et al.* 2010; Chen *et al.* 2011; Rawat *et al.* 2011).

Numerous chemical substances such as ferric sulphate, ferrous sulphate, ferric chloride and ferric chloride sulphate are used as coagulants and flocculants. However, the new trend is to use natural substances such as *Moringa oleifera* and *Strychnos potatorum* seeds, as these substances are free of toxic by-products such as carcinogenic compounds and are also low in cost. The efficiency of natural flocculants in improving the water quality characteristics and harvesting of microalgae biomass has been reported in literature (Deshmukh *et al.* 2013; Hamid *et al.* 2014; Mohamed *et al.* 2014).

M. oleifera is a tropical tree that grows in India, South Saharan Africa, and South America. It is found abundantly in the Malaysian climate; therefore, it represents an alternative for water and wastewater treatment and removal of heavy metals (Okuda *et al.* 1999; Vieira *et al.* 2010; Vijayaraghavan *et al.* 2011; Sivakumar 2013; Hamid *et al.* 2014). *M. oleifera* seeds contain edible oil and water soluble substance and protein, which have active coagulation properties, as well as 1% active polyelectrolytes that neutralize the negatively charged colloids in the dirty water (Sotheeswaran *et al.* 2011; Mangale *et al.* 2012). *S. potatorum* seeds are another natural flocculant which have anionic polyelectrolytes that destabilize particles in water by means of inter-particle bridging. The authors in the literature have established that the seed extracts also contain lipids, carbohydrates and alkaloids containing the –COOH and free –OH surface groups, which enhance the extracts' coagulation capability (Tripathi *et al.* 1976). Both *M. oleifera* and *S. potatorum* seeds are suggested for use in the coagulation and flocculation stage of the proposed treatment system.

MICROBIOLOGICAL ASPECTS OF THE HYBRID TREATMENT SYSTEM

Greywater has low suspended solids in comparison to sewage; however, it has a non-negligible bacterial load, since the presence of practical solids in the wastewater improves the colonization of bacterial cells. The bacterial diversity in the untreated greywater includes total coliforms (TC), FC and *Enterococcus* in concentrations greater than 10^4 CFU/100 mL (Santasmasas *et al.* 2013; Katukiza *et al.* 2014; Bani-Melhem *et al.* 2015; Al-Gheethi *et al.* 2015a). Greywater also contains *S. aureus* and *P. aeruginosa*, which live as a normal flora on the human body (Ottoson & Stenström 2003; Gross *et al.* 2007; Winward *et al.* 2008). The reduction of the microbial load in wastewater represents an acritical point to enhance the efficiency of the phycoremediation process. This is because some of the bacteria have algicidal activity against microalgae which might negatively affect the phycoremediation process. Algicidal activity is defined as the potential for natural bacteria to kill algae. It was stated that algicidal bacteria affect microalgal growth by direct contact with the algae cell, releasing chemical substances to the surrounding area (Lovejoy *et al.* 1998). Moreover, the filtration process also contributes significantly to the reduction of bacterial loads. It has been demonstrated that the filtration process by wetland and sand filtration reduces coliform bacteria by more than 99% (Gross *et al.* 2006; Mohamed & Ali 2012; Nnaji *et al.* 2013). Therefore, the greywater generated from the primary process would have a low bacteria load and could be subjected to the phycoremediation process with a minimum effect of bacteria on the microalgae growth.

On the other hand, in wastewater, the microalgae grow fast during the phycoremediation process due to their ability to obtain carbon and energy from sunlight as photosynthetic organisms, followed by bacterial growth, which occurs after the microalgae are dead. This process is called succession, which plays an important role in the treatment of wastewater. Therefore, the application of phycoremediation process for 6 days or less and the utilization of a flocculation process might prevent the bacterial growth. The solar radiation and thermal treatment would also contribute significantly to the reduction of the bacterial load (Al-Gheethi *et al.* 2013a; Al-Gheethi *et al.* 2016). Caslake *et al.* (2004) reported that sunlight might reduce the concentrations of FC in wastewater by 99.99% within 30 min in the summer season, as a result of the synergistic effect of UV-A radiation and temperature, which enhance the lethal effect on the microorganism cells (Berney *et al.* 2006). However, on cloudy days, the inactivation of bacterial cells might extend to more than 48 h (Parsons 2002; Oates *et al.* 2003). Nonetheless, the phycoremediation process is carried out for more than 3 days, which might be enough for the reduction of bacterial loads to be less than the detection limits. The effect of sunlight on the bacterial load in greywater might be more efficient than that in sewage due to the absence of suspended solids in the greywater, which might prevent the penetration of UV light. The bactericidal effect of shorter wavelengths is visible, and ultra-violet radiation has been reported to cause damage, thus preventing successful growth and reproduction (Davis-Colley *et al.* 1995).

In order to improve the microbiological quality of the treated greywater before reuse for irrigation, it can be stored at room temperature for a week to enhance the reduction of bacterial loads. The effectiveness of the storage system on the reduction of the bacterial load in effluents has been reported by Al-Gheethi et al. (2013b). In that study, the FC and Enterococcus had reduced to less than the detection limits within 1 week of storage at room temperature.

In regards to the microalgae biomass resulting from the coagulation and flocculation processes, they could be used as fertilizers, but should be subjected to a further process to ensure the reduction of possible bacteria that might be harvested with the microalgae biomass. Air drying in the basin exposed to the direct sunlight might be enough to remove the water content by evaporation and then inactivate the bacterial cells (Rouch et al. 2011). Drying occurs faster and more completely in warm and dry weather, and slower and less completely in cold and wet weather. The density of pathogenic bacteria will be reduced by approximately 2 log under these conditions of air drying. Air-drying might be more effective in semi-arid to arid countries, where the temperatures range from 27 to 50°C (FAO 2008). Besides, this process is not expensive and is easily implementable (Al-Gheethi et al. 2015c).

CONCLUSIONS

It can be concluded that the hybrid system (filtration unit, phycoremediation and flocculation processes) would be able to produce high quality treated greywater. The combination of primary and secondary process is considered to be the most economical and feasible solution for GWT.

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