

Chapter 1

Qualitative Characterization of Household Greywater in Developing Countries: A Comprehensive Review



Adel Ali Saeed Al-Gheethi, Efaq Ali Noman,
Radin Maya Saphira Radin Mohamed, J. D. Bala
and Amir Hashim Mohd Kassim

Abstract Greywater is a type of wastewater generated from household activities which include bathing, laundry and kitchen activities. Greywater has a lower quality than potable water, but it is of higher quality than sewage. This article is a qualitative review presenting the quantities and qualitative characteristics of greywater in developed and developing countries. The chapter aims at highlighting the presence of nitrogen, phosphorus and pathogenic microorganisms. This paper provides a comprehensive review of greywater in order to understand the physiochemical and microbiological composition of greywater which represents the first step in choosing the most appropriate technology for the treatment process and to best evaluate the health risks associated with greywater discharge into the environment.

Keywords Chemical · Physical · Microbiological composition · Indicator bacteria

A. A. S. Al-Gheethi (✉) · R. M. S. Radin Mohamed (✉) · A. H. Mohd Kassim
Micro-Pollutant Research Centre (MPRC), Department of Water and Environmental Engineering,
Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia (UTHM),
86400 Parit Raja, Batu Pahat, Johor, Malaysia
e-mail: adel@uthm.edu.my

R. M. S. Radin Mohamed
e-mail: maya@uthm.edu.my

E. A. Noman
Faculty of Science, Technology and Human Developments, Universiti Tun Hussein Onn Malaysia
(UTHM), 86400 Parit Raja, Batu Pahat, Johor, Malaysia

J. D. Bala
Department of Microbiology, School of Life Sciences, Federal University of Technology, P.M.B
65, Minna, Niger State, Nigeria

1.1 Introduction

The rapid increase in the total population in developing countries and their activities alongside the deficiency in clean water resources as well as the absence of advanced technology required to produce high quality treated wastewater leads to an increase in the level of natural water contamination. This is due to the direct discharge of wastewater into water bodies. In most developed countries, black water and greywater are treated separately. In contrast, these practices are common in the rural areas in developing countries in order to reduce the quantity of sewage discharged into the individual septic tank (IST) due to the absence of a central wastewater treatment plant. Besides, these practices are common in arid and semi-arid areas because they use greywater for irrigation purposes.

Research studies in greywater treatment and the reuse or recycling of greywater have started early since the 1990s and have increased significantly after 2005 (Fig. 1.1).

A review of these publications revealed that most of the studies were performed in developed countries. In the period between 1990 and 2000, the publications addressed the characteristics of greywater from different sources. However, in the last few years, they have shifted to the treatment and reuse of greywater for the production of biomass as well as for irrigation purposes. Most papers published in the Middle East region were produced in Jordan which has the best practice in the field of wastewater treatment among the developing countries in the Middle East region, and they are also related to arid and semi-arid weather in Jordan. Therefore, the greywater in

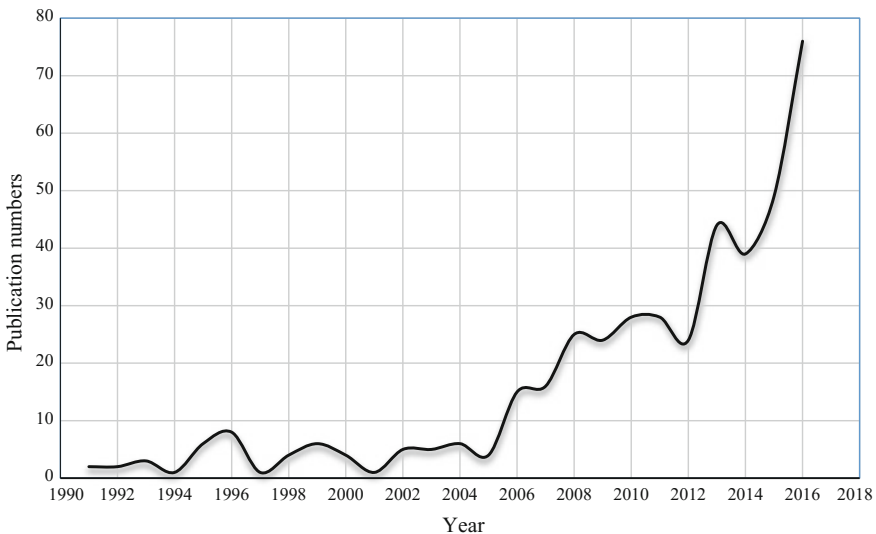


Fig. 1.1 Shows the distribution of 426 publications on greywater in the period between 1991 and 2016. The data were collected from Elsevier, Springer and Wiley publishers

Jordan represents an important alternative source of potable water. In Yemen, which has the least studies in the field of wastewater treatment, only three publications by Al-Mughalles et al. (2012) were found. In Malaysia, most papers on greywater were conducted by researchers working at the universities located in the suburban areas. Moreover, their work focused on the characteristics, treatment and reuse of greywater. The differences between developing countries in the Middle East in comparison to Malaysia are related to the presence of research facilities. There is some reliable information pertaining to the composition of greywater, treatment technologies as well as the potential to reuse and recycle greywater (Eriksson et al. 2002; Jefferson et al. 2004; Palmquist and Hanæus 2005). This gap offers researchers a greater opportunity to explore the qualitative characteristics of greywater which play an important role in the proper management of greywater to be used as an alternative source of fresh water. This chapter aims at viewing the physical, chemical as well as microbiological characteristics of greywater to provide a comprehensive idea of greywater composition.

1.2 Definition of Greywater

Greywater is a general term referring to different types of wastewater generated from household activities. Greywater is quite different from toilet wastewater which is known as black water. Greywater has a lower quality than potable water, but it is of higher quality than blackwater (Prathapar et al. 2005; Jamrah et al. 2006). The term of greywater refers to the colour change in water to grey during storage, but laundry greywater is grey even without the storage period. In some references, greywater is defined as light wastewater, diluted wastewater (Ledin et al. 2001) and reclaimed water (Gregory and Hansen 1996). Wilderer (2004) has classified the wastewater generated from houses into six categories including brown water (wastewater with faeces), yellow water (urine), blackwater (containing both urine and faeces), greywater (containing mainly detergents), green water (contains food particles) and storm water (rainwater). The main difference between black water and greywater is the high level of organic material, nutrients and infectious agents which are available in high concentrations in black water (Klammer 2013; Atiku et al. 2016), while they are lesser by 90% in greywater. In most definitions, kitchen and dishwasher wastewater are excluded from the category of greywater because it contains high levels of microbial loads which might be associated with high levels of organic matter resulting from grease, oil and detergents (Wurochekke et al. 2016). However, Al-Gheethi et al. (2016a, b) mentioned that those dishwasher, kitchen and restaurant wastewaters are closer to greywater than black water in terms of their characteristics. The source of microbial organisms in dishwasher, kitchen and restaurant wastewater might be caused by the washing of vegetables, fruits and meat. The microbial loads of these items are low but they may multiply in the kitchen greywater due to the presence of nutrients necessary for their growth (Friedler 2004). In contrast, the microbial loads in black water are very high even without the reproduction process. These differences

might explain the exclusion of kitchen and restaurant wastewater from the black water category. Nonetheless, more clarifications are needed to justify the classification of these wastes within the greywater definition. This is because the quality of wastewater generated from cooking and dishwashers (both in kitchen and restaurant shops) is also similar to wet market and meat processing wastewater in terms of microbial loads and organic content as well as its nutrient content. Indeed, the classification of wastewater from household activities makes the creation of a separate network transport system for each type more complicated especially in developing countries in which all household wastewater is discharged without separation. Therefore, in order to overcome the confusion between greywater from baths and wastewater from the kitchen, Bodnar et al. (2014) used the term 'light greywater' to represent greywater from baths and dark greywater generated by laundry and cooking. In a report published by Morel and Diener (2006), 12 out of 15 references included kitchen wastewater within the greywater definition. Hence, in this chapter, the concept of greywater will include all the wastewater from household activities except for black water.

1.3 Sources and Quantity of Greywater in Developing Countries

The main source of greywater comes from household activities, including baths, showers, laundry as well as dishwashing. The percentage of greywater generated from household activities represents 50–80% of the total water usage. So far, quantities of greywater depend on domestic water consumption. The data depicted in Fig. 1.2 show that the maximum water consumption is utilized for laundry and shower activities (33 and 23% respectively). The toilets consumed around 20% while dishwashing and cooking consumed 11% of the total water usage.

The percentage of greywater compared to black water in developing countries is more than that in developed countries. For instance, in the UK, the quantities of greywater and sewage produced are equal, while greywater represents 70–80% of total domestic wastewater in Jordan and Oman (Prathapar et al. 2005; Jamrah et al. 2008). In South Africa, greywater is ranging between 65 and 85% of the total household water consumption (Carden et al. 2007). These differences would be also explained based on lifestyle. This indicates that the greywater quantity does not vary greatly.

Al-Mughalles et al. (2012) mentioned that the utilization of Arabic toilets might be associated with high generation of greywater, while the utilization of Western toilets with a flushing system might lead to increased black water production. Indeed, the estimation of greywater quantities in developing countries especially those located in the Middle East region is difficult because in most of those countries, the greywater is discharged with the sewage. Therefore, accurate information about the percentage of greywater in black water is unavailable. However, a more acceptable reason to

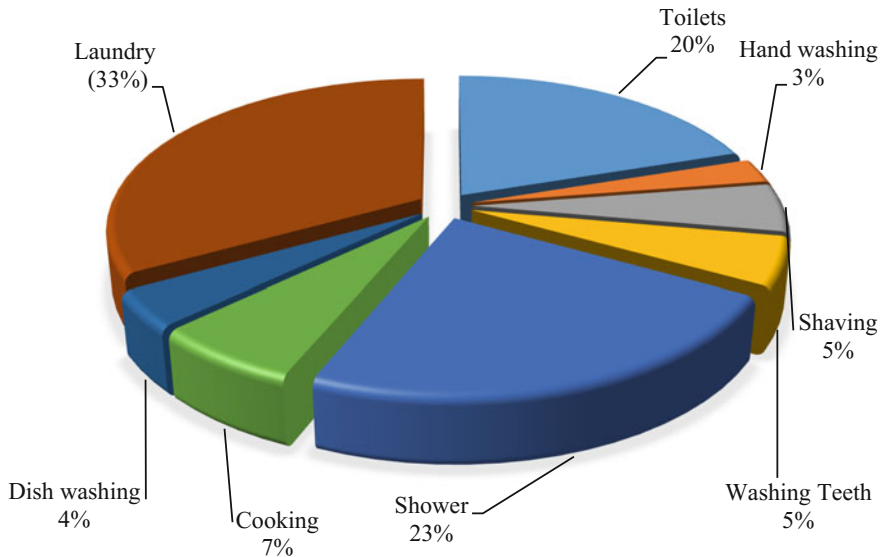


Fig. 1.2 Domestic water consumption per capita per day. (Adopted from Howard et al. 2003)

increase the percentage of greywater in Middle East countries is the ablution water which is generated from the ablution process and discharged along with greywater (Efaq et al. 2016; Mohamed et al. 2016a).

Greywater quantity depends on the number of household members, their age, nature of living, demographics and level of occupancy, geographical location, social habits and water usage pattern and time (Prathapar et al. 2005; Jamrah et al. 2008). Hence, the quantity of greywater produced differs in developed countries compared to developing countries (Fig. 1.3). Bodnar et al. (2014) also indicated that the amount of generated greywater in large cities (120–130 L/p/d) is higher than that in small villages (50–70 L/p/d).

Based on the quantities of greywater in different countries presented in Fig. 1.3, it can be noted that the quantities of greywater generated from household activities depend on the level of development in that particular country. The maximum quantity of greywater is recorded in the USA (281 L/p/d), while the lowest quantities were noted in South Africa (20 L/p/d).

The quantities of greywater in the countries which face a scarcity in freshwater resources such as Yemen (35 L/p/d), Syria (33.8 L/p/d) and Mali (30 L/p/d) are less compared to countries which have several water resources such as Malaysia (125 L/p/d). However, this situation depends on the level of the country's degree of economic development and the availability of facilities in the countries. For instance, in Jordan, the total amount of greywater generated from households is 50 L/p/d. In contrast, in Oman which is located in the same geographical area, the quantity of greywater generated is 184 L/p/d. This might be related to desalinated seawater.

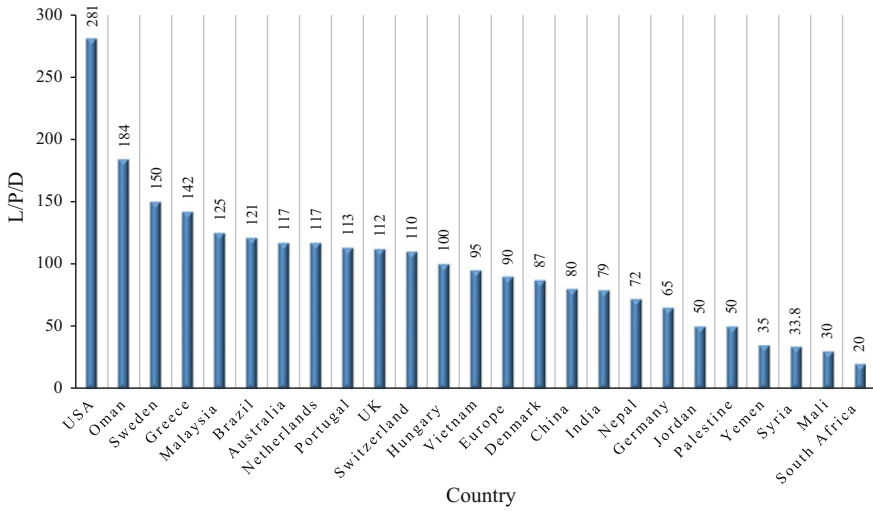


Fig. 1.3 Quantities of greywater (L/p/d) in selected countries. *Source* Faruqui and Al-Jayyousi (2002), Adendorff and Stimie (2005), Alderlieste and Langeveld (2005), Helvetas (2005), Busser et al. (2006), Jamrah et al. (2008); Mourad et al. (2011), Al-Mughalles et al. (2012), Harikumar and Mol (2012), Antonopoulou et al. (2013), Mohamed et al. (2013)

In Saudi Arabia, 15.1 billion cubic metres of desalinated seawater is provided per day (BCM) compared to 1.2 BCM per day of non-renewable groundwater resources (Al-Saud 2010). In Malaysia, greywater generated is estimated to be 100–150 L/p/d (Mohamed et al. 2016b). The common practices among the community might play an important role in the quantities of discharged greywater. Adendorff and Stimie (2005) stated that the low production of greywater in South Africa (20 L/p/d) is due to the lifestyle of the people who use rivers or lakes for washing clothes, utensils and to clean themselves. In comparison to developed countries, the average greywater volume is 113 L/p/d in Australia, 110 L/p/d in Switzerland (Helvetas 2005), 100 L/p/d in Hungary (Bodnar et al. 2014) and between 35 and 150 in Europe (Boyjoo et al. 2013).

The main resources for greywater include bathroom, laundry and kitchen. Greywater from baths constitutes the main percentage of the greywater. It has been reported that the greywater from bathrooms makes up 55% of the total greywater, followed by laundry wastewater (34%) and kitchen wastewater (11%) (Katukiza et al. 2015; Laghari et al. 2015). According to Mara and Cairncross (1989), bathroom greywater is the main greywater source with 54% of the total greywater generated by houses, while laundry greywater makes up 38% of the total greywater generated. In a study conducted by Ghaitidak and Yadav (2013), the percentages of bathroom, laundry and kitchen greywater were 47, 26 and 27% respectively. Mohamed et al. (2016b) revealed that the maximum generation of greywater in Malaysia was recorded from bathing activity, with an average of 50% of total greywater. It was due to frequent bathing among the occupants of more than three times daily. This is also related to

the hot and humid weather in Malaysia. The study also found that laundry greywater contributed 22% of the total greywater. In contrast, the kitchen greywater quantity represented 28% of total greywater. The quantity of greywater during weekends is higher than greywater produced during weekdays (Mohamed et al. 2016b). These differences are due to more household activities on weekends, especially cooking activities. On weekdays, most people have their meals at their workplace thus less kitchen grey water is produced in the absence of cooking.

1.4 Qualitative Characteristics of Household Greywater

1.4.1 General Composition

Greywater is mixed with soap, shampoo, toothpaste, food waste, cooking oil and detergent depending on the utilization of resources by each household (Mohamed et al. 2016b). The main composition for different types of greywater is presented in Table 1.1. The quality of greywater depends mainly on the health status and personal hygiene of the users (Jamrah et al. 2008; Laghari et al. 2015).

The main parameters of greywater include biochemical oxygen demand (BOD), chemical oxygen demand (COD), suspended solids, turbidity, total nitrogen (TN), total phosphorus (TP), pH, alkalinity, electrical conductivity, heavy metals, disinfectants, bleach, surfactants and detergents (Adendorff and Stimie 2005). The quality of organic matter in greywater is similar to that in domestic wastewater but differs in terms of concentration. Moreover, the utilization of low quantities of water for household activities is associated with heavy pollution while high quantities of greywater show that pollutants are subjected to dilution. Previous studies have revealed that the pollutant loads of greywater from developing countries are higher than that reported in developed countries (Carden et al. 2007). This might be explained based on the quantities of greywater in developed countries which are higher in comparison to that in developing countries. Thus, more dilution for pollutants takes place with

Table 1.1 Composition of household greywater from three main resources

Source of greywater	General composition
Bathing	Represents real greywater and contains soaps, toothpaste, shampoos, body care products, shaving waste, body fats, skin, hair, lint, urine and faeces (which are common if there are children in the house), hair dyes, toothpaste, bacteria
Laundry	Sodium, phosphorous, surfactants, nitrogen, foam, bleaches, suspended solids, oils and grease, paints, solvents, fibres, bacteria, viruses, lint
Cooking and dishwashing	Food residues, oil and fat, detergents, suspended solids, nutrients, salt, bacteria, foam

high quantities of greywater. In some developed countries, the term ‘diluted waste’ is used to represent greywater.

1.4.2 *Physical Characteristics*

The physical characteristics of greywater include temperature, colour, turbidity, suspended solids and total dissolved solids. These characteristics depend upon the greywater source. Some of the physical characteristics such as temperature and colour vary depending on the environmental climate and conditions. For instance, wastewater temperature in cold regions ranged from 7 to 18 °C, while in warmer regions it is between 13 and 24 °C. The variations in their values affect the wastewater composition due to their role in chemical and biological reactions. The variations in temperature are associated with the changes in pH, conductivity and saturation level of gases. Besides, the higher temperature of greywater might provide a suitable environmental condition for infectious agents which have a temperature between 20 and 40 °C (Eriksson et al. 2002; Al-Gheethi et al. 2013). Therefore, these parameters should also be considered for the assessment of the quality of greywater. The colour parameter is an indicator of the level of total suspended solids and dyes in wastewater Dubey et al. (2013). In fact, greywater parameters interact and the evaluation for each parameter separately does not reflect greywater quality and the expected effects on the environment as well as the selection of treatment technology. Besides, the composition of wastewater varies seasonally and geographically based on the local activities and total population in the specific area, as well as the presence or absence of the wastewater transport system.

The main physical parameters of greywater are presented in Table 1.2. It can be noted that greywater has a wide range of physical characteristics. Turbidity is a physical parameter which reflects the presence of suspended solids resulting from clothes washing and cleaning dirty floors and leads to cloudiness in greywater.

In contrast, the ‘total dissolved salts’ is a term used for the expression of total concentration of dissolved substances (organic and inorganic) in greywater. The turbidity and TSS are high in greywater generated from laundry and the kitchen due to the presence of solids, fabric softeners and laundry detergent residues. Jong et al. (2010) revealed that the turbidity in mixed greywater from washing, cooking, bathroom and shower ranged from 152 to 4400 NTU, this value is associated with high TSS ranging from 72.5 to 4250 mg L⁻¹. The authors also indicated that kitchen greywater has a high content of TDS ranging between 412.57 and 1232.14 mg L⁻¹ (Bodnar et al. 2014).

In a comparison between developed and developing countries, the concentrations of physical characteristics in greywater from developing countries are higher than those in developed countries with some exceptions. For example, TSS in greywater from the USA and the EU as well as Australia ranged from less than 10 to a maximum of 400 mg L⁻¹. These concentrations are also shown in greywater from India, Malaysia and Yemen, but it was more than 1500 mg L⁻¹ in Uganda, Jordan

Table 1.2 General characteristics of bathroom greywater and related sources

Sources	Country	TSS	TDS	Turbidity (NTU)	References
Bathroom and laundry	Greece	7–250	ND	ND	Fountoulakis et al. (2016)
Bathroom and laundry	Malaysia	23.87 ± 11.01	ND	50.83 ± 6.39	Mohamed et al. (2016b)
Bathroom	Malaysia	81	ND	ND	Teh et al. (2015)
Cleaning and sink activities	Jordan	16–59	280–350	73–173	Bani-Melhem et al. (2015)
Bathroom	Malaysia	78–163	ND	ND	Mohamed et al. (2014)
Shower/bathub, laundry and kitchen	Hungary	13.67–181.2	412.57–1232.14	25.45–357.39	Bodnar et al. (2014)
Mixed greywater	Uganda	2093–732, 828–735	ND	ND	Katukiza et al. (2014)
Bathroom	Nigeria	633.2	ND	ND	Nnaji et al. (2013)
Men hostel	India	564	ND	ND	Gokulan et al. (2013)
Showers and bathroom sinks	Spain		ND	50–158	Santasmassas et al. (2013)
Bathroom and laundry	Malaysia	88–110	ND	ND	Mohamed et al. (2013)
Bathroom	France	125	ND	ND	Chaillou et al. (2011)
Washing, kitchen, bathroom and shower	Korea	72.5–4250	ND	152–4400	Jong et al. (2010)

(continued)

Table 1.2 (continued)

Sources	Country	TSS	TDS	Turbidity (NTU)	References
Village houses	Jordan	23–358	ND	ND	Al-Hamaiedeh and Bino (2010)
Mixed greywater	Jordan	573–1679	ND	ND	Halalshah et al. (2008)
Showers and hand basins	Denmark	7–207	ND	ND	Eriksson et al. (2002)
Bathroom	Australia	48–120	ND	ND	Christova-Boal et al. (1996)
Domestic greywater	Australia	45–330	ND	22–200	Jeppersen and Solley (1994)
Shower/bathtub	Greece	63 ± 38	601 ± 152	ND	Antonopoulou et al. (2013)
Hand basin		61 ± 37	578 ± 193		
Kitchen sink		299 ± 324	595 ± 202		
Total greywater	Jordan	213–803	1113–2930	ND	Ammari et al. (2014)
Bathroom greywater	Malaysia	101.3–206	ND	70.7–160.3	Oh et al. (2016)
Total greywater	Canada	313–543	ND	ND	Finley et al. (2009)
Municipal greywater	Egypt	ND	313–597	ND	Abdel-Shafy et al. (2014)
Bath/shower	India	148	277	ND	Vakil et al. (2014)

(continued)

Table 1.2 (continued)

Sources	Country	TSS	TDS	Turbidity (NTU)	References
Washbasin		48	237	ND	
Kitchen		308	245	ND	
Laundry		1852	1060	ND	
Total greywater	India	13.3	7.5	161.3	Saunya et al. (2015)
Hostel greywater	India	ND	355 ± 33	143±54	Patil and Munavalli (2016)
Primary settling tank	Norway	155–160	ND	ND	Karabelnik et al. (2012)
Bathroom sinks	Brazil	40–105	ND	10.7–16.4	do Couto et al. (2013)
Kitchen sinks		67–208	ND	24.7–123.7	
Showers		64–143	ND	26.52	
Bathroom sinks	Bangladesh	74–84	432–532	74–102	Abedin and Rakib (2013)
Kitchen sinks		1253–2414	615–684	303–345	
Laundry		854–1160	832–1573	386–410	
Total greywater	Yemen	337.1–510.8	ND	266.24–618.60	Al-Mughalles et al. (2012)

ND (Non detected)

and Bangladesh (Al-Mughalles et al. 2012; Abedin and Rakib 2013; Katukiza et al. 2014). Similar trends were observed for turbidity and TDS but with little differences between the greywater in developed and developing countries. However, the data in Table 1.2 show that in some countries such as Korea, the turbidity ranges from 152 to 4400 NTU whereas in Yemen it was between 266.24 and 618.60 NTU (Jong et al. 2010; Al-Mughalles et al. 2012). Finally, it has to be mentioned that the physical properties of greywater might give a general idea of greywater while the real composition needs to be evaluated based on the chemical and microbiological characteristics.

1.4.3 Chemical Characteristics

The chemical characteristics of greywater are illustrated in Table 1.3. These parameters including pH, chemical oxygen demand (COD), biochemical oxygen demand (BOD), total nitrogen (TN) and total phosphate (TP) provide more details on the nature of these wastes in terms of organic and inorganic constituents. Greywater has a more alkaline pH value ranging from 5 to 11 compared to black water which has a pH between 6 and 7.7 (Schäfer et al. 2006). The data in Table 1.3 indicate that there is no clear correlation between pH values and the development level for greywater from different countries.

However, it was noted that the greywater in developed countries has a neutral pH whereas those from developing countries ranged from less than 6 as that reported in Bangladesh, Jordan, Egypt and Yemen (Abedin and Rakib 2013; Ammari et al. 2014; Abdel-Shafy et al. 2014) to more than pH 9 as reported in India (Vakil et al. 2014). Meanwhile, Fountoulakis et al. (2016) found that the pH value in greywater from Greece ranged from pH 6.4 to 10. Nonetheless, pH values in greywater depend on the source of greywater. For bathing and kitchen greywater, the pH value is on average 7, while those generated from laundry has a pH more than 9 due to the presence of high concentrations of surfactants/detergents (Bodnar et al. 2014).

COD parameter is one of the main chemical characteristics which reveals real organic pollutants in greywater (Jais et al. 2016). The concentration of COD depends on the chemical reaction level between organic substances in greywater. Therefore, the increasing levels of COD in greywater indicate active chemical reactions with high consumption of free oxygen available in water. In contrast, BOD is an indicator for the biological oxidation of organic compounds in the presence of molecular oxygen as an oxidizing agent to produce carbon dioxide and water. This process takes place in the microbial cells and uses dissolved oxygen available in water. High concentrations of BOD in greywater are an indirect indicator for high density of microorganisms.

From the concentrations of COD and BOD₅ in previous studies presented in Table 1.3, greywater appears to have higher COD than BOD. Therefore, the COD:BOD₅ ratio (4:1) of greywater is higher than that of sewage. This would be due to the high levels of xenobiotic organic compounds (XOC) in detergent

Table 1.3 Chemical characteristics of bathroom greywater and related sources

Sources	Country	pH	COD	BOD ₅	TN	TP	References
Bathroom and laundry	Greece	6.4–10	26–645	ND	3.6–21	0.1–1	Fountoulakis et al. (2016)
Bathroom	Malaysia	6.1	445	349	NR	NR	Teh et al. (2015)
Bathroom	Malaysia	6.1–6.4	445–621	40–105	NR	NR	Mohamed et al. (2014)
Bathroom	Nigeria	7.7	67.6	60.23	NR	NR	Nnaji et al. (2013)
Men hostel	India	7.48	986	279.6	NR	NR	Gokulan et al. (2013)
Bathroom and laundry	Malaysia	6.8–7.8	180–291	90–130	5.3–30	0.2–6.7	Mohamed et al. (2013)
Bathroom	France	7.6	399	240	3.8–17.0	0.1–2.0	Chaillou et al. (2011)
Mixed greywater	Jordan	6.9–7.8	92–2263	110–1240	38–61	NR	Al-Hamaideh and Bino (2010)
Showers and hand basins	Denmark	7.6–8.6	77–240	26–130	3.6–6.4	0.28–0.779	Eriksson et al. (2002)
Washing, kitchen, cooking, bathroom	Korea	7.02–7.86	119–3740	23.5–392.4	NR	NR	Jong et al. (2010)
Bathroom	Uganda	6–8	4699–8427	929–1861	NR	NR	Katukiza et al. (2014)
Bathroom sinks, baths and showers	UK	NR	33–138	8–34	NR	NR	Winward et al. (2008a, b, c)
Mixed greywater	Jordan	NR	92–668	NR	NR	NR	Bani-Melhem et al. (2015)

(continued)

Table 1.3 (continued)

Sources	Country	pH	COD	BOD ₅	TN	TP	References
Bathing greywater	Sweden	NR	NR	NR	3.72 ± 2.21	3.73 ± 2.65	Günther (2000)
Total greywater	Jordan	NR	NR	1056	75	19.5	Halalshieh et al. (2008)
Shower, laundry and washbasins	Jordan	NR	366 (165)	150 (31)	11.4–12.6	10.2–11.8	Abu Ghunmi et al. (2010)
Total greywater	Sweden	NR	350–500	495–682	8.0–11	4.6–11	Palmquist and Haneus (2005)
Shower, laundry and teeth-brushing	Australia	NR	225	76	0.3	40.8	Chin et al. (2009)
Shower/bath tub	Greece	NR	228–582	NR	8.4 ± 12.6	0.4 ± 0.6	Antonopoulou et al. (2013)
Hand basin		7.07 ± 0.25	335 ± 207	NR	2.6 ± 2.9	0.7 ± 0.9	
Kitchen sink		6.72 ± 0.40	775 ± 363	NR	4.0 ± 4.8	0.4 ± 0.4	
Total greywater	Jordan	5.44	816–2560	600–1710	54.30–155.03	5.20–9.14	Ammari et al. (2014)
Bathroom greywater	Malaysia	6.3–6.73	251–507.5	81–270.8	NR	NR	Oh et al. (2016)
Total greywater	Canada	6.7–7.6	278–435	NR	NR	NR	Finley et al. (2009)
Municipal greywater	Egypt	5.77–7.96	301–526	240–410	7.5–9.2	8.4–12.1	Abdel-Shafy et al. (2014)
Mixed greywater	South African	NR	280–310	NR	206 ± 5.8	40–69	Rodda et al. (2011)

(continued)

Table 1.3 (continued)

Sources	Country	pH	COD	BOD ₅	TN	TP	References
Bath/shower	India	NR	461	NR	2.1–2.6	0	Vakil et al. (2014)
Washbasin		7.5	225	43	1.6–2.5	0	
Kitchen		6.2	602	293	4.7–11.4	5.3	
Laundry		9.4	824	269	10.7–79	18	
Hostel greywater	India	7.36 ± 0.32	146–168	NR	12 ± 1.5	1.33 ± 0.15	Patil and Munavalli (2016)
Primary settling tank	Norway	6.6–7	640–750	NR	13–16.5	6.8–7.5	Karabelnik et al. (2012)
Bathroom sinks	Brazil	7–7.5	68.4–123.5	45.7–79.7	4.5–7.2	0.7–1.4	do Couto et al. (2013)
Kitchen sinks		6.2–7.4	228.3–912.2	95.2–613.0	8.5–12.4	0.8–8.4	
Showers		7.2–7.8	131–159.0	82.590.7	12.7–32.5	1.2–2.4	
Total greywater	Croatia	NR	433 ± 4	75.1 ± 4.1	NR	NR	Grčić et al. (2015)
Bathroom sinks	Bangladesh	NR	560–804	320–420	NR	NR	Abedin and Rakib (2013)
Kitchen sinks		5.4–6.1	1104–2510	560–600	NR	NR	
Laundry		7.3–7.4	1056–1599	25–110	NR	NR	
Total greywater	Yemen	6 ± 0.35	1200–2000	186–518	7.84–11.28	16.10–29.5	Al-Mughalles et al. (2012)

NR (non-reported)

products used in the shower, washing process and dishwashing as well as the absence of organic matter in greywater generated from shower and laundry and the low concentrations of macro-nutrients such as nitrogen and phosphorus in greywater compared to sewage (Jefferson et al. 1999). Greywater has 90% less nitrogen than that available in sewage due to the absence of urine and faeces as well as toilet paper which leads to an increase in organic content (Al-Gheethi et al. 2016a, b). The high ratio in COD/BOD₅ indicates the presence of high concentrations of non-biodegradable compounds in greywater.

The difference in the type of detergents used for each process might have a significant effect on the concentrations of COD. The results in Table 1.3 indicate that the COD concentrations varied based on the source of greywater. Abedin and Rakib (2013) revealed that the greywater from kitchens has more COD than that from laundry (1104–2510 vs. 1056–1599 mg L⁻¹, respectively). However, Vakil et al. (2014) found that the COD in greywater from laundry was higher than that of kitchen greywater (824 vs. 602 mg L⁻¹). Moreover, COD in greywater from baths is less than that in laundry and kitchen greywater. So far, the reports in literature revealed that the concentrations of BOD₅ in kitchen greywater are more than that in bathing and laundry greywater due to high organic content.

The nutrients in greywater refer to total nitrogen and total phosphorous. Nitrogen in greywater is usually present in organic forms such as ammonia (NH₄⁺, NH₃⁻N) and inorganic forms such as nitrate (NO₃⁻) and nitrite (NO₂⁻). Some studies in the literature indicated that ammonium represents the main source of nitrogen more than nitrate and nitrite. Orthophosphate (PO₄³⁻) is a common form of TP in greywater which results from the utilization of detergent builders and hygiene products (Eriksson et al. 2002).

Both TN and TP are usually determined by the authors, since they reflect the quantity of nutrients. The concentrations of TN and TP in greywater depend on the source. Many authors indicated that TN and TP are high in kitchen greywater while they are present in low concentrations in shower and laundry greywater due to the absence of organic matter. However, detectable concentrations of TN and TP in shower and laundry greywater have been revealed. Vakil et al. (2014) found that the laundry greywater in India contained between 10.7 and 79 mg L⁻¹ of TN compared to 4.7–11.4 mg L⁻¹ in kitchen greywater. This might be due to the presence of urine which comes from houses with children. Another source of ammonium nitrogen in greywater is the cationic surfactants of fabric softeners and laundry disinfectant agents.

Based on the data presented in Table 1.3, it can be noted that the TN concentrations in most reported studies are more than TP, except for some studies which indicated that the TP was more than TN. For example, Al-Mughalles et al. (2012) found that the TP concentrations in greywater from Yemen were higher than that of TN. A similar result has been reported in a previous study conducted in Australia, where the TN was 0.3 mg L⁻¹ while the TP was 40.8 mg L⁻¹ (Chin et al. 2009).

In a review of chemical parameters of greywater from developed and developing countries (Table 1.3), the results revealed that the greywater from developing countries has high concentrations of COD and BOD₅ in comparison to that of developed countries. For instance, the COD in greywater generated from household activities in Yemen ranged from 1200 to 2000 mg L⁻¹. In Uganda, it was between 4699 and 8427 mg L⁻¹, in Jordan, it was on average 16.88 mg L⁻¹ and in Malaysia, the COD was between 180 and 621 mg L⁻¹ (Al-Mughalles et al. 2012; Ammari et al. 2014; Katukiza et al. 2014; Mohamed et al. 2013, 2014). In contrast, the average COD was 399 mg L⁻¹ in France (Chaillou et al. 2011). In Denmark, the COD ranged from 77 to 240 mg L⁻¹ (Eriksson et al. 2002). Similar results were reported for BOD₅, among different countries. The maximum concentration was noted in greywater from Jordan (600–1710 mg L⁻¹) and Uganda (929–1861 mg L⁻¹) (Ammari et al. 2014; Katukiza et al. 2014). The maximum concentration of BOD₅ of the greywater from developed countries was recorded in Sweden (495–682 mg L⁻¹) (Palmquist and Hanæus 2005).

Little information is available about the concentrations of TN and TP as most studies focus on main parameters which include COD, BOD and pH. The results presented in Table 1.3 from different studies indicate the absence of an association between TN and TP concentrations and development levels for the country. Moreover, the highest concentrations of TN were noted in greywater from Jordan (54.30–155.03 mg L⁻¹) while the lowest concentration was reported in Egypt (7.5–9.2 mg L⁻¹) and Yemen (7.84–11.28 mg L⁻¹) (Al-Mughalles et al. 2012; Abdel-Shafy et al. 2014). However, these differences were not related to the development level of the countries, Jordan, Egypt and Yemen are developing countries and located in the same geographical area. So far, the studies conducted in Jordan which are presented in Table 1.3 indicate that the TN of different types of greywater is high. This might be due to the low quantities of greywater generated compared to the quantities in other countries. The high amount of water usage might lead to the dilution of the main parameters of greywater. A similar observation was also noted for TP where the maximum concentration was recorded in greywater from South Africa (40–69 mg L⁻¹) (Rodda et al. 2011), while the minimum concentration was noted in Greece (0.1–1 mg L⁻¹). This may be due to limited use of phosphorus-containing detergents in baths and washing machines (Fountoulakis et al. 2016).

Based on the above discussion, it can be concluded that the main parameters of greywater vary in their concentrations. These findings were also noted by previous studies which indicated that greywater has a wide range in the most common constituents compared to wastewater. Moreover, the differences in the characteristics of greywater among developed and developing countries might be related to the differences in tap water quality and experimental protocols used for greywater sampling as well as the small sample size in terms of participants surveyed (Eriksson et al. 2002).

1.4.3.1 Heavy Metals

Heavy metals is a term which refers to a wide range of elements in the periodic table. These metals are classified into groups based on toxicity and biological roles. Some heavy metals such as Cu, Zn and Ni play an important role as cofactors at low concentrations for biological reactions during the metabolic and anabolic pathways of cells. These metals are called trace elements or microelements, but a high concentration of these metals is toxic to the cells. In contrast, other metals such as Pb, Cd, Hg, Ag, Cd and Co are toxic even at low concentrations and have no function in biological processes. Heavy metals in greywater originate mainly from the detergents and chemical products used for bathing and clothes washing as well as dishwashing (Leal et al. 2007).

Others metals including Na, K, Ca and Mg which have no toxicity are called macro-elements (Lim et al. 2010). However, the main concern with heavy metal lies in their accumulation in the plant tissue and their transmission into humans and animals since heavy metals are non-biodegradable. Hence, their accumulation in the organs can cause several diseases in high doses (Epstein, 2002; Banana et al. 2016). The list of the most common metals in greywater is presented in Table 1.4. These heavy metals are present in concentrations less than the standard, while macro-elements are available in greywater in high concentrations.

Palmquist and Hanæus (2005) detected 22 metals ions in the greywater generated from ordinary Swedish households including Al, Ba, Bi, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, Pt, S, Sb, Sn, Te and Zn.

1.4.4 Microbiological Characteristics

Authors assume that greywater is free from harmful bacteria due to the absence of solid faeces (Finley et al. 2009). Many infectious agents in greywater have been reported in literature. Among them, *Staphylococcus aureus* and *Pseudomonas aeruginosa*, total coliforms (TC), faecal coliforms (FC), *Escherichia coli*, Enterococci, *Klebsiella pneumoniae* and *Salmonella* spp. as well as *Cryptosporidium parvum* and *Giardia lamblia* (Rangel-Martínez et al. 2015; Al-Gheethi et al. 2016a). Total coliform (TC) is a bacterial group which includes four genera which are *Citrobacter* sp. *Enterobacter* sp. *Escherichia* sp. and *Klebsiella* sp. These genera are Gram-negative bacteria with rod shapes and have the ability to ferment lactose and produce gas at 37 °C within 24–48 h. Faecal coliform is a subgroup of TC and includes *E. coli* and some strains of *K. pneumonia* which have the ability to ferment lactose and produce gas at 44.5 °C within 24 h.

The diversity of infectious agents in greywater depends on public health and the number of occupants in a house. These variations occur not only geographically but also seasonally on the same site. In houses with a high number of occupants, high concentrations and a diversity of microbial species are present with low levels of infectious agents even in the presence of some infected residents. In contrast, in

Table 1.4 Elements found in greywater and related sources

References	Elements concentrations (mg L ⁻¹)										
	Al	As	B	Ba	Ca	Cd	Cl	Cr	Cu		
Matos et al. (2014)	5.8–5.1	0.01	0.2	0.02	9.0–12.0	0.07	72.0–83.0	0.1	0.16		
Leal et al. (2007)	0.49–7.35		0.42–0.87		60.79–65.53				0.08–0.12		
Palmquist and Haneus (2005)	1.48 3.39			0.02	31–38	0.00006 0.0002		0.002–0.005	0.047 0.07		
Eriksson and Donner (2009)						0.0001–0.0002					
Eriksson et al. (2002)						0.52–0.63					
Surendran and Wheatley (1998)						0.056–2.5					
Jefferson et al. (2000)	0.003				47.9				0.006		
Ammari et al. (2014)					52–80		126–216				
Turner et al. (2016)	0.05–1.5	0.0001–0.012	0.005–0.52			0.0002–0.002		0.0003–0.003	0.008–0.390		
Finley et al. (2009)					30–44						
Rodda et al. (2011)									0.1 ± 0.1		
Saunya et al. (2015)					4.654						

(continued)

Table 1.4 (continued)

References	Elements concentrations (mg L ⁻¹)										
	Fe	K	Mg	Mn	Na	Ni	Pb	Hg	Zn		
Matos et al. (2014)	0.48-0.63		6.0-7.0	0.1	170-200	0.1	0.1				0.11-0.1
Leal et al. (2007)	0.11-1.28		6.15-30.55		86.35-159.75						
Palmquist and Hanaeus (2005)	0.18-0.57	7.69-8.85	5.30-6.22	0.01-0.14	61.4-92.4	0.04-0.03	0.002-0.003	0.00002			0.06-0.08
Eriksson and Donner (2009)						0.005, 1-0.027	0.0049-0.010	0.0006-0.036			
Eriksson et al. (2002)						<25	3-5	0.29			
Surendran and Wheatley (1998)						1.3-28	0.61-6.9	0.022-0.26			
Jefferson et al. (2000)	0.017	5.79	5.29	0.04							0.03
Ammari et al. (2014)			14.3-64.4								
Turner et al. (2016)	0.002-0.56			0.002-0.06		0.0003-0.01	0.0002-0.01				0.017-0.31
Finley et al. (2009)	0.09	2.2-2.5	8.0-9.9		20-27						0.04-0.42
Rodda et al. (2011)		31 ± 2.7	7.5 ± 1.7		188 ± 27						0.24 ± 0.4
Saunya et al. (2015)	0.203	3.286	25.23		3.768		1.72				

Other elements reported in literature include Ag, Sn, Sb, Co and Bi

houses with few occupants, the concentration and diversity of microorganisms may be low but the percentage of infectious agents might be high if some members are infected.

Pathogen diversity in greywater depends on the source of waste. A high concentration of microorganisms in greywater is related to the presence of nutrients. Suspended and dissolved solids provide a suitable medium for microbial growth in greywater. For example, kitchen sink and dishwasher greywater are often highly contaminated due to the presence of food and grease particles. Showers, hand basins and washing machines might also be a source for pathogenic bacteria in greywater. However, pathogenic microorganisms in the greywater from showers are different from that of kitchen greywater. Moreover, the main hazard of greywater is associated with faecal contamination which comes from contaminated faecal washing clothes, child care and washing raw meats. Marjoram (2014) revealed that the TC and FC are high in bathroom and laundry greywater in houses with children. The greywater generated from the houses with children are associated with high concentrations of FC. This is because faeces and urine represent the main source for FC. The pathogenic bacteria diversity with their concentration in greywater from developed and developing countries can be found in Table 1.5. The most common pathogenic bacteria in greywater include *E. coli*, Enterococci, *P. aeruginosa*, *S. aureus*, *K. pneumoniae*, *C. perfringens* and *Salmonella* spp. The researchers in developed and developing countries are looking for different bacterial species. However, TC and FC can be detected by all of them. Furthermore, in developed countries such as the UK, Sweden and Israel, researchers focus on the detection of *P. aeruginosa*, *S. aureus* and *C. perfringens* while they focus only on TC and FC in developing countries. This would be due to the absence of advanced technologies in developing countries which is required to isolate and identify pathogenic bacteria.

The most common pathogenic bacteria in the greywater generated from bathing and laundry are *P. aeruginosa* and *S. aureus* because these bacteria are part of the normal flora which colonizes the body surface as well as the mouth, nose and ears. In contrast, the content of *Salmonella* spp. and *Campylobacter* spp. might be high in kitchen greywater. Moreover, inclusion of bathing and laundry greywater with kitchen greywater might improve the bacterial multiplication and growth due to the presence of high nutrient content (Rose et al. 2002; Ottoson and Stenström 2003; Al-Gheethi et al. 2016a). The pathogenic bacteria in greywater are available in very low concentrations. Therefore, the presence or absence of specific bacteria in greywater would depend on the quantity and number of greywater samples analysed as well as the efficiency of the analysis technique. Hence, in many countries, the evaluation of microbiological quality for greywater depends mainly on the concept of indicator bacteria (Sect. 1.4.4.1).

Besides the most common pathogenic bacteria illustrated in Table 1.5, there are other species found in greywater as reported in the literature including *Aeromonas* spp. (Albrechtsen 2002), *Legionella pneumophila* (Birks et al. 2004), *Mycobacterium* spp. (Albrechtsen 2002) and *Campylobacter* sp. (Albrechtsen 2002). These pathogens were also listed by a study conducted by Winward (2007). Ukwubile

Table 1.5 Concentration of pathogenic bacteria in greywater

Country	Concentration of bacteria (cell 100 mL ⁻¹)										References
	TC	FC	<i>E. coli</i>	Enterococci	<i>P. aeruginosa</i>	<i>S. aureus</i>	<i>K. pneumoniae</i>	<i>C. perfringens</i>	<i>Salmonella</i> spp.		
USA	8.03×10^7	5.63×10^5		2.38×10^2	1.99×10^4					Casanova et al. (2001)	
UK	5.4×10^5		2.8×10^2	2.8×10^2	4.4×10^4	3.4×10^3				Winward et al. (2008c)	
Uganda	8.72×10^7		3.7×10^6					2.73×10^4		Katakiza et al. (2014)	
Jordan	3.1×10^5	4.4×10^5								Bani-Melhem et al. (2015)	
Israel			1.4×10^5		7.9×10^2	5×10^3				Maimon et al. (2014)	
Portugal	$4.8-13 \times 10^7$	$3.7-43 \times 10^4$								Matos et al. (2014)	
UK					4.4×10^4	3.37×10^3				Winward et al. (2008c)	
Jordan	1×10^7	3×10^5	2×10^5							Halalshah et al. (2008)	
Jordan	7.1×10^7 to 1.27×10^8		$1.4-1.9 \times 10^6$							Ghummi et al. (2010)	
Israel			$4.1-6.3 \times 10^3$		9.4×10^1 to 3.1×10^4	1.2×10^2 to 4.1×10^5	4.1×10^2			Benami et al. (2016)	

(continued)

Table 1.5 (continued)

Country	Concentration of bacteria (cell 100 mL ⁻¹)										References
	TC	FC	<i>E. coli</i>	Enterococci	<i>P. aeruginosa</i>	<i>S. aureus</i>	<i>K. pneumoniae</i>	<i>C. perfringens</i>	<i>Salmonella</i> spp.		
Jordan	6.2×10^4 – 3.89×10^6		3×10^4 to 4.1×10^5								Ammari et al. (2014)
Malaysia	8.5 – 53.2×10^4		2.5×10^4 to 6.1×10^5								Oh et al. (2016)
Canada	4.7×10^4 to 8.3×10^5			110 – 3.8×10^5							Finley et al. (2009)
Sweden	5.5×10^5 to 8.7×10^8		4.3×10^4 to 6.8×10^6	3×10^3 to 5.1×10^5			2.3×10^2 to 4.8×10^4				Ottoson and Stenström (2003)
Israel		3.8×10^4			3.3×10^3						Gilboa and Friedler (2008)
Bangladesh		7.33×10^2 to 22.6×10^4									Abedin and Rakib(2013)
Yemen		18.5 – 19×10^6									Al-Mughalles et al. (2012)

(2014) revealed the presence of *S. typhi*, *Vibrio cholera*, *E. coli*, *C. jejuni*, *S. aureus* and *Shigella dysenteriae* in greywater in Nigeria.

On the other hand, the most common parasites reported in greywater include *Cryptosporidium* sp. and *Giardia* sp. with more than 10^7 cell/100 L (Birks et al. 2004; Birks and Hills 2007). Parasites in greywater might be transmitted from faeces and urine but they can also be present in kitchen greywater which are transmitted from vegetables and fruits irrigated with contaminated water since both *Cryptosporidium* sp. and *Giardia* sp. have high potential to form cysts which have a long period of survival in the environment.

1.4.4.1 Indicator Bacteria

Indicator bacteria are a bacterial group or species used as a model to indicate the presence or absence of pathogens in greywater. The indicator bacteria concept has become more popular since 1870 because the direct detection of different types of pathogenic bacteria, viruses, cysts of protozoan parasites and helminths in greywater is an unpredictable and time-consuming procedure.

The indicator bacteria are present in a concentration higher than that of pathogens. The data presented in Table 1.5 show that the concentrations of TC ranged from 10^5 to 10^6 cell 100 mL⁻¹, FC ranged between 10^4 and 10^6 cell 100 mL⁻¹, *E. coli* was present between 10^2 and 10^6 cell 100 mL⁻¹ and Enterococci ranged between 10^2 and 10^5 cells 100 mL⁻¹. In contrast, *P. aeruginosa* was between 10^1 and 10^4 cell 100 mL⁻¹, *S. aureus* was present ranging between 10^2 and 10^3 cell 100 mL⁻¹, *Salmonella* spp. and *C. perfringens* were on average 10^3 cell 100 mL⁻¹.

There are several bacterial species suggested as an indicator of the presence of pathogens. Nevertheless, the historical and traditional indicator bacteria are TC and FC, since they exhibited correlation with pathogens such as viruses and parasites. Moreover, some recent studies indicated the absence of correlation between TC, FC and *E. coli*, and some pathogens such as *Salmonella* spp. and *Campylobacter* spp. (Polo et al. 1999; Hörman et al. 2004). Besides, the main criteria for indicator bacteria are that they should not increase and multiply in the environment but Byapanahalli and Fujioka (1998) revealed that FC and *E. coli* have grown in tropical soil environments. Therefore, researchers are looking for alternative indicators with more correlation to the pathogens and at the same time possess resistance towards environmental conditions without growth. In biosolids and sewage effluents, FC and *E. coli* are preferred as indicators because these wastes contain faeces and urine which represent the main source of coliform bacteria. In contrast, in medical waste, *P. aeruginosa* and *S. aureus* were suggested by STAATT (2005) as indicators because these bacteria are opportunistic organisms and thus are associated with clinical waste. *S. aureus* was proposed as an indicator of hospital hygiene for microbiological standards (Dancer 2004). Jin et al. (2012) used *S. aureus* as an indicator to evaluate the hydrothermal treatment process to achieve hygienic safety for food waste. Celico et al. (2004) claimed that Enterococci is a more reliable indicator than TC and FC

because they have high potential to survive in the environment in comparison to FC. Enterococci are used frequently as a reference microorganism for pasteurized foods.

The selection of the indicator depends on the type of the waste as it has to reflect the real microbial diversity and loads of the waste (Al-Gheethi et al. 2016b). Therefore, with reference to the microbial diversity in greywater revealed by previous studies, it can be noticed that they include TC, FC, *E. coli*, Enterococci, *P. aeruginosa*, *S. aureus*, *K. pneumoniae*, *C. perfringens* and *Salmonella* spp. Among these organisms, TC, FC, *E. coli* and *K. Pneumoniae* as well as Enterococci originated from greywater with faecal contamination with some exception for *K. pneumoniae* as well as Enterococci which have non-faecal sources. *K. pneumoniae* was the first indicator bacteria suggested by Von Fritsch (Geldreich 1978). However, further research studies indicated that this bacteria has low correlation with pathogenic bacteria compared to *E. coli* (Al-Gheethi et al. 2013). FC and especially *E. coli* may be used as indicators but it failed to reflect the actual load of pathogens due to the absence of faecal source in many types of greywater such as kitchen and sink greywater. *Salmonella* spp. was suggested in some references as an indicator for the evaluation of the treatment process of biosolids since it is typically present in higher densities than other bacterial pathogens and has the ability to survive for a long time in the environment (USEPA 2003). So far, *Salmonella* spp. might be not suitable as an indicator for greywater because it might be present in kitchen greywater resulting from the washing of vegetables and chicken meat, but not from showers and laundry greywater. *C. perfringens* was also suggested in the literature as an indicator for wastewater (Rouch et al. 2011). However, other authors stated that the hardy spores of this bacterium make it too resistant to be useful as an indicator organism (Vierheilg et al. 2013). Besides, some pathogenic bacteria such as *Salmonella* spp. and *C. perfringens* have been suggested as indicators which have a narrow range to represent the total microbial load in greywater. These bacterial species might be more suitable as models to determine the effectiveness of the treatment process of wastewater but are not to be used as indicators to evaluate the microbiological characteristics of different types of wastewater including greywater.

Based on previous studies conducted on the microbiological characteristics of greywater especially that related to microbial loads, *S. aureus* and *P. aeruginosa* might be considered as an indicator for the pathogenic bacteria in greywater due to its importance as an opportunistic pathogen. Besides, these bacteria were reported in different types of greywater such as those generated from showers, laundry and kitchen activities. Both bacterial species are not related to faecal contamination but they can be used as indicators for pathogenic bacteria regardless of its sources. *P. aeruginosa* was suggested for the first time as an indicator in freshwater streams by Wheater et al. (1980). Before, Kenner and Clark (1974) revealed that *P. aeruginosa* has better potential as an indicator than FC in bathing and recreational water. These suggestions are in agreement with the study performed by Warrington (2001), in which *P. aeruginosa* exhibited more efficiency than *E. coli* as an indicator for marine water. Moreover, recently, *P. aeruginosa* was proposed as a new indicator for determining the microbiological quality of sewage effluent (Coronel-Olivares et al. 2011). The authors in literature have revealed that *P. aeruginosa* and *S. aureus* were

isolated from wastewater in which *E. coli* was less than the detection limit (Garland et al. 2000; Gross et al. 2007a, b).

1.5 Conclusions

This qualitative review has attempted to give a comprehensive idea about the quantities and qualitative characteristics of greywater in developed and developing countries so that the reader can get an idea of the characteristics of these wastes and the differences in their composition based on the source of generation. Therefore, this aspect needs to be investigated further in order to facilitate the selection of treatment processes and best understand their adverse effects on the environment. Moreover, greywater with a high content of nutrients and pathogenic organisms need to be disposed with care or reused for irrigation purposes which is the common practice in the developing countries.

Acknowledgements The authors wish to thank the Ministry of Higher Education (MOHE) for supporting this research under FRGS vot 1574 and also the Research Management Centre (RMC) UTHM for providing grant IGSP U682 for this research.

References

- Abdel-Shafy HI, Al-Sulaiman AM, Mansour MS (2014) Greywater treatment via hybrid integrated systems for unrestricted reuse in Egypt. *J Water Process Eng* 1:101–107
- Abedin SB, Rakib ZB (2013) Generation and quality analysis of greywater at Dhaka City. *Environ Res Eng Manage* 64(2):29–41
- Adendorff J, Stimie C (2005) Food from used water-making the previously impossible happen. *The Water Wheel*. South African Water Research Commission (WRC), pp 26–29
- Albrechtsen HJ (2002) Microbiological investigations of rainwater and graywater collected for toilet flushing. *Water Sci Technol* 46(6–7):311–316
- Alderlieste MC, Langeveld JG (2005) Wastewater planning in; Djenné, Mali. A pilot project for the local infiltration of domestic wastewater. *Water Sci Technol* 51(2):57–64
- Al-Gheethi AA, Ismail N, Lalung J, Talib A, Kadir MOA (2013) Reduction of faecal indicators and elimination of pathogens from sewage treated effluents by heat treatment. *Caspian J App Sci Res* 2(2)
- Al-Gheethi AA, Mohamed RM, Efaq AN, Hashim MA (2016a) Reduction of microbial risk associated with greywater by disinfection processes for irrigation. *J Water Health* 14(3):379–398
- Al-Gheethi AA, Mohamed RMS, Efaq AN, Norli I, Hashim MA, Ab Kadir MO (2016b) Bioaugmentation process of sewage effluents for the reduction of pathogens, heavy metals and antibiotics. *J Water Health* 14(5):780–795
- Al-Hamaiedeh H, Bino M (2010) Effect of treated grey water reuse in irrigation on soil and plants. *Desalination* 256(1):115–119
- Al-Mughalles MH, Rahman RA, Suja FB, Mahmud M, Jalil NA (2012) Household greywater quantity and quality in Sana'a, Yemen. *EJGE* 17:1025–1034
- Al-Saud M (2010) Water sector of Saudi Arabia. *The 2nd Japan-Arab Economic Forum*, Tunisia

- Ammari TG, Al-Zubi Y, Al-Balawneh A, Tahhan R, Al-Dabbas M, Ta'any RA, Abu-Harb R (2014) An evaluation of the re-circulated vertical flow bioreactor to recycle rural greywater for irrigation under arid Mediterranean bioclimate. *Ecol Eng* 70:16–24
- Antonopoulou G, Kirkou A, Stasinakis AS (2013) Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. *Sci Total Environ* 454:426–432
- Atiku A, Mohamed RMSR, Al-Gheethi AA, Wurochekke AA, Kassim AH (2016) Harvesting microalgae biomass from the phycoremediation process of greywater. *Environ Sci Pollut Res* 23(24):24624–24641
- Banana AS, Radin Maya Saphira RM, Al-Gheethi AA (2016) Mercury pollution for marine environment at Farwa Island, Libya. *J Environ Health Sci Eng* 14:5
- Bani-Melhem K, Al-Qodah Z, Al-Shannag M, Qasaimeh A, Qtaishat M, Alkasrawi M (2015) On the performance of real grey water treatment using a submerged membrane bioreactor system. *J Membrane Sci* 476:40–49
- Benami M, Busgang A, Gillor O, Gross A (2016) Quantification and risks associated with bacterial aerosols near domestic greywater-treatment systems. *Sci The Total Environ* 562:344–352
- Birks R, Hills S (2007) Characterization of indicator organisms and pathogens in domestic greywater for recycling. *Environ Monit Assess* 129(1–3):61–69
- Birks R, Colbourne J, Hills S, Hobson R (2004) Microbiological water quality in a large in-building, water recycling facility. *Water Sci Technol* 50(2):165–172
- Bodnar I, Szabolcsik A, Baranyai E, Uveges A, Boros N (2014) Qualitative characterization of household greywater in the northern great plain region of Hungary. *Environ Eng Manage J* 13(11):2717–2724
- Boyjoo Y, Pareek VK, Ang M (2013) A review of greywater characteristics and treatment processes. *Water Sci Technol* 67(7):1403–1424
- Busser S, Nga PT, Morel A, Anh NV (2006) Characteristic and quantities of domestic wastewater in urban and peri-urban households in Hanoi. In: Proceedings of the environmental science and technology for sustainability of Asia, The 6th general seminar of the core university program, Kumamoto
- Byappanahalli MN, Fujioka RS (1998) Evidence that tropical soil environment can support the growth of *Escherichia coli*. *Water Sci Technol* 38(12):171–174
- Carden K, Armitage N, Sichone O, Winter K (2007) The use and disposal of greywater in the non-sewered areas of South Africa. WRC Report No. 1524/1/07, Water Research Commission, Pretoria, South Africa
- Casanova LM, Gerba CP, Karpiscak M (2001) Chemical and microbial characterization of household greywater. *J Environ Sci Health, Part A* 36(4):395–401
- Celico F, Varcamonti M, Guida M, Naclerio G (2004) Influence of precipitation and soil on transport of fecal enterococci in fractured limestone aquifers. *Appl Environ Microbiol* 70(5):2843–2847
- Chaillou K, Gérente C, Andrès Y, Wolbert D (2011) Bathroom greywater characterization and potential treatments for reuse. *Water Air Soil Pollut* 215(1–4):31–42
- Chin WH, Roddick FA, Harris JL (2009) Greywater treatment by UVC/H₂O₂. *Water Res* 43(16):3940–3947
- Christova-Boal D, Eden RE, McFarlane S (1996) An investigation into greywater reuse for urban residential properties. *Desalination* 106(1):391–397
- Coronel-Olivares C, Reyes-Gómez LM, Hernández-Muñoz A, Martínez-Falcón AP, Vázquez-Rodríguez G, Iturbe U (2011) Chlorine disinfection of *Pseudomonas aeruginosa*, total coliforms, *Escherichia coli* and *Enterococcus faecalis*: revisiting reclaimed water regulations. *Water Sci Technol* 64(11):2151–2157
- Dancer SJ (2004) How do we assess hospital cleaning? A proposal for microbiological standards for surface hygiene in hospitals. *J Hosp Infect* 56(1):10–15
- do Couto EDA, Calijuri ML, Assemany PP, da Fonseca Santiago A, de Castro Carvalho I (2013) Greywater production in airports: qualitative and quantitative assessment. *Res Conserv Recycl* 77:44–51

- Dubey A, Goyal D, Mishra A (2013) Zeolites in wastewater treatment. *Green Mater Sustain Water Rem Treat* 23:82
- Efaq AN, Saeed AA, Mohamed RMSR (2016) Current status of greywater in Middle East countries, a glance at the world. *Waste Manage* 49:1–5
- Epstein E (2002) Land application of sewage sludge and biosolids. CRC Press
- Eriksson E, Donner E (2009) Metals in greywater: sources, presence and removal efficiencies. *Des* 248(1):271–278
- Eriksson E, Auffarth K, Henze M, Ledin A (2002) Characteristics of grey wastewater. *Urban Water* 4:85–104
- Faruqui N, Al-Jayyousi O (2002) Greywater reuse in urban agriculture for poverty alleviation: a case study in Jordan. *Water Int* 27(3):387–394
- Finley S, Barrington S, Lyew D (2009) Reuse of domestic greywater for the irrigation of food crops. *Water Air Soil Pollut* 199(1–4):235–245
- Fountoulakis MS, Markakis N, Petousi I, Manios T (2016) Single house on-site grey water treatment using a submerged membrane bioreactor for toilet flushing. *Sci Total Environ* 551:706–711
- Friedler E (2004) Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. *Environ Technol* 25(9):997–1008
- Garland JL, Levine LH, Yorio NC, Adams JL, Cook KL (2000) Greywater processing in recirculating hydroponic systems: phytotoxicity, surfactant degradation, and bacterial dynamics. *Water Res* 34(12):3075–3086
- Geldreich EE (1978) Bacterial populations and indicator concepts in feces, sewage, stormwater and solid wastes. Galveston Bay Bibliography, GBIC Materials Available at Jack K. Williams Library
- Ghaitidak DM, Yadav KD (2013) Characteristics and treatment of greywater—a review. *Environ Sci Poll Res* 20(5):2795–2809
- Ghunmi LA, Zeeman G, Fayyad M, van Lier JB (2010) Grey water treatment in a series anaerobic–aerobic system for irrigation. *Bioresour Technol* 101(1):41–50
- Gilboa Y, Friedler E (2008) UV disinfection of RBC-treated light greywater effluent: kinetics, survival and regrowth of selected microorganisms. *Water Res* 42(4):1043–1050
- Gokulan R, Sathish N, Kumar RP (2013) Treatment of grey water using hydrocarbon producing *Botryococcusbraunii*. *Int J Chem Tech Res* 5(3):1390–1392
- Grčić I, Vrsaljko D, Katančić Z, Papić S (2015) Purification of household greywater loaded with hair colorants by solar photocatalysis using TiO₂-coated textile fibers coupled flocculation with chitosan. *J Water Process Eng* 5:15–27
- Gregory AW, Hansen BE (1996) Practitioners corner: tests for cointegration in models with regime and trend shifts. *Oxford Bull Econ Stat* 58(3):555–560
- Gross A, Kaplan D, Baker K (2007a) Removal of chemical and microbiological contaminants from domestic greywater using a recycled vertical flow bioreactor (RVFB). *Ecol Eng* 31(2):107–114
- Gross A, Shmueli O, Ronen Z, Raveh E (2007b) Recycled vertical flow constructed wetland (RVFCW)—a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere* 66(5):916–923
- Günther F (2000) Wastewater treatment by greywater separation: outline for a biologically based greywater purification plant in Sweden. *Ecol Eng* 15(1):139–146
- Halalshah M, Dalahmeh S, Sayed M, Suleiman W, Shareef M, Mansour M, Safi M (2008) Grey water characteristics and treatment options for rural areas in Jordan. *Bioresour Technol* 99(14):6635–6641
- Harikumar PS, Mol B (2012) A synoptic study on the preparation of a liquid waste management plan for Kerala State, India. *Environ Natural Res Res* 2(2):74
- Helvetas (2005) Water consumption in Switzerland (in German: Wasserverbrauch in der Schweiz), Helvetas, Schweizer Gesellschaft für Zusammenarbeit
- Hörman A, Rimhanen-Finne R, Maunula L, von Bonsdorff CH, Torvela N, Heikinheimo A, Hänninen ML (2004) *Campylobacter* spp., *Giardia* spp., *Cryptosporidium* spp., noroviruses, and indicator organisms in surface water in southwestern Finland, 2000–2001. *Appl Environ Microbiol* 70(1):87–95

- Howard G, Bartram J, Water S (2003) Domestic water quantity, service level and health. World Health Organization, Geneva
- Jais NM, Mohamed RM, Al-Gheethi AA, Hashim MA (2016) The dual roles of phycoremediation of wet market wastewater for nutrients and heavy metals removal and microalgae biomass production. *Clean Technol Environ Policy* 1–16
- Jamrah A, Al-Omari A, Al-Qasem L, Ghani A (2006) Assessment of availability and characteristics of greywater in Amman. *Water Int* 31(2):210–220
- Jamrah A, Al-Futaisi A, Prathapar S, Al Harrasi A (2008) Evaluating greywater reuse potential for sustainable water resources management in Oman. *Environ Monit Assess* 137, 315e327
- Jefferson B, Laine A, Parsons S, Stephenson T, Judd S (1999) Technologies for domestic wastewater recycling. *Urban Water* 1:285–292
- Jefferson B, Palmer A, Jeffrey P, Stuetz R, Judd S (2004) Grey water characterization and its impact on the selection and operation of technologies for urban reuse. *Water Sci Technol* 50(2):157–164
- Jeppesen B, Solley D (1994) Domestic greywater reuse: overseas practice and its applicability to Australia. Urban Water Research Association of Australia
- Jin Y, Chen T, Li H (2012) Hydrothermal treatment for inactivating some hygienic microbial indicators from food waste-amended animal feed. *J Air Waste Manage Assoc* 62(7):810–816
- Jong J, Lee J, Kim J, Hyun K, Hwang T, Park J, Choung Y (2010) The study of pathogenic microbial communities in graywater using membrane bioreactor. *Des* 250(2):568–572
- Karabelnik K, Kóiv M, Kasak K, Jenssen PD, Mander Ü (2012) High-strength greywater treatment in compact hybrid filter systems with alternative substrates. *Ecol Eng* 49:84–92
- Katukiza AY, Ronteltap M, Niwagaba C, Kansime F, Lens PN (2014) A two-step crushed lava rock filter unit for grey water treatment at household level in an urban slum. *J Environ Manage* 133:258–267
- Katukiza AY, Ronteltap M, Niwagaba CB, Kansime F, Lens P (2015) Grey water characterisation and pollutant loads in an urban slum. *Int J Environ Sci Technol* 12(2):423–436
- Kenner BA, Clark H (1974) Detection and enumeration of *Salmonella* and *Pseudomonas aeruginosa*. *J Water Poll Control Fed* 2163–2171
- Klammer I (2013) Policy of onsite and small-scale wastewater treatment options in Finland. *Environmental Engineering*, Tampere University of Technology, Finland
- Laghari A, Ali Z, Haq MU, Channa A, Tunio M (2015) An economically viable method by indigenous material for decontamination of greywater. *Sindh Univ Rese J-SURJ (Sci Ser)* 47(3)
- Leal LH, Zeeman G, Temmink H, Buisman C (2007) Characterization and biological treatment of greywater. *Water Sci Technol* 56(5):193–200
- Ledin A, Eriksson E, Henze M (2001) Aspects of groundwater recharge using grey wastewater. Chapter 18. In: *Decentralized sanitation and reuse*. IWA Publishing
- Lim S, Chu W, Phang S (2010) Use of *Chlorella vulgaris* for bioremediation of textile wastewater. *J Bioresour Technol* 101:7314–7322
- Maimon A, Friedler E, Gross A (2014) Parameters affecting greywater quality and its safety for reuse. *Sci Total Environ* 487:20–25
- Mara DD, Cairncross S (1989) Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture: measures for public health protection. World Health Organization, Geneva
- Marjoram C (2014) Graywater research findings at the residential level. Department of Civil and Environmental Engineering, Colorado State University Fort Collins, Colorado
- Matos C, Pereira S, Amorim EV, Bentes I, Briga-Sá A (2014) Wastewater and greywater reuse on irrigation in centralized and decentralized systems—an integrated approach on water quality, energy consumption and CO₂ emissions. *Sci Total Environ* 493:463–471
- Mohamed RM, Kassim AH, Anda M, Dallas SA (2013) Monitoring of environmental effects from household greywater reuse for garden irrigation. *Environ Monit Assess* 185(10):8473–8488
- Mohamed RM, Chan CM, Senin H, Kassim AH (2014) Feasibility of the direct filtration over peat filter media for bathroom greywater treatment. *J Mater Environ Sci* 5(6):2021–2029
- Mohamed, RMSR, Al-Gheethi AA, Kassim AHM (2016a) Reuse of ablution water to improve peat soil characteristics for ornamental landscape plants cultivation. In: 2nd international conference

- on Sustainable Environment and Water Research (ICSEWR 2016), 5–6 December 2016, Novotel Melaka, Malaysia
- Mohamed RM, Al-Gheethi AA, Jackson AM, Amir HK (2016b) Multi natural filter for domestic greywater treatment in village houses. *J Am Water Works Assoc (AWWA)*
- Morel A, Diener S (2006) Greywater management in low and middle-income countries, review of different treatment systems for households or neighbourhoods. Swiss Federal Institute of Aquatic Science and Technology (Eawag), Dübendorf
- Mourad KA, Berndtsson JC, Berndtsson R (2011) Potential fresh water saving using greywater in toilet flushing in Syria. *J Environ Manage* 92(10):2447–2453
- Nnaji CC, Mama CN, Ekwueme A, Utsev T (2013) Feasibility of a filtration-adsorption grey water treatment system for developing countries. *Hydrol Curr Res*
- Oh KS, Poh PE, Chong MN, Chan ES, Lau EV, Saint CP (2016) Bathroom greywater recycling using polyelectrolyte-complex bilayer membrane: advanced study of membrane structure and treatment efficiency. *Carbohydr Polym* 148:161–170
- Ottoson J, Stenström TA (2003) Faecal contamination of greywater and associated microbial risks. *Water Res* 37(3):645–655
- Palmquist H, Hanæus J (2005) Hazardous substances in separately collected grey-and blackwater from ordinary Swedish households. *Sci Total Environ* 348(1):151–163
- Patil YM, Munavalli GR (2016) Performance evaluation of an integrated on-site greywater treatment system in a tropical region. *Ecol Eng* 95:492–500
- Polo F, Figueras MJ, Inza I, Sala J, Fleisher JM, Guarro J (1999) Prevalence of *Salmonella* serotypes in environmental waters and their relationships with indicator organisms. *Antonie Van Leeuwenhoek* 75(4):285–292
- Prathapar SA, Jamrah A, Ahmed M, Al Adawi S, Al Sidairi S, Al Harassi A (2005) Overcoming constraints in treated greywater reuse in Oman. *Desalination* 186(1):177–186
- Rangel-Martínez C, Jiménez-González DE, Martínez-Ocaña J, Romero-Valdovinos M, Castillo-Rojas G, Espinosa-García AC, Maravilla P (2015) Identification of opportunistic parasites and helminth ova in concentrated water samples using a hollow-fibre ultrafiltration system. *Urban Water J* 12(5):440–444
- Rodda N, Salukazana L, Jackson SA, Smith MT (2011) Use of domestic greywater for small-scale irrigation of food crops: effects on plants and soil. *Phys Chem Earth Parts A/B/C* 36(14):1051–1062
- Rose BE, Hill WE, Umholtz R, Ransom GM, James WO (2002) Testing for *Salmonella* in raw meat and poultry products collected at federally inspected establishments in the United States, 1998 through 2000. *J Food Prot* 65(6):937–947
- Rouch DA, Mondal T, Pai S, Glauche F, Fleming VA, Thurbon N, Deighton M (2011) Microbial safety of air-dried and rewetted biosolids. *J Water Health* 9(2):403–414
- Santasmás C, Rovira M, Clarens F, Valderrama C (2013) Grey water reclamation by decentralized MBR prototype. *Res Conserv Recycl* 72:102–107
- Saumya S, Akansha S, Rinaldo J, Yayasanri MA, Suthindhiran K (2015) Construction and evaluation of prototype subsurface flow wetland planted with *Heliconia angusta* or the treatment of synthetic greywater. *J Cleaner Prod* 91:235–240
- Schäfer AI, Nghiem LD, Oschmann N (2006) Bisphenol A retention in the direct ultrafiltration of greywater. *J Membr Sci* 283(1):233–243
- STAATT (2005) Technical assistance manual: state regulatory oversight of medical waste treatment technology. Report of the state and territorial association on alternative treatment technologies (STAATT)
- Surendran S, Wheatley AD (1998) Grey-water reclamation for non-potable re-use. *Water Environ J* 12(6):406–413
- Teh XY, Poh PE, Gouwanda D, Chong MN (2015) Decentralized light greywater treatment using aerobic digestion and hydrogen peroxide disinfection for non-potable reuse. *J Cleaner Prod* 99:305–311

- Turner RD, Warne MSJ, Dawes LA, Vardy S, Will GD (2016) Irrigated greywater in an urban sub-division as a potential source of metals to soil, groundwater and surface water. *J Environ Manage* 183:806–817
- Ukwubile CA (2014) Microbial analysis of greywater from local bathrooms and its health implications in bali local government area Taraba state Nigeria. *J Adv Biotechnol* 2(1):48–57
- USEPA (2003) Ultraviolet disinfection guidance manual. Office of Water; 2003. U.S. Environmental Protection Agency, Washington, D.C
- Vakil KA, Sharma MK, Bhatia A, Kazmi AA, Sarkar S (2014) Characterization of greywater in an Indian middle-class household and investigation of physicochemical treatment using electrocoagulation. *Sep Purif Technol* 130:160–166
- Vierheilg J, Frick C, Mayer RE, Kirschner AKT, Reischer GH, Derx J, Farnleitner AH (2013) *Clostridium perfringens* is not suitable for the indication of fecal pollution from ruminant wildlife but is associated with excreta from nonherbivorous animals and human sewage. *Appl Environ Microbiol* 79(16):5089–5092
- Warrington PD (2001) Water quality criteria for microbiological indicators overview report. Resource Quality Section Water Management Branch, Ministry of Water, Land and Air Protection, U.K
- Wheater DWF, Mara DD, Jawad L, Oragui J (1980) *Pseudomonas aeruginosa* and *Escherichia coli* in sewage and fresh water. *Water Res* 14(7):713–721
- Wilderer PA (2004) Applying sustainable water management concepts in rural and urban areas: some thoughts about reasons, means and needs. *Water Sci Technol* 49(7):7–16
- Winward GP (2007) Disinfection of Greywater. Thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy, Cranfield University Centre for Water Sciences, Department of Sustainable systems, School of Applied Sciences, p 189
- Winward GP, Avery L, Stephenson T, Jefferson B (2008a) Chlorine disinfection of grey water for reuse: effect of organics and particles. *Water Res* 42, 483e491
- Winward GP, Avery LM, Frazer-Williams R, Pidoua M, Jeffrey P, Stephenson T, Jefferson B (2008b) A study of the microbial quality of grey water and an evaluation of treatment technologies for reuse. *Ecol Eng* 32:187–197
- Winward GP, Avery LM, Stephenson T, Jefferson B (2008c) Chlorine disinfection of grey water for reuse: effect of organics and particles. *Water Res* 42:483–491
- Wurochekke AA, Mohamed RMS, Al-Gheethi AA, Amir HM, Matias-Peralta HM (2016) Household greywater treatment methods using natural materials and their hybrid system. *J Water Health* 14(6):914–928