Chapter 4
Reuse of Greywater for Irrigation Purpose

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Abstract Reuse of greywater for the irrigation is an alternative water source in the new water management strategy of the countries that face a severe deficiency of water resources such as the Middle East Countries. Several studies have been evaluated the effects of greywater on the soil structure and plants. Greywater with a high level of nitrogen and phosphorus as well as macro-elements induce the plant's growth. However, the reuse of these effluents at excessive rates might produce detrimental effects on soil and crops. Some of the heavy metals in the greywater are toxic to plants, while others have toxicity for human and animals. The main consideration in the reuse of greywater in the irrigation lies in the transfer of pathogenic microorganisms to humans directly or indirectly. In developed countries, the utilisation of greywater for the irrigation subject for strict regulation which lies in the method of irrigation as surface or subsurface. In contrast, the surface irrigation is the common practice in

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the developing countries. In this chapter, the benefits of the greywater for the soil and plants as well as the adverse effects are reviewed. Based on the literature review in this chapter, it can be concluded that the criteria required to reuse greywater in the irrigation include aesthetics, hygienic safety, environmental tolerance, and technical and economic feasibility.

Keywords Greywater · Microbial risk · Human health · Reuse · Irrigation

4.1 Introduction

Greywater represents very good alternative water resource among the countries with air and semi-arid zones, since these countries face many of the challenges related to food security due to the absence of water resources. Therefore, the application of greywater for the irrigation purpose is an indispensable solution for the irrigation purpose. These practices might limit the deficiency in the food supply. Besides, the composition of greywater with nutrients and microelements might improve the quality of plant growth and crops. So far, the chemical and biological aspects of greywater should be considered before applying the greywater in the irrigations. The developed countries such as USA, Japan, Germany and Australia have good experience in greywater reuse for irrigations (Ottoson and Stenström 2003). The main concepts in those counties are to reuse the treated or partially treated greywater. In contrast, many of developing countries used the untreated greywater due to the absence of facilities required for the treatment process.

On the other hands, the concerns related to the utilisation of greywater for irrigation lie in the distribution of pollutants such as chemical agents, organic micro-pollutant (OMPs) and pathogens into the soil and plant crops and then the direct or indirect transmission into the human via the food chain. Besides, the high salinity of greywater deriving from detergents represents the major concern. The level of salinity in the soil is quantified in terms of sodium adsorption ratio (SAR) index (Lazarova and Asano 2005). SAR in greywater generated from laundry might reach 12.32 mg L^{-1} which is generated from the detergents that have more 3000 mg L^{-1} of SAR (Abu-Zreig et al. 2003). The accumulation of Na in the soil due to the frequent irrigation with greywater leads to the degradation of soil permeability and composition, and SAR in the soil leads to reduce saturated hydraulic conductivity (Ksat) (Gross et al. 2008).

The overutilisation of greywater in the irrigation might cause an elevation in pH values due to the high contents of alkaline detergents (Travis et al. 2010; Sivongxay 2005). The increase in pH values in the soil is associated with the increase in soil cation exchange capacity (CEC) (Sivongxay 2005; Anwar 2011). It has revealed that the soil properties of the sandy type have changed after being irrigated with surfactant-rich laundry greywater (Anwar 2011). The present chapter focuses on the benefits of reuse greywater in the irrigation and their negative effects on the plant growth, crops and soil characteristics.

4.2 Effect of Irrigation with Greywater on Plant and Soil

4.2.1 *Chemical Effects*

The domestic greywater is rich with many of chemical detergents which are used in the bathing and washing process of vegetables, fruits and washing machines. The surfactant which is most common in the laundry greywater is organic compounds consisting of the hydrophilic and hydrophobic group with the long chain of alkyl C10–C20 (Anwar 2011). The agricultural surfactants which are known as "spreaders and stickers" help the fertiliser and pesticides to spread through the soil matrix and then comply with plant leaves. The reduction in the surface tension of surfactant-rich greywater may increase the hydraulic conductivity of the soil.

Surfactants (surface-active agent) represent the major xenobiotic compounds in the greywater because it used in the generation of detergents and hygiene products which are utilised extensively in the batting and clothes washing. The surfactants included the compounds generated from amphoteric, cationic, anionic and nonionic detergents. Among these classes, anionic and cationic surfactants include methyl ester sulphonate, olefin sulphonate, alkyl benzene sulphonates, alkyl ether sulphates, isotridecanol ethoxylates, benzalkonium chloride, n-hexadecyl trimethyl and ammonium chloride. The utilisation of these detergents depends on their potential to provide cleaning action, disinfection agents and low price (Jakobi and Lohr 1987; Lange 1994; Belanger et al. 2002).

Another negative effect of soil irrigated with the untreated greywater is the elevation in pH values due to the high contents of alkaline detergents (Sivongxay 2005; Travis et al. 2010). High pH in laundry greywater acts as the dispersing agent which causes soil particles to split and leads to the increase of soil cation exchange capacity (CEC) (Sivongxay 2005; Anwar 2011).

It has been revealed that the soil properties of the sandy type have changed after being irrigated with surfactant-rich laundry greywater (Anwar 2011). However, the effects discharged laundry greywater on the soil composition in developing countries have not been reported yet. This might be related to the concept of greywater and the effects associated with the disposal in these countries raised within few last years, in comparison with the developed countries. For instance, in Australia, the local governments are gravely considering the application of greywater (generated from laundries and bathrooms) as an option for irrigating household lawns and gardens, thereby reducing residents demand for filtered water (Mohamed et al. 2013). Besides, there are no regulations for discharge of greywater into the environment in the developing countries. These are associated with the absence of the studies which assessed the adverse effects of disposal of greywater on the soil composition in many of developing countries.

The toxicity of the high concentrations of Na ions in the greywater on the plants lies in the bioaccumulation in the roots and leaves. The bioaccumulation of Na ions affects negatively the uptake of water from the soil. The increasing of soil salinization and sodic conditions leads to reduce the ability of the soil to support plant growth

(Morel and Diener 2006). Rodda et al. (2011) investigated the use of household's greywater for irrigating of *Beta vulgaris* (an aboveground crop) and *Daucus carota* (a belowground crop) in comparison with tap water and a hydroponic nutrient solution. The sub-irrigation method was used for six growth cycles. The characteristics examined included growth rate of plant and crop yield as well as the concentrations of macro- and micronutrients in the yielded crops and soil composition. The results revealed that the utilisation of greywater improved the plant growth and nutrients contents with the slight differences in the plants irrigated with tap water. Moreover, the highest plant growth and crop yields were recorded with the hydroponic nutrient solution. The electrical conductivity of the soil and metal contents increased with the utilisation of greywater and correlated with the metal and sodium concentrations in the crops. The study concluded that the greywater might provide an alternative water resource for plant irrigation and some fertiliser properties. However, the precautions regarding the metal and salts accumulation have to be considered.

The dispersion of clay particles in Ca–soil column leached by Na ions and NaCl aqueous solution led to an irreversible decrease in soil hydraulic conductivity (Yaron et al. 2012). Datnoff et al. (2001) stated that the surface-induced swelling clay is the main mechanism for decreasing of Ksat in the clay. The main cause of Ksat reduction can be rationalised as a small pore clogging in the soil due to the adsorption of surfactant. Surfactant effects on water infiltration and on percolation in soils are a function of soil type and surfactant characteristics (Kuhnt 1993). Surfactants decrease capillary rise of water in soil columns when mixed with sandy or clayey soils by decreasing water surface tension (Smith and Gillham 1999). This might be caused by swelling of some clay particles, which changes the hydraulic capacity of the soil profile and resulted in reduced retention of soil water and increased the depth of infiltration (Karagunduz et al. 2001; Crites et al. 2014).

Heavy metals in the greywater are originated from the detergents. Therefore, the reuse of the greywater for irrigation might lead to transmission of the metal ions into the soil and plants. The transfer of heavy metal ions from greywater used in the irrigation to plant might lead to reduce plant's growth and affect soil microorganisms, and their activities depend on the application rate and its frequency, the soil removal mechanism and the removal capabilities of plant species (Dahdoh and El-Hassanin 1994; Logan et al. 1997; Giller et al. 1998).

Metal has important role in the metabolic and anabolic pathway as cofactors for the enzymes and as stabilisers of protein structures in the living cells. Some of these metals including Fe, Cu, Mn, Na, Zn, Co, K and Ca ions are essential nutrients as trace elements/macro-elements. In contrast, others such as Ag, Hg, Pb and Al ions have no biological role (Bruins et al. 2000; Jais et al. 2017). Moreover, the presence of macro-elements with high concentration leads to increase their toxicity for the biological functions in the cell (Al-Gheethi et al. 2016a).

4.2.2 Microbial Effects

The potential effect for reusing greywater for irrigation on the human health is associated with the presence of pathogens (Finley et al. 2009). The level of hazards depends on the plant type and pathogens, while the mode of transmission takes place directly or indirectly. In terms of plant types, the vegetables irrigated with the greywater represent the high risk for human, because they are consumed without cooking. The trees, which produce their crops far away from the soil surface, have less risk because the crops have not contacted directly with the greywater. In contrast, the plants that produce their crops on the soil surface or underground have more risk due to the direct contact with the pathogens in the greywater.

The pathogens in the greywater are originated mainly from the human bodies (shower and laundry greywater) and plants and animals (kitchen greywater). Therefore, the pathogens from shower and laundry greywater are more likely to cause the infection for human, because they have already adapted to the human temperature and acquired resistance for the human immunity. Some of those pathogens have no potential to compete with the indigenous organisms in the environment and would not multiply in the environment due to the absence of growth factors required for their growth. However, they can survive for a long time and transmit through the food chain into the human.

The pathogens from kitchen greywater especially those originated from the washing of fruits and vegetables have high levels of the pathogens which are pathogenic for the plant more than their pathogenicity for the human. They are more likely to cause the diseases ìn the plant, and so far affect negatively on the plant growth and crop production. These pathogens have high potential to grow on the plant's roots and leaves. The most common pathogens in those wastes included helmets and microbes, which are more available in the rhizosphere layers of the soil as well as caused the potato brown rot. However, Finley et al. (2009) indicated that there were no differences between the concentrations of faecal coliforms (FC) and faecal streptococci (FS) in the crops irrigated with treated and untreated domestic greywater as well as tap water. Moreover, the differences were noted between the bacterial species and the plant, where FC was presented with high concentrations in carrots, while FS was being highest on lettuce leaves. The study mentioned that the concentrations of these pathogens in the greywater were high in the greywater. However, their concentrations were low and did not represent a significant health risk. Similar findings were also reported by Jackson et al. (2006) who indicated that there is no significant difference in the bacterial concentrations on the plant surfaces irrigated with greywater, tap water, or hydroponic solution. So far, previous studies have found that the crop portions matured underground or near the surface of the soil irrigated with wastewater contain high concentrations of pathogenic bacteria (Armon et al. 1994).

In comparison between the health risk of human pathogens and plant pathogens, it can be indicated that most plant pathogens are sensitive to the treatment process of greywater; therefore, the primary and secondary process might be effective to reduce these pathogens to less than the detection limits. Conversely, the human pathogens exhibited more resistance to the treatment process. Besides, most of the plant pathogens are very specificity to infect the plant and have a narrow host range. Indeed, the ability of pathogens to reach the human and cause the infection depends on the survive time which is defined as the time in which the pathogenic cells have the potential to cause the infection for the human.

Regarding the ability of pathogens to survive and transmits through the food chain into the human. The irrigation method is the main factor which influences effectively and can detect the final fate of the pathogens available in the greywater. The utilisation of surface irrigation leads to the distribution of pathogens. However, the survival period of these pathogens is less due to the effect of sunlight and deficiency in the water contents in the surface soil which is required for microbial multiplication and growth. So far, the pathogens, which have the ability to form spores or cysts such as *Bacillus* spp. and helminths, might tolerate the hard environment and then transmitted to the human. The utilisation of subsurface irrigation method might be alternative to prevent the distribution of pathogens into the plant crops. However, the sanitary implications lie in the transmission of these pathogens to underground waters (Al-Gheethi et al. 2016b).

Najafi et al. (2015) examined three irrigation methods including surface, subsurface drip, and furrow irrigation for evaluating the distribution of faecal coliform bacteria from wastewater. The study revealed the usage of surface drip and furrow irrigation associated with high pollutions of the plants and soil. In contrast, the utilisation of subsurface drip irrigation reduces the distribution of faecal coliform bacteria.

Dixon et al. (1999) stated that four actors are associated with the presence of microbial health risk from greywater reuse which included populations, exposure, dose-response and delay before reuse. Based on this factor, the utilisation surface irrigation method of stored greywater for a long time with the high concentration of infectious agents has high risk. The health risk for reuse of greywater depends also on when and where the greywater will be used. The level of the risk associated with the greywater relies on the hazards level and exposure time (Fig. 4.1). It can be noted that the exposure to the hazards for long time (greywater at the source) might be more dangerous from the exposure to high dose of the hazards for only short time (greywater at the reusing point).

Indeed, the absence of epidemiology reports on the infection diseases resulted from the exposure to the hazard risks in the greywater might represent the main obstacle to assess the health risk for the greywater. But it has to be mentioned that the presence of pathogenic organism in the greywater indicates to present a risk, the level of these hazards depends on the transmission method. The availability of epidemiological studies and quantitative microbial risk assessment (QMRA) provides more details on the level of microbial and hazardous chemicals risks correlated with the reuse of greywater. QMRA consists of four steps include; Hazard Identification (Hazard ID), which aim is to identify the pathogenicity of the microbe cell and transmission routes, infective dose depends on the pathogens species and whether the pathogen need for intermediate host before the reaching to the final host and

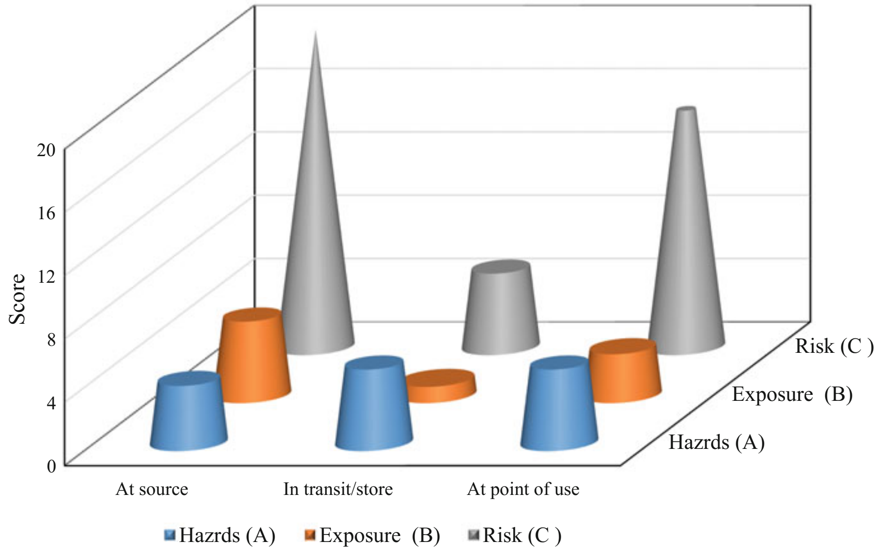

Fig. 4.1 Show the health risk associated with reuse of greywater at source, in transit and at point of use; for A and B the score is 1 (low), 3 (Intermediate), 4 (Interm-Higher) and 5 (Higher). C is calculated as A*B, the score was calculated as 5 (low), 15 (Intermediate), 20 (Interm-Higher) and 25 (higher) (Dixon et al. 1999)

the exposure assessment which describe the exposure to the pathogens (inhalation, direct contact, digesting). The risk for each pathogen depends on the hazard, infective dosage and exposure levels (Fig. 4.2).

Based on Fig. 4.2, it can be indicated that health risk level of infectious agents is a result of available three factors which contribute to the increase of the risk level. The exposure for the high dose of pathogens with high pathogenicity increases the level of health risk. An available one of the factor with the low score (1) in the presence high score of other factors reduce the health risk percentage level to 28.57%, however, presents an intermediate score for one factor lead to increase the percentage of the risk level to 57.2%.

According to World Health Organization (WHO 2005), the infectious pathogens are classified into four levels including risk group I which included the infectious agents with no or low individual and community risk. The pathogens with moderate individual risk but low community risk are classified in risk group II. The potential of pathogens to have the high individual risk and low community risk is classified as risk group III. Finally, the pathogens classified within risk group IV included those having high individual and community risk. Based on the pathogens available in the greywater which were presented in Chap. 1, *Enterococcus faecalis*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* are classified within the risk group (II), while *E. coli* and *Salmonella* spp. are classified within the risk group II and III. In comparison between those pathogens, both *E. coli* and *Salmonella* spp.

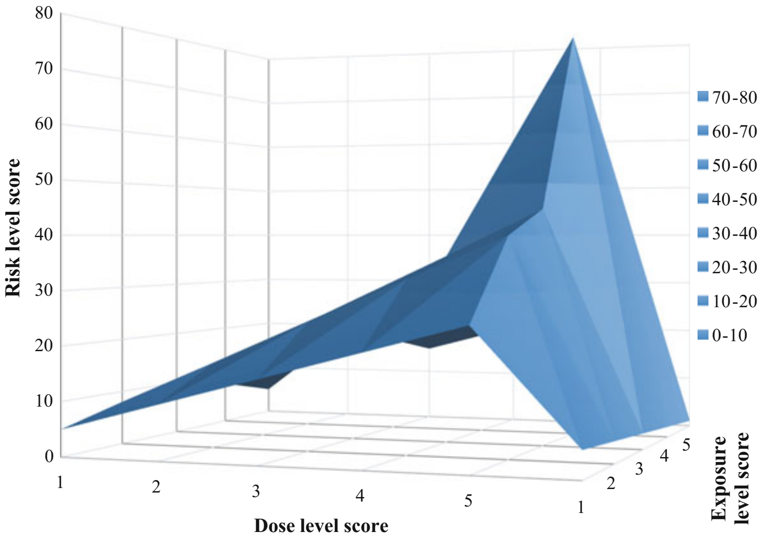

Fig. 4.2 Show the QMRA of pathogens in the greywater, the dose, exposure and hazards levels is expressed in the range (1–5); very low (1); low (2); Intermediate (3); Interm-Higher (4); Higher 95) (Higher); the risk level is divided into seven classes based on the correlation between dose, exposure and hazards levels; the high-risk level takes place above 30 scores

have high pathogenicity with the low dose (ranged from 10^3–10^6 cells). *E. coli* is presented in the greywater with concentrations ranged from 10^2 to 10^6 which is within the dose concentrations required to cause the infection. There are no more studies which have estimated the *Salmonella* spp. concentrations in the greywater because these studies focused only on the presence or absence this bacterium. However, Katukiza et al. (2014) mentioned that the concentrations of *Salmonella* spp. in greywater from Uganda were 2.73×10^4 cell/100 mL. These concentrations might be enough to cause disease if the person consumed more 100 mL of greywater with the food or with the drinking water. *P. aeruginosa* and *S. aureus* are available with concentrations between 101 and 10^4 cell/100 mL of the greywater. The infective dose of *P. aeruginosa* is 10^8–10^9 cells and for *S. aureus*, it is 10^3–10^8 cells (Sewell 1995; Rusin et al. 1997). Therefore, based on this information, it can be indicated that the pathogens in the greywater might have no high health risk for the human and animals. So far, one of the serious points associated with the pathogenic bacteria is their ability to multiply and regrow in the environment. It can be increased in their number to reach the infective dose which enables them to cause the disease for the human and animals as well as the plants (Al-Gheethi et al. 2016b).

The helminths such as *Ascaris* sp., *Necator* sp., *Ancylostoma* sp., *Strongyloides* sp., *Hymenolepis* sp., *Trichuris* sp., *Taenia* spp. and *Toxocara* sp. as well as Trematodes (*Opisthorchis* sp., *Clonorchis* sp., *Schistosoma* spp. and *Fasciola* sp.) and parasites such as *Giardia lamblia* and *Cryptosporidium* spp. have no ability to increase in their numbers in the environment because they need the intermediate host for their life cycle. Nevertheless, they have long survival periods and low infective dose (10–100 cysts) which enable them to represent a risk for the human (Robertson and Nocker 2010).

Based on QMRA, the microbial risk associated with the reusing greywater in the irrigation lies in the ability of these pathogens to survive in the environment sufficiently long to pose health risks (QMRA 2015). These pathogens are transmitted by the direct contact with these pathogens during the irrigation of the plant or harvesting process of the crops and by the consumption, the fruits and vegetables contaminated with the pathogens (Fig. 4.3). Therefore, the washing of fruits and vegetables are required for preventing the infection by the infectious agents. Some

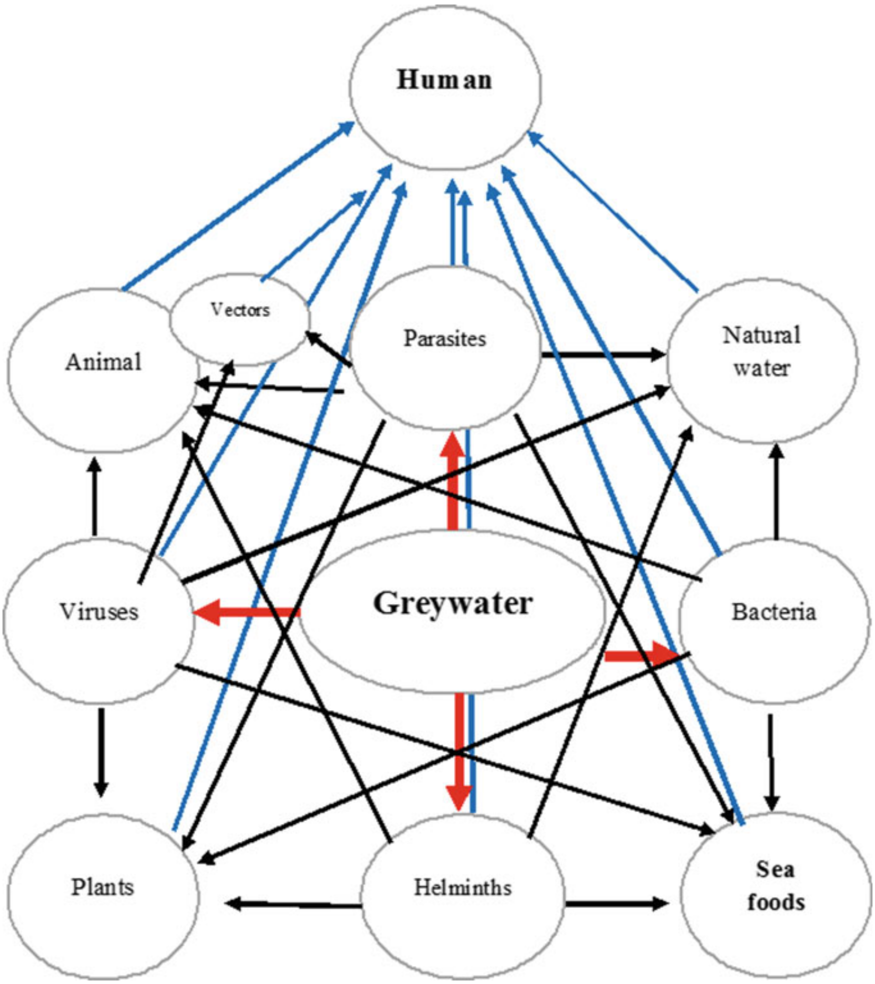

Fig. 4.3 Direct and indirect transmission routes for pathogens from greywater into human

of the food is subjected to cooking which might contribute effectively to the reduction of the pathogens and prevent their transmission in the human. Another concern related to the presence of pathogens such as dengue virus, Plasmodium spp. Japanese encephalitis virus and *Wuchereria bancrofti* lies in the transmission route of these pathogens which are transmitted to human by the vector contact (Chorus and Bartram 1999; Van der Hoek et al. 2005).

The pathogens in the greywater represent a health risk for a wide range of the people included consumers, farm workers and their families, and nearby communities (WHO 2006). The presence of these pathogens on the plant surface and the crops has been reported in the literature which is an evidence of the presence of a health risk for the plants irrigated with the greywater. However, there is no evidence confirming that the disease recorded among the consumers was originated from these pathogens. This might be due to the absence of advance technology which might detect the source of the pathogen which caused the infection (Al-Gheethi et al. 2016b). Among the farm workers and their families and nearby communities, the health risk is considered to be based on the exposure factors since the studies confirmed the presence of pathogens in the greywater and on the surface of plant leaves and crops. The farmers are more susceptible to infectious agents (Blumenthal and Peasey 2002).

4.3 Regulations for Reuse of Greywater

The effects reusing greywater in the irrigation on the soil structure and composition in many developing countries have not reported yet. This might be related to the fewer developments in the field of greywater in those countries, and the application and reuse of greywater in the developing countries located in the Middle East region such as Jordan raised within few last years. However, there are no specific regulations for the reuse of greywater in the agriculture. In contrast, in Australia, the local governments are gravely considering the application of greywater (generated from laundries and bathrooms) as an option for irrigating household lawns and gardens, thereby reducing residents demand for filtered water (Mohamed et al. 2013). Many of the developing countries adopted the WHO guidelines for microbiological regulation of the wastewater (WHO 1989) in which wastewater are classified into three classes (A–C) based on the final concentrations of FC and treatment methods (Table 4.1). The microbiological and chemical regulations for reusing greywater in the irrigation among different countries are illustrated in Tables 4.2 and 4.3.

Dixon et al. (1999) proposed a framework for regulating the reuse of greywater and some more guidelines to that adopted by WHO (1989) as follows: the storage period of the greywater should be minimised to reduce the microbial multiplication and formation of biofilm as well as the exposure. Besides, the odour is supposed to be kept at the minimum level.

Table 4.1 Guidelines for using treated wastewater in agriculture (WHO 1989)

Category	Reuse conditions	Exposed group	Intestinal nematode[a] (arithmetic mean no eggs/L)[b]	Coliform (geometric mean/100 mL)[b]	Wastewater treatment expected to achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[c]	Workers, consumers, public	≤ 1	≤ 1000	A series of stabilisation ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[d]	Workers	≤ 1	No standard recommended	Retention in stabilisation ponds for 8–10 d or equivalent helminthic and FC removal
C	Localised irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pre-treatment as required by irrigation technology, but not less than primary sedimentation

[a] *Ascaris* and *Trichuris* species and hookworms
[b] During the irrigation period
[c] A more stringent guideline (200 FC/100 mL) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact
[d] In the case of fruit trees, irrigation should cease 2 weeks before the fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should be used

Table 4.2 Microbiological regulation for greywater reused for irrigation

Country/Organization	TC	FC	*Pseudomonas aeruginosa*	References
USA, California		2.2 MPN/100 mL (23 MPN/100 mL in 30 days)		U.S. EPA (2004)
Australia		<30 CFU/100 mL^{-1}		NSW (2000)
Australia		<10 CFU/100 mL^{-1}		
Germany	<10^4 CFU/100 mL	<1000 CFU/100 mL	<100 CFU/100 mL	Nolde (1999)
WHO		Class A (<1000 CFU/100 mL) Class (B) No standard recommended		WHO (1989)
Mexico		≤2000 CFU/100 mL		Peasey (1999)
Korea		Must not be detected		Jong et al. (2010)
UK	10 CFU/100 mL	–	–	BS-8525-1 (2010, BS-8525-2 2011)
Portugal	104 CFU/100 mL	200 CFU/100 mL	–	ANQIP (2011)
Jordan		Category A (Cooked Vegetables) 100 MPN/100 mL Category B (Tree crops) 1000 MPN/100 mL		Duqqa (2002)
Japan	<50	<10		Al-Jayyousi et al. (2003)
USA		<200		
China	<10,000			
Egypt		100		Egyptian regulation (1994)

Table 4.3 Chemical regulations for reuse greywater in the irrigation

Parameters	Korea	USA	Japan	China	Germany	Egypt
BOD	<10 mg L	30	<3	<6	5	20
COD	<20 mg L					40
pH	5.8–8.5	6–9	5.8–8.6	6–9	6–9	
Turbidity	<2NTU		<5	<5	1–2	
TSS		30				20
TP				<0.5		
Reuse application	Reuse application Restricted reuses[a]	Reuse application Restricted reuses	Environmental (limited public contact)	Restricted impound-ments and lakes	Toilet flushing	

[a]Irrigation of areas where public access is infrequent and controlled golf courses, cemeteries, residential and greenbelt

4.4 Conclusion

It can be concluded that the reuse of untreated greywater for the irrigation purpose has several issues on the soil and plants. The main concern lies in the accumulation of heavy metals ions in the plants which are then transmitted to the human. Similar concerns are associated with the pathogens which might have the potential to survive in the hard environment and then transmitted by the food chain into the human. It has to be mentioned that the greywater has less microbial loads in comparison to the black water. However, the health risk associated with those pathogens is not their virulence factor since also their ability to transmit the antimicrobial resistance gene into the pathogens and thus increase their pathogenicity.

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