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THE POTENTIAL GREYWATER REUSE FOR IRRIGATION: A MINI-REVIEW

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Abstract

Freshwater scarcity has become increasingly common in many regions of the world in the context of global climate change. The reuse of greywater for irrigation is an effective solution to save water and reuse some nutrients in greywater. However, greywater reuse also contains some potential risks to soil, human health, and the yield of plants. In this review, we would like to provide a general overview of greywater characteristics, the potential of its reuse for irrigation, the possible risks, and benefits.

Keywords: Biomass Yield, Greywater, Irrigation, Potential Risk, Reuse, Scarcity.

1. INTRODUCTION

Freshwater scarcity is becoming more frequent and long lasting not only in arid or semi-arid regions but also in many countries around the world in the context of global climate change and steady population growth. Many countries in the Middle East and North Africa are facing severe water scarcity, which is also spreading to Asia and South Africa [1]. This problem is increasing because water availability is limited by agriculture activities, urbanization together with climate change, threatening ecosystems over the globe. Indeed, the area where two-thirds of the world's population lives are always facing water shortages for at least one month in the year [2]. Moreover, one-half of the population is living in India and China facing water shortages [2]. With the current threat level, two-thirds world's population will be faced water shortages in 2025 [3].

To deal with water scarcity, many countries as Australia, the United States (US), and the Middle East have applied treatment and greywater reuse. In addition, there are interested in developed policies, techniques treatment for irrigation, flushing toilet [4, 5]. Greywater is an available water source that has the potential to improve the pressure of water scarcity [6]. Tombola et al. [7] implied that greywater reuse improves the stating water scarcity because reducing wastewater discharge, demands freshwater, saving water and energy. Besides, many guidelines for the reuse of greywater have been issued in the United Kingdom (UK), Australia, Israel, California (US), and many countries around the world [8, 9]. The World Health Organization (WHO) also issued a guideline that only required control of microorganisms (the number of helminth eggs and E. coli) for restricted

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and non-restricted greywater reuse for agricultural irrigation [10]. Parallel, many technological solutions have also been applied as physical, chemical, biological processes for greywater treatment to increase its quality for reuse [11]. However, depending on the purposes of reuse that raw greywater can be used directly, diluted with freshwater, or combined with freshwater for irrigation; or treated to achieve a standard for reuse in households such as toilet flushing.

Raw greywater or preliminary treatment of greywater in a single household is often applied for on-site reuse to irrigate grass or plants, landscape/plants in gardens. Generally, irrigation for grass or landscape plants does not need high-quality water as potable/tap water so greywater is easily accepted because of enough the amount of irrigation water, presence of nutrients, and no requirements of high quality [12]. According to a study using water in many cities in Australia was reported by Pinto and Maheshwari [13], using the water for irrigation of gardens and grass around the home were consumed about 30% of total tap water. Therefore, an appropriate irrigation design for greywater reuse in the gardens can save 38% of potable water [14].

This paper reviews critically many previous studies related to potential greywater reuse for irrigation and their effects. The structured review presents an overview of greywater in households, potential, and challenges greywater reuse for irrigation. Objectives of the article are (a) overview of household greywater quantity and quality, (b) potential and risk of greywater reuse, (c) overview guidelines for greywater reuse, (d) impact on human health, soil, groundwater, and the yield of plants by using greywater.

2. GREYWATER

Greywater is defined as wastewater from households that includes flows from baths, hand basins, showers, tubs, and laundry machines without kitchen sinks, dishwashers, and toilets [14]. However, some different definitions of greywater include all sources from a household, excepting that from toilets [15, 16]. In addition, Gross et al. [15] distinguished two categories: light greywater (generated from a bath, shower, and hand basin), and dark greywater (generated from kitchen sink and washing machine).

In general, greywater has better quality than combined household wastewater because of excluding wastewater from toilets or kitchens [15]. Greywater represents up to 50 – 80% of total residential wastewater volume [17]. Greywater can be collected from single houses, office buildings, or public showers and the component properties of greywater contain hair, soap, suspended solids, salts, and bacteria. Greywater has not only potential but also interest in irrigation of plants because pathogens and pollutant contaminants are lower than in domestic wastewater and contain some nutrients for growing plants [8]. Moreover, the organics and detergents in the greywater are decomposed rapidly and do not affect the growth negatively of plants, so reuse of greywater for irrigation of lawn or landscape is common and advantages [8, 16].

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The characteristics of greywater were depended not only on a household scale or a community scale but also on many factors as the culture, the living standards and the habits of the residents in the area, the activities and the income of the household, geographical features, and climate, features of water supply pipes and greywater collection piping, and quality supply of water source [15, 18-20]. Generally, greywater has a high potential for reuse however it can involve some risks and unsafe if there is no suitable method for reuse.

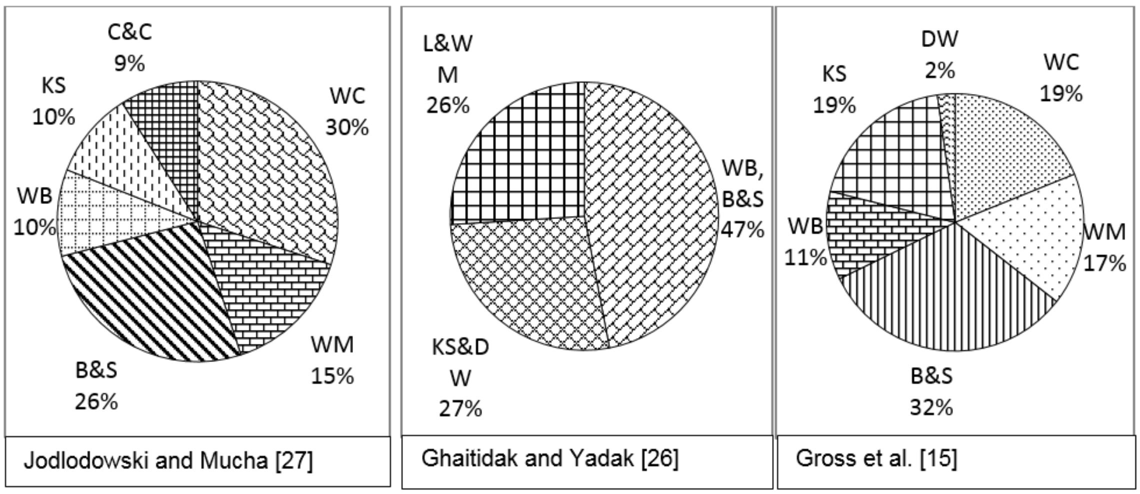
2.1 Quantity of greywater

The amount of greywater generated per person for a day in households has great differences in many countries depending on economic level, climate, and other factors. Base on the review of Li et al. [11] that the quantity of greywater generation depends on country statuses. In developed countries, the standard using water for living was from 100 to 200 $L.person^{-1}.day^{-1}$ and 60% - 70% of this water supply became greywater while in developing countries were about 20 – 30 $L.person^{-1}.day^{-1}$ of greywater generator [11, 21]. Indeed, in the United States, the average greywater was generated from laundry, baths, and the shower was from 127 - 151 $L.person^{-1}.day^{-1}$ [22]. Similarly, the result of a study in Greek showed that the average wastewater production was 135 $L.person^{-1}.day^{-1}$ in which greywater accounted for 72.5% [19]. Moreover, the following Guidelines for residential properties in Canberra 2007, average greywater of a household was generated from laundry and bathroom was 300 $L.house^{-1}.day^{-1}$ [23]. However, the following study by Dobrzanski and Jodlowski [24] was conducted on single houses for 6 months, which were installed water collection generator equipment. The result of the study recorded average of 24.6 $L.person^{-1}.day^{-1}$ of greywater which was collected from a washing basin, shower, and a washing machine was 4,7 L/d, 13,8 L/d, and 6,1 L/d, respectively [24]. While Merc and Stepniak [25] reported that the daily water consumption per person in Poland was approximately 95 dm^3. Recently, a study by Shaikh and Ahamed [20] based on 80 studies reported about water consumption, greywater generation, and return factor (%) in low-income countries and high-income countries showed that were 173±76 and 126±59 $L.person^{-1}.day^{-1}$ of water consumption, 71±30 and 131±44 $L.person^{-1}.day^{-1}$ of greywater generation, 41-89% and 55-82% of return factor, respectively. Moreover, the ratio between water consumption and greywater generation is also different in many countries. These ratios are 0.75, 0.49, 0.57, 0.7, 0.77, and 0.53 in Australia, India, Senegal, Jordan, North Africa, and Poland, respectively [15, 24].

The following Matos et al. [12], the average greywater from bath, washbasin, and washing machine in Portugal was 38.2 $L{\cdot}person^{-1}{\cdot}day^{-1}$, 10.4 $L{\cdot}person^{-1}{\cdot}day^{-1}$, and 7.5 $L{\cdot}person^{-1}{\cdot}day^{-1}$ (total greywater was generated 56.1 $L.person^{-1}{\cdot}day^{-1}$), respectively.

Greywater is produced from different sources as laundry, bathroom, washing basin, dishwasher, and washing machine. The percentage contribution of greywater from water consumption source per person.day in the household on three synthesis studies separately of Jadlowski and Mucha [27], Ghaitidak and Yadav [26] and Gross et al. [15] has small difference which is shown as figure 1.

Figure 1: The percentage contribution of greywater from water consumption for a person per day in household from three different synthesis studies



WM: Washing machine; B&S: Bath and shower; WB: Washing basin; DW: Dishwasher; WC: Toilet flushing; KS: Kitchen sink; L: Laundry; C&C: Cleaning and Cooking

While Shaikh and Ahamed 2020 reported that greywater generation from the bathroom, hand basin, kitchen and laundry in low-income countries and high-income countries were 27±14, 21±17, 28±17, 19±7% and 40±19, 10±15, 22±10, 25±10%, respectively [20].

Additionally, the amount of greywater production from households fluctuates daily. From 8:00 to 10:00 and between 17:00 and 20:00, the flow rate of generated greywater was the maximum because of this time many activities in the households [28]. Furthermore, the amount of water consumed varies by month of the year, day of the week, and hour of the day. The study of Bugajski and Kaczor 2005 showed that the highest amount of water was consumed in August, and the lowest in April of the year; the highest on Saturday, Sunday, and the lowest on Thursday of the week. Especially, the maximum daily peak factor laid between 1.4 and 2.4, the highest on days of May and the lowest on days of December [29]. Thus, building a reservoir to ensure the flow of greywater for reuse and the uniformity of its composition is essential.

2.2 Quality of greywater

Not all greywater is of the same quality. Quality of greywater is not only involved in the living standards, social and culture area of residents, water shortage level but also related to the trace of many categories and production materials of soap, toothpaste, salt, shampoos, detergents [15]. Greywater has the concentration of solids, organic matter, and pathogenic microorganisms lower than compared to those of total wastewater from

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households [30]. The greywater quality is different in many countries, which are shown in table 1. In addition to the common pollution parameters in the greywater, SAR (Sodium Adsorption Ratio) is a concern parameter that depends on the presence of ion sodium, magnesium, calcium in the greywater. As in table 1, the SAR fluctuates from 2–13.5, 2.6–7.5, and 16-25 in some studies investigating in Israel, Jordan, and India, respectively. This value always changes in countries or regions because of the quality of water supply and ingredients of detergent.

Table 1: Greywater quality in some countries

Parameters	India	Jordan	Germany	Israel	UK	USA	Poland*
pH	7.3-8.1	6.4-7.9	7.6	6.3-8.2	6.6-7.6	6.4	7.33
Turbidity (NTU)		49	29	23-35	26.5-164	31.1	114
EC ($\mu m \cdot S^{-1}$)		89-703	64.5	120-170	32.7	23	675
TS (mg/L)	497	659-2653		777-2891			
TSS (mg/L)	100-283	94-845		30-298	37-153	17	360
COD (mg/L)	250-375	58-1712	109	840-1340	96-587		1240
BOD_5 (mg/L)	100-188	36-942	59	74- 890	39-155	86	305
Total oil (mg/L)	7	164					
Tot. N (mg/L)		6.44-52	15.2	10-34.3	4.6-10.4	13.5	6.2
Nitrate (mg/L)	0.67	0.68		0.7-3.5	3.9		
Tot. P (mg/L)	0.012	0.69-51.58	1.6	1.9-48	0.4-0.9	4	
MBAS (mg/L)		39	0.3	3.3-61			150
Na^+ (mg/L)	32-50	70-302		89-641			
Ca^{2+} (mg/L)	0.13	15.1-23		79.6			
Mg^{2+} (mg/L)	0.11	24-60		47.6			
FC (CFU/100 mL)		$13\text{-}3.10^5$	$1.4.10^5$	$3.5.10^4\text{-}4.10^6$			

(Gross et al. [15],* Dobrzanski and Jodlowski [24]).

The quality of greywater depends on sources of generation, the contamination components are created from different sources that shown in table 2 following the study of Gross et al. [15], Ghaitidak and Yadav [26],. As table 2, the quality of greywater from bath, shower, washing basin, or washing machine source was lower than from kitchen sink and dishwasher. According to Noutsopoulos et al. [19], the majority load of organic carbon and suspended solids in the greywater were generated from laundry and kitchen sink while bathtubs and hand basins contributed a low level of contaminants. Indeed, kitchen sink and dishwasher account for 31% of the total volume of domestic greywater however the concentration of contaminants of kitchen sink account for a high ratio of a total load of COD, total oil, and Methyl blue active substances (MBAS) were 42%, 43%, and 40%, respectively [19]. The SAR value of different sources in table 2 shows that are 4, 12–16, 5.3–29 of sources from the shower, laundry, kitchen, respectively. Moreover, the greywater from the dishwasher contributed to the increased in SAR because the way that dishwasher salt works is by providing sodium for the dishwasher's 'ion-exchange resins'. Likewise, the analysis results of the greywater characteristics from many sources shown that the nutrients (nitrogen, phosphorus) are present in the most of sources. The concentration of nutrients, pathogens in the greywater from the bathroom, laundry, and

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washing basin sources are lower than in these sources adding kitchen flow because these sources do not present food, and meat [15, 19].

Table 2: Quality of greywater at different sources

Sources	Washing basin	Bathroom	Shower	Laundry	Kitchen sink	Dishwasher
pH	7–7.3	7.1–7.6	7.3–7.5	8.3–9.3	6.5–7.7	8.2–8.3
Turbidity (NTU)	164	59.8	84.8–375	328–444	133–211	
EC (μS/cm)		43.7	1.4–89	2.9–703	1.4–97	90.61
TS (mg/L)	835	777	520–1, 090	2,021–2,700	679–1,272	2,819
TSS (mg/L)	153–259	58–78	89–353	188–315 5	134–625	52
COD (mg/L)	386–587	230–367	77–645	58–1,339	58–1,340	1,296
BOD_5 (mg/L)	155–205	129–173	40.2–424	44.3–462	40.8–890	470–4,450
Total oil (mg/L)	135	77	164	181	232	328
Tot. N (mg/L)	10.4	6.6	8.7–10.92	14.28	6.44–6.44	
Tot. P (mg/L)			1.12	51.58	0.69	
MBAS (mg/L)	3.3	15	14.9–61	42–118.3	41.9–59	11.1
B (mg/L)	0.44	0.41	0.35–0.35	0.4	0.02	3.8
Na^+ (mg/L)	131	112	109.5–184.5	302.1–667	70.1–148.9	641
Ca^{2+} (mg/L)			15.7–59.9	18.7–24	19.69–23.6	
Mg^{2+} (mg/L)			23–56.1	15.1–60.8	16.6–21	
FC (CFU/100 mL)	$3.50 \cdot 10^4$	$1.5 \cdot 10^5$–$4 \cdot 10^6$	64–$4.0 \cdot 10^6$	13–$4 \cdot 10^6$	200.5–$1.2 \cdot 10^6$	$6.0 \cdot 10^4$ –$3.2 \cdot 10^5$

(Gross et al. [15])

In addition, according to the study of Fanggue [11], the microorganisms in bathroom and laundry greywater are lower than in other streams.

Therewith, the difference in compositions have been mentioned above these are fibres that exist in the greywater. The fibres in the greywater originate from washing of textile synthetic to be through discharged by fibres from washing machines that is a group of microplastic [31]. Microplastic is accumulated in the environment, which has the potential to affect the health of humans and impact ecosystems [32]. The concentration of fibres in the greywater from the washing machine depending on textile materials and washing conditions. According to Napper and Thompson [33], when washing 6 kg of synthetic materials can discharge about 138,000–729,000 fibres per a washing time, however, the amount of fibres will be decreased when the clothes are increased by the number of times of washing [33]. Moreover, with calculating 220–300 kg laundry per capita per year with that 30-50% of all productions are made from synthetic, the fibres discharge average from 1–100 gram per capita per year [31, 32, 34]. A similar result produced 120 grams of fibres per capita per year in Norway [35].

3. POTENTIAL GREYWATER REUSE FOR IRRIGATION

General considerations of the quantity and quality of greywater show that greywater has potential reuse for irrigation. Indeed, the quantity of greywater from a household ensures enough irrigation for lawn and garden areas. In a study conducted by Edwin et al. [36] in urban residential in Indian, it was shown that the average consumption of water for gardening irrigation was 2.5±0.6 $L.person^{-1}.day^{-1}$. Specifically, the amount of irrigated water for lawns or landscape in the garden depends on many factors as the type of plants, area, and type of soil, geographic location, and weather. According to a study was cited

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by Matos [12], the houses had garden areas or lawns with an average area of 40 m^2 account for 30% of the total 64% of homes were house in Portugal. And the quantity of greywater in the household would ensure supply for an area of 20 m^2 during months of dry season 11,5 mm/day [12].

The amount of irrigated water for plant requirements is calculated following Eq. (1). in the form:

$$\mathrm{ET_c} = \mathrm{K_c}.\mathrm{ET_0} \quad (1)$$

Where: ET_c: crop evapotranspiration, mm;

K_c: crop coefficient;

ET_0: reference evapotranspiration, mm;

The following Israel Water Authority [37], crop coefficient (K_c) of lawn is 0.45 and 0.55–0.6 for regular maintenance and high maintenance, respectively [15]. Besides, the K_c of ryegrass (0.85–1), alfalfa-winter (0.3-1), and Sudan grass (0.3–1.1) (depending on growing stage) are recommended by Allen 2005 [38]. And reference evapotranspiration estimated by the Penman-Monteitha (FAO-56) equation [39].

For example, many studies by Fu et al. [40], Xinmin et al. [41], Demirel et al. [42], Bastug et al. [43] have shown that the total seasonal irrigation water requirements of lawns were 244–1085 mm/season (about 26 weeks). And other studies for investigating greywater production, the total volume of greywater production was 71±17.03 $L.person^{-1}.day^{-1}$ (59±14.15 $L.person^{-1}.day^{-1}$ when not including the kitchen and dishwashing), and 98.4±11 $L.person^{-1}.day^{-1}$ (68±10.4 $L.person^{-1}.day^{-1}$ when not including the kitchen and dishwashing) were reported by Noutsopoulos [19], Edwin [36], respectively. Consequently, the greywater production (not including kitchen and dishwashing) from a person can calculate to supply irrigation water requirements for an area of lawn from 10 – 55 m^2.

Furthermore, the ingredient from many sources of greywater generated in the household is not a high concentration of contaminant excepting from kitchen sink and dishwasher. Although greywater contains many pollutants have potential risk for soil, plants, and human for reusable objects such as pH, salt, SAR, organic matter, nutrient, detergent, heavy metal, pathogens, it also has the potential to be reused for the irrigation because the concentration of contaminants is not severe.

The following table 2, the greywater from bathroom, washing basin, and laundry sources have a high organic concentration (COD: 230-1339 mg/L; BOD_5: 44–426 mg/L). However the organic of these sources are decomposed faster than of blackwater, and the root zone of plants when is irrigated greywater assists assimilation even further biodegraded [8]. The organic matter is considered to be good for soil, which improves soil structure and moisture, helps the soil activate better [10]. According to Mohamed [44], the physical and chemical characteristics of greywater without kitchen sinks are the same as diluted wastewater, which becomes a source of appropriate household reuse options.

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Greywater reuse for irrigation with an excessive concentration of salt can have negative impacts on soil, plants, groundwater, and surface water. The TDS, EC in the soil increase when salt is accumulated in the soil. It can affect microbiological activity and fertility. The characteristic effect of these factors relates to the sodium adsorption ratio (SAR). SAR in the soil will change because of receiving sodium cation (Na^+) from greywater [45]. Sodium has a high concentration level in the greywater because it is common in domestic use (especially from the dishwasher) [15]. SAR is the ratio between sodium ion concentration and magnesium with calcium ions in the form as Eq. (2). :

$$\mathrm{SAR} = \frac{[\mathrm{Na^+}]}{\sqrt{([\mathrm{Mg^{2+}}]+[\mathrm{Ca^{2+}}])}} \quad (2)$$

Where:

- SAR is the sodium adsorption ratio
- $[Na^+]$, $[Mg^{2+}]$, and $[Ca^{2+}]$ are the cation concentrations of sodium, calcium, magnesium, respectively, in (mmol/L).

When SAR value is too high it deteriorates soil structure, decreases the hydraulic conductivity of soil, and reduces yield and growth of plants. The value of SAR recommended for irrigation is less than 5 [15], and according to Decree-law No. 236/98 (Portugal), this value is 8 [46]. While according to Gross et al. [15], many studies have been cited with the largest SAR of greywater was about 6.

In addition, Boron is a metal in the ingredient of detergent, which has potential risk for soil and plant at a high concentration level however it is also an essential element to plant growth. It is sensitive with slightly higher than benefit level can injury or death to plants. The following Guidelines for water reuse [47], the concentration of Boron for optimum yields is about a few –tenths mg/L, it becomes toxic for the plant at 1 mg/L but most grasses can withstand at 2–10 mg/L [48]. Besides, greywater also contains some trace elements and heavy metals, however, it often exists in the form trace is not required treatment for non-potable reuse [36].

The nutrient composition presents popular in greywater such as nitrogen, phosphorus, potassium however not all greywater is the same. Nitrogen is a nutrient source for plant take up however excess nitrogen for plants leads to the potential risk of the aquifer because of leaching to groundwater [48]. Besides, phosphorus and potassium always have low concentrations in the greywater, which does not affect the environment and harmful plants [10].

The detergent surfactant that exists in greywater is capable of accumulating in the soil, which can change some of the physical properties of the soil [49]. The detergent is a salient feature in greywater however its presence is not a severe problem because it is biodegraded quickly (less than an hour) and does not potential risk to plants [8, 50].

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4. STORAGE AND DIVERSION GREYWATER REUSE

Types of irrigation are usually applied for the garden including surface irrigation, sprinkler irrigation, drip irrigation in which surface irrigation is one of the most common forms of irrigation throughout the world. The irrigation water of the surface irrigation method is distributed over the soil surface by gravity. While sprinkler irrigation distributes the water the same rainfall by a system connecting the pump with pipes. With drip irrigation, the water supplies onto the soil at very low rates (2 - 20 L/h) by many small holes close to plants on the pipe. More specifically, the irrigation for plants/ lawn in the garden is usually normal sprinkler, subsurface, on the surface, flood, or hosing methods [15]. Each method has advantages and disadvantages. Based on the type of soil, weather, category of the plant can choose the available method. To avoid human contact with greywater for garden lawn watering, the irrigation method that restricts exposure to air is safe [51]. Sprinkler or spray methods are not recommended for applying greywater for garden lawn watering because many aerosols can contain bacteria and virus easily exposing to the environment [10]. Furthermore, the time interval between consecutive irrigations and dose for irrigation are important factors, which can affect plants and groundwater level.

The following Australian Capital Territory [23], greywater contained a high concentration of organic matter, which must not be stored for more than 1 day as creating odors because of the growth of microorganisms. The raw greywater could transfer to the plant by bucket or siphon. However, treated greywater can be stored for more than one day to irrigate when applying subsurface (underground level 100–300 mm); or soil-surface irrigation (underground level >300 mm) with treated greywater to quality 20 mg/L of BOD_5, 30 mg/L of SS. Covered surface drip, surface irrigation with treated and disinfected greywater is applied to quality 20 mg/L of BOD_5, 30 mg/L of SS, and 10 CFU thermo-tolerant Coliforms per 100/cm^3 [23].

5. REGULATIONS AND GUIDELINES FOR GREYWATER REUSE FOR IRRIGATION

The following F. Shoushtarian et al. [9], more than 70 regulations, guidelines, standards, criteria, and acts were published over the world for agriculture water reuse. The first international guideline for agricultural water reuse was published in 1973 by WHO [10] while a separate standard, guideline, or others for greywater was not popular in many countries on the world. Too recently, some regulations and guidelines that applied greywater for irrigation have issued in Britain, Australia, Jordan, Japan, China, the USA, Germany, India, and Canada [52]. However, some parameters of greywater were showed in regulations as pH, turbidity, faecal bacteria for regulations in the USA, Britain, and Australia while more than parameters were in guidelines of Jordan, China, Canada, and Germany as table 3.

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Table 3: Some regulations and guidelines for greywater reuse over the world

Parameter	Regulations					
	Britain [60]		**US (NSF/ANSI 350-2011) [61]**		**Western Australia [62]**	
	Sprinkler use	**Non-sprinkler use**	**Residential**	**Commercial**	**Irrigation**	**Household**
pH	5-9.5	5-9.5	6-9	6-9	6-9	6-9
BOD$_5$ (mg/L)			<10	<10	<20	<20
Turbidity (NTU)	<10	<10	<5	<2		
Faecal bacteria (MPN/100 ml)	Not detected	25 (E.coli)	0	0	<1	<4
	Guidelines					
	Germany [63]	**Jordan [64]**	**Slovakia [65]**	**China [66]**	**India [67]**	**Canada [68]**
pH	6-9	6-9	7-9	6-9	6-9	7-9
EC (μS/cm)		10000				
BOD$_5$ (mg/L)	20	30-300		10-20	<30	200
COD (mg/L)		100-500	200	<15	<250	280
TSS (mg/L)	~0	50-150	80	15-50	<200	<100
Turbidity (NTU)	~0	2-10		<10		<2
Anionic surfactants (mg/L)		30-100	1	0.5-1	<10	
Sodium (mg/L)		230				
TN (mg/L)		50-70	10	15-20		
TP (mg/L)		30	1	1-5		
Boron (mg/L)		1				
Faecal bacteria (MNP/100mL)	<100 faecal	<1000 faecal				2-200 faecal

Besides, the guidelines for greywater reuse over the world encourage and recommend greywater reuse. Almost all guidelines focus on the effect of greywater reuse on the health risks related to the use of non-treated greywater [52].

6. IMPACTS OF GREYWATER REUSE FOR IRRIGATION

6.1 Human health

A lot of studies are cited that greywater has potential irrigation for plants or lawn in the garden or expanding outside garden. However, it can have some risks for human health because some types of irrigation can make pathogens in greywater disperse into the environment.

Greywater reuse is acknowledged potential benefits for irrigation however greywater may contain pathogens that can affect environmental health if methods are unreasonable. According to Hawaii State Department of Heath [53], greywater contains many contaminants, which can be harmful to human health. Moreover, bacteria can exist and

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develop inside the supply and storage system of greywater. Since, greywater reuse for the lawn in the garden, the golf yard should prevent direct contact. The method of subsurface drip irrigation was suggested in some states of the USA (Arizona, California) [8]. Furthermore, irrigation of greywater needs monitor to avoid leading to runoff, mosquito breeding, affect groundwater, and plants by ponding [53].

A reported study by Maimon [21] shown that kitchen effluent was one of the main factors which created a high pollution level for greywater has the potential risk when its reuse. Furthermore, the study suggested that greywater should be disinfected, or limited contact with air, human such as drip irrigation, wearing gloves when maintenance to reduce the risk for human health [21]. Since greywater reuse must be excluded from kitchen flow, dishwasher reduce many risks.

6.2 Soil

The soil planted can deteriorate when the irrigated water has a high concentration level of Boron (B) and surfactants, which are common in detergents of washing machines, in the long–term [15]. To reduce the risk for soil in greywater reuse that can change by friendly production with environment or dilution with freshwater for reuse for irrigation [54]. The high concentration of surfactants affected the reduction of hydraulic conductivity however it depends on the structure of the soil, surfactant characteristics, and their concentration [55]. Furthermore, according to research results of Wiel-Shafran et al. [56], the capillary force in soil decreased when increasing surfactant concentration because of the reduction of water surface tension.

However, Alfiya et al. [57] conducted a study on ryegrass with three categories of irrigation water as freshwater, light greywater (from shower and washbasin), and treated greywater. The result of the study showed that the soil characteristics and plant (ryegrass) were not impacted harmful, and were no statistically significant differences ($p \geq 0.05$) on applying three categories of irrigation water because the value of SAR, pH, EC, and alkalinity of soil was the same. Furthermore, the study concluded that ryegrass did not detect any signs of phytotoxicity when irrigated light greywater. However, the study found that the surfactant accumulated in the soil planted, causes the soil to become hydrophobic [57]. Indeed, with surfactant-rich greywater (range from 0.7–70 mg/L) irrigated soil increased water repellent soils, and affected to flow and productivity of soils because of surfactant accumulation [56].

The study of Reichman [5] shown that irrigation with greywater from low environmental impact (a detergent marketed as “minimal environmental impact”) laundry detergent or greywater from the standard (a conventional detergent) laundry detergent effected the soil as increasing pH soil, salt build in the soil, enzyme activity, and worm avoidance however greywater from low environmental impact laundry detergent was safer for soil and plant than from standard laundry detergent [5]. Furthermore, the pH, EC, SAR of soil planting tomato and green bean was irrigated with raw greywater increased higher than with treated greywater which is treated by volcanic tuff filter [58].

Similarly, Pinto and Maheshwari [13] have conducted a study on silverbeet (Betavulgari s) with four irrigation regimes including tap water, raw greywater, mixed raw greywater with tap water (1:1 ratio), and irrigating alternate with tap water and raw greywater next time. The result of the study showed that the same as other studies with increasing EC, pH of soil when irrigated with raw greywater, but with irrigating alternate with tap water and raw greywater next time resulted that the change EC and pH was the same value with irrigation water by tap water [13]. This has the potential reducing impact on soil depend on the quality of greywater and the regime of irrigation.

6.3 Groundwater

The potential risk for groundwater is an inevitable consequence because the leaching salts, pathogens, and nutrients from the root-zone can penetrate the groundwater when the soil was irrigated these excesses. The potential risks of groundwater quality depend on soil structure, type of soil, contaminant constituents in the greywater, and dose of irrigation water. Moreover, it depends on the depth of the groundwater table level, which is affected by the time delay because of the dose of irrigation water or rainfall in the area.

Particularly, nitrate (NO_3^-) is a pollutant that is always interested in the quality of groundwater. Nitrate in the wastewater or greywater has a possible impact on groundwater quality when an excess amount is applied to the soil. Indeed, the following result study of Valentina [1] reported that the concentration of nitrate in the area with irrigation wastewater was higher than with irrigation freshwater. Potential leaching nitrate of irrigation water from greywater to groundwater was low in case this source excluded greywater from the kitchen, and urine from the toilet because the total nitrogen of greywater was not high which ranged from 0.6 – 21 mg/L [59]. Also following Valentina [1], leaching salt, boron, and other contaminants to groundwater associated with the quality and method of wastewater reuse for irrigation.

6.4 Yields

Some studies have shown decreasing biomass yield or disease by irrigation greywater while other studies showed that was not different biomass yield (statistically significant at 95% confidence interval) or the health of plant applying irrigation greywater compare to treated greywater or freshwater. The cause of this difference was due to differences in the composition, characteristics, origin of greywater, and the type of crops was observed.

Indeed, decreasing biomass yield was demonstrated in the study of Reichman [5] that the lettuces (disambiguation) were irrigated by the standard greywater from laundry had resulted in the lowest biomass compared to tap water, or nutrient solution, or greywater from low environmental impact laundry detergent. Moreover, lettuces were irrigated with raw greywater, which had negatively affected plant growth, or increased concentration of Cu, Fe in plants [5]. Besides, chlorosis appears on lettuce plants irrigated with raw greywater because of the elevated salinity and Boron levels in the leaves [15].

In contrast, Alfiya [57] conducted the study on ryegrass (Lolium perenne) with three different types of irrigation water including tap water, raw light greywater, treated greywater (effluent of rotating biological contactor). The result showed that raw light greywater did not have detrimental effects on plants. The biomass yield was not different statistical significance (confidence interval 95%) between ryegrass irrigated with tap water and with raw light greywater. However, biomass yield and the growth rate with irrigation of treated greywater from rotating biological contactor was higher than others [57]. Similarly, another study on the silverbeet (Betavulgari s) showed that the biomass yield was no significant differences ($p \geq 0.05$) when having different four categories of irrigation water; with irrigated water were tap water, raw greywater, mixed tap water with raw greywater (1: 1 ratio), and irrigating alternate with tap water and greywater next time [13].

Meanwhile, Al-Zou [58] concluded that different effects on the type of crops were irrigated by raw greywater, treated greywater (outlet of volcanic tuff filter), or tap water. Al-Zou [58] conducted a study on tomato (Lycopersicon esculentum) and green bean (Phaseolus vulgaris) showed that no statistically significant differences ($p \geq 0.05$) with irrigated water were tap water, raw greywater, or treated greywater on number of fruit per pot, the weight of fruit, a circumference of fruit, number of leaves, plant height, and biological yield of tomato. Similarly, the number of beans, number of leaves, and number of branches of green bean were not statistically significant differences ($p \geq 0.05$) however the significant differences ($p \leq 0.05$) was shown on fruit weight, circumference, and biological weight of green bean therein all observed parameters of green bean were the same with irrigation water between treated greywater and tap water [58].

7. CONCLUSION

The review is conducted to provide an overview of the quantity and quality of greywater, potential for reuse, and some problems associated with risks when greywater reuse for irrigation. The review can be concluded following

- The quantity of greywater is different in countries, regions, cultures, living conditions, but greywater always ensure enough irrigation water for the garden in the household; expanding for irrigation in golf yard, park, cemetery, landscape to cope with water scarcity in the arid and semi-arid areas;
- The quality of greywater excluding kitchen and dishwashing does not significantly affect the soil and yield of some plants. However, greywater reuse contains high SAR, and fibres have potential risks for environmental soil when was irrigated for a long time;
- The groundwater, human health, soil have the potential to be affected by greywater reuse for irrigation. However, this effect can reduce or restrict when greywater is treated to achieve a consistent quality; or irrigation is planned and calculated right;

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- Treated greywater, raw light greywater, or greywater from low environmental impact laundry detergent are used for irrigation which shows significantly higher biomass yield than using raw greywater;
- Greywater reuse has to apply for suitable plants to ensure safe, sanitary, aesthetics, and productivity.

The reuse of greywater is crucial in the water scarcity areas and plays an important role in saving and protecting water resources globally. Greywater reuse for efficient irrigation not only the environmental impact is the lowest but also the plants are not affected by decreasing yields. Therefore, the problem that needs to be investigated is to determine the reusability method, level, and method of greywater treatment to maximize efficiency.

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Author Contributions

H.T.N (Ph.D.) wrote and revised the manuscript. C.N.T (Ph.D.) also wrote and revised the manuscript. Contribution of each individual author in this article is equal.

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