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Research Article

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Greywater Sources, Characteristics, Utilization and Management Guidelines: a review

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Abstract
Greywater is defined as a domestic wastewater that is uncontaminated by direct contact with human excreta. Sources of grey water include kitchen sinks, showers, baths, washing machines and dishwashers. Most greywater streams produce effluents high in dissolved contaminants and low in turbidity and suspended solids. As global water resource supplies are worsening and water shortages will affect 2.7 billion people by 2025, resulting in poverty and famine. Reusing greywater is a good way to solve this water shortage problem. As greywater contains fewer pathogens than domestic wastewater (black water), it is safer to handle, easier to treat and reuse onsite for toilet flushing and landscape or for crop irrigation and other non-potable uses. Greywater use in gardens or toilet systems helps to achieve some of the goals of ecologically sustainable development including: (a) reduced freshwater extraction from rivers and aquifers, (b) less impact from septic tank and treatment plant infrastructure, (c) reduced energy use and chemical pollution from treatment plants, (d) groundwater recharge and (e) reclamation of nutrients. However, the biological oxygen demand (BOD), surfactants, oil and grease, detergent residues (nitrogen, phosphorous, sulfate, ammonium, sodium, and chloride) must be considered when handling greywater streams. Several countries have developed guidelines for the reuse of treated greywater to flush toilets and irrigation systems for ornamental garden and lawn watering, depending on the type of grey water and treatment level. Many developed and developing countries have established regulations and guidelines for greywater treatment and reuse. However, some countries have strict rules compared to others. Egypt appears to be a world leader in the treatment and reuse of wastewater and has several laws in place for treatment options and selection of crops to be irrigated with treated wastewater. Given the water shortage in Egypt and the growing population, the government of Egypt imparked on several mega projects of 4-level wastewater treatment throughout the country for use in agricultural production.

Keywords: Greywater, Sources, Utilization, Characteristics, Guidelines for Reuse

Introduction
Greywater is defined as a domestic wastewater that is uncontaminated by direct contact with human excreta. Greywater is a general term used to describe wastewater discharge, excluding domestic wastewater (wastewater from toilets) which would be classified as black water. Sources of grey water include kitchen sinks, showers, baths, washing machines and dishwashers as well as vehicle wash wastewater [1-5]. Some authors excluded wastewater originating from kitchen sinks because of its high content of oil and food particles while other authors excluded carwash water because of its oil and harmful chemicals[6-11].

White water (potable water) becomes grey in color because of its use and introduction of cleaning process residues. This wastewater is categorized as light greywater or dark greywater. Dark greywater may contain high levels of oil and grease. On the other hand, human waste and high food residue produces blackwater or sewage [12]. However, in this document wastewaters originating from kitchen sinks, showers, baths, washing machines, dishwashers and carwash stations are classified as greywater and recognizes the requirement for special attention during treatment. In addition, commercial and office wastewater streams can also be segregated as greywater streams as is the case with vehicle washing stations [13].

Table 1 shows the main sources of greywater and their constituents [13-15]. Table 2 shows the quality characteristics of various greywater sources [16]. Table 3 shows some of the physical, chemical, and biological characteristics of greywater [17-23]. The biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), surfactants, oil and grease, detergent residues (nitrogen, phosphorous, sulfate, ammonium, sodium, and chloride) are of typical concern when handling domestic greywater streams. On the other hand, oil, grease, metal (paint chips), phosphates, detergents, cleaners, surfactants, halogenated hydrocarbons, road salts and other chemicals are of higher concentrations in carwash greywater compared to domestic greywater [11]. Most of domestic waste stream produces an effluent high in dissolved contaminants and low in turbidity and suspended solids. However, carwash effluents May have higher amount of solid grit, but the concentrations of organic pollutants are similar to those of domestic greywater (meaning that the COD: BOD ratio could be as high as 4:1) due to a deficiency of macronutrients available to degrading bacteria [10,11,13,15]. The aim of this study was to examine the characteristics of greywater and its utilization and to review the current guidelines and legislation for managing greywater in various countries

Table 1: Greywater sources and their constituents.

Greywater Source	Constituents
Kitchen	Kitchen greywater contains food residues, high amounts of oil and fat and dishwashing detergents. It may occasionally contain drain cleaners and bleach. Kitchen greywater is high in nutrients and suspended solids. Dishwasher greywater may be very alkaline (due to detergent builders) and it contains high suspended solids and salt concentrations [14].
Bathroom	Bathroom greywater is regarded as the least contaminated greywater source within a household. It contains soaps, shampoos, toothpaste and other body care products. Bathroom greywater also contains shaving waste, skin, hair, body-fats, lint and traces of urine and faeces. Greywater originating from shower and bath may thus be contaminated with pathogenic microorganisms [14].
Laundry	Laundry greywater contains high concentrations of chemicals from soap powders (such as sodium, phosphorous, surfactants, nitrogen) as well as bleaches, suspended solids and possibly oil paints, solvents and non-biodegradable fibers from clothing. Laundry greywater can contain high amounts of pathogens from washing nappies [14].
Carwash	Carwash wastewater contains dissolved, suspended and settleable solids, oil and grease, nitrogen in the form of ammonium and nitrate, phosphorus as well as metals such as antimony, arsenic, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver and zinc [13,15],

Table 2. Quality characteristics of various greywater sources [16].

Greywater Source	Characteristics
Washing Machine	Contains bleach, foam, grease and oil, nitrate, phosphate, soaps, sodium and suspended solids. It has high pH, salinity, and turbidity.
Dish Washer	Contains bacteria, foam, food particles, oil and grease, organic matter, soaps, suspended solids. It has high pH, turbidity, salinity and high oxygen demand.
Bath and shower	Contains bacteria, oil and grease, soaps, suspended solids, hair and hot water. It has odor and turbidity and high oxygen demand.
Sinks (washroom and Kitchen)	Contains bacteria, food particles, oil and grease, organic matter, soaps, suspended solids and hot water. It has odor, turbidity and high oxygen demand.

Table 3. Some characteristics of greywater reported in different studies.

Parameter	Scheumann et al. [17]	Jefferson et al. [18]	Nolde [19]	Friedler et al. [20]	Burnat and Mahmoud [21]	Gross et al. [22]	Dallas et al. [23]
pH	6.3-7.1				6.7-8.4	6.3-7.0	
Turbidity (NTU)	85				619	32	29
Conductivity (µS/cm)	664-1046				1585	1040-2720	400
Oil and Grease (Mg/L)	7						
BOD (mg/L)	37-69	59-149	50-100	95	590	280-690	167
COD (mg/L)	101-143	92-322	100-200	270	1270	700-980	
BOD/COD	0.36-0.48	0.46-0.64	0.50-	0.35	0.46	0.4-0.70	
TSS (mg/L)			1389		1396	85-286	
TDS (mg/L)			573			102	
TN (mg/L)	11-22	9.6	5-10			25-45	
TKN (mg/L)	9.5-14.3	0-8		11		0.1-0.5	
NH_4-N (mg/L)	4.1-9.1			2.7	3.8	17-27	
NO_3-N (mg/L)	0-1.8			0.24			
TP (mg/L)	0.45-1.5	0-7	0.2-0.6				
PO_4-P (mg/L)	0.6-1.4				4.4		16
BOD/NH_4-N/PO_4-P	1/.06/.001-1/.13/.02				1/.006/.007		
Mg (mg/L)		0.11					
Ca (Mg/L)		0.13					
Na (mg/L)	32-35						
Cl (mg/L)	53						
FC(CFU)	$(1.2\text{-}3.6)10^3$		1-10		3.1x104	$5x10^5$	$1.5\text{-}1.6x10^4$

Greywater Utilization

According to United Nations report on water availability, global water resource supplies will continue to worsen, and water shortages will affect 2.7 billion people by 2025. This means 1 out of every 3 people in the world will be affected by the water shortage problem which will result in poverty and famine [24].Therefor, reusing greywater appears to be a good way to solve this water shortage problem [14]. As grey water contains fewer pathogens than domestic wastewater (black water), it is generally safer to handle and easier to treat and reuse onsite for toilet flushing and landscape or for crop irrigation and other non-potable uses [15-22].

The application of grey water reuse in urban setting provides substantial benefits for both the water supply system by reducing the demand for fresh clean water, and for the wastewater system by reducing the amount of wastewater required to be conveyed and treated [23,25]. Greywater use in gardens or toilet systems helps to achieve some of the goals of ecologically sustainable development. These goals include: (a) reduced freshwater extraction from rivers and aquifers, (b) less impact from septic tank and treatment plant infrastructure, (c) reduced energy use and chemical pollution from treatment plants, (d) groundwater recharge and (e) reclamation of nutrients [26].

Several studies have shown that greywater use for irrigation or toilet flushing appears to be a safe practice and no additional burden of disease were observed among greywater users for irrigating their lands[27-30]. A few organic micropollutants were found in greywater at very low concentrations. Peripheral pathogens (from skin and mucous tissue) and food-derived pathogens are the major sources of pathogens in greywater. However, depending on the levels of pathogens, organic matter, chemical content and turbidity, greywater can be classified into various categories. Each level maintains the potential risk of these contaminants, only at different concentrations. Therefore, when considering treatment methods, the contaminants and their concentrations must be accounted for when designing a greywater recovery and reuse system.

Physical Characteristics of Greywater

Generation Rate

The analyses of greywater will be frequently compared to blackwater, as there is a large database available for blackwater. In an average residence, greywater can account for 50-80% of the total wastewater [31]. This value would fluctuate depending on the source of its use as shown in Table 4 [5,14, 32-42]. Even within a given residence, the number of occupants, demographic, and personal habits can cause noticeable shifts from the expected production level [6,22].

Temperature

Temperature plays a key role in all chemical and biochemical reactions. Temperature affects the activity of all organisms and the microbial activity needed for biological degradation processes. Water temperature affects the growth and diversity of biota inhabiting water courses a temperature of 20 °C is considered ideal for most biological reactions. Also, many of the functions and tests (BOD5, COD, DO, pH, EC and total bacterial count) are synchronized and measured with temperature [43].

Greywater temperature varies within the range of 18–30 °C which is higher than that of clean water. The high temperature is attributed to the use of warm water for personal hygiene and cooking. It is, however. not critical for biological treatment processes such as aerobic and anaerobic digestion which occur within the range of 15–50 °C, with the optimal being within the range of 25– 35 °C. On the other hand, higher temperatures can cause increased bacterial growth and decreased CaCO3 solubility, causing precipitation in storage tanks or piping systems [44].

Table 4. Greywater generation rates reported in different studies.

Location	Generation (L/p/d)	Reference
Jordon	50	Al-Hamaiedeh and Bino [32], Halalsheh et al. [33], Faraqui and Al-Jayyousi [34]
Africa (Several Countries)	50-160	Morel and Diener [14]
Asia (Several Countries)	72–225	Morel and Diener [14]
South America (Several Countries)	50-170	Morel and Diener [14]
Arizona, USA	123	Casanova et al. [35]
Australia	113	Morel and Diener [14]
Israel	98	Friedler [36]
Malaysia	225	Martin [37]
Mali	30	Alderlieste and Langeveld [38]
Nepal	72	Shresta [39]
Oman	151	Jamrah et al. [40]
South Africa	20	Adendorff and Stimie [41]
Stockholm	65	Ottoson and Stenstrom [5] x
Vietnam	80–110	Busser et al. [42]

Solids

Total solids (TS) in wastewater are made of dissolved solids (DS), suspended solids (SS) and settleable solids (SeS). Higher levels of total solids in water bodies will: (a) make drinking unpalatable and might have an adverse effect on people health, (b) affect water clarity and decrease the passage of light through water which will slow photosynthesis by aquatic plants, (c) make water to heat up more rapidly and hold more heat which might adversely affect aquatic life and (d) reduce the efficiency of water treatment plants. Dissolved solids consist of chlorides, fluoride, calcium, magnesium, sodium, potassium, iron, nitrate, sulfate, phosphate, carbonate, bicarbonate, organic acids, and other particles that will pass through a filter with pores of 2 microns in size. Suspended solids include soil particles, fine organic debris, and other particulate matter that will not pass through a 2-micron filter. Higher concentrations of suspended solids can: (a) serve as carriers of toxic substances, which readily cling to suspended particles and (b) clog irrigation devices. Settleable solids are those solids that will settle to the bottom of an Imhoff cone in 60 minutes. The test is useful for determining the amount of solid entering a wastewater treatment plant, as well as for estimating the amount of sludge to be expected during the treatment process. Although this settling improves water clarity, the increased settling solids in a water body can smother benthic organisms and eggs [43 45,46].

Food, oil and soil particles from kitchen sinks, hair from bath and non-biodegradable clothing fibers (polyester, nylon, polyethylene) from laundry can lead to high solid content in greywater which cause turbidity and may result in clogging of pipes, pumps and filters used in the treatment processes. Also, powdered detergents and soaps as well as colloids are the main reasons for physical clogging. Katukiza et al [47]. reported total solid values for laundry, bathroom and kitchen effluents of 168, 92 and132 g/p/d, respectively. Suspended solids concentrations in greywater are within the range of 50–300 mg/L but can be as high as 1,500 mg/L in isolated cases [31,40,48].

Suspended solids concentrations strongly depend on the amount of water used and the highest concentrations of suspended solids are typically found in kitchen and laundry greywater. Studies on greywater from several countries (Nepal, Malaysia, Israel, Vietnam, and the United States) revealed average suspended solids loads of 10–30 g/p/d, contributing to 25–35% of the total daily suspended solids load in domestic wastewater [10].

Electrical Conductivity

The conductivity of water refers to the ability of water to conduct an electrical current. Because the electrical current is transported by the ions in solution, the conductivity increases as the concentration of ions increases in the solution. Therefore, the electrical conductivity (EC) indicates how much dissolved substances, chemicals, and minerals are present in the water. When chemicals and salts dissolve into the water, they will turn into negatively charged and positively charged ions. The positively charged ions include potassium, magnesium and sodium whereas the negatively charged ions include carbonate, bicarbonate, chloride, nitrate, phosphate and sulfate. Higher amounts of these impurities lead to a higher EC [43].

The values reported in the literature for electrical conductivity for greywater are within the range of 14-3000 μS/cm [49-51]. Kotut et al. [512 reported electrical conductivity values for greywater in Kenya in the range of 483-826 μS/cm. Oteng-Peprah et al [52]. reported electrical conductivity average values for greywaters of 23.7, 64.5 and 23 μS/cm in UK, Germany and USA, respectively. Scheumann et al [17]. reported electrical conductivity values for greywater in Morocco in the range of 464-1046 μS/cm. Burnat and Mahmoud reported an average electrical conductivity value of 1585 μS/cm for greywater in Jordan. Gross et al [21, 22]. reported electrical conductivity values in the range of 1040-2720 μS/cm for greywater in Israel. Dallas et al [23]. reported an electrical conductivity value of 400 μS/cm for greywater in Costa Rico.

Turbidity

Turbidity is the measure of relative clarity of a liquid. Material that causes water to be turbid include clay, silt, inorganic and organic matter, algae, dissolved colored organic compounds, plankton and other microscopic organisms. At no time can turbidity of water go above 5 nephelometric turbidity units (NTU). High turbidity can: (a) reduce the aesthetic quality of rivers, lakes and streams which result in harmful impact on recreation, (b) increase the cost of water treatment for drinking and food processing, and (c) harm fish and other aquatic life by degrading spawning beds, affecting gill function, killing fish or reducing their growth rate and reducing their resistance to disease [54]. Discharge of greywater into water courses can cause turbidity and as a result affect the quality of water.

Oteng-Peprah et al [53]. reported turbidity values for greywaters of 85 NTU in Niger, 619 NTU in Yemen, 31 NTU in USA, 20 NTU in Spain, 29 NTU in Germany and 26-164 NTU in UK. Merz et al [55]. reported a turbidity value of 29 NTU for greywater in Morocco. RTC reported turbidity values in the rang of 20-200 NTU for greywater in Egypt [56].

Oil and Grease

The oil and grease concentrations in greywater depends on its source. Greywater may contain high concentrations of fate and grease (cooking grease, vegetable oil, food grease) coming from kitchen sinks and dishwashers. Oil and grease concentrations ranging between 37 and 78 mg/L and 8–35 mg/L 8–35 mg/l have been observed in bathroom and laundry greywaters, respectively [50]. The oil and grease content of kitchen greywater strongly depends on the cooking and disposal habits of each household. Values as high as 230 mg/L were observed by Al-Jayyousi in Jordan for mixed greywater from a household [6]. Also, concentrations ranging between 1,000 and 2,000 mg/L were reported by Crites and Tchobanglous for a restaurant greywater.

Tilley et al [58]. reported that inclusion of kitchen basin water and dishwasher water could substantially increase the oil and grease load to 90%. As soon as greywater cools down, grease and fat congeal and can cause mats on the surface of settling tanks, on the interior of pipes and other surfaces which may cause the need to shut down the treatment process. Busgang et al [39]. stated that it is necessary to keep oil and grease in greywater below the acceptable level of < 30 mg/L. However, most greywater reclamation systems require this waste stream to be separately directed to blackwater collection as it is damaging to agricultural soil [8, 16,17,60].

Chemical Characteristics of Greywater

pH and Alkalinity

pH is a measure of how acidic or basic water is. The range goes from 0 to 14, with 7 being neutral. A pH of less than 7 indicate acidity and a pH of greater than 7 indicates a base. The pH of water is a very important measurement of water quality. Most aquatic creatures prefer a pH range of 6.5-9.0, though some can live in water with pH levels outside of this range [16]. A slight change in the pH of water can increase the solubility of phosphorus and other nutrients, making them more accessible for plant growth. With more accessible nutrients, aquatic plants and algae thrive, increasing the demand for dissolved oxygen and creating eutrophication (an environment rich in nutrients and plant life but low in dissolved oxygen concentration) in which other organisms living in the water will become stressed [18.61].

pH levels of greywater fluctuate depending on its source. A higher level of oil and grease may lower the pH levels to 5.7-7.6. Also, pH levels would be in the alkaline range if detergents were in excess as the case with laundry greywater streams. For this reason, it is critical to properly align the greywater source to an appropriate use to achieve the best management plan [2,40,61].

Scheumann et al [17]. reported pH values for greywater in Morocco in the range of 6.3-7.1. Burnat and Mohamed reported pH values for greywater in Palestine in the range of 6.7-8.4. Gross et al [21, 22] reported pH values for greywater in Israel in the range of 6.3-7.0. Kotut et al [52]. reported pH values for greywater in Kenya in the range of 7.1-9.5. Lamine et al [62]. reported pH values for greywater in the range of 7.5-7.9. RTC reported pH values for greywater in Egypt in the range of 6.6-8.7. Oteng-Peprah et al [53,56]. reported pH values of 7.3-8.1 for greywater in India, 6.2 for greywater in Pakistan, 6.9 for greywater in Niger, 6.0 for greywater in Yemen, 6.4 for greywater in USA, 6.6-7.6 for greywater in UK, 7.6 for greywater in Spain and 7.6 for greywater in Germany.

Heavy Metals

Domestic graywater my contain several ions including sodium, calcium, magnesium, chlorine and boron. Detergents are the main sources of these ions in greywater. These ions can cause water hardness, soil salinity, high sodium adsorption ratio and plant toxicity.

Hardness

Hard water is water that has high mineral content. The permanent hardness of water is determined by the concentration of multivalent cation in the water. Multivalent cations are positively charged metal complexes with a charge greater than 1+. Usually, the cations have the charge of 2^+ such as Ca^{2+} and Mg^{2+} [63]. Permanent hardness is usually caused by the presence of calcium sulfate/calcium chloride and magnesium sulfate/magnesium chloride. The following equilibrium reaction describes dissolving and formation of calcium carbonate and formation of calcium bicarbonate:

$$CaCO_3\,(s) + CO_2\,(aq) + H_2O\,(l) \rightleftharpoons Ca^{2}+\,(aq) + 2\,HCO_3-\,(aq) \quad [1]$$

Graywater containing dissolved carbon dioxide that can react with calcium carbonate and carry calcium ions away with it. The calcium carbonate may be re-deposited as calcite and the carbon dioxide is lost to atmosphere. Calcium and magnesium ions can sometimes be removed by water softeners but permanent hardness is generally difficult to remove by boiling [64].

Temporary hardness is also caused by the presence of dissolved bicarbonate minerals (calcium bicarbonate and magnesium bicarbonate). When dissolved, these types of minerals yield calcium and magnesium cations (Ca^{2+}, Mg^{2+}) and carbonate and bicarbonate anions (CO_3^{2-} and $HCO-_3$). The presence of the metal cations makes the water hard. However, unlike the permanent hardness caused by sulfate and chloride compounds, this temporary hardness can be reduced either by boiling or by the addition of softener (calcium hydroxide) [64]. Boiling promotes the formation of carbonate from the bicarbonate and precipitates calcium carbonate out of solution, leaving water that is softer upon cooling [65].

$$2\,HCO_3- \rightarrow CO_3^{2}- + CO_2 + H_2O \quad [2]$$
$$CO_3^{2}- +Ca^{2+} - \rightarrow CaCo_3 \quad [3]$$

Untreated hardwater can not be reused for car washing. With hard water, soap solutions (cleaning detergent) form a white precipitate (scum) instead of producing lather or foam, because the 2^+ ions destroy the surfactant properties of the soap by forming a solid precipitate (the soap scum). A major component of such scum is calcium stearate which arises from sodium stearate (main component of soap):

$$2\,C_{17}H_{35}COO^-\,(aq) + Ca^{2+}\,(aq) \rightarrow (C_{17}H_{35}COO)_2Ca\,(s) \quad [4]$$

Thus, hardness can be defined as the soap-consuming capacity of a water sample, or the capacity of precipitation of soap as a characteristic property of water that prevents the lathering of soap. It must be noted that synthetic detergents do not form such scums. Hard water also forms deposits ($CaCO_3$, $Mg(OH)_2$ and $CaSO_4$) called scale that clog plumbing [63, 66]. The resulting build-up of scale restricts the flow of water in pipes [65].

It is, therefore, desirable to soften hard greywater. Most detergents contain ingredients that counteract the effects of hard water on the surfactants. For this reason, greywater softening is often unnecessary to prevent or delay inefficiencies and damage due to scale formation in equipment [7]. A common method for water softening involves the use of ion exchange resins (which replace calcium ions by twice the number of mono cations such as sodium or potassium ions) or washing soda (Na_2CO_3) which has long been used as a water softener for domestic laundry, in conjunction with the usual soap or detergent [65].

Salinity

Greywater contains salts as indicated by electrical conductivity (EC). Electric conductivity measures all ions dissolved in greywater including negatively charged ions (Cl^-, NO_3^-) and positively charged ions (Ca^{++}, Na^+). The most common salt is sodium chloride (conventional table salt). Important sources of salts are sodium-based soaps, nitrates and phosphates present in detergents and washing powders. Another source of sodium chloride is the road salt spread in winter in cold climate countries. The electrical conductivity of greywater is typically in the range of 300-1500 µS/cm [17, 21, 23]. A higher value of 2700 µS/cm was also reported [22].

Salinity of greywater can become a hazard when greywater is reused for irrigation. The effect of salt in greywater and its reuse for irrigation were discussed by several authors [12, 26-30, 32]. High electric conductivity of irrigation water can considerably reduce yield [12]. This problem can be overcome by choosing more salt-tolerant plants when using greywater with high electric conductivity for irrigation.

Aside from the immediate effects on the crop, there is a long-term impact of salt loading of the soil. Use of saline greywater for irrigation over a longer period may lead to increased salinization of the topsoil [29]. This problem occurs especially in clay and loamy soils with low percolation rates and in arid regions with high evaporation rates.

Therefore, permissible electric conductivity limits of greywater are strongly dependent on crop type, soil characteristics and weather conditions. However, the suggested limits vary in the literature. Al-Hamaiedeh et al [32]. and Grattan suggested a maximum electric conductivity below 1300 µS/cm and indicated that irrigation with more saline greywater requires well functional drainage system and use of salt tolerant plants. Bauder et al [67, 68]. suggest conductivity limits for greywater irrigation up to 3000 µS/cm with an optimum electric conductivity below 750 µS/cm.

Sodium Absorption Ratio

While electric conductivity determines all soluble salts in greywater, the sodium hazard is defined separately due to its detrimental effect on the soil physical properties. The sodium hazard is indicated as the sodium adsorption ratio (SAR) which is the ratio of sodium ion (Na^+) to calcium (Ca^+) and magnesium (Mg^{++}) ions. SAR values for greywater depend mainly on the quantity of detergent powders used. Sodium salt is usually used as filler in laundry detergents. Friedler reported a sodium concentration of 530 mg/L in laundry greywater stream. A typical SAR value for greywater is in the range of 2-10. [28,36, 69]. However, Patterson reported a SAR value exceeding 100 for some powder detergents[70].

Sodium is of special concern when applied to loamy soils poor in calcite or calcium/magnesium. High SAR may result in the degradation of well-structured soils (dispersion of soil clay minerals), thus limiting aeration and water permeability. The sodium hazard can best be avoided by using low sodium products such as liquid laundry detergents. European and North American countries recommend irrigation water with SAR < 15 for sensitive plants [71]. However, Patterson [701 observed hydraulic conductivity problems in Australian soils irrigated with greywater with a SAR value > 3.

Plant Toxicity

Grey water may contain metal compounds in high concentrations that can be toxic to plants when used untreated for irrigation. Although several elements are essential micronutrient for plants, excessive amounts are toxic. Uptake of heavy metals by plants and subsequent accumulation along the food chain is a potential threat to animal and human health. For human and animals, it can affect the central nervous function leading to mental disorder, damage the blood constituents, lungs, liver, kidneys, and other vital organs, thereby promoting several disease conditions. Also, heavy metal overload has inhibitory effects on the development of aquatic organisms (phytoplankton, zooplankton, and fish). The metallic compounds could disturb the oxygen level and mollusks development, byssus formation, as well as reproductive processes [72-74].

Gross et al [22]. indicated that using greywater for crop irrigation may result in toxicity problems if boron ions are taken up by plants and accumulate to concentrations high enough to cause crop damage or reduced yield. They observed boron concentrations reaching 3 mg/L in laundry greywater. The recommended maximum value of boron for irrigation water is 1.0 mg/L for sensitive crops such as lemon, onion and bean [67].

Tao et al [75]. assessed the distribution and bioaccumulation of heavy metals in aquatic organisms of different trophic levels and the potential health risk. Heavy metals (Cu, Zn, Cr, Ni, Cd, Pb) were measured in phytoplankton, zooplankton, two species of zoobenthos, and eight fish species as well as in the water column and bottom sediments of Taihu lake in China. The results showed that the concentrations of Cu and Zn for all organisms were much higher than for other metals, and Cd was the lowest in all species. Generally, heavy metal concentrations in phytoplankton were higher than in zooplankton. In zoobenthos, the concentration in *Bellamya sp.* (human edible snail) was higher than that in *Corbiculidae* (bivalve). Metal concentrations had no significant difference between fish species but tended to be higher in predator fish such as *Coilia ectenes and Erythroculter ilishaeformis* than in herbivorous fish.

Surfactants and Other Substances

Synthetic surfactants are components of household and industrial detergents [76]. Surfactants are organic chemicals that are adsorbed at the interface between air and water or at the interface between oil and water in the case where water is mixed with oil. In recent years, surfactants have widely been used in many industries and daily life for their interfacial functional capabilities. Carwash wastewaters have been reported to contain significant concentrations of surfactants [77].

Surfactants are organic chemicals altering the properties of water. They consist of a hydrophilic head and a hydrophobic tail that lower the surface tension of water to allow the cleaning solution to wet surfaces (clothes, dishes and other surfaces) more rapidly. Surfactants emulsify oily stains and keep oil dispersed and suspended in water and not settle back on the surface [30,60,78].

The most common surfactants used in household cleansing chemicals are linear alkylbenzene sulfonate (LAS), alcohol ether sulphate (AES) and alcohol ethoxylate (AE). Although non-biodegradable surfactants have been banned in in most Western countries in the 1960s, these environmentally problematic organic chemicals are still used in many developing countries such as Pakistan and Jordan [62, 79]. Laundry and automatic dishwashing detergents are the main sources of surfactants in greywater. Other sources of surfactants include personal cleansing products and household cleaners.

The concentration of surfactants present in greywater is strongly dependent on the type and amount of detergent used. Several studies reported surfactant concentrations in greywater in the range of 1-60 mg/L with an average of 17–40 mg/L. The highest concentrations were observed in greywater originating from laundr, shower and kitchen sink [18,35,80].

There are many conflicting reports in the literature on the fate and impact of surfactants on the natural environment. While some studies indicate full biodegradation of common surfactants in aerobic environments such as aerobic treatment systems and unsaturated soils, other studiesindicated a potential accumulation of surfactants in greywater-irrigated soil, leading to a reduction in capillary rise and build-up of hydrophobic soils[18,77-81].

Additional substances of concern in greywater are bleach, disinfectants and solvents. Inhibition of the biological process by bleach begins at a concentration as low as 1.4 ml/L, with a substantial inhibition occurring at a concentration of 3 ml/L. Using environmentally friendly household chemicals and refraining from pouring hazardous substances such as paint and solvents into the sink can significantly reduce the levels of toxic substances in greywater low [80].

Biological Characteristics of Greywater

Greywater is frequently represented as a cleaner stream than blackwater. However, for public safety, it should be treated with the same methods used for treating black water as its constituents are similar, only lower in concentration. Greywater contains biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), surfactants, organic contaminants (oil and grease), detergent residues (nitrogen, phosphorous, sulfate, ammonium, sodium, and chloride) which are of typical concern when designing a biological treatment process.

COD and BOD

The biological oxygen demand (BOD) is an important parameter for determining the amount of biodegradable organic pollutants in water by measuring the amount of oxygen required to break down these organic substances by microbial reactions. The BOD test has the widest application in measuring waste loadings of treatment plants and in evaluating treatment efficiency. BOD is a definitive indicator of the required treatment of wastewater and estimating BOD is an important part of wastewater treatment process control. BOD testing uses microorganisms that consume oxygen while feeding on the organic compounds in a wastewater sample over a five-day period. While this test is a good model of the aerobic waste treatment process, in some cases the microorganisms can become poisoned by toxic substances in the untreated wastewater. However, the the five-day BOD test does not provide the real-time information necessary to make process control decisions [16,18, 43,45,46].

The chemical oxygen demand (COD) is a measurement of the amount of oxygen required to break down pollutants (organic substances) in water by chemical reactions. Many wastewater treatment facilities use COD test to estimate BOD level as the COD is complete in two hours and the reproducible COD result correlates with BOD. Toxic materials in the sample do not affect the oxidant, so the COD test is a good indicator of organics in industrial wastewater containing heavy metals and cyanides. COD testing assesses all chemically oxidizable substances and can be directly related to the true oxygen demand imposed by the effluent if released into the environment. Because each organic compound differs in the amount of oxygen necessary for complete oxidization, the COD test reflects the effect of an effluent on the receiving stream more directly than the measurement of carbon content [46,83].

The BOD:COD ratio is an important tool in evaluating wastewater treatment. The ratio of BOD:COD indicates the biodegradability of organic materials in wastewater. A high BOD:COD ratio indicates that the organic compounds are easily oxidized. A shift in the BOD:COD ratio in the influent means a change in the type of organic compounds entering the system, which can impact the effectiveness of the process. Discharge of a wastewater high in BOD:COD ratio into water bodies will have serious health and environmental problems [60,10, 81].

Nutrients

Greywater normally contains low levels of nutrients compared to toilet wastewater [17,20-22]. Nonetheless, nutrients such as nitrogen and phosphorous are important parameters given their fertilizing value for plants, their relevance for natural treatment processes and their potential negative impact on the aquatic environment. The high phosphorous contents sometimes observed in greywater can lead to algae growth in receiving water [17,46].

Levels of nitrogen in greywater are relatively low (urine being the main nitrogen contributor to domestic wastewater). Kitchen wastewater is the main source of nitrogen in domestic greywater. The lowest nitrogen levels are observed in bathroom and laundry greywater. The nitrogen in greywater originates from ammonia and ammonia-containing cleansing products as well as from proteins in meats, vegetables, protein-containing shampoos and other household products [40]. Typical values of nitrogen in mixed household greywater are found within the range of 0.5–50 mg/L with extreme values of 76 mg/L reported by Siegrist et al [2,17,18,22,44]. in kitchen greywater.

In countries where phosphorous-containing detergents have not been banned, dishwashing and laundry detergents are the main sources of phosphorous in greywater. Average phosphorous concentrations are typically found within the range of 0.6–16 mg/L in regions where non-phosphorous detergents are used [2,17,21]. However, they can be as high as 45–280 mg/L in greywater from households where phosphorous detergents are utilized, as observed in Israel and Thailand [48,72].

Biodegradability

The readily biodegradable proportion of greywater (expressed as the ratio BOD:COD) and the microbial nutrient available in greywater (expressed as the ratios COD:NH4-N:PO4-P) can result in deterioration of greywater during storage resulting in production of odor. The ratio of BOD:COD reported in the literature for greywater varied between 0.25 and 0.44 [2,20,33,62]. The average ratio of COD:H4-N:PO4--P reported in the literature is typically 100:5:1 for domestic wastewater [41]. Kargi and Uygur [84) reported an optimum COD:NH4-N:PO_4-P ratio of 100/3.33/0.7 for a maximum nutrient removal in the activated sludge process. Jefferson et al [18]. reported a higher COD:NH_4-N:PO4-P ratio of 1030/2.7/1 for greywater. indicating a macro-nutrient limitation. The high concentrations of detergents in grey water are known to be slowly biodegraded.

Microbes

Greywater usually contains some traces of excreta that come from bathing (washing the anal area in the bath and shower) or from the laundry (washing underwear and diapers). Table 5 shows the concentration of microbes reported in the literature [33,85-98]. However, the small traces of faces that enter the grey water stream via effluent from the shower, sink, or washing machine do not pose practical hazards

Table 5: Microbial contamination of greywater.

Microorganism	Concentration (counts/100 mL)	References
Total coliforms	From 1.2×10^3 To 8.2×10^8	Alsulaili et al. [85], Dwumfour-Asare et al. [86], Mandal et al. [87], Masi et al. [88] Oteng-Peprah et al. [89].
E. coli	Up to 6.5×10^6	Masi et al. [88], Oteng-Peprah et al. [89], Atanasova et al. [90]; Friedler et al. [91], Khalaphallah and Andres [92], Kim et al. [93], Paulo et al. [94].
Faecal coliforms	Up to 1.0×10^6	Halalsheh et al. [33], Mandal et al. [87].
Pseudomonas aeruginosa	Up to 1.4×10^4	Benami et al. [95], Khalaphallah and Andres [92].
Staphylococcus aureus	From 1.2×10^2 To 1.8×10^3	Kim et al. [93], Benami et al. [95], Maimon et al. [96], Shoults and Ashbolt [97].
Salmonella typhi	Up to 5.4×10^3	Kim et al. [93].
Salmonella spp.	Up to 3.1×10^3	Oteng-Peprah et al. [89].
Legionella pneumophila		Blanky et al. [98]

Under normal conditions [18,25]. However, the quality of grey water can deteriorate rapidly during storage because it is often warm and contains some microbes and nutrients (organic matter such as dead skin cells). This will lead to odor nuisances [44].It should be noted that introducing greywater to irrigation or landscaping fields, toilet flushing, infrastructure fittings, care washing, or groundwater recharge could result in unintended damage if the composition and concentration of its constituents are not identified properly. Failure to recognize this may create hazards or additional costs that challenge the benefits of recovery. For example, using greywater for car washing, consideration to health from aerosolization via washing nozzles, corrosion of fixtures and residues remaining on the vehicle surface would specify certain greywater characteristics to be inappropriate for reuse [5,11,35]. Therefore, concern with chemical and biological contaminants when using greywater for car wash is of high priority. Surface transfer of microorganisms from vehicles washing, hand washing in sinks, or proliferation of organisms during storage could provide a mechanism of transfer to receiving consumers of greywater [1,52].

The risk to human health by pathogens is dependent on the species population size and the nature of their infection in humans [5,23]. Successful reproduction of pathogenic bacteria, fungus and protozoa occurs under warmer conditions where biodegradable matter is available as nutrient in greywater [52,60]. Greywater stored under warm temperature conditions for longer than 24 h is not recommended for safe use. After this time, opportunistic pathogens (*Pseudomonas aeruginosa, Aeromonas spp*.) and biofilm growth (*Legionella spp., Mycobacterium avium*) occurs in stagnant water. Furthermore, some pathogens such as E. coli (bacterial indicator of coliform organisms) and other coliforms endure long periods under unfavorable conditions [5,95-99].

Identifying microorganisms within greywater effluent must be classified into three different areas in order to correlate with various infection risks. Coliforms typically indicate the presence of fecal – oral contamination by bacteria, including *Campylobacter jejuni, Shigella spp., Salmonella spp.*, as well as *E. coli.* Protozoa and viruses are more difficult to inactivate by standard removal and disinfection and must be referenced by indicator species within their own classifications. Norovirus, hepatitis A or E, rotavirus, and enteroviruses (poliovirus, echovirus) are common enteric virus species to be cautious of. Waterborne protozoan pathogens include *Cyclospora cayetanensis, Giardia lamblia, and Cryptosporidium parvum*, the latter of which is a good indicator species because of its especially high chlorine resistance. Microscopic helminth eggs of macro parasites also cause waterborne infections but are of limited concern within the climate and living standards of Canada [12,37].

Greywater Use Guidelines in Some Developed Contries

Canadian Guidelines

Although Canada is a water-rich country, it freezes in the winter and droughts happen in summers. There are locations in some municipalities where watering outdoors is restricted during the dry summer periods. At present, the standards for grey water reuse are not strict compared with other countries. The National Plumbing Code, which is adopted in whole or in part by the provinces, indicates that non-potable water systems should only be used to supply toilets and underground irrigation systems. Collecting rainwater with roof gutters is included as a form of grey water [100].

Health Canada has published a guideline to use grey water for toilet flushing [99]. These guidelines are not mandatory at this time, but the Canada Mortgage and Housing Corporation (CMHC) has endorsed these guidelines with the view that these may become federal regulations in the future [101]. CMHC has developed standards for water reuse and has two approaches for treatment goals. The first standard is two tiered and distinguishes between low risk and high-risk applications. The second standard is single tiered with one standard for water reuse in toilet flushing. Because of the potential for direct contact, vehicle washing is considered high risk.

The CMHC report compared the standards to worldwide standards and the following conclusions were made: (a) only 10 percent of the international standards had the same or higher BOD concentration adopted, (b) the high-risk standard for TSS concentration adopted was within the 10 per cent of the international standards, (c) no international standards that have lower turbidity levels, (d) no international standards that have lower total or fecal coliform and (e) no international standards that have lower residual chlorine requirements [101].

Out of the ten provinces (Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland and Labrador, Nova Scotia, Ontario, Prince Edward Island, Quebec and Saskatchewan) and three territories (Northwest Territories, Nunavut and Yukon) in Canada, there are six provinces (British Columbia, Alberta, Saskatchewan, Manitoba, Prince Edward Island and Ontario) that permit water reuse [101]. British Columbia has the only standards that divide the reuse application into high or low risk as shown in Tables 6 [102]. The Prairie Provinces (Alberta, Saskatchewan, Manitoba) all permit reuse for crop irrigation [103-105]. Prince Edward Island allows golf course irrigation with preauthorized approval on a case-by-case basis [106]. Ontario does not have any specific guidelines but issues a Certificate of Approval for disinfected effluent for irrigation on a case-by-case basis [107]. Nova Scotia does not have specific legislation to deal with grey water disposal or reuse and wastewater treated on-site is legislated and has regulations set out in the On-Site Sewage Disposal Systems [108]. The province treats the disposal of greywater as any other wastewater (human waste or wastewater) emitted from a building, dwelling or structure which includes wastewater from ablutions, culinary activities, or laundering[109]. Section 5 of the Nova Scotia Guidelines for Wastewater Disposal addresses the design of systems intended for residential flows in excess of 1500 L/day. However, municipalities have the option to develop their wastewater management and by-laws that can provide a mechanism forcontinued on-site septic system management.

USA Guidelines

Greywater by legal definition is considered in some jurisdictions to be sewage (all wastewaters including grey water and toilet waste), but in the U.S. States that adopt the International Plumbing Code, it can be used for subsurface irrigation and for toilet flushing, and in States that adopt the Uniform Plumbing Code (UPC), it can be used in underground disposal fields that are used as shallow sewage disposal fields. UPC is a model code developed by the International Association of Plumbing and Mechanical Officials (IAPMO) to govern the installation and inspection of plumbing systems as a means of promoting the health, safety and welfare of the public. The UPC is developed using the American National Standards Institute (ANSI) consensus development

Table 6: British Columbia two-tier testing protocol water reuse standard [102].

Parameter	Low Risk*	High Risk+
BOD (mg/L)	≤ 30	≤ 10
TSS (mg/L)	≤ 30	≤ 10
Turbidity (NTU)	≤5	≤ 2
Cl residual (mg/L)	0.1-1.0	-
Fecal Coliform (CFU/100 mL)	≤ 200	< 1
E. Coli (CFU/100 mL)	≤200	<1
Total Coliforms (CFU/100 mL)	-	≤ 23

*Toilet flushing and subsurface irrigation
+Landscape

+Landscape procedures, a process that brings together volunteers representing a variety of viewpoints and interests to achieve consensus on plumbing practices [110].

The USA has a great number of States with individual standards and guidelines. All the states' standards and guidelines meet the United States Environmental Protection Agency (USEPA) standards as a minimum. The California's Title 22 has been adopted by the USEPA for federal guidelines. The State of Wyoming allows surface and subsurface irrigation and other non-specific use of greywater under the Department of Environmental Quality Policy enacted in 2010. The States of California, Utah, Arizona and New Mexico and some other States allow true subsurface drip irrigation of greywater but surface irrigation is not permitted. In Arizona, greywater is defined as wastewater with a BOD less than 380 mg/L, TSS less than 430 mg/L and the Fats, Oil, and Grease (FOG) content less than 75 mg/L. There are three types of use in Arizona: up to a quota of 1500 L/d no permission is required for greywater use, between 1500 and 11,355 L/d permission is required and above 11,355 L/d it is considered as conventional wastewater venture [15].

Where greywater is still considered sewage, it is bound by the same regulatory procedures enacted to ensure properly engineered septic tank and effluent disposal systems are installed for long system life and to control spread of disease and pollution. In such regulatory jurisdictions, this has commonly meant domestic greywater diversion for landscape irrigation was either not permitted or was discouraged by expensive and complex sewage system approval requirements. The Uniform Plumbing Code, adopted in some US jurisdictions, prohibits gray water use indoors [111].

United Kingdom Guidelines

Greywater recycling in UK is relatively uncommon because the financial cost and environmental impact. In UK, greywater systems should comply with British Greywater Systems- Code of Practice (BS8525), Domestic Greywater Treatment Equipment. Requirements and Test Methods (BS8525-1) and Code of practice for the selection of water reuse systems (BS8595) and the Water Supply (Water Fitting) Regulation in order to avoid risks to health. Greywater from single premise has the potential to be reused on site for ornamental, garden and lawn irrigation, toilet flushing. The reuse treatment options include horizontal flow reed bed (HFRB), vertical flow reed bed (VFRB), green roof water recycling system (GROW), membrane bioreactor (MBR) and membrane chemical reactor (MCR) [102, 113, 20].

Australia Guidelines

Household greywater from a single contaminated site may be re-used on-site for the ornamental garden and lawn watering, toilet flushing, and laundry uses, depending on the type of grey water and treatment level. Some people wisely re-use greywater while others use it without any treatment, simply transferring laundry water to the lawn where children and pets may be exposed directly. The Department of Health and Community Services (DHCS) focuses on protecting public health and then takes action to control and minimize the public health risks associated with greywater re-use [114].

Southeast Queensland encountred one of the worst droughts on record. To help protect the State's drinking water supply, changes were made to the laws surrounding the use of greywater. Appropriately treated greywater can be used to irrigate lawns and gardens, wash walls, footpaths and vehicles and flush toilets. States like Queensland Tasmania and Victoria have developed their own guidelines and fact sheets for greywater treatment and uses[115-117].

Israel Guidelines

There is a significant body of research on greywater characterization, treatment and use in Israel [20,22,27,29,35,47,58,60,81,90,94,95,97]. As a result, there is a public desire, emanating from the water shortage and environmental awareness, to reclaim greywater for reuse for gardening and toilet flushing. However, the government concern with reusing greywater is the danger to public health as greywater may contain a high concentration of microorganisms that might pose risk to human health upon contact with greywater as a result of failures in the treatment and reclamation systems or contact with improperly treated greywater used for irrigation.

Therefore, in June 2008, the Ministry of Health published guidelines that allow the promotion of installation of greywater treatment plants by license, requiring local authorities and businesses to use advanced treatment and reclamation technologies that will ensure a high level of greywater purification. The guidelines refer to the location of the plant, the location of the water returning areas, the required treatment level, the engineering measures required in the plant, the plant ownership and the responsibility for its operation. The Ministry of Health reviews the plans for the separation, treatment and reclamation of the greywater, approves the plans and oversees the actual carrying out of the instructions. Any use of greywater in a public building or the industry requires the approval of the Ministry of Health [48,61].

However, there is a concern that greywater treatment facilities in private homes or apartment buildings will be operated without professional skills, will not remove the disease generating microorganisms to the required extent, and will be more prone to maintenance problems and operational failures. For these reasons, the Ministry of Health banned reuse of greywater in private homes and apartment buildings [48,61,96].

Egypt Guidelines

Egypt is in arid zone known for its scarcity of annual rainfall, very high rates of evaporation and consequently extremely insufficient renewable water resources. A major part of Egypt water resources is limited to Egypt's share from the Nile water. Effort to overcome the unsatisfied water demand in Egypt include water demand management and mobilization of non-conventional water resources like sea water desalination, rainwater harvesting, cloud seeding, wastewater reuse and domestic greywater reuse [118].

Sustainable management of water resources is a must, as water scarcity is becoming more and more constraint impeding the economic growth [119]. The increasing water shortage over the past decades is caused primarily by the growing population (now 100 million) combined with lifestyle changes which led to increased conflict between agricultural and other water uses. Sustainable water management in Egypt is currently becoming a dominating topic with focus on long-term objective of closed loop recycling to close the gap between demand and supply.

There is a significant body of research on greywater treatment and reuse in Egypt [56,92, 118-135]. However, most greywater treatment systems installed in Egypt for reuse in irrigation are based on degreasing tanks in combination with constructed wetlands [121-124]. However, high cost and low public perception limit the application of this technology in small communities in rural areas. In urban areas, the most feasible greywater reuse option is for toilet flushing, which can reduce individual in-house net water demand by 40–60 L/d and total urban water 10–25% [125].

Egypt is a world leader in treating and recycling wastewater. Treated wastewater (TWW) reuse for irrigation has been practiced historically in Egypt for wood production via forest plantation for decades. However, Egypt does not have a single general law on integrated water resource management. It has several sectorial laws and decrees including laws on water and environment (93/1962, 48/1982, 4/1994, 9/2009), and laws and regulation for wastewater reuse (93/1962, 44/2000, 603/2002, 171/2005, 1038/2009) and Egyptian Codes (501/2005, 501/2015). The Law 93/1962 controls the reuse of wastewater in agriculture as described in the following rules: (a) it is acceptable to reuse treated wastewater for agricultural purposes, only if it would be in accordance with the conditions and criteria mentioned in Law, (b) it is prohibited to harvest yields, which were irrigated with a treated wastewater until two weeks after stopping irrigation, and (c) it is prohibited to use treated wastewater to irrigate cattle pasture [126].

The Ministry of Housing, Utilities, and Urban Communities published two versions of the Egyptian Code for reusing TWW [127]. The 2005 version (ECP 501, 2005) classified TWW into three categories (A, B, and C), while (ECP 501, 2015) classifies TWW into four grades (A, B, C, and D) depending on the level of treatment as shown in Table 1. The Egyptian Code prohibits the reuse of TWW for any raw vegetables, such as cucumber or tomatoes. Moreover, the Code specifies the allowable crops for each TWW category as shown in Table 2 [126].

The Ministry of Water Resources and Irrigation stated that TWW are mainly used in Egypt for greenbelt and non-food agricultural production based on several factors including: (a) the balance of supply and demand, (b) treatment type and level, (c) availability of cultivation area, (d) irrigation method, (e) cropping pattern, (f) environmental impacts, and (g) costs. Utilizing TWW for irrigation is recommended in case of improving wastewater treatment and continuous monitoring to prevent the accumulation of toxic elements and to maintain microbiological loads within permissible levels in soil and plants [128].

Table 7: Criteria for wastewater treatment levels in Egypt [126].

Criteria	Treatment Level			
	A	B	C	D
Total Suspended Solids (mg/L)	<10	<30	<50	<300
Turbidity (NTU)	<5	ND	ND	ND
Biological Oxygen Demand (mg/L)	<15	<30	<80	<350
E, Coli (Cells/100 ml)	<20	<100	<1000	ND
Intestinal Nematodes (cells/L)	<1	<1	<1	ND

ND: Not Defined

Table 8: Crops for each TWW category in Egypt [126].

Treatment Level		Agricultural Crops	Description
A	A1	Green landscapes in educational establishment, public and private parks	All type of grass and hedge plants and all kind of flowers
B	B1	Grain crops, vegetable used cooked and processed	All kind of vegetables that will be processed and/or cooked, all dry crops such as wheat, corn, barley, rice, beans, sesame and lentils
	B2	Fruit trees	Fruit trees with sustained and deciduous leaves such as citrus, olive, palm, mango, pecan, pomegranate
	B3	Medicinal plants	All herbs including anise, hibiscus, cumin, marjoram, ammi, fenugreek, moat, fennel, chamomile and sage
C	C1	Dry grain crops, fruits, medicinal plants as in Group B	Same species in addition to sunflower plant providing that spray irrigation is not used
	C2	Noon food seeds	All seeds for major propagation for major food crops such as wheat and corn and all kinds of vegetable seeds,
	C3	All types of seedlings which are then transplanted in permanent fields	Seedlings of live, pomegranate, citrus, bananas. Palm, figs, mango, apples and pears
	C4	Roses and cut flowers	Roses farm yard, rosa canina, bulbs such as algeladiols, bird of paradise and all kind of ornamental plants
	C5	Rees suitable for planting in highway sand green belt	Alcazurina, camphor, oleander, tamarisk, and some types of ornamental plants
	C6	All types of fiber crops	Cotton, linen, jute, kenaf
	C7	Grassy forage crops and leguminous crops	Sorghum and shamrock
	C8	Mulberry to produce silkworm silk	All kind of berries
	C9	All plants and ornamental trees nurseries	Ficus décor, Ficus nata, ambassndr and acacia
C	D1	Solid biomass crops	All crops for production of biodiesel fuel and energy oils such as soybean, rapeseed, jojoba, jatropha an castor
	D2	Crops to produce cellulose	All non food crops for the production of glucose and its derivatives like ethanol and acetic acid
	D3	Timber trees	All trees for timber production such as alcaaa, camphor and mahogany

Selecting crops suitable to be irrigated with TWW is a key for achieving the successful use of TWW. Oil crops such as canola and sunflower are suitable for TWW irrigation [129]. Additionally, cultivating jatropha with TWW is recommended because of the availability of marginal desert soil and the socio-economic benefits associated with biofuel production [130].Treated and partially treated wastewater has been used for irrigation at Elgabal Elasfar Farm in the Eastern Desert (25 km North-East Cairo) since 1911. This farm was initially established for wood production and was then converted to citrus and field crop. The quality of the irrigation water meets acceptable levels and the levels of heavy metals in the soil are monitored [131].

The Ministries of State for Environmental Affairs, Agriculture and Land Reclamation, and of Housing, Utilities, and Urban Communities conducted national programs of using 2.4x109 m3 of TWW for afforestation and greenbelts [132]. Also, the Ministry of State for Environmental Affairs, in cooperation with the United States Agency for International Development, evaluated the safe reuse of TWW to irrigate different crops (jatropha, jojoba, sorghum, flax, flowers) in Luxor Governorate using drip irrigation techniques while conducting risk reduction measures for protecting the workers involved. Jatropha is a bio-oil crop cultivated in Egypt since the 1990s using TWW to irrigate over 855 ha Upper Egypt Governorates and has promising economic potential [133].

The Greater Cairo Sewage Water Company (GCSWC) operates the El Berka Wastewater Treatment Plant in the North-Eastern part of Greater Cairo. Only 5% of its secondary treated wastewater is used for irrigating lemon trees, cactus, trees for wood production (Khaya senegalensis) and industrial oilseeds (Jojoba and Jatropha) on a pilot basis. In addition, 1,500 tenant farmers renting government land use another 12% of the treated wastewater (free of charge) to irrigate about 1,000 ha to support their livelihoods. The majority of the entity's revenue comes from household wastewater fees levied on around 1 million connected households, helping achieve a high-cost recovery for the treatment of the wastewater. The plant raises additional revenue from selling one third of the generated sludge for composting. There is significant potential for expansion into the agroforestry sector [134].

The Red Sea governorate begun an unprecedented experiment in Egypt of using greywater to clean streets and irrigate gardens in Hurghada, in order to save upto 40% of water. Specially equipped cars were are used to carry out the task. The idea started with the installation of independent greywater treatment units in houses, in order to reuse water in gardening and street cleaning, and to be the first model of implementing the idea to the rest of residential areas in Hurghada. The graywater treatment unit consists of 3 stages: separation of oils and fats and materials used for cleaning is carried out in the first stage, greywater filtration by gravel, sand and coal is carried out in the second stage, and the last stage is for storing the filtered water. This project was done with the aim of spreading environmental awareness and contributing into saving water and reducing pressure on the sewage networks. The officials of the Holding Company for Water and Sanitation and the Directorate of Education were intrusted of implementing the idea in schools by encouraging them to use the greywater in irrigation of crops within the school's courtyard [135].

There are four key challenges to reusing TWW: social (public acceptance of wastewater reuse), management (crop selection, irrigation practice, and soil-based practices), human health risk, and environmental threats. There are significant opportunities to maximize the benefits of TWW reuse in Egypt as less than 75% of collected wastewater is currently being treated [128].

Greywater Use Guidelines in Some Devceloping Contries

The emphasis on the use of grey water in many developing countries has two main purposes: water conservation and socioeconomic aspects. Several countries including Brazil, China, Costa Rico Egypt Ghana India Jordan Kuwait Malaysia Mali, Mexico Nepal Oman, Palestine South Africa, Taiwan Thailand Tunisia and Uganda promote research on greywater treatment and use. Some of these research projects are funded by national and/or internatio nal organization [60,75,23,56,92,86,89,87,6,32,34,40,69,85,37,38 ,11,13,55,39,51,21,41,25,73,62,136].

For example, the Amman Islamic Water Development and Management Network (INWRDAM) in Jordan promoted research on graywater treatment and reuse in Jordan which was funded mainly by the International Development Research Center (IDRC) of Canada. The aim is to install and use greywater systems based on the establishment of small wetland treatment systems in private households at a cost of about $500 per household.

Another example is the Egyptian-German Private Sector Development Programme (PSDP) which was financed by the German Ministry for Economic Cooperation and Development (BMZ) and implemented in cooperation with the Egyptian Ministry for Trade and Industry (MTI), with technical assistance provided by the German Technical Cooperation (GTZ). It was established in 2005 (continued for 10 years) and encouraged large and small scale users to conserve water for their own benefit and also to reduce environmental pollution problems. About 35% reduction of water consumption in residential units was achieved with simple technology for greywater recycling and reus in toilet flushing and irrigation.

Barriers to Recycling Greywater on a Large Scale

Although many governments are willing to examine the possibility of er recycling greywater, there remain a number of barriers that must be addressed:

1. The concerns fear of endangering the public health by using greywater in the urban sector, a fundamental objection to the decentralization of water treatment facilities, and a preference for transport of sewage to centralized facilities.
2. A lack of clear regulations from the central government regarding greywater recycling and reliance on the personal views of district engineers which in many cases lake uniformity of opinion.
3. The conservative nature of construction entrepreneurs and contractors, and their abstention from promoting environmental causes due to regulation, financial uncertainty, or the obscurity regarding the image and the marketing value of greywater recycling.
4. Claims that the greywater recycling on a national level would be undesirable due to the fact that it reduces sewage water, the recycling of which in many countries is used for agricultural irrigation. These claims may cause the agricultural lobby to

raise objections to greywater reuse.
5. An engineering fear that greywater recycling will cause a lowering of the fluid ratio sewage pipes, causing the solids content to rise and resulting in obstructions and transport problems.

Conclusion

Greywater is defined as a domestic wastewater that is uncontaminated by direct contact with human excreta. Sources of grey water include kitchen sinks, showers, baths, washing machines and dishwashers. Most greywater streams produce effluents high in dissolved contaminants and low in turbidity and suspended solids. However, the biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), surfactants, oil and grease, detergent residues (nitrogen, phosphorous, sulfate, ammonium, sodium, and chloride) are of typical concern when handling domestic greywater streams.

According to the United Nations, global water resource supplies are worsening, and water shortages will affect 2.7 billion people by 2025. This means 1 out of every 3 people in the world will be affected by the water shortage problem. Countries in arid zone which is known for its scarcity of annual rainfall, very high rates of evaporation and those with extremely insufficient renewable water resources will suffer the most. Therefor, reusing greywater has become a good way to solve this problem. There is a significant body of research on greywater characteristics, treatment and reuse in both developed and developing countries. As greywater contains fewer pathogens than domestic wastewater (black water), it is generally safer to handle and easier to treat and reuse onsite for toilet flushing and landscape or for crop irrigation and other non-potable uses. The application of greywater reuse in urban setting provides substantial benefits for both the water supply system by reducing the demand for fresh clean water, and for the wastewater system by reducing the amount of wastewater required to be conveyed and treated. Greywater use in gardens or toilet systems helps to achieve some of the goals of ecologically sustainable development including: (a) reduced freshwater extraction from rivers and aquifers, (b) less impact from septic tank and treatment plant infrastructure, (c) reduced energy use and chemical pollution from treatment plants, (d) groundwater recharge and (e) reclamation of nutrients. Greywater is seen as one of next forthcoming water resources primarily in the growing mega-cities in addition to roof runoff water harvesting and condensing water from air-conditioning systems.

Several countries have developed guidelines for the reuse of treated greywater, Although, some countries have strict rules compared to others. The National Plumbing Code in Canada indicates that non-potable water systems should only be used to supply toilets and underground irrigation systems but the guidelines are not mandatory. USA has a great number of States with individual standards and guidelines, all of h meet the United States Environmental Protection Agency (USEPA) standards as a minimum. Most guidelines indicate that greywater should only be used to flush toilets and subsurface irrigation systems. Greywater recycling in UK is relatively uncommon because the financial cost and environmental impact. In Australia, household greywater from a single site may be reused on-site for the ornamental garden and lawn watering, toilet flushing, and laundry uses, depending on the type of grey water and treatment level. The focus of the Israeli guidelines for greywater reuse is on the private and single house. While the problem is less rigorous in public facilities, where the amounts are relatively large, and the raw greywater is relatively diluted. Egypt appears to be a world leader in the treatment and reuse of wastewater and has several laws in place for treatment option and crop selection. Given the water shortage in Egypt and the growing population, the Government is imparking on several mega 3 and 4 level-treatment of waste water for use in agricultural production.

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript

Competing Interests

The authors have declared that no competing interests exist.

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