


Review

Greywater as an Alternative Solution for a Sustainable Management of Water Resources—A Review

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Abstract: In this paper, a comprehensive review on greywater is presented. Emphasis is given to the techniques used to treat and recover greywater, and special emphasis is placed on the risk of the existence of the novel coronavirus “SARS-CoV-2” in greywater and the possibility of its spread via the reuse of this water. In general, greywater is considered wastewater collected from domestic sources, with the exclusion of toilet water (which is considered as blackwater). Greywater represents 50% to 80% of the total volume of wastewater all over the world. This review provides various aspects related to greywater, such as origins, characteristics, and existing guidelines for greywater proper treatment and reuse. Several approaches and techniques have been developed to study the performance of different greywater treatment systems. These methods are critically discussed in this article. In the context of sustainable development, water management, and taking into account the scarcity of water resources, particularly in arid and semi-arid areas, the use of treated greywater is one of the alternatives methods that can reduce the burden of withdrawals from the resource. In addition, some successful examples of greywater valuation experiences in Tunisia were examined.

Keywords: greywater; sustainable management; reuse; COVID-19 pandemic; SARS-CoV-2 risk



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1. Introduction

Demographic growth in a context marked by urbanization and economic development exerts an accentuated strain on conventional water resources in the world. Increased attention to alternative water resources has become necessary, especially in semi-arid and arid regions, where the scarcity and variability of rainfall and high evaporation affect the water and salt balance in the soil [1].

Water scarcity is currently one of the most important challenges for human health and the integrity of the environment in most regions of the world and especially in Tunisia. The uneven distribution of precipitation and the temperatures in these countries are the key factors of an imbalance between water supply and demand [2]. Tunisia will suffer from a physical water shortage (high indicator > 1), which will cause a deficit in cereal production [3]. The availability of surface-water resources in Tunisia is medium in the long term. According to statistics published by the Ministry of the Environment and Sustainable Development, Tunisia’s water potential increased by 19% from 1980 to 2005. The rate of exploitation of the surface water mobilized is approximately 25%. The groundwater exploitation rate is 108% for water tables and 81% for deep water tables. The rate of exploitation of available water resources is 51%. The annual quota per inhabitant is 480 m³/year/inhabitant, below the poverty line (1000 m³/year/inhabitant) and fairly close

to the scarcity threshold (500 m³/year/inhabitant). Tunisia will be among the countries that will import more than 10% of their cereal consumption in 2025. Therefore, this situation forces us to search some alternate water sources. In this regard, the use of treated greywater can play a significant role in the water demands and development of the sustainable water-resource management [4].

Greywater is the domestic wastewater from showers, hand-washing basins, laundry, washing machines, and kitchen sewage, excluding toilet wastes and food wastes derived from garbage grinders, which are considered blackwater [5]. Greywater contribution to domestic wastewater is 50–80% of the water volume and includes 18–22%, 20–32%, and 9–14% of potassium (K), phosphorus (P), and nitrogen (N), respectively, so it can be reused after a simple treatment [6].

The exploitation of treated greywater includes indoor reuse, such as flushing toilets, and outdoor reuse, such as irrigation and vehicle washing [7]. Recycling capacity was developed in agriculture whenever the treated greywater conforms to different health and environmental standards established for this purpose [8].

Given the numerous problems of the water-resource scarcity, an effective method of using alternative resources is the greywater reprocessing and its reuse, especially in the agriculture sector. According to the National Sanitation Utility (ONAS 2018), the reuse of treated water for irrigation is a strategic choice that aims to preserve Tunisia's limited water resources, because this sector is the largest consumer of water, at 80%. TWW derived from 122 of Tunisia's wastewater treatment plants, which are located close to the cities, and the secondary treatment is used in most of this sector, as it is the largest consumer of water, at 80%. The reuse of greywater recycled in agriculture can be beneficial for the environment, because it reduces the load on the source and the discharge of wastewater in ecosystems [9]. The nutrients contained in these waters, mainly N and P, can improve plant growth, instead of polluting the aquatic environment, and requires only some simple treatment operations through less expensive processes. These nutrients originate from detergents and chemicals used in kitchens, dishwashers, or washing machines [10]. In many regions of the world, particularly where the water sources are unavailable, the economic incentive to reuse is substantial. For example, in countries such as Kuwait, Italy, Spain, Malta, Germany, Jordan, or USA, treated greywater is already used for irrigation [11]. It is estimated that 20 million farmers worldwide use untreated or partially treated wastewater [12]. However, in the current context of the COVID-19 pandemic caused by a new type of severe acute respiratory syndrome coronavirus (SARS-CoV-2), the reuse of greywater is facing new challenges brought by the pandemic, especially since traces of this SARS-CoV-2 virus have been found in the wastewater of several countries around the world [13–15]. This raises the question of the effects and risks on the environment and public health.

The objective of this paper was to review some agricultural valorization of greywater through success experiences, as well as considering the various treatment processes from Tunisia and assessing the impact to preserve freshwater and protect the environment.

2. Origin and Characteristics of Greywater

Greywater is defined as wastewater without any blackwater discharge, and it corresponds to a large volume of wastewater with a high potential for reuse and application. Greywater's origin and composition depend on the lifestyle, population structure, availability of water, and climatic conditions, which are different from one country to another [16]. Greywater quantities vary from 90 to 120 lpd in houses with water supply system. This range corresponds with that determined by Mandal et al. (2011) [17]. In fact, greywater average is 110 lpd: 80 lpd from bathing, cloth washing, and wash basins; and 30 lpd from kitchen greywater. Greywater consists of a wide range of organic materials [18], heavy metals [19–22], and *E. coli* [22].

The characteristics of greywater depend essentially on the quality of water used for the initial supply. In addition, the type of habitat, the number and the sanitary state of the occupants, the source and volumes of water collected, the treatments used, and the

storage conditions can influence the greywater characteristics. These elements vary for each country, considering the differences in climate and demography. Temporal variations in greywater in the same area may be due to a change in the behavior of the inhabitant or to a specific use of a product [23].

Before thinking of recycling greywater, the first step is to characterize its chemical, physical, biological, and microbiological properties [24]. Because there is no specific standard for greywater use, the general quality can be compared with standards used for treated wastewater quality. The pH is slightly alkaline for greywater from washing machines and, to a lesser extent, for greywater from bathrooms. Total suspended solids (TSSs) and turbidity in greywater are heterogeneous: water that comes from bathrooms has lower TSS concentrations than that from washing machine. The concentrations of biological oxygen demand (BOD), chemical oxygen demand (COD), and nutrients (nitrate (N) and phosphorus (P)) are higher in the laundry-washing water. This difference observed is due to detergents containing carbon and phosphate products, especially in countries where their use is not yet banned [25].

For heavy metals and organic pollutants in greywater, they are generally low in different types of greywater. The work carried out by Filali et al. in 2017 [10] showed that the different heavy metals (Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) analyzed in the greywater of kitchens and bathrooms are low and below the limit. For microbiological parameters, the characteristics of the two types of water are equivalent. In general, greywater from bathrooms contains elements brought by human activity (hair, skin, shampoos, and solvents). Greywater from washing machines mainly contains detergents and textile fibers, but sometimes it contains organic matter provided by the dirt on clothes [20].

3. Risks Related to the Greywater Reuse

The chemical and microbiological hazards in untreated and treated greywater are variable because these qualities depend on human behavior and the materials discharged into greywater. Given the small number of publications identified and the diversity of greywater reuse situations, the available data only provide some indication related to the chemical and microbiological composition of greywater, but they cannot be considered as being representative of the chemical contamination and microbiological of all greywater. Untreated greywater from households contains a high concentration of compounds with harmful effects on all of the environment [26]. Faulwetter et al. (2009) [27] determined that the microbial activity of the soil can be affected by the untreated greywater used for plants' growth; long-term irrigation with greywater can also increase the alkalinity of the soil, the rate of sodium adsorption, and electrical conductivity [10,28].

3.1. Environmental Risks

One of the main environmental risks resulting from the reuse of greywater is groundwater pollution. It is possible that some of the substances found in greywater influence the groundwater supplies [29,30]. Sanae Kholtei et al. (2007) [31] have highlighted several determining factors [31] in the contamination of groundwater by greywater pollutants: the supply of nitrogen fertilizers, the nature of the soil, the lithology, and the permeability of the aquifer. To reduce the impact of greywater reuse on groundwater, the potential user must analyze and study the nutrient requirements by plants and soil. Wiel-Shafran et al. (2006) [12] suggested that the accumulation of surfactants in the soil due to greywater irrigation can create water-repellent soils, thus affecting their flow profiles and productivity. In a study conducted by Al-Hamaiedeh and Bino (2010) [11] to assess the effect of the treated greywater reuse on the soil properties and irrigated plants, the results exhibited increases in the soil salinity and organic matter contents. The chemical properties of irrigated olive trees and vegetable crops were not affected, while the organic quality of some vegetable crops was negatively affected. The main effects of greywater on the soil are linked to (i) the increase in the hardness and salinity of the soil; (ii) the reduction of the capacity of the soil

to absorb and retain water; and (iii) the increase in alkalinity, due to the presence of sodium, potassium, or calcium salts in greywater, in particular, in detergents (OMS, 2006).

3.2. Sanitary Risks

Epidemiological studies and microbiological analyses are necessary to evaluate the health risks associated with greywater. These risks depend on the treatment applied, the routes of exposure, and the source of the pathogens [32]. Ottoson and Stenstrom (2003) [33] showed that the prevalence of pathogens has served as the basis for a quantitative evaluation of the microbial risk at the screening level that has been undertaken for *rotavirus*, *Salmonella typhimurium*, *Campylobacter jejuni*, *Giardia lamblia* and *Cryptosporidium parvum*. The different scenarios of direct exposure, irrigation of sports fields, and recharge of groundwater have shown unacceptable risks of *rotavirus* despite a low fecal load. The quantitative microbial risk assessment (QMRA) methods have shown that the growth conditions of *Salmonella* in sediments increased the probability of infection by 1000 times, but it was even lower than the risk of rotavirus infection.

Other greywater studies elaborated by Rodda et al. (2011) [8] have detected the effect of greywater on crop irrigation, *Beta vulgaris* variety *Cicla* and a carrot crop, *Daucus carota*. The results indicated that soils irrigated with greywater showed a risk of salinity and sodicity increasing, coupled with high concentrations of heavy metals.

The pathogenic and non-pathogenic microorganisms present in greywater are of the same nature as those found in domestic wastewater [32]. In addition, certain pathogens can multiply due to the composition of greywater. These waters contain low levels of fecal contamination, provided that it is strictly separated from blackwater. These pathogens can be ingested, leading to gastroenteric disorders; can be inhaled as water droplets or aerosols responsible for respiratory infections; or cause infections of the skin or healthy or damaged mucous membranes [34].

Some substances produced by bacteria could also constitute a risk, such as endotoxins, the health impact of which is still little studied. Maimon et al. (2010) [9] determined the presence of various pathogens in the digestive system.

- *Risk of SARS-CoV-2 transmission through greywater*

Despite the disinfection practices followed by users of recycled water [35], the real health risk remains linked to microbial and/or viral contamination. This leads us to reflect on the consequences of COVID-19 epidemic, as well as the impact of SARS-CoV-2 virus on the composition of greywater, which can worsen the health risk associated with the reuse of this water. Indeed, several studies have identified a great similarity (up to 82%) [36,37] of this virus with that of SARS-CoV-1, which appeared in 2003 [13]. This one has shown its ability to spread in sanitation systems [38]. Several studies have suggested that SARS-CoV-1 infection was caused by breathing in aerosols created in faulty plumbing systems and toilet flushes [39]. Therefore, wastewater has been defined as a route of indirect contamination with SARS-CoV-1 [40]. For the new virus responsible for the COVID-19 epidemic, intensive studies have shown that SARS-CoV-2 can enter sanitation systems via human excretions, such as stool, urine, saliva, etc. [13,41,42], and the spread of the virus via the fecal/oral route has become highly probable [15,43]. Indeed, gastrointestinal disturbances were considered among the key symptoms of SARS-CoV-2 infection, where 80% of patients affected by COVID-19 had diarrhea, constipation, and vomiting [15,42]. Studies have confirmed the detection of SARS-CoV-2 RNA in 66.67% of stool samples from patients with gastrointestinal symptoms [15]. In addition, it is not only for these patients, but SARS-CoV-2 RNA shedding was observed also in asymptomatic patients [15]. SARS-CoV-2 RNA has been found in stool samples even after recovery from respiratory infection [44]. Other works have shown that the SARS-CoV-2 virus has been found in wastewater from several countries, such as the United States, Sweden, The Netherlands, Israel, etc. [13,14,45–47]. This means that even greywater from areas where COVID-19 patients are located could be a potential source for the virus to spread, as well as its transmission. Contamination of greywater with SARS-CoV-2 is a significant concern, as

it can threaten human and environmental health, especially in countries that allow the use of greywater without any treatment, as in Bangladesh, Pakistan, and Iran [48–50], where irrigation with untreated wastewater is a common practice in urban, peri-urban, and gardens areas. Moreover, in comparison with wastewater, we can say that greywater is more likely to spread the coronavirus, due to the simple treatment it undergoes on the one hand, and the large quantity produced of greywater during the COVID-19 pandemic on the other hand. Indeed, one of the best ways to prevent and break the chain of infection of COVID-19 is to wash hands with soap and water several times during the day [51]. This requirement increases the production of greywater.

4. Greywater Recovery Systems

The characterization of greywater and its comparison with domestic wastewater have shown the advantage of recycling this water category. Greywater recycling processes are, in general, based on the conventional processes for domestic, urban, and industrial wastewater treatment [52]. Thus, as in the field of wastewater treatment, greywater treatment systems most often constitute a treatment sector. Generally, the physical (sand filters, activated carbon filters, membrane filters, etc.), chemical (coagulation, ion exchange, chlorination, etc.), and biological (filtering marshes, RBC, SBR, and sludge blanket) treatment processes of greywater are preceded by pretreatment (sieving, decantation) to reduce the rates of particulate load of oils and greases and functioning as a basin of regulation/homogenization of the flow of the load of pollution of untreated greywater [53–55]. Several studies relating to alternatives and methods for recovering treated greywater have been evaluated according to the characteristics of greywater, their standardization, directives, and recommendations in force. Overall, all types of greywater have shown a good biodegradability. Greywater from bathrooms and washing machines is deficient in nitrogen and phosphorus, while greywater from kitchens has a balanced N:P ratio. These researches also showed that the physical greywater treatment processes are not sufficient. To ensure adequate reduction of organic matter, nutrients, and surfactants, a chemical process can effectively reduce suspended solids, organic matter, and surfactants from greywater. The combination of aerobic biological processes with physical filtration and disinfection has been considered as the most economical and practical solution for recycling greywater from collective urban residential buildings [53]. The selection of a greywater recovery-type process, as well as its dimensioning, depends on the flows and the composition of greywater to be treated, the application process scope, and the quality of treated greywater required by applicable regulations, guidelines, and standards [56].

4.1. Physical Systems

These treatment methods are most often used in combination with another method, such as disinfection and adsorption on activated carbon. The sand filter is a simple technology, easy to implement, and inexpensive. Some authors use, in addition to or instead of sand, other materials, such as activated carbon. These authors have shown the limits of the performance of sand filters in the recovery of greywater. This physical process only provides coarse filtration and allows limited treatment. Gual et al. (2008) [57] obtained between 15% and 25% elimination of TSS and COD from greywater. A study by Itayama et al. (2006) [58] showed that BOD₅, COD, TSS, and total nitrogen (TN) values of greywater from kitchen sinks were reduced from 477 mg/L, 271 mg/L, 105 mg/L, and 20.7 mg/L to 81 mg/L, 40.6 mg/L, 23 mg/L, and 4.4 mg/L, respectively, by a soil filtration system. This greywater treatment system is capable of partially removing organics and particulate pollutants, as well as nitrogen and phosphorus nutrients. The quality of the treated greywater obtained by Gual et al. (2008) [57] has shown that organic material and suspended matter remains high, and this can limit the chemical disinfection process [6]. Dalahmeh et al. (2012) [59] found that the best performance of greywater treatment with an active carbon filter was able to achieve 98%, 97%, and 94%, respectively, for the reduction of total nitrogen, BOD₅, and COD. Mandal et al. (2011) [17] achieved a reduction of 1 log₁₀

in total coliforms by a sponge and gravel filter system. Brewer et al. (2001) [60] achieved a reduction of 4 log₁₀ in total coliforms by a filtration system followed by disinfection.

Sand filtration combined with activated carbon adsorption and disinfection has been reported for the treatment of greywater. Pidou et al. (2007) [61] revealed some improvement in the reduction of suspended solids and turbidity. However, a reduction in microbial load is limited. The dissimilarities observed in the various studies can be explained by the characteristics of the greywater specific to a dwelling or by the characteristics of filter used (applied load, filtration speed, properties of the filtering materials, etc.). In order, to limit environmental and health risks, Diaper et al. (2001) [62] recommended the use of greywater, after treatments, only for toilets, because of the uncertainties on risk outcomes. Francis W. et al. (2012) [63] confirmed that the use of greywater from the bathroom and linen is safe for flushing toilets and irrigating food crops after microfiltration treatment.

If we consider the greywater reuse for green-spaces irrigation, typically it is necessary to choose an advanced treatment that makes it possible to obtain a better-quality effluent. For example, membrane-filtration techniques applied to the recovery of greywater have been much studied in recent years. Ramon et al. (2004) [22] compared the purifying performance of ultrafiltration and nano-filtration membranes. With ultra-filtration, only 49% and 94% of reduction were obtained for COD and turbidity, while 93% and 98% were obtained with nano-filtration.

Sostar-Turk et al. (2005) [64] studied the purifying performance of an ultrafiltration membrane (0.05 µm pore size) for the treatment of greywater. This ultrafiltration process allowed for a reduction in BOD₅ from 195 to 86 mg/L (56%), values that do not ensure the standard limits for greywater reuse. According to Pearce (2007) [65], this technology makes it possible to obtain water with acceptable quality. In fact, the almost-total retention of molecules makes it possible to obtain a quality permeate which complies with most of the regulations in force for the reuse of treated greywater

4.2. Chemical Systems

The chemical processes applied to greywater treatment include coagulation, electrocoagulation, photo-catalytic oxidation, disinfection, etc. These main chemical processes seem to be relatively effective for the recovery of greywater. Several studies have shown significant reductions in organic load (COD and BOD₅). Lin et al. (2005) [66] studied the performance of electrocoagulation, followed by a disinfection step, for the recovery of greywater. The values of COD, BOD₅, turbidity, and TSS in greywater decreased from 55 mg/L, 23 mg/L, 43 NTU and 29 mg/L to 22 mg/L, 9 mg/L, 4 NTU and 9 mg/L, respectively.

For the microbiological parameters, Lin et al. (2005) [66] did not detect *E. coli* bacteria in greywater. Moreover, Bani-Melhem and Smith (2012) [67] obtained reductions of 4 log₁₀ for total coliforms and *E. coli* by using an electrocoagulation system coupled to a membrane bioreactor. In a study conducted by Pidou et al. (2007) [61], the coagulation and ion-exchange resin processes were applied for the recovery of greywater from showers.

Under optimal conditions, coagulation with aluminum salt reduces COD from 791 to 287 mg/L, BOD₅ from 205 to 23 mg/L, turbidity from 46.6 to 4.28 NTU, TN from 18 to 15.7 mg/L, and orthophosphates from 1.66 to 0.09 mg/L. In addition, total coliforms, *E. coli*, and fecal enterococci in the greywater recovered are all less than 1 CFU/100 mL. These researchers have also shown that it is possible to reduce BOD₅, turbidity, total nitrogen, and orthophosphates to 33 mg/L, 8.14 NTU, 15.3 mg/L and 0.91 mg/L, respectively, by using ion-exchange resins in their treatment process. The total coliforms and *E. coli* in the greywater recovered were 59 CFU/100 mL and 8 CFU/100 mL, respectively. An advanced oxidation process based on photo-catalytic oxidation with the combination of titanium dioxide and UV for the treatment of greywater has shown its proof in the removal of 90% from organic matter and 6 log₁₀ in the reduction of total coliforms [68].

4.3. Biological Systems

Biological processes are the most common large-scale treatments used to treat greywater. These processes can operate aerobically, anaerobically, or in a combined process. Some studies present different results related to the performance of biological processes with suspended and fixed biomass, and in the case of biofilters' use for greywater recovery. Otterpohl et al. (1999) [69] recommended the use of fixed biomass processes rather than suspended biomass processes, considering the process complexity and the used space. Furthermore, the use of a fixed biomass process makes it possible to increase the total biomass in the reactor and consequently improve the performance of the treatment [70].

A study by Elmitwall et al. (2007) [71] showed a reduction in COD, total, total nitrogen (TN), and total phosphorus (TP), respectively reaching 31%, 24%, and 39% with a sludge bed. Baban et al. (2010) [42] reported reductions of 94% for TSS, 86% BOD₅, 95% COD 88% NT, 71% for PTP, and 100% for turbidity by using a sequenced batch reactor (RBC SBR) biological process. Regarding the microbiological part, the reduction in total coliforms by this biological process was only 1 log₁₀. It is therefore useful to add a disinfection treatment to reduce the microbial load. Lamine et al. (2007) [72] evaluated the performance of a sequenced batch reactor (SBR) for the treatment of greywater. The results found reductions of 30% TSS, 93% BOD₅, 88% COD, and 96% respectively in turbidity of greywater.

The recovery of greywater via a membrane bioreactor (MBR) was also considered as an innovative technology, given the stability of the process and its potential to eliminate pathogens. Lin et al. (2005) [66] reported that the values of COD, BOD₅, and anionic surfactants were decreased from 322 to 18 mg/L, from 221 to less than 5 mg/L, and from 8 or 9 mg/L to less than 0.5 mg/L on average in the permeate. Other research [71] showed that the upflow anaerobic sludge blanket (biological process UASB) allowed a reduction from 31% to 41% of the total COD, from 24 to 36% of the TN, and from 10 to 24% of TP.

The biological filter processes have been considered the most environmentally friendly, low-cost, and effective treatments for greywater. The studies from the literature related to the use of biological filter have shown interesting performances, particularly in terms of BOD₅, TSS, and turbidity elimination. Gross et al. (2007) [73] observed more than 89% and 96% reduction, respectively, for TSS and BOD₅. From a microbiological point of view, Dallas et al. (2004) [74] found that it is possible to reduce the load of total coliforms at 6 log₁₀, while Travis et al. (2010) [26] were able to reduce this same load only at 3 log₁₀. Regarding maintenance, these filter processes require little maintenance and therefore have a low operating cost. Plant maintenance must be carried out by cutting, as well as cleaning, every 5 to 10 years in order to remove the sludge accumulated at the bottom of the lagoon [75]. Moreover, these processes have the advantage of being integrated into the landscape and contribute to the fauna and flora diversification.

4.4. Hybrid Systems

Other hybrid processes considered as innovative technologies, such as membrane bioreactors alone or associated with membrane filtration (nanofiltration (NF) or ultrafiltration (UF)), or aerated biofilter processes alone or associated with filter marshes, have been tested for greywater recovery. The overall performance of these processes is very satisfactory, because the coupling of the two processes ensures both physicochemical and microbiological purification. Some research showed important reductions greater than 95%, 75%, 93%, and 85% for turbidity, TSS, BOD₅, and COD [53,67,76]. Concerning the surfactants, the reductions obtained by the BRM/UF processes and by the aerated biofilter processes are greater than 95%. Only total phosphorus appears to be difficult to reduce. The reduction of phosphorus by the BRM/NF processes and by the aerated biofilter processes coupled to the filter marshes was, respectively, 31% and 61%. At the microbiological level, these hybrid processes (BRM/UF) seem to be efficient, with the regular reduction of fecal coliforms of 4 log₁₀ [67,77]. At the expense of improving the quality of greywater through hybrid physical and biological processes, there is also a significant increase in the production cost of treated greywater.

5. Existing Regulations for Greywater

The reuse of treated wastewater has experienced tremendous global growth. Today, treated wastewater is considered in many countries, and particularly in Tunisia, as an important new resource with many interests, both from an environmental and economic standpoint. The development of the treated wastewater reuse is encouraged in Tunisia, despite the challenges and constraints related to various aspects (legislative, health, economic, environmental, agronomic, technological, etc.). Several international organizations in charge of regulation have made it possible to identify regulations, guidelines, and recommendations, as well as international standards, relating to the reuse of treated wastewater for various agricultural, urban, and domestic uses. Table 1 presents the regulations and standards identified in Tunisia and abroad, relating to the reuse of treated wastewater, in general, and greywater, in particular. The physicochemical and microbiological quality criteria of wastewater or treated greywater have been defined by certain states within the framework of regulations or recommendations for reuse. These water-quality criteria, as well as the threshold values for reuse defined by some developed countries (Australia, Germany, Japan, and United Kingdom) and by other countries (Spain, Jordan, and Tunisia), were mainly interested in agricultural utilization, and urban and domestic irrigation. Other countries have established limit values for other types of reuse, such as fire protection, vehicles washing, and possible toilet uses. In Tunisia, greywater does not have specific standards for reuse, it is included with all the wastewaters sent to treatment stations. Therefore, the standard adopted in Tunisia refers to the reuse of treated wastewater processed for agricultural purposes (NT 106-.03) (INNORPI, 1989). Water quality is monitored by physicochemical and biological indicators of wastewater pollution (pH, COD, BOD₅, TSS, turbidity, etc.) and microbiological contamination indicators (CT, CF, *E. coli*, Enterococci, and Legionella), as well as and parasitic (protozoan) indicators.

Table 1. Regulations and standards identified in Tunisia and abroad relating to the reuse of treated wastewater in general and greywater in particular.

Countries	Australia	Jordan	Spain				Tunisia
	Treated Greywater	Treated Wastewater	Treated Wastewater				Treated Wastewater
Use	Domestic irrigation	Agricultural irrigation	Agricultural irrigation	Domestic irrigation	Fire protection	Vehicle washing	Agricultural irrigation
EC	ND	ND	ND	ND	ND	ND	ND
pH	ND	6.5–9	ND	ND	ND	ND	6.5–8.5
DBO ₅	<10 mg O ₂ L	<30 mgO ₂ L	ND	ND	ND	ND	<30 mgO ₂ L
COD	ND	<100 mgO ₂ L	ND	ND	ND	ND	<90 mgO ₂ L
TSS	<10 mg L	<50 mg/L	35 mg L	10 mg L	<20 mg L	<20 mg L	<30 mgO ₂ L
Bore	ND	ND	ND	ND	ND	ND	<3 mg L
Fluor	ND	ND	ND	ND	ND	ND	<3 mg L
Turbidity	ND	ND	ND	<2 NTU	<10 NTU	<10 NTU	ND
<i>E.coli</i>	ND	100 UFC mL	<100 UFC mL	0 UFC mL	200 UFC 100 mL	<200 UFC 100 mL	1000 UFC 100 MI
Helminthes	ND	<1 œuf L	ND	ND	ND	ND	<1 œuf L
Nematodes	ND	ND	1 œuf.10 L	1 œuf.10 L	1 œuf 10 L	1 œuf 10 L	ND
Legionella	ND	ND	100 UFC L	100 UFC L	100 UFC L	100 UFC L	ND
CT	10 UFC L	ND	ND	ND	ND	ND	ND
References	EPA, Victoria, 2013	Jordanian Standards	Ministerio de la presidencia, 2007				Tunisian Standards NT 106,03

5.1. Guidelines of International Organizations

To regulate the reuse of wastewater and greywater, some international organizations have relied on health risks. In this review, we focus on the World Health Organization (WHO) [35] and the Food and Agriculture Organization of the United Nations (FAO) [78]

WHO developed guidelines in 1989, revised in 2006 for the use of treated wastewater in agriculture, based on a process of health-risk assessment. These recommendations are based on an analysis of health risks for domestic uses (watering gardens, flushing toilets,

and washing cars). However, secondary treatment of treated greywater with disinfection is recommended. The development of a local management plan for the use of treated greywater from buildings and residential facilities is advised. According to WHO [35], BOD₅, SS, and TC are, respectively, 240 mg O₂ L⁻¹, 140 mg L⁻¹, and 100 CFU 100 mL⁻¹ for agricultural irrigation. In the case of fire protection, vehicle washing, and toilet-flush supply, these same parameters are set at 10 mg O₂ L⁻¹, 10 mg L⁻¹, and 10 CFU 100 mL⁻¹.

5.2. Some Tunisian Experiences of Greywater Treatment

Greywater constitutes a major part of domestic wastewater. If properly valued and treated, these waters can be a resource for a variety of uses. We tried to evidence some examples of Tunisian experiences that opted for greywater treatment and reuse with successful results.

In a partnership between two teams of Tunisian and German researchers, as a part of a demonstration project, water-saving measures and a dual-piping system concrete example was set up of a local greywater management. This is a study carried out in a community dwelling in Central Berlin, Germany, which consists of three residential buildings that accommodate around 71 families (around 223 inhabitants) [79] in which greywater from showers, bathtubs, sinks, kitchens, and washing machines was advanced physico-biologically treated in a multistage moving-bed biofilm reactor (MBBR), followed by sand filtration and UV disinfection treatment. The treatment system installed in the residential building consisted of nine biological reactors, a sedimentation reactor, and a storage tank, each with a capacity of 1.3 m³. The system was designed to treat 8 to 11 m³ of greywater, depending on the daily water demand. This treated water was reused to flush 90 toilets and to irrigate the gardens. Results of this study showed the high performance of the reactor for the removal of COD, dissolved organic carbon DOC, BOD₅, ammonia NH₄-N, and TN, with an efficiency of elimination of 93%, 80.7%, 90%, 89%, and 77% respectively. In addition, a good correlation was determined between the simulated and experimental concentrations of COD from different reactors of the MBBR system.

As another example of greywater reuse, a study was carried out by Chaabane et al. (2017) [80] to examine the suitability assessment of an upflow-and-downflow siliceous sand/marble filtration system for the treatment and reuse of greywater collected from the bathrooms of the student residential complex of the Medjez El Bab Higher Institute of Engineering (Tunisia). The optimization of a greywater pretreatment system was performed by using a filtration system operated at different hydraulic loading rates and media-filter proportions. By this configuration, the study assessed the suitability of the treated greywater for agricultural purposes according to the risk of salinity, the danger of magnesium, and the permeability index. Moreover, to assess the quality of greywater for industrial reuse, the assessment was made in terms of foaming, corrosion, and scaling. The results showed that the quality of treated greywater by an upflow–downflow siliceous sand/marble filtration system could be accepted for reuse in irrigation. However, the treated greywater was not found to be suitable for industrial use, due to high concentrations of calcium and sodium, which can produce foam and scale in boilers.

Intensified work was unrolled at Center of Researches and Technologies of Waters (CERTE) by Lamine et al. (2007) [72]. This study had two main purposes: to investigate the application of sequencing batch reactors technology (SBR) for the treatment of greywater collected from the student residence shower room and to establish an approach to remove nutrients from greywater in an SBR and the feasibility of this cost-efficient system. The SBR reactor was made up of a transparent Plexiglas cylinder (19.0 cm in diameter), with a total volume of 11 L and a working volume of 5 L. The reactor was equipped with two peristaltic pumps for the supply and discharge. Mechanical stirring (30 rpm) was operated for complete mixing. The results showed that the SBR system could effectively remove nutrients and promote biodegradation of organic matter for domestic greywater up to 90% COD removal. In addition, the application of two hydraulic retention times (HRTs)

showed that the removal of nitrogen and phosphorus could be improved while adapting the load variations.

6. Conclusions

In recognition of the importance of conserving water resources, considering greywater as an alternative source is essential. This study reviewed the characteristics of greywater from a qualitative and quantitative point of view, as well as the treatment processes, to evidence some possibilities of greywater uses. From the list of reviewed treatment systems, the integration of other complementary systems (such as UV disinfection, reactors, and others) with traditional filtration systems seems to be more efficient for a better water quality. Many countries around the world have established guidelines and standards for the reuse of greywater, but the implementation always remains minimalist, especially in developing countries. The greywater standards summarized in this study can be used to study the effectiveness of new treatments and the potential uses of treated greywater. It is important to understand and assess the risks and dangers associated with the reuse of greywater after the COVID-19 pandemic where the potential of greywater may be a route of transmission of the SARS-CoV-2 virus, which could affect the environment and public health in the case of several countries, such as Tunisia, where the standards intended for the reuse of treated wastewater are applied to assess greywater, with no specific standards for greywater quality. For the cases of some Tunisian experiences of greywater, the techniques used for recycling it are always developed with the aim of eliminating certain specific pollutants and not for a complete treatment. To conclude, we can admit that reusing greywater can be considered both an economically and environmentally friendly solution in the context of water management. A proper greywater-management system can contribute to the conservation of natural resources and the fight against drought. In general, all the aspects related to greywater depends on the public reaction, regulations, and the implementation of proper systems by encouraging households to install greywater treatment systems.

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