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A Review of Sustainable Greywater Treatment Processes

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ABSTRACT

Greywater (GW) reuse is becoming a more well-liked method of water conservation worldwide as a result of the depletion of water resources and the rise in water demand. All wastewater produced by a household, excluding sewage, is referred to as GW. The makeup of GW is different, reflecting the residents' way of life and the chemicals they use in their homes. GW flow from a household typically makes up around 65% of the total wastewater flow. Approximately 50% of the total GW is further light greywater. As a result, GW offers a great deal of possibilities for treatment, recycling, and reuse. The primary objective of this article is to study and review the literature analysis on the various properties of GW and the available treatment techniques. Technologies for treating GW can be classified as physical, chemical, biological, or as a mix of these systems. Based on the analysis the inference that, physical methods by themselves cannot provide a sufficient removal of organics, nutrients, and surfactants. Chemical approaches are successful in eliminating the suspended particles, surfactants, and organic compounds present in the low strength GW. The most practical and affordable method for recycling GW is thought to involve the use of an aerobic biological process in conjunction with physical filtering and disinfection. For collective urban housing constructions, the membrane bioreactor (MBR) appears to be a particularly attractive solution.

Keywords: Greywater, Greywater sources, Greywater characteristics, Reuse, Treatment System.

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1. INTRODUCTION

Numerous uses for freshwater exist in the residential, commercial, and energy domains. The quantity and quality of scarce, valuable freshwater resources are declining as a result of overexploitation of these resources and rising wastewater production [1,2,3]. The pressure on natural sources including water, land (earth), and energy is increasing due to unchecked population growth, urbanization, and industrialization worldwide. Essential to many economic endeavors, human welfare, and the life of ecosystems, water is a necessary component [4]. Human needs are greatly outweighed by the overall amount of freshwater on Earth. Because the majority of Earth's water resources—roughly 97%—are found in the seas, only 3% of all water resources are directly accessible, making water a rare resource [5]. Water is distributed unevenly in space and time, which influences how it is used in some geographic locations and deprives others of this resource. A major deficiency of freshwater due to human activity, excessive use of water resources that eventually depletes them, and severe droughts in many parts of the world [6]. Water stress is estimated to affect 750 million people globally today, and by 2025, that number is expected to increase to 3 billion. [7,8]. Many parts of the world are now obliged to consider using alternative water sources due to water shortages and the loss of natural water supplies [9,10]. Particularly in water-stressed places like arid and semi-arid regions, on-site greywater (GW) treatment and reuse is receiving more attention globally. GW reuse has a lot of potential as a constant resource that can be used for non-potable purposes [11].

The increasing awareness of the importance of using GW in local and national programs to reduce pollution, enhance food security, lessen the impact of climate change, and increase the amount of potable water available is leading to a growing acceptance of this practice [12]. Blackwater is wastewater from toilets, while greywater is wastewater from bathtubs, showers, hand basins, kitchen sinks, dishwashers, and washing machines [13–16]. However, wastewater from kitchen sinks is frequently classified as blackwater [17]. The various treatment methods are determined by the characteristics of the site and the greywater. The quality of the water, the amount that needs to be treated, and the intended usage all influence how a greywater treatment system is designed [18]. Wastewater can be converted into a valuable source of water by recycling a significant amount of it. While GW contributes 75–90 L/day to the generation of household wastewater in low-income nations, in high-income and European Union nations, it can make up as much as 75% of wastewater production [19]. Treatment is necessary for the most polluting part of residential wastewater. GW source separation can reduce the amount supplied to wastewater treatment facilities [3,20,21]. Plant and human life are much at risk from untreated greywater. Greywater's properties and intended use are the primary determinants of how it should be treated. Although several research works have concentrated on the literature concerning greywater treatment alternatives [22–24]. Additionally, this study provides a brief overview of the benefits and drawbacks of the most popular biological and physicochemical technologies for treating GW.

2. SOURCES OF GREYWATER AND THEIR COMPOSITION

The features of greywater are contingent upon various factors such as the population size, age distribution, life patterns and water consumption, living standards, social and cultural customs, types and amounts of household chemicals (e.g., soaps, toothpastes, shampoos, detergents, etc.) utilized, and the amount of time that greywater is held before being utilized [9,25,26].

The complexity of greywater is demonstrated by the presence of multiple pollutants [27]. High amounts of chemicals found in paints, oils, solvents, bleaches, and non-biodegradable fabric used in clothes and soap powders (such as salt, phosphorus, nitrogen, and surfactants) are found in laundry greywater [28,29], but other substances include biological microorganisms like salmonella and faecal coliforms, as well as general hydro-chemical components and xenobiotic organic chemicals (XOCs) [30]. The main sources of GW are kitchens, laundry rooms, bathrooms, and wash basins. Based on the source's pollutant content, greywater (GW) is typically separated into two categories in the literature: light GW (LGW) and dark GW (DGW) [17,31]. Compared to dark greywater, light greywater is less contaminated. Total GW is sometimes referred to as mixed greywater (MGW), which includes greywater all of light and dark greywater resources [32]. Figure 1 lists a few sources of greywater as well as some of its components.

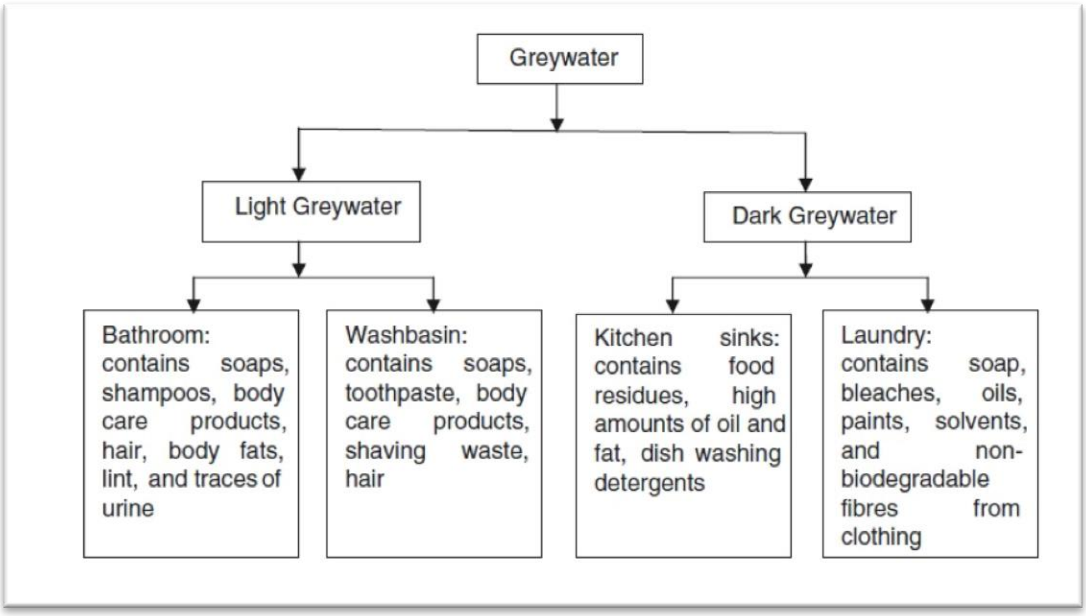

Fig. 1: Greywater sources and their constituents [19,28,29]

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2.1 Qualitative features of Greywater

Many factors affect the characteristics of greywater quality, such as the plumbing system, GW source (domestic or commercial) in the plumbing system, the plumbing system, the location, the water source, the residents' routines and way of life, and many others [33,34]. Furthermore, a number of other factors impact the quality of GW, including cleaning product usage, laundry procedures, bathing routines, and patterns for washing dishes and disposing of home chemicals [35]. Greywater from the bathroom or hand basin often includes less particulates, organic carbon, and germs than that from the kitchen and laundry [36].

Most of the time, fresh GW cannot be analyzed right away after discharge, and the amount of time that GW is stored until analysis affects its quality. Storage has a significant impact on GW quality for solids and a modest impact on organics [37]. Therefore, depending on the home wastewater volume [38,39], greywater can account for 50% to 80% or even over 90% of the total volume if vacuum toilets are fitted [40]. Although the average amount of greywater is between 90 and 120 l/p/d, in low-income nations with ongoing water scarcity, As little as 20 to 30 l/p/d of GW may be present [29]. Additionally, there are differences in the amount of greywater between urban and rural areas. Figure 2, shows the various sources of greywater [19,41,42].

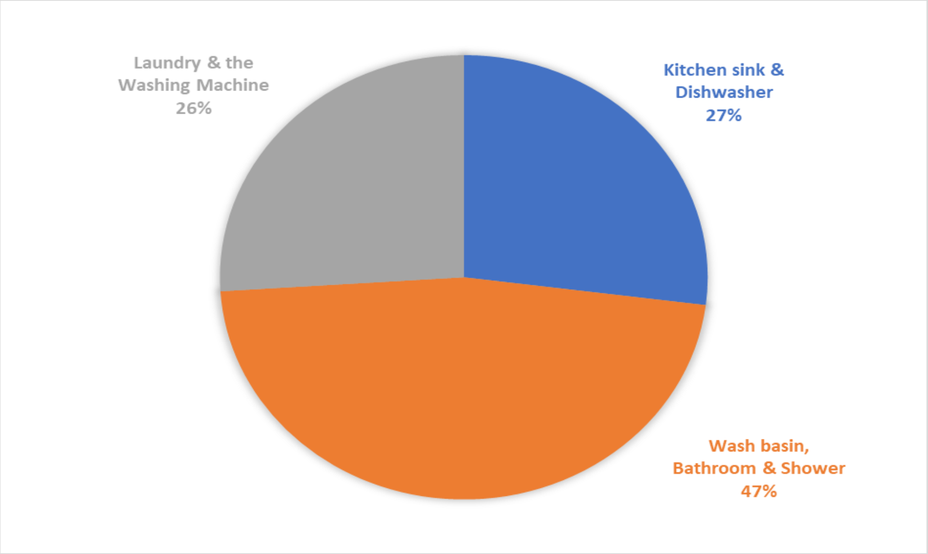

Fig. 2: Greywater distribution at various sources [19,41,42].

Knowing the physical, chemical, and biological properties of greywater and how they vary is essential when choosing a greywater treatment system. Table 1 lists the greywater's chemical, biological, and physical components.

Table 1: Greywater's chemical, biological, and physical components

No.	Constituent Types	Parameters	Range	References
1	Physical constituents	Temperature	17–35 °C	[43]
		Turbidity	20 – 440 NTU	[44]
		Electrical conductivity	15 – 3000 µS/cm	[45]
		Suspended solids	200–530 mg/l	[46,47]
2	Chemical constituents	pH	7.5 – 8.2	[48]
		Nitrates	0.65 mg/l	[49]
		BOD	100 – 180 mg/l	[46]
		COD	250 – 370 mg/l	[50]
		Phosphates	0.01 mg/l	[51]
		Chlorides	50 mg/l	[43]
		Oil and grease	10 mg/l	[52]
		Magnesium	0.1 mg/l	[53]
		Calcium	30 – 50 mg/l	[54]

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3	Biological Constituents	Total coliforms (counts/100 ml)	1×103 – 8×108	[32,33]
		E. coli	Up to 6×106	[17,46,55]
		Fecal coliforms	Up to 1×106	[56,57]
		Pseudomonas aeruginosa	1×104	[58,59]
		Staphylococcus aureus	1×102 – 1.5×103	[58,60,61]
		Salmonella typhi	5×103	[62]
		Salmonella spp.	3×103	[46]

3. GREY WATER TREATMENT SYSTEMS

For storage and use, raw greywater treatment is required. Greywater should be treated to a higher degree before reuse since it presents health risks to people and their environment if left untreated [63,64]. Reuse standards must be met, as well as health, cosmetic, and technical issues (caused by organic debris, particulates, and pathogens) must be resolved [65]. Various technologies with varying levels of complexity and effectiveness have been the subject of numerous studies on greywater treatment [64]. Physical, chemical, biological, or a combination of these systems are the several types of GW treatment technologies according to the treatment principle they employ [48,64,65]. Screening, grit removal, sedimentation, sludge thickening, ion exchange, multimodal filtration, adsorption, reverse osmosis, and ultrafiltration are examples of physical and chemical techniques. The two basic categories of biological techniques are aerobic and anaerobic. The two categories of aerobic technologies are attached growth (such as misleading filters, rotating biodiscs, created wetlands, etc.) and suspended growth (such as activated sludge processes, aerated lagoons, waste stabilization ponds, etc.). Anaerobic treatments comprise sludge digesters, contact beds, up-flow anaerobic sludge blanket reactors and anaerobic ponds [66]. Pre-treatment, primary treatment, and post-treatment are the three separate therapy steps that precede most of these technologies, as shown in Figure 3. Septic tanks, filter bags, screens, and filters are examples of pre-treatment methods used to reduce the quantity of debris, oil and grease to avoid clogging the treatment in the future (Li et al., 2009). On the other hand, the post-treatment disinfection phase is utilized to satisfy the microbiological requirements.

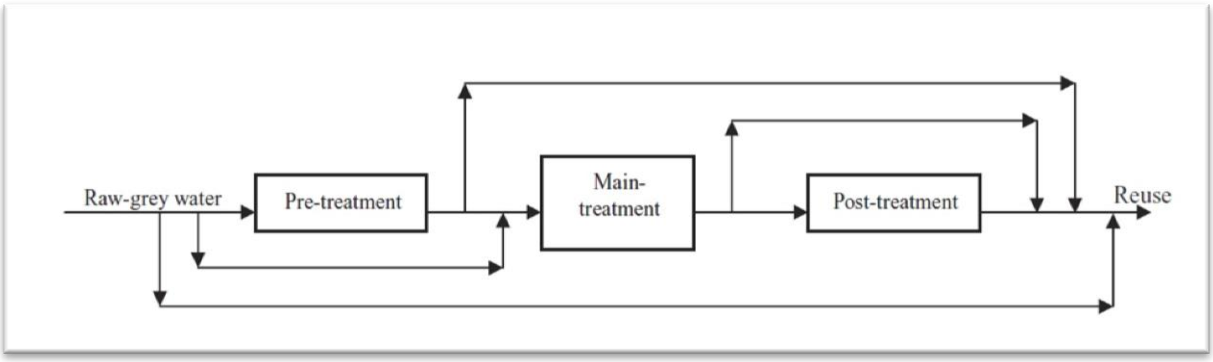

Fig. 3: Potential procedures and pathways for the recycling and treatment of GW [65]

3.1 Physicochemical Treatment

Physicochemical technology clears significantly more water and removes organic impurities from greywater [53]. Dust, gritty sand, and membrane separation are examples of common physical therapies. Three methods are used in a typical physical procedure to clean water: (i) Particle screening by physical means; (ii) Chemical sorption of pollutants onto the soil surface; and (iii) Absorption, occurring when aerobic microorganisms consume wastewater and take up its nutrients. The most widely used physical and chemical treatment options for GW treatment systems are disinfection units coupled with sand filters [67]. The distribution of contaminants with different sizes in greywater and the porosity of the filters affect the filtration methods' efficacy; in general, higher effluent quality corresponds with lower porosity of the filters. As a result, the amount of contaminants that coarse filters can remove from greywater is restricted [19,48,64,65].

According to Chaillou et al. (2011), sand filters efficiently eliminate TSS, TDS, and turbidity from greywater [68]. More than 76% of the turbidity, TDS, and TSS were removed in the investigations by Friedler & Alfiya, and Samayamanthula et al. [69,70]. Sand's hydrophobic properties, which draw TSS in large quantities, are mostly to blame for this. Additionally, through ion exchange and adsorption processes, finer sand particles draw in negatively charged colloidal particles [67)]. One of the main causes of organic matter removal in sand filters is the development of a schmutzdecke layer. The quantity of organic matter reduced in sand filtration treatment units is insufficient, nevertheless, as it only forms on the top surface of the sand filters [71]. Sand filters can work more efficiently by employing pre-treatment methods like coagulation and sedimentation [72]. According to March et al. (2004), the low strength bath GW treatment system used a nylon sock-style filter, followed by a sedimentation and disinfection stage [73]. COD, turbidity, SS, and TN were 170 mg/l, 20 NTU, 45 mg/l, and 11.5 mg/l in the influent and 76 mg/l, 16.4 NTU, 18.5 mg/l, and 7.2 mg/l in the effluent, respectively. GW is treated using ultra-filtration (UF) and nanofiltration (NF) in the Ramon et al. (2004) study without any prior treatment [74]. The UF wastewater exhibited a removal rate of 45–75% for COD and above 90% for turbidity, with very little BOD5 removal. NF showed more than 90% elimination of organic materials in the same research [74)]. But phosphorus and dissolved nitrogen can flow through microfiltration and UF pores with ease [75]. In all of the filtering systems, very little nutrient removal occurs, including nitrogen and phosphorus. When coagulants like calcium hydroxide ($CaOH_2$) and ferric chloride ($FeCl_3$) are added to greywater, the result is a significant pH shift during the coagulation process and an excellent removal of COD and BOD_5. This is mostly because the coagulants react with the nitrates in the greywater [76]. The use of physical processes as the only means of treatment for greywater is inadequate, unless the organic strength is very low, as this approach does not ensure a considerable reduction of organics, nutrients, and surfactants [19,64,65].

3.2 Biological Treatment

One important factor in the biological breakdown of pollutants in greywater is oxygen. Through the aeration process, oxygen is disparaged to promote the growth of bacteria in the aerobic biological process [47]. Usually, the size of the particles, the quantity of gas, and the viscosity of the solution control how much oxygen diffuses during aeration [77]. Greywater treatment has made use of a number of biological treatment methods, such as Sequencing Batch Reactors, Membrane Bioreactors, Rotating Biological Contactors and the Up flow Anaerobic Sludge Blanket. Boyjoo et al. (2013) state that biological systems normally go through a pre-treatment stage of coarse filtration before being exposed to a stage of sedimentation or filtration to remove biosolids or sludge. This is followed by a post-treatment step of disinfection using UV or chlorination to eliminate bacteria [48].

A unique type of activated sludge process (ASP) known as a sequencing batch reactor (SBR) allows for full treatment to occur inside the reactor tank, negating the need for separate clarifiers. With this procedure, wastewater is treated in batches, with each batch going through a different step of the treatment process. In a single tank, SBR achieves equalization, biological treatment, and secondary clarity using a time-controlled procedure. It is one of the technologies used in tiny communities to remove traditional boundaries. It provides excellent operational flexibility for efficient nutrient removal. Fill, respond, settle, draw, and idle are the five fundamental processes that make up the SBR operation [78]. Shower greywater treated by SBR (Lamine et al., 2007) meets NH_4–N, BOD, and COD criteria for wastewater reuse; COD removal ranged similarly, with BOD removal ranging from 80 to 98%. This degree of efficiency was attained using the Hydraulic Retention Time (HRT) in 36 hours, which is extremely high but regrettably unfeasible for practical use [79]. It was not examined how well SBR systems performed for reuse criteria including as turbidity, TC, TSS, FC, and E. Coli [19]. Scheumann & Kraume (2009) conducted a study that was comparable to this one, using a pilot scale SBR with different retention times. The study found that the removal of COD, NH_4-N, and TN was adequate to fulfill discharge reuse requirements [80]; however, Lamine et al. (2007) also mentioned that this study's nitrification occurred [79]. Hermawan et al. (2019), came to the conclusion that SBR could effectively remove five chemical compounds known as paraben biocides and lower BOD to less than 5 mg/L. The bacterial community was using paraben as a source of carbon for reproduction, according to their research, which explained why the selected biocides' eradication efficiency ranged from 87 to 99%. A similar procedure was used to treat high-strength greywater in an SBR with a 15-day sludge retention period and an 11.7-hour retention period. Concentrations of COD (132 mg/L), TP (6.8 mg/L), TN (34.5 mg/L), and ammonia (0.42 mg/L) were found in the treated effluent, that were significantly lower than the influent's concentrations of TN (53.6 mg/L), COD (830 mg/L),

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TP (7.7 mg/L), and ammonia (1.2 mg/L) [81]. One of the most popular biological treatment methods, the SBR reduces COD in greywater by 90% [80,82]. The relatively large percentage of colloidal COD in greywater, which is easily removed by aerobic processes, is the primary cause of the high removal in the aforementioned investigations [83].

A membrane bioreactor (MBR) combines an ultrafiltration (UF) or microfiltration (MF) device with biological treatment (aeration alone). To separate the particulates from the liquid, a membrane is utilized rather than a clarifier. After biological treatment, the membrane stage offers a beneficial method of liquid solid separation by preventing biological solids from being lost in the wastewater and permitting the reactor to hold a larger concentration of biomass [66]. Since post-filtration and disinfection procedures are not necessary, this is the only approach that can achieve sufficient removal efficiency of organic compounds, surfactants, and microbiological contaminations, the MBR is acknowledged as a cutting-edge GW treatment technique. MBR systems were able to achieve a variety of effective removal rates, including turbidity (98–99.9%), TSS (almost 100%), BOD (92–98%), COD (88–99%), total N (50–65%), PO_4–P (15–45%), total P (20%), and FC (99.9%) [19]. The MBR effluent's characteristics met a number of reuse requirements [48,84]. MBR appears to be a promising technological solution for GW recycling, particularly in shared urban residential complexes, as it produces little surplus sludge, a compact structure, excellent and stable effluent quality, and a high organic loading rate [85]. When a building is larger than 37 stories, On-site MBR-based GW treatment techniques can be practically and financially feasible, according to Friedler & Hadari's (2006) research [17]. For the purpose of treating bath grey water with low strength, A Mitsubishi Rayon (polyethylene, 0.4 µm pore size) submerged MBR was described by Liu et al. (2005). According to the study's findings, the effluent's BOD_5, NH_4-N concentration, and COD levels were all reduced. Ionic surfactants (AS) were found in the influent at concentrations between 3.6 and 9 mg/l and in the effluent at concentrations below 0.5 mg/l. The effluent had no color, no odor, and no SS content. The amount of fecal coliform was below the threshold for determination. In order to provide steady and superior effluent water quality, this study showed that the majority of the pollutants were eliminated by biological degradation, with the remaining pollutants being further removed by membrane separation [86]. After operating for 50 days, According to Smith & Bani-Melhem, at constant transmembrane pressure, the MBR-based GW treatment system removed about 92% of TSS and 85% of BOD_5 [87]. Biological processes are superior to physicochemical and sophisticated oxidation methods for the removal of nutrients from greywater. In the trials carried out by Lamine et al., phosphate was also decreased by 66%, and over the 2.5 day aerobic treatment procedure, GW was cleaned of 51% nitrite and nearly 92% of ammoniacal nitrogen. However, the absence of denitrification in the aerobic zone restricts the amount of nutrients that can be fully removed from the GW [80]. The aforementioned data suggests that membrane-based treatments shown excellent efficacy in the reclamation of greywater. The sustainability of membrane technology was improved by developments in membrane-based systems. But the membrane-based system's main drawbacks are its expense and upkeep. Future research in membrane systems will focus on a combination of less advanced technology and methods found in nature. This could strengthen the already-established technique and help it overcome the problems associated with GW reclamation [27].

Fixed bed reactors equipped with revolving disks positioned on a horizontal shaft are known as rotating biological contactors (RBC). As wastewater passes through them, they rotate and get partially immersed. The treatment's microorganisms are periodically exposed to the atmosphere in order to aid in the aeration, assimilation, and breakdown of dissolved organic contaminants and nutrients [19,46]. Using the RBC stage, the BOD can be reduced to below 5 mg/l, as the Eriksson et al. (2007) study shows. Additionally looked at the pilot GW treatment system removal efficiency of five particular trace organic component types. According to their research, the treatment plant is capable of efficiently eliminating the five paraben biocides—methyl, ethyl, propyl, butyl, and iso-butyl esters of parahydroxy benzoic acid—which indicates that microorganisms have evolved to use parabens as a carbon source for growth. The biocides that were chosen exhibited removal efficiencies ranging from 87% to 99%, surpassing the COD, BOD, and TOC removal efficiency of the composite parameters [88]. Gilboa & Friedler (2008) looked into the efficacy of sedimentation followed by RBC in removing Pseudomonas aeruginosa sp., Staphylococcus Aureus sp., Clostridium perfringens sp. and faecal coliforms (FC) from greywater. According to the study's findings, up to 99% of the microorganisms present in the greywater were eliminated by the system. In terms of pH, BOD5, COD, microbial load reduction, and producing effluents that adhere to discharge regulations, RBC systems function well [89]. The effectiveness of a single-stage RBC on greywater in Pakistan was investigated by Pathan et al. (2011). Plastic sheets and textured plastic disks were used to create the RBC [90]. Up to 40% of the time the greywater was held in the

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system, the rotating discs were submerged in it. The ability of RBC to eliminate particular pathogens (such as Pseudomonas aeruginosa sp. and Staphylococcus aureus sp.) and indicator bacteria (such as faecal coliforms and heterotrophic bacteria) was investigated by Friedler et al. in 2011. RBC eliminated 88.5–99.9% of all four bacterial types, according to the study's findings [91]. According to Abdel-Kader (2013), the RBC is another aerobic method that is commonly used to treat greywater and has shown good removal of BOD5 and TSS by 93% and 95%, respectively. However, these aeration systems are not suitable for use in small pilot-scale treatment units due to their high space requirements [92].

For a variety of wastewater types, the most popular and effective high-rate anaerobic system is the up-flow anaerobic sludge blanket (UASB) reactor. The UASB reactor may be operated at a cheap cost and high focus of active suspended biomass using straightforward methods. Additionally, the granular sludge that is developing is more methanogenic and better able to settle than flocculent sludge, increasing the maximum loading rate of the UASB system [93]. For many different kinds of wastewater streams, the UASB continues to be one of the most popular wastewater treatment systems [46]. In the Elmitwalli et al. (2007) investigation, a UASB was used to treat mixed grey water at room temperature. According to the study, ongoing operations at HRT of 20, 12, and 8 hours decreased overall COD by 31-41%, TN by 24-36%, and TP by 10-24%, respectively [93]. Additionally, a UASB grey water treatment system operating at 35 °C was described by Hernandez et al. (2008). Hernandez et al. (2008) found that at HRT of 7.0 and 12.5 hours, the UASB system can remove about 55% of the COD and 25% of the anionic surfactants [94]. A manufacturing facility's UASB Greywater treatment equipment was developed by Hernandez et al. (2011). They found that at HRTs of 7.0 at 12.5 hours, the UASB system could remove 24% of anionic surfactants and almost 50% of chemical oxygen demand [95]. Anaerobic degradability of a single-stage UASB reactor was higher than that of a typical septic tank even at minimal temperatures, according to research on UASB reactors for GW treatment conducted by the Hamburg University of Technology in Germany. Moreover, Okeng et al. (2018) state that a two-stage UASB reactor may significantly lessen its hydraulic retention [46].

4. CONCLUSION

The current investigation demonstrates that the creation and properties of greywater vary greatly. Greywater can be effectively treated by isolating it from its source because it is less contaminated than black water. Even while GW isn't as dirty as sewage or BW, it still needs to be treated before being used again. Actually, none of the untreated GW features meet the requirements and rules for reuse. Based on the characteristics of grey water and the suggested standards, recycled grey water is reused in metropolitan areas. Based on the literature review, the following inferences can be made:

1. The COD:BOD_5 ratios for all varieties of grey water indicate good biodegradability. Both nitrogen and phosphorus are lacking in the grey water used for washing and bathrooms. The COD:N:P ratio of the gray water in the kitchen is balanced. Kitchen grey water should be combined with other streams if biological treatment is the plan for treating the water to prevent macronutrient and trace nutrient deficiencies.
2. Reducing organics, nutrients, and surfactants to a suitable level cannot be ensured by physical processes alone. As a result, recycling grey water is not advised.
3. The low strength grey water can be effectively cleaned of suspended particles, organic compounds, and surfactants using chemical procedures.
4. Because anaerobic processes are not very effective at removing organic contaminants and surfactants, they are not recommended for treating GW.
5. The majority of treatment technologies used for treating GW are highly energy-intensive techniques like SBR, MBR, etc. While less energy-intensive techniques like sand or granular activated carbon filtration are less effective at removing pollutants, combining these systems can result in higher pollutant removal efficiencies and better-quality effluents from GW treatment.
6. Particularly in common urban housing complexes with more than 500 residents, the MBR appears to be a particularly alluring choice for recycling medium- and high-strength GW.

7. Aerobic biological processes like RBC and SBR can be employed for medium- and high-strength GW treatment. It is believed that combining an aerobic biological process with physical filtering and disinfection is the most economical and practical way to recycle GW.

REFERENCES

[1] Manju S and Sagar N (2017). Renewable energy integrated desalination: a sustainable solution to overcome future fresh-water scarcity in India. *Renewable and Sustainable Energy Reviews*, 73:594–609.

[2] Rajasulochana P and Preethy V (2016). Comparison on efficiency of various techniques in treatment of waste and sewage water—a comprehensive review. *Resources Technology,* 2:175–184.

[3] Boano F, Caruso A, Costamagna E, Ridolfi L, Fiore S, Demichelis F, Galvão A, Pisoeiro J, Rizzo A and Masi F (2020). A review of nature-based solutions for greywater treatment: Applications, hydraulic design, and environmental benefits. *Science of the Total Environment,* 711:134731.

[4] Kounina A, Margni M, Bayart JB, Boulay AM, Berger M, Bulle C, Frischknecht R, Koehler A, Milà Canals L. and Motoshita M. (2013). Review of methods addressing freshwater use in life cycle inventory and impact assessment. *International Journal of Life Cycle Assessment*, 18(3):707–721. https://doi.org/10.1007/s11367-012-0519-3.

[5] Qadir and Manzoor (2017). Uncover Resources: Alleviating global water scarcity through unconventional water resources and technologies. *United Nations University Institute for Water, Environment and Health (UNU-INWEH)*.

[6] Eakin BW and Sharman GF (2010). Volumes of the world's oceans from ETOPO1. *NOAA, National Geophysical Data Center*. Accessed 22nd October 2017.

[7] United Nations (2018). Sustainable Development Goal 6, Synthesis Report on Water and Sanitation. SDG 6 Synthesis Report 2018 on Water and Sanitation | UN-Water (unwater.org).

[8] Qureshi ME and Hanjra MA (2010). Global water crisis and future security in an era of climate change. *Food Policy*, 35: 365–377. https://doi.org/10.1016/j.foodpol.2010.05.006.

[9] Spychala M, Niec J, Zawadzki P, Matz R and Nguyen TH (2019). Removal of volatile solids from greywater using sand filters. *Applied Sciences,* 770: 2–13.

[10] Shi K, Wang C and Jiang S (2018). Qualitative microbial risk assessment of greywater onsite reuse. *Science of the Total Environment*, 635: 1507–1519.

[11] Chong MN, Cho YJ, Poh PE and Jin B (2015). Evaluation of Titanium dioxide photocatalytic technology for the treatment of reactive Black 5 dye in synthetic and real greywater effluents. *Journal of Cleaner Production*, 89: 196-202.

[12] Drechsel P, Mahjoub O and Keraita B (2015). Social and Cultural Dimensions in Wastewater Use. *Wastewater*. Springer :75-92. https://doi.org/10.1007/978-94-017-9545-6_5.

[13] Gyasi SF, Kuranchie FA and Ntibrey RA (2020). Antimicrobial and coagulation potential of Moringa oleifera seed powder coupled with sand filtration for treatment of bath wastewater from public senior high schools in Ghana. *Heliyon*, 6: 1-10.

[14] Oron G, Adel M, Agmon V, Friedler E, Halperin R, Leshem E and Weinberg D (2014). Greywater use in Israel and worldwide: standards and prospects. *Water Research*, 58: 92–101.

[15] Oh KS, Leong JYC, Poh PE, Chong MN and Von Lau E (2018). A review of greywater recycling related issues: Challenges and future prospects in Malaysia. *Journal of Cleaner Production*,171:17–29.

[16] Barzegar G, Wu Jand Ghanbari F (2019). Enhanced treatment of greywater using electrocoagulation /ozonation: investigation of process parameters. *Process Safety and Environmental Protection*, 121:125–132.

[17] Friedler E and Hadari M (2006). Economic feasibility of on-site greywater reuse in multi-storey buildings. *Desalination*, 190: 221-234.

[18] Albalawneh A and Chang TK (2015). Review of the Greywater and proposed greywater recycling scheme for Agricultural irrigation reuses. *International Journal of Research – Granthaalayah*, 3(12): 16-35.

[19] Ghaitidak DM and Yadav KD (2013). Characteristics and treatment of greywater—a review. *Environmental Science and Pollution Research*, 20(5):2795–2809.

[20] Remy Cand Jekel M (2008). Sustainable wastewater management: life cycle assessment of conventional and source-separating urban sanitation systems. *Water Science & Technology*, 58(8):1555–1562.

[21] Larsen TA, Alder AC, Eggen RI, Maurer M and Lienert J (2009). Source separation: will we see a paradigm shift in wastewater handling. *Environmental Science & Technology*, 43:6121–6125.

[22] Arden S and Ma X (2018). Constructed wetlands for greywater recycle and reuse: a review. *Science of the Total Environment*, 630:587–99. https://doi.org/10.1016/j.scitotenv.2018.02.218.

[23] Wu B (2019). Membrane-based technology in greywater reclamation: a review. *Science of the Total Environment*, 656:184–200. https://doi.org/10.1016/j.scitotenv.2018.11.347.

[24] Cecconet D, Callegari A, Hlavínek P and Capodaglio AG (2019). Membrane bioreactors for sustainable, fit-for-purpose greywater treatment: a critical review. *Clean Technologies and Environmental Policy*, 21:745–62. https://doi.org/10.1007/s10098-019-01679-z.

[25] Abedin SB and Rakib ZB (2013). Generation and quality analysis of greywater at Dhaka City. *Environmental Research, Engineering and Management*, 64(2):29–41.

[26] Katukiza AY, Ronteltap M, Niwagaba CB, Kansiime F and Lens PNL (2015). Grey water characterisation and pollutant loads in an urban slum. *International Journal of Environmental Science and Technology*, 12(2):423–436.

[27] Awasthi A, Gandhi K. and Rayalu S. (2023). Greywater treatment technologies: a comprehensive review. *International journal of Environmental Science and Technology*, 21:1053–1082.

[28] Noah M (2002). Greywater use still a gray area. *Journal of Environmental Health*, 64(10):22–25.

[29] Morel A and Diener S (2006). Greywater management in low and middle-income countries, review of different treatment systems for households or neighbourhoods. *Swiss Federal Institute of Aquatic Science and Technology*, 14(6): 107.

[30] Kassinos FD, Kalavrouziotis IK, Koukoulakis PH and Vasquez MI (2011). The risks associated with wastewater reuse and xenobiotics in the agroecological environment. *Science of the Total Environment*, 409: 3555–3563. https://doi.org/10.1016/j.scitotenv.2010.03.036.

[31] Birks R and Hills S (2007). Characterisation of indicator organisms and pathogens in domestic greywater for recycling. *Environmental monitoring and assessment*, 129: 61-69.

[32] Alsulaili AD and Hamoda MF. (2015). Quantification and Characterization of greywater from schools. *Water Science & Technology*, 72: 1973–1980.

[33] Asare DB, Nyarko KB, Awuah E, Essandoh HA, Anim KK and Quaye A (2018). Greywater in the drains of a sewered community in Ghana. *Water Practice and Technology.*, 13: 965–979.

[34] Gani P, Sunar NM, Matias-Peralta HM, Latiff AA, Kamaludin NS, Parjo UK, Emparan Q and Er CM (2015). Experimental study for phytoremediation of Botryococcus sp. on greywater. *Applied Mechanics and Materials,* 773-774: 1312–1317.

[35] Prathapar SA, Jamrah A, Ahmed M, Al-Adawi S, Al-Sidairi S and Al-Harassi A. (2005). Overcoming constraints in treated greywater reuse in Oman. *Desalination*, 186: 177–186.

[36] Kariuki FW, Kotut K and Nganga VG (2011). The potential of a low-cost technology for the greywater treatment. *Open Environmental Engineering Journal,* 4: 32–39.

[37] Katukiza AY, Ronteltap M, Niwagaba CB, Kansiime F and Lens PNL (2014). Greywater treatment in urban slums by a filtration system: optimisation of the filtration medium. *Journal of Environmental Management*, 146: 131–141.

[38] Jenssen P and Vråle L (2003). Greywater treatment in combined biofilter/constructed wetlands in cold climate. *Second International Conference on Ecological Sanitation, Germany,* 875-881.

[39] Flowers B (2004). Domestic Water Conservation: Greywater, Rainwater and Other Innovations. *Canadian Standards Council.*

[40] Leal LH, Temmink H, Zeeman G and Buisman C (2011). Characterization and anaerobic biodegradability of grey water. *Desalination*, 270: 111-115.

[41] Jamrah A, Al-Omari A, Al-Qasem L and Ghani NA (2006). Assessment of availability and characteristics of greywater in Amman. *Water international*, 31: 210-220.

[42] Al-Mughalles MH, Rahman RA, Suja FB, Mahmud M and Jalil N (2012). Household greywater quantity and quality in Sana’a, Yemen. *Electronic Journal of Geotechnical Engineering,* 17: 1025-1034.

[43] Prabhakar DK, Singh AK, Kumar M, Kumar A, Sarkar S and Alam MM (2019). Characterization of grey water and its influence on some basic soil properties. *International Journal of Communication Systems*, 7(3):3644–3647.

[44] Khuntia HK, Chandrashekar S and Chanakya HN (2019). Treatment of household greywater laden with household chemical products in a multi-chambered anaerobic biofilm reactor. *Sustainable Cities and Society*, 51:101783.

[45] Ciabattia I, Cesaro F, Faralli L, Fatarella E and Tognotti F (2009). Demonstration of a treatment system for purification and reuse of laundry wastewater. *Desalination*, 245(1–3):451–459.

[46] Oteng-Peprah M, De Vries NK and Acheampong MA (2018). Greywater characterization and generation rates in a peri urban municipality of a developing country. *Journal of Environmental Management*, 206:498–506.

[47] Edwin GA, Gopalsamy P, Muthu N (2014). Characterization of domestic gray water from point source to determine the potential for urban residential reuse: a short review. *Applied Water Science*, 4(1):39–49.

[48] Boyjoo Y, Pareek VK and Ang M (2013). A review of greywater characteristics and treatment processes. *Water Science & Technology*, 67(7):1403–1424.

[49] Parjane SB and Sane MG (2011). Performance of grey water treatment plant by economical way for Indian rural development. *International Journal of ChemTech Research*, 3(4):1808–1815.

[50] Rakesh SS, Ramesh PT, Murugaragavan R, Avudainayagam S and Karthikeyan S (2020). Characterization and treatment of grey water: a review. *International Journal of Communication Systems*, 8(1):34–40

[51] Almuktar SA, Abed SN and Scholz M (2018). Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review. *Environmental Science and Pollution Research*, 25: 23595-23623.

[52] Elhegazy H and Eid MM (2020). A state-of-the-art-review on grey water management: A survey from 2000 to 2020s. *Water Science and Technology*, 82(12): 2786–2797.

[53] Shaikh IN and Ahammed MM (2020). Quantity and quality characteristics of greywater: a review. *Journal of Environmental Management,* 261:110266.

[54] Sushmitha MB, Chanakya HN and Khuntia HK (2019). Efficient grey water treatment and reuse options for India—a review. *Waste Water Recycling and Management*, 3: 143–149.

[55] Atanasova N, Dalmau M, Comas J, Poch M, Rodriguez-Roda I and Buttiglieri G (2017). Optimized MBR for greywater reuse systems in hotel facilities. *Journal of Environmental Management*, 193:503–511.

[56] Mandal D, Labhasetwar P, Dhone S, Dubey AS, Shinde G and Wate S (2011). Water conservation due to greywater treatment and reuse in urban setting with specific context to developing countries. *Resources, Conservation & Recycling*, 55(3):356–361.

[57] Masi F, El Hamouri B, Abdel Shafi H, Baban A, Ghrabi A and Regelsberger M (2010). Treatment of segregated black/grey domestic wastewater using constructed wetlands in the Mediterranean basin: the zer0-m experience. *Water Science and Technology*, 61(1):97–105.

[58] Benami M, Gillor O and Gross A (2015). The question of pathogen quantification in disinfected graywater. *Science of the Total Environment*, 506:496–504.

[59] Khalaphallah R and Andres Y (2012). The effect of various abiotic factors on the survival growth of Escherichia coli and Pseudomonas aeruginosa in bathroom greywater. *Journal of Water Reuse and Desalination*, 2(2):92–101.

[60] Maimon A and Gross A (2018). Greywater: limitations and perspective. *Current Opinion in Environmental Science & Health*, 2:1–6.

[61] Shoults DC and Ashbolt NJ (2017). UV disinfection of hand-rinse greywater and performance testing using indigenous Staphylococcus spp. *Water*, 9(12): 963.

[62] Kim J, Song I, Oh H, Jong J, Park J and Choung Y (2009). A laboratory scale graywater treatment system based on a membrane filtration and oxidation process—characteristics of graywater from a residential complex. *Desalination*, 238(1–3):347–357.

[63] Winward GP, Avery LM, Frazer-Williams R, Pidou M, Jeffrey P, Stephenson T and Jefferson B (2008). A study of the microbial quality of grey water and an evaluation of treatment technologies for reuse. *Ecological engineering*, 32: 187-197.

[64] Li, F, Wichmann K and Otterpohl R (2009). Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment*, 407: 3439-3449.

[65] Ghunmi LA, Zeeman G, Fayyad M and Van Lier JB (2011). Grey water treatment systems: A review. *Critical reviews in environmental science and technology*, 41: 657-698.

[66] Arceivala SJ and Asolekar SR (2007). Wastewater treatment for pollution control and reuse. *Tata McGraw Hill Education Private Limited*, New Delhi.

[67] Kurniawan S, Yuliwati E, Ariyanto E, Morsin M, Sanudin R and Nafisah S (2023). Greywater treatment technologies for aquaculture safety. *Journal of King Saud University - Engineering Sciences*, 35(5):327–34.

[68] Chaillou K, Gérente C, Andrès Y and Wolbert D (2011). Bathroom greywater characterization and potential treatments for reuse. *Water, Air, & Soil Pollution*, 215: 31-42.

[69] Friedler E and Alfiya Y (2010). Physicochemical treatment of office and public buildings greywater. *Water Science and Technology,* 62(10):2357–2363. https://doi.org/10.2166/wst.2010.499.

[70] Samayamanthula D, Sabarathinam C and Bhandary H (2019). Treatment and effective utilization of greywater. *Applied Water Science*, 9(4):90. https://doi.org/10.1007/s13201-019-0966-0.

[71] Sze YS, Aris A, Zaidi NS and Bahrodin MB (2021). Performance of sand filtration system with different sand bed depth for polishing wastewater treatment. *Journal of Environmental Treatment Techniques*, 9(2):452–7.

[72] Antonopoulou G, Kirkou A and Stasinakis A (2013). Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. *Science of the Total Environment*, 454-455: 426-432. https://doi.org/10.1016/j.scitotenv.2013.03.045.

[73] March JG, Gual M and Orozco F (2004). Experiences on greywater re-use for toilet flushing in a hotel. *Desalination*, 164:241–247.

[74] Ramon G, Green M, Semiat R and Dosoretz C (2004). Low strength graywater characterization and treatmentby direct membrane filtration. *Desalination*, 170:241–250. https://doi.org/10.1016/j.desal.2004.02.100.

[75] Ou Z, Yediler A, He Y, Jia L, Kettrup A and Sun T (1996). Adsorption of linear alkylbenzene sulfonate (LAS) on soils. *Chemosphere*,32(5):827–39. https://doi.org/10.1016/0045-6535(95)00350-9.

[76] El-Khateeb MA, Emam WM, Darweesh WA and El-Sayed ES (2019). Integration of UASB and downflow hanging non-woven fabric (DHNW) reactors for the treatment of sewage. *Desalination and Water Treatment*, 164:48–55. https://doi.org/10.5004/dwt.2019.24459.

[77] Germain E and Stephenson T (2005). Biomass characteristics, aeration and oxygen transfer in membrane bioreactors: their interrelations explained by a review of aerobic biological processes. *Reviews in Environmental Science and Bio/Technology*, 4:223–33.

[78] Main JS and Ingavale BC (2012). Sequencing batch reactor for greywater treatment. *EXCEL International Journal of Multidisciplinary Management Studies*, 2:88-107.

[79] Lamine M, Bousselmi L and Ghrabi A (2007). Biological treatment of grey water using sequencing batch reactor. *Desalination*, 215: 127-132. https://doi.org/10.1016/j.desal.2006.11.017.

[80] Scheumann R and Kraume M (2009). Influence of hydraulic retention time on the operation of a submerged membrane sequencing batch reactor (SM-SBR) for the treatment of greywater. *Desalination*, 246: 444–451. https://doi.org/10.1016/j.desal.2008.03.066.

[81] Hermawan AA, Talei A, Leong JYC, Jayatharan M, Goh HW and Alaghmand S (2019). Performance assessment of a laboratory scale prototype biofiltration system in tropical region. *Sustainability*, 11(7):1947.

[82] Shao X, Peng D, Teng Z and Ju X (2008). Treatment of brewery wastewater using anaerobic sequencing batch reactor (ASBR). *Bioresource Technology*, 99(8):3182–3186. https://doi.org/10.1016/j.biortech.2007.05.050.

[83] Hernández LL, Temmink H, Zeeman G and Buisman CJN (2010). Comparison of three systems for biological greywater treatment. *Water*, 2(2):155–69. https://doi.org/10.3390/w2020155.

[84] Bani-Melhem K, Al-Qodah Z, Al-Shannag M, Qasaimeh A, Qtaishat MR and Alkasrawi M (2015). On the performance of real grey water treatment using a submerged membrane bioreactor system. *Journal of Membrane Science*, 476: 40-49.

[85] Lazarova V, Hills S and Birks R (2003). Using recycled water for non-potable, urban uses: a review with particular reference to toilet flushing. *Water Supply*, 3: 69-77.

[86] Liu R, Huang H, Chen L, Wen X and Qian Y (2005). Operational performance of a submerged membrane bioreactor for reclamation of bath wastewater. *Process Biochemistry*, 40(1):125–130.

[87] Smith E and Bani-Melhem K (2012). Grey water characterization and treatment for reuse in an arid environment. *Water science and technology*, 66(1):72–78. https://doi.org/10.2166/wst.2012.167.

[88] Eriksson E, Yan X, Lundsbye M, Madsen TS, Andersen HR and Ledin A (2007). Variation in grey wastewater quality reused for toilet flushing. *Proceeding of the 6th IWA Specialty Conference on Wastewater Reclamation and Reuse of Sustainability*, 9-12 October 2007, Antwerp, Belgium.

[89] Gilboa Y and Friedler E (2008). UV disinfection of RBC-treated light greywater effluent: kinetics, survival and regrowth of selected microorganisms. *Water Research*, 42: 1043–1050. https://doi.org/10.1016/j.watres.2007.09.027.

[90] Pathan AA, Mahar RB and Ansari K (2011). Preliminary study of greywater treatment through rotating biological contactor Mehran Univ Res. *Journal of Engineering Technology*, 30: 531–538.

[91] Friedler E, Yardeni A, Gilboa Y and Alfiya Y (2011). Disinfection of greywater effluent and regrowth potential of selected bacteria. *Water Science and Technology*, 63: 931–940. https://doi.org/10.2166/wst.2011.272.

[92] Abdel-Kader AM (2013). Studying the efficiency of grey water treatment by using rotating biological contactors system. *Journal of King Saud University - Engineering Sciences*, 25(2):89–95. https://doi.org/10.1016/j.jksues.2012.05.003.

[93] Elmitwalli TA (2000). Anaerobic treatment of domestic sewage at low temperature. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands. http://library.wur.nl/WebQuery/wda?dissertatie/nummer=*.Accessed13August2012.

[94] Hernandez L, Temmink H, Zeeman G, Marques A and Buisman C (2008). Comparsion of three systems for biological grey water treatment. Proceedings of Sanitation Challenge: New Sanitation Concepts and Models of Governance, 357-364, Wageningen, The Netherlands.

[95] Hernandez Leal L, Temmink H, Zeeman G, Buisman CJN (2011). Characterization and anaerobic biodegradability of grey water. *Desalination* ,270:111–115.

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