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A review of the most popular systems for greywater treatment

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ABSTRACT

With the scientific evidence of climate change is occurring, water conservation has now become extremely important and every drop of water counts. More than 60% of the domestic wastewater is a by-product of households, municipal wastewater. Known as greywater, it can be easily recycled but has historically been discarded instead. However, countries, municipalities, and communities have now realized the importance of graywater recycling and reuse. Studies and practices have been started to remove and or eliminate major pollutants so that the recycled water can be used for irrigation, toilet flushing, and many other uses. Different types of filtration systems can be used, such as slow sand filtration, rapid sand filtration, slanted soil, and others common systems techniques like sequencing batch reactor, upflow anaerobic sludge blanket reactor used in wetlands. This review aims to discuss the most efficient systems for greywater treatment, by comparing more than 20 systems for their biological, chemical and physical removal of pollutants.

Keywords: Constructed wetlands; Filtration; Greywater treatment; Slanted soil; Sand filtration

1. Introduction

The reuse of wastewater is becoming more and more a necessity around the world, this is due to the growing concern about the shortage of available freshwater supply, notably driven by low amounts of rainfall, drought conditions, high evaporation, and large demands for freshwater, growing population, higher standards of living, and economic considerations. These issues are forcing countries to search for alternative solutions as a substitute to freshwater consumption and resources. Reusing and recycling greywater is receiving increasing attention as a key to overcome high urban water demand. The number of recycling Greywater (GW) studies has increased from 38 studies in 2008 to 110 studies in 2017, and is continuing to grow. GW is defined as domestic wastewater excluding toilet waste and can be classified as either low-load GW (excluding water from kitchen) or high-load GW (including water from kitchen). GW accounts for 61% of the total domestic wastewater stream [1], and has different origins: bathroom that constitutes 50–60% of greywater, kitchen for 10% and washing machines for remaining 25–35%. Greywater can be reused for toilet flushing, irrigation of lawns, athletic fields, cemeteries, parks, golf courses and domestic garden, washing of vehicles and windows, concrete production, and groundwater recharge [2]. Different studies were conducted to address challenges of different types of greywater, taking into considerations the personal hygiene habits, socio-economic status, cultural practices, the lifestyle of residents, the products and chemicals used at homes for bathing and laundry, the frequency of cleaning, cooking habits, and length of showers. All of these factors affect the quantity, composition, and the quality of greywater generated. Understanding those is critical to select the best appropriate treatment method of greywater when dealing with chemicals, solid, and microbial characteristics of greywater. High concentration of sodium, phosphate, boron, surfactants, ammonia, chlorine, nitrogen as well as high suspended solids and oxygen demand; originated from soap, shampoo and cleaning products could be found in greywater. Nitrogen and phosphorus concentration can change from user to user, because some countries ban the use of these two components in detergents and other do not. From study to study and from type to type; physical,

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chemical and microbial characteristics of greywater can vary. Factors effecting such variations of water sources are temperature from hand basin, kitchen sinks, and bathtubs. Other factors are, users age, microbial characteristics, presence of human dead skin cells, dirt, body oils, and fecal coliforms.

In this review we will list and compare several popular methods used to treat greywater and that can deliver high efficiency based on the input, the type of wastewater, and the quality of greywater. Because of the numerous studies made on this subject, only studies that provide results for at least one chemical, physical or microbial parameters will be mentioned.

2. Treatment systems

As discussed earlier, greywater is divided into 2 main categories, low load and high load, and treatment method should be analysed separately for each type. We will start below by the most popular methods used for treating low greywater load, and will address the methods for high greywater load.

2.1. Low load greywater treatment systems

Slow sand filtration (SSF) is the most studied method, because it is well suited for rural communities, as it does not require a high degree of operator skill or attention. This technic that has been used for hundred years is simple to use, reduces protozoa, operates for up to 10 years and the materials are available [1]. But slow sand requires large surface, maintenance and is not effective on viruses. Plus the major problem that slow sand faces is clogging and that it cannot be used on high turbid water. This filter consists of a layer of sand supported by a layer of graded gravel [3]. Previous studies [4–7] reported the efficiency of SSF in water treatment in terms of average of COD, BOD, DOC, Tot-N, turbidity, OM, TOC, *E. coli*, total coliform and fecal coliform removal. Zipf et al. [4], took the water in this study from lavatory sinks in a university campus and had 35.8 ± 45.1 NTU for turbidity, 7.7 pH, 56.0 ± 15.9 mg/L for BOD, 145.8 ± 79.1 for COD, 8.3 ± 3.5 mg/L of surfactants and 1.8 × 105 ± 4.4 × 105 NMP/100 mL of total coliforms. By using slow sand filtration, the average removal efficiency was 61%, 56%, 56%–70% and 61% for turbidity, BOD, COD, surfactants and total coliforms, respectively. Li et al. [5] used landscape water to prove if slow sand filtration could eliminate pollutants. In this study, raw water had 2.96 ± 11.40 NTU for turbidity, 22 ± 50 mg/L for COD, 2.45 ± 9.88 mg/L for BOD and 1.06 ± 3.87 for total nitrogen (Tot-N). After 46 d of test, the average removal of turbidity, BOD, COD and Tot-N was 86%, 67%, 34% and 59% respectively. The third study [6] founded the typical removal efficiencies for slow sand filter when operating in Colombia. Raw water was monitored for over 2 y and then a mean of each parameter was calculated. The mean of turbidity was 64 NTU, fecal coliforms was 63.29 CFU/100 ml, DOC had 18 mg/L. Working with a filtration rates between 0.04 and 0.2 m/h; the removal efficiency of turbidity, coliforms, DOC and BOD were 99%, 90–99%, 5 to 40%, 46 to 75% respectively. The forth study monitored [7] COD, turbidity and total bacterial counts for more than one year using slow sand filtration and had 43.9% removal of COD, 89.5% for turbidity and 73.5% for total bacterial count. One study done by Kader Yettefti et al. [8], reported higher percentages when used river sand from Morocco with 88% for COD, 72% for Tot-N, 65% for Tot-P and 86% for TSS. Therefore we can conclude that changing conditions of media can increase the percentage of elimination.

The *rapid sand filters (RSF)* are also commonly used for light load greywater but also can be used for high load. This filter is large sand grains (1–2 mm) supported by gravel (5 –20 mm) and captures particles throughout the bed [9]. The advantages of rapid sand filters are that it treats a broad range of water, effectively removes colors, and requires smaller land and lower labor cost. Moreover, it is a simple and low cost technology. It is moderately effective on guinea worm larvae, iron, manganese and turbidity; a little effective on bacteria, odor, taste and organic matter (OM). However, similar to the SSF, the RSF can disturb by the clogging problem and it requires chemicals addition and a high level of operator skills. Numerous studies have focused on the influence of certain parameters on the efficiency of RSF [10–13]. Yousaf et al. [10] have reported the efficiency of RSF to eliminate 25% of COD when they have tested 80 mg/L as input water from canal water near Peshawar. Higher efficiency of elimination has been reported by Van Haute et al. [13] with 70.4% because of the use of coagulation flocculation before RSF. Low elimination was reported for BOD with only 14% [10]. RSF is not appropriate to eliminate DOC and TOC with only 2.7% and 20% respectively [11,12]. However, turbidity elimination by RSF is satisfying with >98% of removal [13,14]. Previous works were also interested in studying the *roughing filter,* which can be classified according to flow as vertical or horizontal. The horizontal flow-roughing filter is more commonly used because of its unlimited filter length and its simple layout. In this type of flow solids settle on the top of the filter medium surface and then grow into aggregates. Part of these aggregates will drift towards the bottom as soon as they become unstable [15]. Comparing to other technics the roughing filter is the cheapest and it doesn't require chemical addition sand large amount of space. Nkwonta and Ochieng [16] have repported the modifications impact to roughing filtration technology. Different case studies have been done in Iran, Malaysia, Africa, India and Sri-Lanka, and each study used a different type of medium (*local Iranian sand and gravel* with decreasing sizes: 25 mm–4 mm, *limestone* with ranging particulate sizes: 1.91–16.28 mm, *broken burnt bricks and charcoal*, *fiber glass sheeting* filed with gravel and coarse). Limestone roughing filter achieved the best removing efficiency with 51–67% of BOD, 79–88% of TSS, 75–92% of turbidity, and 67–96% of total coliform. The filtration rate depends on the type of the filter. The efficiency increases with the decrease of flow rate and optimal flow rate was obtained at 0.5 m^3/h [17–19].

Another technique is *Slanted soil*, it is simple to implement at a low cost and can perform during 3 y without maintenance and is known to treat low load greywater [20]. This slanted soil system consists of several chambers containing soil that can be stacked vertically, which requires only smaller space. According to two studies used the Kanuma soil (Japan) which consists of alumina and hydrated silica, this system could remove organic pollutants, total nitrogen, total phosphorus and suspended solids [21,22]. In Iyatama et al. [21] study, influent COD, BOD, SS, Tot-N and the Tot-P were reduced from 271 mg/l, 477 mg/l, 105 mg/l, 20.7 mg/l and 3.8 mg/l in the influent to 40.6 mg/l, 81 mg/l, 23 mg/l, 4.4 mg/l and 0.6 mg/l, respectively, in the effluent. Same results were showed when using the same media [22]. Another study done by Ushijima et al. [23], used crushed baked mud brick, with different sizes ranging from 1 mm to 9.5 mm and with synthetic greywater and were divided into two groups: shower and laundry. During the days these 2 types were fed according to 3 periods of the day (morning and noon) and with different quantities. The average removal of COD and suspended solids were approximately equal to the previous studies with 94% and 80% respectively. Crushed baked mud brick eliminated more than granite and gravel that felled behind for the COD, BOD and suspended solids average removal. Based on two studies done in the international institute of water and environmental engineering in Burkina Faso, using granite (1 to 6 mm) in slanted soil system [24,25], the results showed that granite can remove 67.6% COD, 95.56% BOD and 90% suspended solids; gravel removed even lower percentages with 33%, 78% and 46% for COD, BOD and suspended solids respectively. Finally, we can conclude that the concept of this system is innovative and showed great results. However, slanted soil presents some disadvantages such as throwing out the water volume and temperature of the treatment system.

Silica filter issued for both single and dual filtration. However, there are only very few studies that have focused on this technique. Soyer et al. [26] have reported that single filtration can eliminate 98% of turbidity when raw water coming from 3 different greywater sources in Istanbul had between 6 to 14 NTU.

The *BioSand Filter (BSF)* is a filtration system adapted from the slow sand filters. It is a combination of biological and physical processes that take place in a sand column covered with a biofilm. This new technology has been applied in the developing countries either constructed with concrete or plastic filled with gravel, followed by coarse sand and then fine graded quartz sand [27]. Duke et al. [27] have used a biosand provided by Prostar Industries in Victoria, B.C. and water samples were collected from seven Victoria areas. As reported 62% of DOC, a range of 60 to 94% of turbidity and 70% of TOC can be removed by BSF. BSF can eliminate 76% and 83% of COD and BOD respectively when using 1 mm of sand diameter according to Abudi study when they took water from the college campus in Mustansiryiah University and used 3 sets of experiments each with a different sand diameter (1 mm, 0.75 mm and 0.35 mm) [28]. This filtration technique is also appropriate to treat the TSS, turbidity and TDS with the efficiency respectively of 66.6%, 60% and 48.64% and an absence of *E. coli*, if we used a filter with crushed rocks with 10 mm in diameter [29].

The *Greensand* also known, as manganese greensand is an oxidizing medium used generally for iron, manganese and for turbidity removal. Greensand is a clay mineral that comes from glauconite, a sedimentary rock, which typically has a green color [30]. It is manufactured by coating small particles of iron silicate mineral with manganese sulfate and potassium permanganate [31]. Therefore, iron and manganese oxides fixed on the sand grains adsorb soluble iron and manganese. This medium is quite new and for this reason there is a lack of information regarding its ability to remove pollutants.

Wetlands ecosystems were used as sinks, sources or used to transform nutrients and carbon [32], the idea of using this concept for greywater treatment has therefore grown all over the world. Constructed wetlands will use wetland hydrology, soils microbes and plants to assist in treating greywater [33]. This man-made system is combining three mechanisms: biological which is through the transformation of nutrients using anaerobic and aerobic bacteria and plant root metabolism, the second is physical which is by filtration and sedimentation, and finally the chemical mechanism through the absorption and decomposition that will helps purify waste water. Constructed wetlands are used in small communities for it is cheap and efficient water treatment. It is a technique that is basically divided into two major group based on water flow regime: surface flow and sub-surface flow. Commonly only vertical and horizontal sub-surface flow are well studied. According to Lavrova and Koumanova [34], and after doing a laboratory subsurface vertical-flow wetlands system using *Phragmites australis* as a plant concluded that this system can eliminate 93.1% of COD, 43.3% of BOD and 53.7% of nitrogen. In the same study, constructed wetland system was joined by aerobic activated sludge reactor, a combination approach which allowed to attainment of 97.1% for COD elimination, 54.2% for BOD and 93.7% for nitrogen removal. Ammari et al. [35] constructed a subsurface flow constructed wetlands pilot plant planted with *Typha latifolia* and filled with gravel and fine gravel and was fed with raw domestic wastewater. A pilot that resulted in a good removal yield has been reported for BOD, Tot-N and TSS with the removal of 97%, 86% and 76.5% respectively. Due to the importance and efficiency of this system, many studies tried to modify this concept and a result we have the modified constructed wetlands called "EvaTAC" that combine evapotranspiration and treatment tank with anaerobic digestion chamber followed by a horizontal subsurface flow-constructed wetland. Using different plants and strategies, numerous case studies were made all over the world in order to enhance constructed wetlands knowledge.

Despite the fact that *gravel* is a low cost media, easy to obtain and to install and is used as a media in most water treatment technique, only few have focused on its removal efficiency. Dario Sanchez et al. [36] have conducted a study on the four gravel process namely dynamic gravel filters, horizontal flow gravel filters, downflow gravel filters in series and upflow gravel filters in layers. A dynamic gravel filter consists of two or more parallel units packed with 3 layers of gravel of different sizes ranging from coarse at the bottom to fine at the surface. In this study, raw water had 64 NTU for turbidity, 172 mg/L for total solids, 14.3 mg/L for COD, and 63.29 CFU/100 ml for fecal coliforms. After testing the different types of gravel; dynamic gravel filter offers the best efficiency to remove COD (44%), TSS (80%), turbidity (79%) and fecal coliforms (52.50%).

Anthracite filter media is a series of anthracite coal products designed for water filtration. Anthracite is characterized by a higher service flow, longer filter runs and lighter than sand filters. Jiang et al. [37] have conducted their study on eight filter media (gravel, zeolites, anthracite, shale, vermiculite, ceramic filter media, blast furnace steel slag and round ceramic). Comparing these media, and depending on the nature of the substrate and the adsorption mechanism; the highest removal rates of BOD, Tot-N, Tot-P and TOC were obtained with anthracite media filter. Zhang et al. [38] have studied the removal efficiency of Tot-N and COD for 3 anthracite particle size (1–3 mm, 3–5 mm and 0.5–1 mm) in vertical flow constructed wetland columns. The best efficiency was obtained with 1–3 mm with 88.3% and 73% of removal for COD and Tot-N respectively. A dual media filter with anthracite coupled with silica sand was compared with a single layer system in the studies of Kazemi et al. [39] and Katukiza et al. [40]. With the use of anthracite, the results were increased and the removal of TOC was 65.59% and COD was 63.95%.

Recently, Lava rocks were selected as a new medium for greywater treatment. In a laboratory scale, Katukiza et al. [41] investigated the efficiency of lava rocks in treating greywater by implementing 2 uPVC (unplasticized polyvinyl chloride) columns with an exact dimensions and hydraulic loading rate (HLR) in 10 Kampala city households. Both columns were packed differently. The first was filled with 60 cm of lava rock while the second was filled with 30 cm lava rock and silica sand. With a 20 cm/d HLR, the first column had 90% COD removal, 77% TOC and DOC, whereas the second column had 84% elimination of COD, 72% of TOC and 67% of DOC. Another study done by the same group showed better results when working with two step crushed lava rocks filter [41]. A pilot was set in the same city, and was composed of 2 identical filters made of plastic material. Those filters were composed of 10 cm of crushed gravel, 30 cm of graded crushed lava rock. Results showed 90% of COD removal, 59.5% of Tot-N, 69% of Tot-N, 3.9 log removal of *E. coli*, 3.5 log removal of Salmonella species and 3.9 log removal of total coliforms [41].

Cotton, silk, polyester, burlap and many other *fabric materials* are found in every house.

Therefore it's very important to study the efficiency of using these fabrics to eliminate water pollutants and nutrients, unfortunately, but not many researchers have. Tammisetti and Padmanabhan [42] have reported the use of cotton, silk, polyester and burlap to remove the turbidity from water collected from pond in Shrewsbury. The impact of folds (0, 1, 2 and 3 folds) has been study and the results show that folding the material into 3 folds offer the best efficiency with the removal of turbidity of 48.23% for cotton, 43.39% for silk, 57.28% for the burlap and the polyester was not applicable. Colwell et al. [43] have used a cheapest Sari and Nylon filters to appreciate the elimination of cholera, Sari filter was the most effective in eliminating cholera. The removal of COD, BOD and other nutrients hasn't been studied.

Ceramic and *Clay* are considered as a porous medium to treat water, and most Asian countries use ceramic filter because they are easy to manufacture and inexpensive [44, 45]. Erhuanga et al. [45] have described a new ceramic filter included clay, laterite, charred cattle bones and charcoal, then all materials were crushed and processed to dry powdered forms to create a ceramic pot filter. Results showed an improvement in TDS and TSS and lead treatment and as for bacterial removal 78% of bacterial count were eliminated and 99% of coliforms were reduced. The removal of total coliform was equal to another study which indicated that ceramic filter can remove 98% of *E. coli* and total coliforms [46]. A new system that combines aquatic plant filter, bio-zeolite filter, bio-ceramic filter and gravel bed filter was built in an artificial landscape pond to monitor its efficiency [47]. The whole system can remove an average of 38.7% of COD, 57.2% of Tot-N and 45.6% of Tot-P, but it is worth mentioning that the bio-ceramic filter accounted for the primary COD removal. Another technique is clay vessels, and indeed clay can be used as a substitute to zeolite in water treatment. This was proved by the study of Varkey and Dlamini [48] where clay aggregates were used instead of zeolite in different indoor tests and had a removal yield of 70% for COD, 88% for Tot-N, 98% for Tot-P and 70.55% for TSS. Clay can also be used in combination with sawdust to remove the *E.coli*, total coliform and turbidity [49]. The grain size of clay pots had an influence on the removal yield; clay pots of 600 µm outperform the 900 µm pots. The removal yield was as following, 99.9% for *E. coli*, 99.3% for total coliform and 86% for turbidity in pots with 600 µm. Using clay pipes, Naddafi et al. [50] wanted to analyze its performance, this water entering clay pipes was then collected and studied. The removal yield of turbidity was more than 90%.

2.2. High load greywater treatment systems

Bacteria are usually used to eliminate the organic matter substances from municipal wastewater. This mechanism requires constant oxygen therefore requires lot of expertise, manpower and huge amount of money. However, algae release oxygen in the process of photosynthesis and this continuous supply emerged to be the solution as an alternative to bacteria [51]. With low energy requirement, reduction in sludge formation, reduction in greenhouse gas and a production of useful algal biomass, many countries such as Australia, USA, Thailand, Taiwan and Mexico are interested in using algae treatment technique [52–57]. Colak and Kaya [58] have reported the efficiency of algae to eliminate 67.2% of COD from wastewater and 68.4% of BOD. Krishnan and Neera [59] have obtained lower elimination yield with 58.1% of BOD and 53.97% of COD when using a combination of 2 algae *Oedogonium* and *Chara*. The elimination can be improved from 68.4% to 90% of BOD elimination by adding activated sludge [60]. For the Tot-N and Tot-P respectively 56.42% and 71.59% can be eliminated with the combination of *Oedogonium* and *Chara* [59]. *Oedogonium* and *Chara* seems to not be appropriate for the elimination of turbidity with only 13.1% [59]. In comparison, *Chlorella vulgaris* showed better results with 86% for Tot-N and 78% for Tot-P [61]. Activated sludge may also increase the elimination of Tot-P with 80% when added to the algae system, but with extra light the percentage will even increase more, Lau et al. [61] have showed that the elimination of Tot-N will increase to 99.2% and Tot-P to 83.9%.

The activated carbon is a common media used for water treatment due to its excellent adsorption capacity. In the study done by Al-Jlil [62], water was collected from a technical college in Riyadh with a raw BOD of 128.5 mg/L, a COD of 130.33 mg/L, a Tot-N of 1.8 mg/L and a Tot-P of

1.9 mg/L and after using activated carbon for treatment we had an efficiency of 97.6% BOD, 92.1% COD, 89.7% of Tot-N and 67.8% of Tot-P. After collecting greywater from different houses, and passing it through a bed of granular activated carbon, Siong et al. [63], this showed an average pH of 7.13, turbidity of 0.79 NTU, TSS of 7 mg/L, COD of 258 mg/L, BOD of 26.14 mg/L as in input. After treatment however, turbidity decreased to 0.23 NTU, TSS to 1 mg/L, and COD to 5 mg/L also BOD 5 mg/L. Even in removing color and odor, activated carbon can easily do the task [64]. Even though this media effectively removes also bad odors and taste and significantly reduces hydrogen sulfide and heavy metals, the activation of carbon is expensive and has thus limited its use in water treatment [65]. Therefore, biochar was getting the attention for the mutual similarity with activated carbon. Biochar is obtained when biomass, such as wood, manure or leaves is thermally decomposed with little or no available oxygen and at relatively low temperatures (<700ºC), this carbon-rich product therefore incorporate both charcoal and biocarbon [66]. It is generally used for soil improvement, waste management, climate change mitigation, and energy production and of course pollutant removal [66]. Biochar offer similar and sometimes better efficiency than the activated carbon. In a 50 cm columns activated carbon and biochar were packed and fed with artificial greywater in order to evaluate their efficiency [67]. Over the course of 10 weeks, chemical parameters were analyzed. Biochar and activated carbon delivered good results with 99% removal efficiency for COD. Biochar removed Tot-P more than activated carbon with 89%. As for Tot-N activated carbon eliminated 96.6%; a value higher than with biochar 90.9% [67]. In another perspective, a study done by Lobo et al. [68], powdered electrocoagulation was integrated with granular biochar to assure higher treatment efficiency where water samples had a turbidity of 400 NTU and total suspended solids of 514 mg/L. The results showed that this combination can achieve 99% of turbidity and 90% of total suspended solids removal [68–70]. In order to investigate the efficiency of biochar in eliminating *E. coli* [71,72], synthetic water was applied and *E. coli* were cultured, centrifuged and suspended in the synthetic water, and this showed that biochar eliminate 96% of *E. coli*.

Moving bed biofilm reactor (MBBR), is a combination of the process of activated sludge and the biofilter process. These biofilm provide a large protected area and optimum conditions for bacterial culture to grow. The MBBR has many advantages: it takes smaller footprint, uses the whole tank volume for biomass and produces less sludge and an ease of operation. This system is commonly used for treating wastewater and showed over the year's great results in the removal of most pollutants. A case study, done in Morocco, greywater was taken from a sports club. Merz et al. [72] have reported good results with the elimination yield of 98% for turbidity, 85% for COD, 94% for BOD, and 99% for fecal coliforms except for Tot-N with 19% has been removed with an influent composed of 29 NTU turbidity, 109 mg/L COD, 59 mg/L BOD and 100/mL fecal coliforms. Another study conducted in Belgium showed similar results for turbidity, COD and BOD with 98%, 93.5%, 97% and better results were obtained for Tot-N and Tot-P with 58%, and 79.5% respectively when operating with submerged MBR [73]. Although the MBBR offer great results, this technique has proven to be costly.

Coagulation is a major step in water or wastewater treatment; coupled with flocculation these two techniques are widely used for their simplicity and cost-effectiveness. Used as a pre- or post-treatment coagulation-flocculation can affect the overall treatment performance. Coagulation is a chemical reaction, which occurs when a chemical called coagulant is added to the water, this coagulant incites the destabilization of colloidal material present in the solution to join together into flocs [74]. With the use of appropriate chemicals so-called coagulant agents: usually aluminum or iron salts water is then gently stirred to allow the particles to come together and form larger particles for better sedimentation. Through the years the concept of coagulation has evolved, and was combined with energy to create the new electrocoagulation method. This evolution was based on the principle that iron and aluminum anodes can produce cations, which can increase the coagulation of contaminants in water. According to Moreno-Casillas et al. [75], electrocoagulation (EC) can remove metals, anions, organic matters (BOD, COD), suspended solid matters, colloids and even arsenic.

Aluminum sulfate can be used for greywater treatment [76], with average removal of 60% for COD, which was lower than electrocoagulation 88.5% [77–79].

Long life, cheap maintenance, ion exchange resins are polymers that have the ability to exchange particular ions within the polymer within the solution. Water that usually contains calcium and magnesium will pass through a sodium resin and ions will be exchanged; this will then decrease the hardness of water. Although this treatment system seems easy and suitable, only few studies have reported the efficiency of this system's ability to remove the physical, biological and chemical pollutants. A new system emerged from the concept of ion exchange resin, magnetic ion exchange resin (MIEX). The MIEX has a magnetic component in its structure, which facilitates agglomeration and settling. It is 2–5 times smaller than traditional ion exchange resin and has a high surface area for adsorption. Pidou et al. [78] carried out a study that compares MIEX and coagulation for the treatment of greywater. This study showed that MIEX could decrease the COD, BOD, turbidity and Tot-N by 65.6%, 83.9%, 82.53% and15% respectively, after collecting greywater samples from baths, showers and hand basin of 18 flats within Cranfield University residence. The magnetic ion exchange resin process failed to reduce the turbidity and the BOD to the levels required for both unrestricted and restricted reuses. In the same study a combination of MIEX and coagulation resulted in 64% COD and 53% BOD removal [78].

The Upflow anaerobic sludge blanket reactor (UASB) is considered to be the most used technique in anaerobic treatment [82].The waste are introduced in the bottom of the reactor and greywater flows upward through a sludge blanket composed of biologically formed granules or particles [83]. First, a study compared different hydraulic retention time of 16, 10 and 6 h using an UASB reactor feed with collected greywater from a settlement in Luebeck, Germany [83]. The results showed that with HRT equal to 16h COD can be 64% removed and 30% of Tot-N, 21% of Tot-P. The low percentage of elimination of both azote and phosphorus is due to the 3 processes of physical sedimentation, filtration and incorporation into biomass. In the same spirit as the last study, another HRT were tested (20, 12 and 8 h) [84]. The HRT equal to 12 h had better results in the elimination of COD with 41%, a value lower then the previous study with HRT equal to 16 h. As for Tot-P HRT of 20 h and 12 h, this had the approximately the same elimination percentage with 21.6–24%. For Tot-N HRT with 12 h had the highest elimiation with 35.6%.A case study was done in the airport in Brazil in order to test the efficiency of this anaerobic process [85]. The efficiency of this case study was 73% BOD elimination, 72% COD, 77% TSS and 88% turbidity. In another proof that UASB is not appropriate to remove Tot-N and Tot-P, a study collected greywater from 32 houses in Sneek, Netherlands, and 5 L were fed to the UASB system [86]. Results were as the following, 51% elimination of COD, 15% for Tot-N and 11% for Tot-P.

The sequencing batch reactor (SBR) is an alternative of conventional biological treatments due to its simplicity and flexibility [87]. Consisting of 5 stages operating in a septic tank, it can adapt to various volumetric flows and pollutants concentrations [87–90]. The SBR have been proved to be efficient for treating different kinds of effluents. Even with one of the most difficult wastewater types to treat, SBR can eliminate 85.3% of COD, 63.7% TSS and 39.2% Tot-N from dairy wastewater treatment [91]. With the same type of wastewater, another study also choose the SBR system to treat industrial milk factory wastewater and had a slightly higher percentage of elimination of COD with 90% [92]. Combined with coagulation, SBR can treat up to 94% of COD from municipal sewage using poly aluminum chloride as a coagulant [93]. As for greywater SBR can remove the COD up to 90% according to Pidou et al. study [78] biological aerated filter (BAF) because they are both aerobic techniques. BAF can remove COD similarly to SBR with the elimination yield from 85% to more than 96% [94,95]. The BAF is a biological treatment technology that can provide secondary treatment for wastewater and is now popular in Europe for its compactness and easy to implement [96]. Concerning BOD removal, BAF can eliminate 93% from a paint production factory wastewater with 1711 mg/L COD as raw water [95]. However, for Tot-N, BAF can be more efficient with removal yield up to 72% than SBR that can only remove 37% [85]. The efficiency can be improved by adding of an anoxic cycle for denitrification of Tot-N; the removal can therefore be up to 93.5% for Tot-N and Tot-P can reach up to 70% [86,97].

3. Discussion

From this review we can see that there is a large variation and evolution in the greywater treatment systems. Greywater is an important source that we cannot let it go in vain and it is clear now that each type of technology perform differently because of the variation of raw greywater. Comparing and choosing between this numbers of treatment systems is difficult but to simplify the task the average of each parameter from each system will be taken and will be then compared. Table 1 illustrates low load greywater treatment systems and their average parameter value and Table 2 illustrates high load greywater treatment systems and their average parameters.

Constructed wetland showed good results concerning the elimination of major parameters and due to its advantages this system is currently growing all over the world. However, choosing certain plants can affect the output of this system. Concerning different media that were illustrated in this review (silica, biosand, gravel, anthracite, lava rocks) most of them were used in low load greywater. Every media has its own characteristics and because lava rocks comparing to other showed the best porosity and

Table 1
Average percentage of physical chemical and biological elimination of low load greywater pollutants

Methods	COD	BOD	DOC	TOC	Tot-N	Tot-P	TSS	Turbidity	*E. coli*	Total coliform	Fecal coliform	References
Slow sand	55.4%	61%	22.5%	ND	68.5%	65%	86%	84%	ND	78%	ND	[4–8]
Rapid sand	47.70%	14%	2.70%	20%	ND	ND	ND	98%	ND	ND	ND	[10–14]
Roughing	59%	ND	ND	ND	ND	ND	83.5%	83.5%	ND	81.5%	ND	[16]
Slanted soil	82.2%	85.5%	ND	ND	78.7%	84.2%	82.6%	ND	ND	ND	ND	[21–25]
Silica	ND	ND	ND	ND	ND	ND	ND	98%	ND	ND	ND	[26]
Biosand	76%	83%	62%	70%	ND	ND	66.6%	68.5%	100%	ND	ND	[27–29]
Constructed wetlands	95.1%	64.8%	ND	ND	77.8%	ND	76.5%	ND	ND	ND	ND	[32–35]
Gravel	44%	ND	ND	ND	ND	ND	80%	79%	ND	ND	52.5	[36]
Anthracite	76%	ND	ND	65.6%	73%	ND	ND	ND	ND	ND	ND	[38,39]
Lava rocks	88%	ND	72%	74.5%	59.5%	69%	ND	ND	99.9%	99.9%	ND	[40,41]
Fabric	ND	ND	ND	ND	ND	ND	ND	49.6%	ND	ND	ND	[42,43]
Ceramic	38.7%	ND	ND	ND	57.2%	45.6%	ND	ND	98%	99%	78%	[45,46]
Clay	70%	ND	ND	ND	88%	98%	70.5%	88%	99.9%	99.3%	ND	[48–50]

ND: No Data available

Table 2
Average percentage of physical chemical and biological elimination of high lowed greywater pollutants

Methods	COD	BOD	Tot-N	Tot-P	TSS	Turbidity	*E. coli*	Fecal coliform	References
Algae	66.8%	63.2%	71.2%	74.8%	ND	ND	ND	ND	[58–61]
Activated carbon	95%	89.2%	89.7%	67.8	85.7	70.8	ND	ND	[63–65]
Biochar	98%	ND	90.94%	89%	90%	99%	96%	ND	[68–71]
MBBR	89.2%	95.5%	39%	79.5%	ND	98%	ND	99%	[73,74]
MIEX	64.8%	68.4%	15%	ND	ND	82.5%	ND	ND	[81]
UASB	57%	73%	26.9%	18.2%	77%	88%	ND	ND	[84–87]
SBR	89.8%	ND	39.2%	ND	63.7%	ND	ND	ND	[81], [92–94]
BAF	90.5%	93%	82.7%	70%	ND	ND	ND	ND	[87], [95–97]

ND: No Data available

filtration capacity, this medium provided great results when comparing to other concerning the elimination of COD, DOC and bacteria. Although slanted soil system can be considered as a simple and easy to modify system; even when using different types of medium (Kanuma soil, crushed baked mud) elimination percentages of COD, BOD, Tot-N, Tot-P and TSS were amazingly removed compared to slow sand, rapid sand and roughing sand system. In therms of porous and fabrics filters, these systems are considered primitive despite the fact that clay can offer good elimination percentages.

Activated carbon and biochar are known for their amazing removal of pollutants and that is why they are used in eliminating different pesticides, heavy metals and various other unwanted pollutants; also in treating greywater, they both had high percentages of elimination in all parameters studied. Algae capacity of treatment is always related to the type of algae used, but the overall efficiency can be used in treating high lowed greywater. Using algae alone to treat greywater is not the most accurate approach to choose, same as MIEX system that had approximately similar results as algae. BAF is more efficient than SBR and UASB in most of the pollutants elimination.

4. Conclusion

As discussed above the greywater offers environmental and economic benefits, but in order to have efficient results each case demands special media and special technique depending on the water input and reuses guidelines. The study of various literatures concluded that the performance and efficiency of some techniques were more interesting than others. Constructed wetlands, slanted soil, activated carbon and biochar were the most efficient compared to others. To deal with the environmental changes, reusing greywater is the answer to decreasing water consumption; and when choosing a treatment system we need to take into consideration the economic situation and the budget allocation, how the recycled water will be used, as well the source of the raw water and characteristics.

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