Characterization and treatment of grey water: A review

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Abstract
Wastewater generated from households is categorised in to two types, greywater and black water, greywater constituting the largest flow. Greywater refers to the household wastewater generated from showers, washing machines and bathroom sinks excluding toilet wastes and that it has low pathogenic and organic contaminants. The greywater from residential apartment accounts for 50 – 70 per cent. The composition of greywater varies greatly according to its origin (i.e., bathroom, laundry or kitchen greywater) and is influenced by the water quality of the locality. A variety of contaminants including acidic and alkaline substances, suspended and dissolved solids, fats, oil and grease, heavy metals, synthetic chemicals and pathogenic organisms are likely to be present in greywater. The organic fractions in greywater is around 30 per cent, while the nutrient fraction constitute 9 – 20 per cent. Heavy metals, xenobiotic compounds, nitrates, phosphates, quaternary ammonium compounds (QUATS) were reported as contaminants in greywater. Most of these originate from body lotions, hair dyes and make-up materials. The presence of these compounds could harm ecosystems if not properly treated and disposed. The greywater needs to be treated and reused for the various household purposes, other than direct consumption.

Keywords: Greywater, heavy metals, xenobiotics, quaternary ammonium compounds

Introduction
Water, elixir of life, is the capital for social and economic development of human beings and for the preservation of healthy environment. India is blessed with the status of having about 4 per cent of World’s freshwater resources; ranking in one among the top ten water wealth countries. Water resources of a Country are an indicator of the well being of its people. The amount of annual precipitation, availability of surface waters, groundwater potential is the factor that decides the water wealth of a Country. India’s per capita surface availability of water is 1588 cu. m, which is projected to reduce further down to 1401 and 1191 m³ by the years 2025 and 2050 (Kumar et al., 2005) [43]. The domestic water consumption in India accounts for about 17 cu. m (FAO, 2010) [27] while the daily production of grey water in an average sized Indian family is estimated at 398.2 litres (Shaban and Sharma, 2008) [63].

Wastewater generated from households is categorised in to two types, greywater and black water, greywater constituting the largest flow (Emmerson, 1998) [22]. Greywater refers to the household wastewater generated from showers, washing machines and bathroom sinks excluding toilet wastes and that it has low pathogenic and organic contaminants (WHO, 2006) [72], Lazarova et al., (2003) [44] estimated that greywater from residential apartment accounts for 50 – 70 per cent of wastewater generated.

Characteristics of greywater
The composition of greywater varies greatly according to its origin (i.e., bathroom, laundry or kitchen greywater) and is influenced by the water quality of the locality. A variety of contaminants including acidic and alkaline substances, suspended and dissolved solids, fats, oil and grease, heavy metals, synthetic chemicals and pathogenic organisms are likely to be present in grey water (Friedler, 2004; Erikssonand Donner, 2009) [29, 23]. Roeleveld and Zeeman (2006) [59] reported that the organic fractions in greywater is around 30 per cent, while the nutrient fraction constitute 9 – 20 per cent.
pH in greywater
The pH in greywater to a large extent depends on the pH and alkalinity in the water supply and normally is within the range of 5–9. The pH in grey water is directly related to certain chemicals such as fabric softeners, bleaching agents and disinfectants (Eriksson et al., 2002) [25]. Braga and Varesche (2014) [13] reported acidic pH (5.6) in greywater, but Friedler (2004) [29] reported extreme alkaline pH (10) in greywaters of Israel. In general, wide variation in pH, ranging from 6.4 to 8.1 was reported in greywater by many researchers (Burrows et al., 1991; Boal et al., 1996; Parjane and Sane, 2011) [14, 10, 56]. Greywater with most of its sources originating from the laundry will generally exhibit high pH due to the presence of alkaline materials used in detergents. The major chemical constituents found in greywater which is generated as a result of cleaning or washing activities are surfactant. These surfactants serve as the main active agent in most cleaning products. They can be either cationic or anionic in nature with a majority of cleaning and laundry products being anionic (Jakobi and Lohr 1987) [160]. Cationic surfactants are generally salt based, and they constitute a source of ammonium in the greywater. Other constituents found in greywater also include nitrates and phosphate which are reportedly from ammonium and cationic surfactants and laundry disinfectants respectively (Eriksson et al., 2002) [25]. Sodium which is also from cooking and preservation activities in the kitchen can also be found in appreciable levels. Sodium-based soaps also contribute significant quantity of sodium into greywater. Nutrients such as N and P are associated with kitchen and laundry activities. Greywater sources with high nutrients concentrations are mostly made up of a high fraction of kitchen and laundry sources (Boyjoo et al., 2013) [12].

Electrical conductivity in greywater
Bodnar et al. (2014) [111] reported conductivity values ranging from 0.52 – 1.27 dSm⁻¹ in greywater. Higher values of upto 4.7 dSm⁻¹ was obtained by Jamrah and Ayyash (2008) [153]. These variations would have been due to differential discharge of laundry, kitchen and floor washings at differential times. The detergents contains phosphates, sodium and potassium in their raw materials leads to the enrichment of the dissolved solids in the detergents leads to increase in the electrical conductivity. The ranges recorded for electrical conductivity in greywater is between 14 and 300 μS/cm (Ciabatti et al., 2009; Prathapar et al., 2005) [16, 57]. Groundwater sources and water scarce areas are mostly associated with high electrical conductivity due to dissolved materials. Poor or old plumbing materials also contribute to the increase in electrical conductivity due to leaching into greywater sources.

Solids in greywater
The solid content of greywater in generally low, indicating that a large portion of the contaminants in dissolved form (Jayyousi, 2003) [39]. Suspended solid content varying from 15 mg L⁻¹ (Smith and Melhem, 2012) [66] to 800 mg L⁻¹ (Braga and Varesche, 2014) [13] were reported in Brazil. The source of suspended solids is body care products, toothpaste, shaving waste, skin, hair, body fats and food particles and fibres from various textiles (Ghaitidak and Yadav, 2013) [31]. Dissolved solids constitutes an important fraction of greywater. Abinaya and Loganath (2015) [1] have reported TDS values of 712 mg L⁻¹ to 990 mg L⁻¹ in greywater collected from Chennai. Shegokar et al., (2015) [65] reported 688.5 mg L⁻¹ dissolved solids in Nagpur. Much higher values of 6888 mg L⁻¹ was also reported in India (Sharma and Chhippa, 2014) [64]. Higher concentration of dissolved divalent ions such as calcium and magnesium in greywater imparts hardness to greywater (Lucy et al., 2011). Extremely high hardness of 7028 mg L⁻¹ was reported in Jaipur by Sharma and Chhipa (2014) [64]. The high temperatures may favour microbiological growth which is undesirable and may also cause precipitation of certain carbonates such as CaCO₃ and other inorganic salts which become less soluble at high temperatures. The concentration of total suspended solids in greywater can range within 190–537 mg/L as has been reported (Edwin et al. 2014; Oteng-Peprah et al., 2018) [64]. Greywater with much of the water originating from the kitchen and laundry accounts for the relatively high values of total suspended solids (TSS), and this may be due to washing of clothes, shoes, vegetables, fruits, tubers and many others which may contain sand, clay and other materials that could increase TSS.

Biological oxygen demand in greywater
Biological Oxygen Demand (BOD) refers to the oxygen requirement in the greywater for microbial breakdown of organic compounds at a constant temperature. Smith and Melhem (2012) [66] reported that the BOD in the greywater has very wider variations (5 mg L⁻¹ to 431 mg L⁻¹). In Chennai, Abinaya and Loganath (2015) [1], who reported BOD range of 120 mg L⁻¹ to 350 mg L⁻¹. In Malaysia, identical result was recorded by Mohamed et al. (2012) [51] with BOD ranging from 155 mg L⁻¹ to 213 mg L⁻¹ in raw greywater. The BOD values of 41.2 mg L⁻¹ in Amman, Jordan (Jamrah et al., 2006) [38] and 31.0 mg L⁻¹ to 40.0 mg L⁻¹ in Senegal (Sall and Takashi, 2006) [62] were also reported. The main contributor to BOD in greywater is the dissolved organics and suspended food particles.

Chemical oxygen demand in greywater
Braga and Varesche (2014) [13] reported COD values of 4800 mg L⁻¹ in Brazil of commercial laundry greywater. In contrast to this, Smith and Melhem (2012) [66] reported lower COD values of 38 mg L⁻¹ to 1843 mg L⁻¹ in greywater. Jefferson et al. (2004) [40] reported that greywater tends to contain fewer solids, as its contaminants are dissolved, which would keep the COD:BOD ratio around 4:1 in greywater. Variations in COD observed in the findings of Tilve (2014) [69] reported COD variations between 238.57 mg L⁻¹ and 434 mg L⁻¹ in Nagpur. Similarly, in Chennai also, Abinaya and Loganath (2015) [1] reported COD values ranging from 254 mg L⁻¹ to 618 mg L⁻¹ in greywater.

Pathogens in greywater
The coliforms represent the faecal contamination in the water. Winward et al. (2008) [74] reported that the faecal contamination of greywater is a common occurrence, creating the risk of a range of fecally transmitted pathogens. Coliform populations of 3 x 10³ to 2.4 x 10⁷ CFU per 100 ml was reported by Eriksson et al. (2002) [25]. Rose et al. (1991) [160] reported that families with children had high coliform count (3.2 x 10⁵ and 1.5 x 10³ CFU per 100 ml) in greywater as compared families without children (6 x 10⁵ and 8 x 10³ CFU per 100 ml). In a study carried out in London, Birks et al. (2004) [9] observed that fecal Enterococci were found in at least 70% of greywater tested. Occurrence of other pathogenic bacteria, was also reported in greywater. Friedler et al. (2011) [10] found skin pathogen
Pseudomonas aeruginosa), respiratory pathogen (Legionella pneumophila) and enteric pathogen (Escherichia coli) in greywater. Not only bacterial pathogens, but the pathogenic protozoan, Cryptosporidium sp. was also reported (Birks et al., 2004) [9]. Enteric pathogenic bacteria, such as Salmonella and Campylobacter, can be introduced by food handling in the kitchen (Cogan et al., 1999) [17] in addition to that from the fecally derived matter.

Fats, oil and grease in greywater

The oil and grease is another important parameter in greywater as kitchen sinks and bathroom showers contribute to this pollutant. The concentration of oil and grease in an untreated domestic wastewater was 50 mg L$^{-1}$ to 100 mg L$^{-1}$ (Techobanglous et al., 2002) [68]. They block the filtration units and hinders with treatment efficiency. Oil and grease leads to formation of oil layer in water to cause reduction in light penetration, oxygen diffusion and photosynthesis by submerged plants (Mohammadi and Esmaelifar, 2005) [52]. Some of the common conventional methods of oily wastewater treatment include flotation, gravitational methods, chemical treatment, biological treatment, dissolved air flotation (DAF) and use of membranes (Chowdhury et al., 2006) [15]. Oil droplets less than 50μm size have been removed by packed beds and dissolved air flotation (Rubio et al., 2002) [61]. Wastewaters containing fat and oils were traditionally treated physically, which is currently considered insufficient if the fat is in a dispersed form (El-Masry et al., 2004) [21]. Baig et al. (2003) [6], studied effectiveness of gravity separation and dissolved air flotation for the removal of oil and grease from industrial and domestic wastewaters and about 85% removal efficiency was achieved in removal as emulsified oil from the wastewaters.

Other compounds

Heavy metals, xenobiotic compounds, nitrates, phosphates, quaternary ammonium compounds (QUATS) were reported as contaminants in greywater (Donner et al., 2010) [19]. Most of these originate from body lotions, hair dyes and make-up materials. The presence of these compounds could harm ecosystems if not properly treated and disposed. XOCs are synthetic organic compounds that are present in household chemicals and pharmaceuticals such as bleaches, surfactants, softeners and builders and beauty products. XOCs can also be formed by partial modification of chemicals in chemical or biological treatment of greywater (Fatta-Kassinos et al., 2011) [28]. XOCs are recalcitrant to conventional treatment protocols and can easily accumulate in plants and animals and subsequently pose risks to the natural environment (Fatta-Kassinos et al., 2011) [28]. Eriksson et al. (2002) [25] identified 900 potential XOCs in greywater solely based on the ingredients of different cosmetics and detergents in Denmark. Le-Minh et al. (2010) [45] identified the presence of antibiotics in greywater which may lead to proliferation of resistant bacteria strains.

Treatment of Greywater

The greywater needs to be treated and reused for the various household purposes, other than direct consumption. Greywater treatment is essentially required to reduce the organic load, nutrients and potent pathogenic microorganisms. Untreated greywater discharged in to any ecosystem is unsafe and hence proper treatment is required for safe discharge of greywater. A review of research works carried out on greywater treatment in India and elsewhere indicates that screening, aeration and filtration are essential components of the greywater treatment unit (Gross et al., 2007; March et al., 2004; Purjane and sane, 2011) [33, 49, 56]. Various materials like sand, pebbles, activated carbon, coconut shell, saw dust, charcoal, wood chips, bricks, rice husk (Purjane and sane, 2011) [56] were tested by researchers to arrive at varied levels of treatment efficiency.

Aeration

Aeration allows for the intimate exposure of water and air by intensely mixing air and water so that chemical reactions occur between them to remove odourous compounds such as hydrogen sulfides and carbon dioxide (Fair et al., 1971) [26]. Aeration also helps supply oxygen for microbial remediation of wastewaters. Improved aeration system like fine bubble aeration are an excellent way to improve the oxygen transfer efficiency (Tarciska et al., 2009) [60]. Various types of diffused aerators like coarse bubble diffusers, fine bubble diffusers and submerged jet aerators are being used.

Filtration

Filtration is a pollutant removal mechanism that includes screening, adsorption and biodegradation. Filtration removes solid materials like hair, fabric pieces and food particles from greywater. Ludwig (2000) [48] proposed the use of natural mulch basin filled with stones and organic mulch (leaves, tree bark etc) to treat greywater. Alaziz and Al-saquer (2014) [3] proposed a filtration system consisting of shallow layers of stone, medium gravel, and pea gravel beneath a deep layer of sand and multimedia filters. A combination of coarse and fine filter was recommended by Hodgson (2012) [135], to achieve 15 ± 10% total organic carbon (TOC) removal and 1 ± 7% turbidity reduction in coarse filters while fine filter achieved 31 ± 17% and 13 ± 11%, reduction in TOC and turbidity respectively. Li et al. (2008) [46] studied an ultrafiltration membrane system that treated greywater from all household sources (including laundry machines, dishwashers and kitchen sinks in addition to baths, showers and hand basins) and the performance is fair. The key principle behind filtration is blocking of impurities from reaching downstream by adsorption and absorption. Adsorption is a process by which the impure constituents are eliminated by physically or chemically binding it to on the surface of suitable adsorbents. In his review on greywater, Katukiza et al. (2013) [42] mentioned physical adsorption using locally available filter media is an effective means to remove ammonia, phosphorous, cations and even partial bacterial load from greywater. In contrast, absorption is a process by which impurities are assimilated by the adsorbent (Watson, 1999) [71].

Sand filters

The sand filtration is a proven method for wastewater purification and is well suited for greywater treatment. Coarse sand, fine sand, beach sand, river sand, silica sand etc are some sand types attempted by scientists to treat greywater. Fine sand filter of 0.3 mm size with respective values of 1.82, 1.48 Mg m$^{-3}$ and 0.4 percent for uniformity coefficient, specific density and porosity (Govahili, 2014) [32]. Other sizes tried include 0.7, 1.3 and 2.5 mm, either as single layer or in multiple layers.

Size alone does not decide the treatment efficiency. The purification performance of sand filtration system is also dependent on hydraulic loading, sand texture and surface chemistry of the sand grains. Typical loadings in the range of...
2 - 10 cm per day were recommended for effective performance, with BOD removal of more than 80 per cent (Jenssen and Siegrist, 1990) \(^\text{[41]}\). Sand filters are not only used during primary treatment, but are also occasionally used as effluent polishing during tertiary treatment to remove residual suspended material and provides a physical matrix for bacterial decomposition of nitrogenous material, including ammonia and nitrates, into nitrogen gas. Besides the physical filtration through the sand, an active biofilm develops. It is attached to the sand particle surfaces and mineralize organic matter from the wastewater (Rodgers et al., 2005) \(^\text{[58]}\).

**Activated charcoal**
Activated charcoal refers to the charcoal that is treated with oxygen to open up millions of tiny pores between the carbon atoms. These active pores adsorb odorous and coloured substances from gases or liquids. Most activated carbons are made from raw materials such as nutshells, wood, coal and petroleum. Typical surface area for activated carbon is approximately 1,000 square meters per gram (m\(^2\)/gm). Berger (2012) \(^\text{[18]}\) reviewed the performance of activated carbon in removing pollutants from greywater and he concluded that activated carbon showed superior performance in reducing organics (upto 97% reduction in COD and 94% reduction in BOD); surfactants (99% reduction), and total phosphorous (91% reduction). Activated carbon also reduced total nitrogen by 98% (Dalahmeh et al., 2012) \(^\text{[18]}\). Granular activated carbon (GAC) filters also have more wider applicability in water treatment units to adsorb different organic macropolutants, disinfectant by-products, as well as odour and taste compounds from water (Velten, 2008) \(^\text{[70]}\).

**Zeolite**
Zeolites refer to aluminosilicate minerals which are porous in nature, which can accommodate cations, by holding them or exchanging them in their active sites. Zeolites are considered excellent trappers of waste products and heavy metals because of its chemical composition and specific lattice structure (Beltcheva et al., 2015) \(^\text{[7]}\). A very unique property of zeolite is that they are highly selective towards cations and many experiments conducted on this aspect proved positive for removal of copper (Cu\(^{2+}\)), manganese (Mn\(^{2+}\)) and Zinc (Zn\(^{2+}\)), which are common contaminants in water (Margeta et al., 2013) \(^\text{[50]}\).

Both natural and synthetic zeolites are porous materials, able to adsorb molecules of appropriate cross-sectional diameter and because of this property, zeolites are used for wide range of industrial and agricultural applications (Mumpton,1999) \(^\text{[53]}\). Assayed et al. (2013) assessed the efficiency of zeolites in greywater treatment in combination with sand bed filter. The treatment efficiency as reported by them was 82-87% for COD; 85-100% for phosphates (PO\(_4^{3-}\)); 64-75% nitrates for (NO\(_3^-\)) and 58-89% for turbidity. The process efficiency for ammonium removal from greywater using zeolite was 97% as reported by Widiastuti et al., (2011). However, he notified that the good performance of zeolite filters depend on contact time, zeolite loading, initial ammonium concentration and pH value. Hydrophobic zeolite pellets were reported to adsorb dissolved organic compounds (Hansen and Davies., 1994).

**Efficiency of different filter models in removing pollutants from Greywater**
Different filter based models have been tried by researchers across the globe to treat greywater. Because of the lesser concentration of conventional pollutants, filtration is foreseen as a low cost option for treating greywater. Assayed et al. (2015) \(^\text{[4]}\) developed a new treatment method called ‘Drawer Compacted Sand Filter (DCSF)’ designed to prevent clogging problem, usually encountered in conventional filters. The results showed that DCSF removed 78-96% of BOD5, COD and 69-98% of TSS. Even earthworms have also been employed for greywater treatment. In Burkina Faso, a West African country, Adunga et al. (2015) \(^\text{[2]}\) employed sand, fine saw dust and vermifilters for greywater treatment and reported that the removal efficiencies of BOD and COD were 25–30% higher than control. However, they could not record any significant removal of TSS and coliforms. Not only filter beds based sysem, but direct and in-situ application of greywater was tried by Pandey et al. (2011) \(^\text{[55]}\) in India. They tried vegetations as filter system in soil using four species viz., Eucalyptus hybrid, Populus deltoids, Salix alba and Melia azedarach and the study revealed that total NPK removal from greywater was 50, 34 and 15% respectively, whereas BOD and COD reduction achieved was 60 and 46% respectively. Eucalyptuswas found to be the better among the four test crops. Some common greywater treatment methods and short comings advanced greywater treatment systems (Table 1). Assayed et al. (2015) \(^\text{[4]}\) compiled the problems encountered by researchers.

| Treatment method                  | Shortcomings                                                                 |
|-----------------------------------|------------------------------------------------------------------------------|
| Sequencing batch reactor (SBR)    | • Requires highly skilled operators                                           |
|                                   | • Continuous power supply needed                                             |
|                                   | • Dissolved oxygen levels and Mixed Liquor Suspended Solids (MLSS) concentration should be maintained uniformly. |
| Uplow anaerobic sludge blanket    | • Achieves less than 70% of COD removal                                       |
| (UASB)                            | • Inadequate for E. coli reduction.                                          |
|                                   | • Strict temperature maintenance for the anaerobic bacteria, which is not easily achievable in many locations. |
| Membrane bioreactor technology    | • High operational and investment cost                                       |
| (MBR)                             | • Not suitable for greywater treatment in poor urban areas                   |
| Constructed wetland (CWT)         | • Large area of land required                                                |
|                                   | • Emission of bad odors                                                     |
|                                   | • Excavation difficulties and other labour works                             |
| Rotating biological contactor     | • Proven and effective results under laboratory conditions                   |
| (RBC)                             | • Insufficient information on their suitability under field conditions        |

Table 1: Problems encountered with advanced greywater treatment systems
Conclusion
The review states that the various characteristics features of greywater, treatment methods and reuse ways in India. A wide variation in characteristics of greywater is mainly due to quality of water use in different domestic activities to fulfill the human needs. The available technologies have been developed to treat or remove specific pollutants and not offer a full treatment of the greywater. However, the implementation of household level greywater treatment system that target a certain reuse option and thereby increase the number of households to implement the treatment options for grey water recycling.

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