# Low cost sustainable materials for grey water reclamation

Dalrene Teresa Keerthika James and Augustine Osamor Ifelebuegu

## ABSTRACT

Grey water reclamation is a sustainable solution for managing water shortages. However, grey water contains high levels of detergents, particularly surfactants, which alongside other chemical constituents can pose a serious risk to human health and the environment. Biological treatments are not effective in the treatment of grey water since the detergents inhibit the activities of microorganisms. Chemical treatment options have an impact on public perception and could be cost prohibitive for domestic and small scale reuse applications. In this paper, we review the characterization of the constituents of grey water and the application of various low cost sustainable materials such as zeolite, activated carbon, mussel shells, tyre granules, fly ash, ground granulated blast furnace slag and silica gel for the treatment and removal of detergent characteristics.

**Key words** | adsorption, detergent characteristics, grey water, low cost materials, treatment system

**Dalrene Teresa Keerthika James**
(corresponding author)
**Augustine Osamor Ifelebuegu**
Faculty of Engineering, Environment and Computing,
Coventry University,
Priory Street, CV1 5FB, Coventry,
UK
E-mail: *jamesd19@uni.coventry.ac.uk*

## INTRODUCTION

In the summer of 2011, there was insufficient water for reservoir refill and ground water recharge due to several months of drought. According to the Met Office, England and Wales experienced a prolonged drought due to the sequence of dry months from winter 2009/2010 to March 2012. This resulted in lower reservoir levels leading to hose pipe bans across North West England, affecting 6 million consumers. The agricultural and environmental sectors were also severely affected due to the periods of drought leading to wild fires (Met Office 2013). Part of North West England received less than 60% of rainfall in the first six months of 2014 and it was followed by the driest summer that led United Utilities to implement another temporary hose pipe and other bans (BBC 2014).

In recent years, the UK and the world at large have experienced extreme weather conditions from flooding to prolonged periods of drought, due to the increasing effects of global warming. Water shortages, as a result of prolonged periods of drought, are here to stay. Also, the quantity of freshwater resources worldwide is in the decline, requiring the need for a more sustainable approach for the utilization of freshwater (Gross *et al.* 2007a, 2007b). Grey water reclamation and reuse offers a sustainable approach in addressing the problem of water shortage in water-stressed regions of the world and has become an integral part of water demand management (Al-Jayyousi 2003; James *et al.* 2016). Grey water reclamation and reuse is a sustainable solution that could cater for non-potable uses such as watering the garden, playing fields and lawns, water closet flushing, recharging fountains and outdoor washing (Jefferson *et al.* 2004; James *et al.* 2016).

A wide range of treatment processes are available for wastewater and grey water treatments and these can be categorized as physicochemical or biological processes. The physicochemical processes often involve a solid–liquid separation step followed by a disinfection step. The use of low cost sustainable materials for the separation of pollutants from wastewater and grey water is growing in significance, in recent times, due to their low cost and environmental sustainability (Wang & Peng 2010; Ifelebuegu & Johnson 2017). In this paper, we review the key detergent characteristics in grey water and the application of sustainable low cost materials, for grey water reclamation and reuse.

## DETERGENT CHARACTERISTICS IN GREY WATER

Components of cleaning products and personal care products are surfactants, bleaches, dyes, emulsifiers, enzymes, fragrances, preservatives, softeners and builders (Eriksson *et al.* 2002). Surfactants are the predominant components.

doi: 10.2166/wst.2018.225

There are four classes of surfactants namely anionic, cationic, amphoteric and non-ionic (Schouten 2009).

Surfactants have an amphipathic structure, a hydrophilic head (water-loving) and a hydrophobic tail (water-hating/oil-loving), as shown in Figure 1 (Schouten 2009). The amphipathic structure helps the aggregation in aqueous solution (water) and removes grease, dirt and oil from clothes. Where one end is attracted to the water and the other end is attracted to oil/dirt (oil or dirt is hydrophobic in nature), the dirt/oil is attached to the hydrophobic end and carried away as shown in Figure 2. (Salager 2002). Hydrophobic tail includes unbranched hydrocarbons or fluorocarbons, an aromatic ring or other non-polar organic groups. The hydrophilic head is a polar and water soluble group, like sulphonate or phosphate, carboxylic or ammonium (Ketola 2016). The primary function of the surfactant is to reduce surface tension, thereby increasing wetting on surfaces (cleaning surfaces/cloth surfaces), and change liquid interfacial properties due to their amphiphilic structure, plus the ability to arrange themselves to micelle and bilayers (Schouten 2009; Ketola 2016).

When surfactants are added to water they line up in the interface. The hydrophobic end gets away from the water to form micelle, whereas hydrophilic end stays near the water molecules. The hydrophilic end of each detergent molecule will point towards the water pole and the hydrophobic regions are grouped to form thermodynamically stable micelle as shown in Figure 2. The concentration at which micelles begin to form is the critical micelle concentration (CMC) (Ketola 2016).

Anionic surfactant carries a negative charge and cationic surfactant carries a positive charge, in their hydrophilic group. Whereas non-ionic surfactant does not carry any charge and the amphoteric surfactant carries both positive and negative charges in their hydrophilic end, as shown in Figure 3. The pH of the solution will determine the charge of the amphoteric surfactant. It exhibits anionic properties at alkaline pH and cationic at acidic pH and at certain times it exhibits both negative and positive charges at the same time (Schouten 2009; Salager 2002). The varieties of different chemical constituents in detergents are given in Table 1.

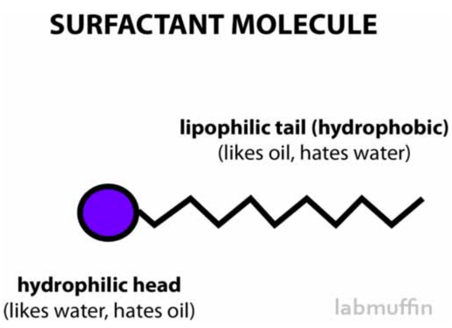

**Figure 1** | Structure of detergent (amphipathic structure) (https://labmuffin.com/fact-check-what-is-micellar-water-and-how-does-it-work-an-update/).

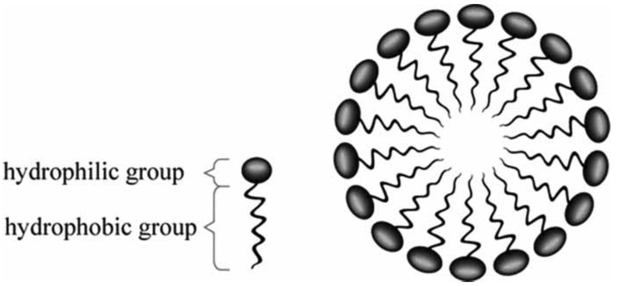

**Figure 2** | Micelle formation (https://www.quora.com/What-are-micelles).

Builders are used in detergent to reduce the hardness (remove calcium and magnesium ions) of water; otherwise these ions (calcium and magnesium ions) will react with the surfactant and reduce the effectiveness in removing dirt and oil. Examples of builders are sodium triphosphate, sodium carbonate, citrates, succinates, gluconates, nitrilotroacetic acid, poly carboxylic acid and zeolites. Other compounds in the builders are phosphonates, silicates, and carbonates. Enzymes in detergent are long chain amino acids, that are used to remove different stains such as protein (protease), starch (amylase) and fats (lipase) at lower temperatures. Bleaches are used to remove stains and improve whiteness of the fabric. Examples of commonly used bleach is sodium percarbonate, sodium hypochlorite,

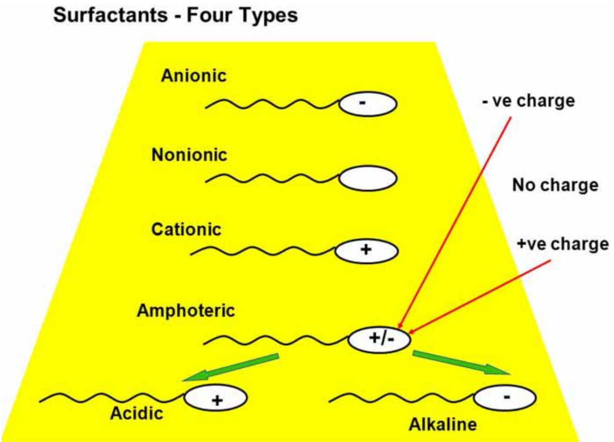

**Figure 3** | Different types of surfactant (http://slideplayer.com/slide/6214458/).

**Table 1** | Examples of chemical substances in cleaning and personal care products that are of great concern (adapted from Salager 2002; Baciocchi *et al*. 2007; Eriksson *et al*. 2002; Ketola 2016; Schouten 2009)

| | Applications | Examples of chemical substances present |
|---|---|---|
| Anionic surfactant | Shampoos, laundry and dishwashing liquid | Alkyl sulphates, alkyl benzene sulphonates, isotridecanol ethoxylates |
| Cationic surfactant | Softeners and disinfecting agents | N-hexadecyltrimethyl ammonium chloride, benzalkonium chloride, dialkyl dimethylammonium and quaternary ammonium based compounds |
| Non-ionic surfactant | Cleaning products | Nonylphenol, alkyl phenol ethoxylate, alcohol ethoxylate, alkyl amine ethoxylates, Triton X100 |
| Amphoteric surfactant | Personal care products, shampoo, body wash, scrubs, dish washing soap | Cocamidopropyl betaine, alkylamide betaines, lauriminodipropionates |
| Bleaches | Bathroom cleaners | Sodium hypochlorite, chlorine |
| Dyes | Hand wash, kitchen liquid, surface cleaners | 3,3′-Dichlorobenzidine, 4,4′-methylenebis-(2-chlorobenzenamine) |
| Fragrances | Cleaning and personal care products | Styrene, hexyl cinnamic aldehyde, styrene |
| Preservatives | Cleaning and personal care products | Bronopol, orinidox, Imidazolidinyl urea, triclosan |
| Builders | All cleaning products | Diisonoylphthalate, phosphonates, ethylenediaminetetramethylene phosphonate, phosphonates |

calcium hypochlorite and sodium dichloroisocyanurate (Salager 2002; Glennie *et al*. 2002).

## DETERGENT CHARACTERISTICS IN GREY WATER/WASTEWATER

Detergent characteristics in grey water are not similar to detergent characteristics in wastewater; therefore traditional wastewater treatment designs cannot be used for treating grey water (James *et al*. 2016). In order to design a grey water reclaiming system grey water characteristics should be studied. Table 2 shows the detergent characteristics in grey water and wastewater from different studies.

The anionic surfactant concentration (Table 2) is much higher in the Braga & Varesche (2014) sample than others. This is because Braga & Varesche (2014) collected grey water from a laundry service centre. Leal *et al*.'s (2012) sample also has high anionic concentration; this is due to the samples being collected from houses (32 houses) where washing applications were taking place. The anionic surfactant in grey water is higher than anionic surfactant in wastewater (Smith & Bani-Melhem 2012; Leal *et al*. 2012; Braga & Varesche 2014; Karimi *et al*. 2014; Narkis & Weinberg 1989).

Toilet waste is excluded from grey water; therefore ammonia and nitrate contents in grey water are lower in concentration and even the lower concentration is due to washing of diapers, baby care and faecal matters from showers (Jefferson *et al*. 2004; Ottoson & Stenstrom 2003). Braga & Varesche (2014) had the highest ammonia contents which resulted mainly from laundry wastewater.

Smith & Bani-Melhem's (2012) sample, which was collected from an office building where the employees only do cleaning and kitchen activities, also showed a higher ammonia and nitrate contents. This is due to the ammonium contents from anionic surfactant (alkyl aminoacids), cationic surfactant (quaternary ammonium compound) or amphoteric surfactant (amino propionic acid) (Salager 2002). Nitrogen is useful for plants, but in nitrates form. Therefore this ammonium content should be converted to nitrates for it to be useful for plants as fertilizer. The ammonium content from wastewater does not account only from detergent, since faecal matter and other organic matter will contribute to it. The ammoniacal nitrogen and nitrates in wastewater are therefore far higher than in grey water (Karimi *et al*. 2014; Ojo and Oso 2009).

The phosphate content, in grey water, ranges from 0.29 to 279 mg/L (Smith & Bani-Melhem 2012; Braga & Varesche 2014). These are the main ingredients for plant growth; therefore this content should not be removed from grey water if the grey water is used for irrigation. It can cause nausea and abdominal pain in humans, if they are accidentally ingested, so it should be treated if it is being used for WC flushing and other uses with human contact.

Boron is needed for plants in small amounts. This amount is already given by the soil to the plant. Therefore boron from grey water (even a little) would be excess for

**Table 2** | Detergent characteristics in grey water and wastewater

| Parameters | Characteristics of grey water | Reference | Characteristics of domestic wastewater | Reference |
|---|---|---|---|---|
| Anionic surfactant or lauryl alkyl benzene sulfonate (LAS) (mg/L) | 5–15[1]<br>10–18.7[3]<br>2.76–16.3[6]<br>80.5[8]<br>12–1023[10] | Weston (1998)[1], Rayen *et al.* (2015)[3], Smith & Bani-Melhem (2012)[6], Leal *et al.* (2012)[8] and Braga & Varesche (2014)[10] | 10.65[11]<br>7.5[14] | Karimi *et al.* (2014)[11]; Narkis & Weinberg (1989)[14] |
| Non-ionic surfactant (mg/L) | 0.4–4.1[1] | Weston (1998)[1] | 4.4[14] | Narkis & Weinberg (1989)[14] |
| Boron (mg/L) | 0.2–0.7[1]<br>0.1[2] | Weston (1998)[1], Gross *et al.* (2007a, 2017b)[2] | | |
| Sodium (mg/L) | 143[5]<br>128[8] | Ghunmi *et al.* (2008)[5], Leal *et al.* (2012)[8] | | |
| Chloride (mg/L) | 10.2–11.3[3]<br>23.6[4]<br>141[5]<br>62.6[8] | Rayen *et al.* (2015)[3], Chin *et al.* (2009)[4], Ghunmi *et al.* (2008)[5], Leal *et al.* (2012)[8] | 36.12[13] | Ojo & Oso (2009)[13] |
| Sulphate (mg/L) | 43.6[4]<br>21.9[8]<br>1.4–102[10] | Chin *et al.* (2009)[4], Leal *et al.* (2012)[8], Braga & Varesche (2014)[10] | 92.7[13] | Ojo & Oso (2009)[13] |
| Phosphates (mg/L) | 0.3–0.7[5]<br>0.29–0.74[6]<br>2.97[8]<br>6.9–8.1[9]<br>9.8–279[10] | Ghunmi *et al.* (2008)[5], Smith & Bani-Melhem (2012)[6], Leal *et al.* (2012)[8], Li *et al.* (2008)[9], Braga & Varesche (2014)[10] | 3.85[12]<br>99.9[13] | Chirila *et al.* (2008)[12], Ojo & Oso (2009)[13] |
| Ammonium (mg/L) | 0–1.4[5]<br>5.43–13.2[6]<br>8[7]<br>7.6–12.6[9]<br>0.3–54.8[10] | Ghunmi *et al.* (2008)[5], Smith & Bani-Melhem (2012)[6], Pidou *et al.* (2008)[7], Li *et al.* (2008)[9], Braga & Varesche (2014)[10] | 110[11]<br>19.21[12]<br>193.5[13] | Karimi *et al.* (2014)[11]; Chirila *et al.* (2008)[12]; Ojo & Oso (2009)[13] |
| Nitrate (mg/L) | 0–1.48[6]<br>1.03–25.7[10] | Smith & Bani-Melhem (2012)[6], Braga & Varesche (2014)[10] | | |

the plant; therefore is toxic and will cause severe damage (WHO 2006). The boron content in grey water was 0.1–0.7 mg/L, which is excessive (Gross *et al.* 2007a, 2007b; Weston 1998). Therefore this concentration should be treated before watering the plants.

Sodium dodecyl benzene sulfonate is an anionic surfactant that is one of the contributors to sodium in grey water. The grey water sample of Ghunmi *et al.* (2008) had more sodium than Leal *et al.* (2012). If grey water with high sodium content is used for irrigation of sports fields or garden plants, it will degrade the soil structure, cause discoloration, burn the leaves and prevent the calcium ions reaching the plants (WHO 2006).

Ghunmi *et al.* (2008) had more chlorides in her grey water samples than others. These are mainly from bleaches in detergent that can harm the plants if they are found in large amounts. Chlorides are more in grey water than in wastewater.

## HEALTH AND ENVIRONMENTAL RISKS DUE TO DETERGENT CHARACTERISTICS IN GREY WATER

Some of the chemicals in cleaning products cause acute harm such as skin diseases, respiratory irritation, eye irritation and chemical burns; whereas others cause long term effects such as endocrine disruptions, cancer and toxicity to the brain and nervous system (Sabharwal 2015). The US Poison Control Center reports that 10% of toxic exposure is from household cleaning products (Mercola 2011).

Sodium lauryl sulphate (SLS) is a surfactant found in all types of cleaning and personal care products. Research studies have shown that SLS is linked to dermal irritation, eye irritation and organ toxicity (Bondi *et al.* 2015). 1, 4-dioxane is a byproduct of SLS, polyethylene glycol (PEG), therefore it is not being listed in the ingredient list of the cleaning/personal care product. Low levels of 1,4-dioxane have been proven to cause cancer in animals (in the laboratory). It also has the potential of being toxic to brain, central nervous system, kidneys, liver and respiratory system (Centers for Disease Control and Prevention 2015).

Nonylphenolethoxylate (NPE) causes endocrine disruptions, kidney and liver damage, affects the reproductive system, disrupts the growth and metabolism and can even cause fatality (Sweeney *et al.* 2015). This ingredient cannot even be removed by sophisticated sewage or water treatment plants (Scott & Jones 2000). Even wastewater treatment processes make this ingredient (nonylphenolethoxylate) more toxic (Mercola 2011).

Phosphate residue from detergent causes nausea, diarrhoea and skin irritation, if they are ingested accidentally from grey water or if they come into contact with skin (through cuts or wounds). The other harmful products are sodium hypochlorite (bleach) and petroleum distillates which are linked to cancer and lung damage; phenols that cause toxicity throughout the body; brighteners cause an allergic reaction and affect development and the reproductive systems (Mercola 2011); ethylene diamino tetra acetate (EDTA) (replacing phosphates) is toxic to humans and animals; artificial fragrance was reported as carcinogenic by the Cancer Institute; benzene is carcinogenic; stabilizers cause eye and lung irritation and, when mixed in grey water or wastewater, they form toxic compounds that cause respiratory diseases, liver and kidney damage (Mercola 2011).

Most of the cleaning products contain diethanoalamine (DEA) and triethanolamine (TEA) and when these chemicals come in contact with nitrites they react to form nitrosamine. Nitrosamines are carcinogenic and they can readily penetrate the skin (Sabharwal 2015). Ethylene glycol may be present in some cleaners and that can causes toxicity to neurones.

The harmful parameters of grey water which can have an adverse effect on plants and the environment are sodium, boron and chloride from detergents, surfactants and bleaches (Rowe & Abdel-Magid 1995; WHO 2006).

Ottoson & Stenstrom (2003) believe that untreated grey water with chemicals (sodium) from detergent and surfactants can lead to harmful consequences such as soil degradation (WHO 2006). The reasons of this effect are reduced permeability and aeration due to the high amount of sodium adsorption (sodium from detergents); ultimately, not allowing the soil to support the plant. The other effects of sodium from grey water are that it could contribute to discoloration and burning of leaves and contribute to the alkalinity of the soil. High sodium concentration can be toxic to plants and it prevents calcium reaching the plants. It disturbs the soil's ability to absorb water (WHO 2006).

Boron is a micronutrient needed for plant growth in limited concentration. The required boron concentration is already given by the soil. Therefore boron from grey water will be in excess for the plants. If boron from grey water is exposed to plants, it damages the plant giving a burnt appearance to the edges of the leaves. Other symptoms of boron toxicity include leaf cupping, chlorosis, branch dieback, premature leaf drop and reduced growth (Vitosh *et al.* 1994; WHO 2006).

Bleaches can also damage plants, particularly if the bleach water makes contact with the leaves. One symptom of chlorine-induced damage is that even the new leaves appear as bleached (WHO 2006). Sawadogo *et al.* (2014) studied the effects of detergent on plants and found that high concentration of detergent is toxic to plants. He also confirmed that it leads to death and slow growth in plants.

## LOW COST MATERIALS TO REMOVE DETERGENT CHARACTERISTICS

Detergent and other cleaning agents contain many harmful chemicals as specified in previous sections. Those characteristics should be removed from grey water to prevent risks to the environment and human beings. At present, there is no official regulation or guidance on the reclaimed water standard for grey water. Therefore, guidelines from the Environmental Protection Agency (EPA) reclaimed water standard for water closet flushing, UK bathing water standard and World Health Organization (WHO) guidelines are being used to standardize treated water quality (James *et al.* 2016). Treatment processes such as coagulation, adsorption, and biological treatment can be used to remove detergent characteristics from wastewater and grey water.

### Removal of anionic surfactant using coagulants

Mahvi *et al.* (2004) used coagulants such as lime, alum and ferric chloride to treat anionic surfactant from wastewater and their removal efficiencies are 17%, 28% and

80%, respectively. Ferric chloride showed the highest removal efficiency in removing the anionic surfactant. However, the other two coagulants had low removal efficiency as single materials but when combined, they give a higher removal efficiency (Mahvi *et al.* 2004). The hydrophilic effect and electrostatic interaction of these coagulants help them be adsorbed into particulate matters (10–35%) and then they are removed by sedimentation (Ghernaout 2014; Mahvi *et al.* 2004). Alumina from clay/ bauxite is used as coagulant in water; it binds the pollutants together to form flocs, thereby increasing settlement or flotation. It has also been used as an adsorbent for the removal of sodium dodecyl sulphate and the maximum removal efficiency in that study was 94% (Adak *et al.* 2005).

## Adsorbent materials and mechanisms of removal of surfactants

The detergent characteristics from grey water or wastewater can be removed by adsorption. These types of materials adsorb the pollutant physically or chemically. Adsorbent that can be used in removal of detergent characteristics are activated carbon from charcoal and coconut shell, mussel shells, moringa seed, powdered Indian elm, holy basil, and feldspar. Verma *et al.* (2013) used powdered Indian elm and holy basil for the removal of anionic surfactant achieving a removal efficiency of 85–90%. Their efficiency was much higher than chemical adsorbents (i.e. lime/alum). Priyantha & Perera (2000) studied the effectiveness of feldspar in the removal of sulphate, phosphate and coloured substance and showed efficiencies of 52%, 42% and 73%, respectively.

In another study, Jones *et al.* (2011) used mussel shells in the removal of phosphates from grey water. The efficiency was more than 90% in the removal of phosphates when they were heat treated, whereas when they were raw, they only achieved 20–30% removal of phosphates. This is because when mussel shells are heat treated they use adsorption as well as precipitation characteristics to remove pollutants (Jones *et al.* 2011).

Activated carbon is widely used in the removal of pollutants and is effective in removing detergent characteristics (Schouten 2009). Their high surface area makes them more suitable in the removal of detergent characteristics (Uta Linke 2014). Activated carbon has 84% removal efficiency in removing non-ionic surfactant with the initial concentration of 6 g/L (Baciocchi *et al.* 2007).

In the application of zeolites for the removal of surfactants, the aluminosilicate structure in the zeolite creates a negative charge in the framework. The negative charge is balanced by the cations on the surfaces; these cations are attached by weak electro static forces, therefore when in grey water these cations in zeolites can be exchanged by the cationic pollutants such as the cationic surfactants, sodium, ammonium, and amphoteric surfactants in acidic pH (Schouten 2009; Salager 2002). If modified by cationic compounds (i.e cationic surfactant) as shown in Figure 4, then it can be used to remove anionic surfactants, phosphates and nitrates in detergent (Widiastuti *et al.* 2008). Organic compounds can also be removed by cationic surfactant modified zeolites because the hydrophobic tail group forms partitions, as shown in Figure 4, where the organic compounds get trapped. Some of the zeolite types (i.e. chabazite) have a large surface area, 520 $m^2/g$ (Widiastuti *et al.* 2008). Therefore, these types of zeolites can be used to remove the other pollutants from grey water by adsorption. Zeolite framework has channels and interconnected voids of discrete size (3-20 $\AA$). Therefore, large surfactant molecules have no access to the internal surface and adsorb only to the external surface (Apreutesei *et al.* 2008).

Granular activated carbon from source material such as black coal, brown coal, charcoal, coconut shell uses the adsorption (physisorption) property to remove pollutants from grey water/wastewater by pollutants adhering to the surface of the activated carbon. This attachment is due to the physical forces such as the van der Waals forces and also, there could be adhesion of pollutants to the surface of the material due to chemical bonding (chemisorption) (Uta Linke 2014; Rashed 2013; Schouten 2009). The other characteristics such as the large surface areas (800–1,500 $m^2/g$), microporous structure, nonpolar characteristics (hydrophobic) and its economic viability makes it more suitable for water/wastewater purification (Schouten 2009; Uta Linke 2014). Therefore, activated carbon can be

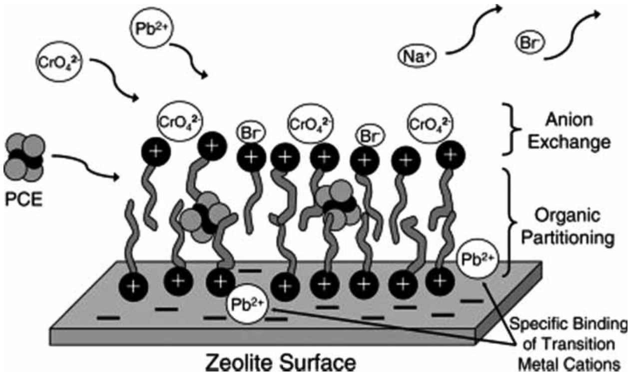

**Figure 4** | Mechanism of modified zeolite adsorption (https://www.sciencedirect.com/science/article/pii/S0167299107811001).

used to remove the grey water characteristics, regardless of their chemical properties of detergents, due to adsorption.

Natural clay minerals such as bentonite, feldspar, mica, kaolinite and vermiculate that have the aluminosilicate feature in their structure can also be used in the removal of detergent characteristics from grey water and wastewater due to their excess negative charge present in the structure (Mimanne *et al.* 2012; Priyantha & Perera 2000). This property of the material can be used to remove the sodium, magnesium, calcium, ammonium, cationic surfactant and amphoteric surfactant (when they are cationic) from grey water. These clays are used in purification also due to their high surface area, high porosity, wider availability and low cost. Their structure differs from each other due to the arrangement of atoms, layer stacking, and the combination of other elements with alumina silicate structure. The other clays such as diatomite, sepiolite are also used in the removal of detergent characteristics. Sepiolite has magnesium silicate structure and they have high adsorption capacity due to their molecular sieve structure (Ismadji *et al* 2015). Bentonite also uses chemisorption property to remove the pollutant in water (Rashed 2013).

Indian elm and holy basil adsorbs pollutants (anionic surfactant) due to the physical attraction or chemical coordination (Verma *et al.* 2013). Moringa seeds use the adsorption, coagulation and flocculation mechanism to remove pollutants from water. The functional groups in the side chain amino acids of the Moringa seed proteins contribute to the removal of pollutants in water. The mechanism coagulation with the seeds of Moringa consists of adsorption and neutralization of the colloidal positive charges that attract the negatively charged impurities in water. At a pH below 10, the Moringa seed proteins are positively charged and thus the seeds, when added to grey or wastewater samples, bind to the negatively charged particles in the samples (Sotheeswaren *et al.* 2011).

Mussel shell is a waste material from the shellfish industry that uses the mechanism, adsorption, to remove the pollutants (phosphates from grey water). The fine particles of mussel shell adsorb more than coarse particles, after being ground, because the smaller the particles are, the greater the surface area is. Mussel shells are aragonite (calcium carbonate) in nature, but when heated at 700–800°C they form into lime (calcium oxide). This heat treatment improves its removal efficiency better than the raw shell because it will have both adsorption and precipitation mechanism to remove the pollutants. The adsorption capacity increased due to an increase in surface area during heat treatment. Finally, the precipitates can be filtered from the water (Jones *et al.* 2011).

Chromium leather waste is used as an adsorbent in wastewater treatment. This waste material has a high content of functional groups that could bind with the hydrophobic and hydrophilic ends of surfactants, by electrostatic forces or hydrophobic bonds. The chromium in it also tends to bind to the surfactants (Mi-na *et al.* 2006). The other waste materials such as fly ash, tyre granules, rice husk and brick granules are used in the removal of detergent characteristics (Rashed 2013). In Purakayastha *et al.*'s (2005) experiment, it was confirmed that tyre granules showed slightly higher removal efficiency than activated carbon. The properties of materials and the treatment efficiency are given in Table 3.

## POTENTIAL COST OF TREATMENT SYSTEMS USING LOW COST MATERIALS

Table 4 shows the costs of low cost materials. These materials are inexpensive in addition to their abundancy, ease of access, natural existence or results as a waste product and harmlessness to the environment makes it more suitable as a treatment product along with their good removal efficiency. This leads to a more sustainable approach in treating grey water.

Capital cost for the following treatment units involved will be for the material and other consumables such as the container in which to place the material bed, pipes, valves, pump (if required) and stainer (Ahmed & EL-Dessouky 2008). When it comes to operational cost, the unit that uses the low-cost materials does not use energy (electricity) for treating the water, and if the flow is towards gravity it also does not use energy for pumping. If it is against gravity then it will use some energy for pumping. Whereas other treatment systems, such as reverse osmosis or advanced oxidation, require energy and their operational costs are high compared to treatment used with low cost materials. In this type of treatment, the maintenance cost will be only for replacing the materials in the system as it reaches its maximum adsorption capacity or as this unit gets fouled. The material replacement period will depend on the material. After replacing the material, the used material bed should be disposed with greater care so could also incur some cost for safe disposal (Schouten 2009; Ahmed & EL-Dessouky 2008).

**Table 3** | Treatment efficiency of materials

| | **Zeolite**[1] (Widiastuti *et al.* 2008; Harutyunyan & Pirumyan 2015)<br>**Diatomite**[2] (Sherief *et al.* 2015; Tsai *et al.* 2006) | **Activated**[3] **carbon** (Purakayastha *et al.* 2005; Schouten 2009)<br>**Moringa**[4] **seed** (Beltran-Heredia & Sanchez-Martin 2009) | **Fly ash**[5] (Ragheb 2013)<br>**Vermiculate**[6] (Li *et al.* 2017) | **Heat treated**[7] **mussel shell** (Jones *et al.* 2011)<br>**Raw mussel**[8] **shell** (Jones *et al.* 2011) | **Kaolinite**[9] (Yahaya *et al.* 2017; Kamal *et al.* 2017)<br>**Bentonite**[10] (Mimanne *et al.* 2012) | **Alumina**[11] (Adak *et al.* 2005)<br>**Hydrotalcite**[12] (Yaper & Yilmaz 2005) | **Waste**[13] **tyre Granules** (Purakayastha *et al.* 2005)<br>**Rice**[14] **husk ash** (Hosseinnia *et al.* 2006; Habeeb & Mahmud 2010) | **Feldspar**[15] (Priyantha & Perera 2000)<br>***Ground***[16] **granulated blast furnace slag** (Ragheb 2013) | **Silica**[17] **gel** (Purakayastha *et al.* 2005)<br>**Tea**[18] **leaves** (Ansari & Khanesar 2013; Bajpai & Jain 2010) |
|---|---|---|---|---|---|---|---|---|---|
| Properties (Units) | | | | | | | | | |
| Surface area $m^2/g$ | 11.8–520[1]<br>3.81–7.5[2] | 875–1400[3] | 106[5]<br>37.2[6] | 1.22–2.53[7,8] | 24.2[9]<br>81–294[10] | 0.09[11]<br>1.9[12] | 0.45–0.78[13]<br>25.3–30.4[14] | 0.45–0.55[16] | 200–800[17]<br>175.5[18] |
| Cation or anion exchanger | *Cation*[1] | | | | Cation[10] | | | | |
| Cation exchange capacity (μ/g) | 0.05–2.5[1] | | | | 0.4[9] | | | | |
| Particle size (mm) | 0–3[1]<br>0.028[2] | | 6.92[5] | 0–10.6[7,8] | | 0.0045[12] | 0.8–2.5[13]<br>0.01–0.06[14] | 0.075–8.0[15] | 0.02–0.5[18] |
| Pore volume ($cm^3/g$ at 0.99 pressure) | 0.015[2] | 0.06–1.7[3] | 0.065[5]<br>0.043[6] | | 0.0351[9]<br>0.09–0.5[10] | | | | 0.7[17] |
| Pore size (nm) | | 1.8–3.0[3] | 2.4[5]<br>6.5[6] | | 4.7–6.9[10] | | | | |
| Density ($g/cm^3$) | 1.74[1]<br>2.82[2] | 0.43–0.48[3]<br>0.97[4] | 0.99[5] | | | 2[12] | 0.284[13] | 2.91[16] | 2.6[17] |
| Specific gravity | | | 2.28[5] | | 2.6[9]<br>2.3–2.4[10] | 3.4–3.6[11] | 2.11[14] | 2.6[15] | 0.28[18] |
| Activation method | $FeCl_2$[2] | $Steam/H_3PO_4$[3] | $H_2O_2$[5] | *Heat*[7] | $HCl,\ H_2O_2$[10]<br>$H_2SO_4$ | | | | |
| Removal efficiency (%) | | | | | | | | | |
| Anionic surfactant | 98[1] | 96[3]<br>80[4] | | | 71[9] | 98[11] | 96.5[13] | | 92[17]<br>75–93[18] |
| Non-ionic surfactant | | | | | | | 79[14] | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Cationic surfactant | 98[1] | | | | | | | |
| Phosphates | ≥ 90[1]<br>85[2] | | 96.9[5] | 90[7]<br>20 – 30[8] | | | | 42[15]<br>96.15[16] |
| Nitrates | | 41–45[3] | | | 22.3[10] | | | |
| Sulphate | | | | | | | | 52[15] |
| Coloured Substances | | | | | | | | 73[15] |
| Phenol | | | | | | 52[12] | 83–87[13] | |
| Ammonium | 95–99[1] | | 89[6] | | | | | |

**Table 4** | Cost of low cost materials

| Material | Cost of material |
|---|---|
| Zeolite | \$1.5–2.2/kg |
| Diatomite | \$0.5–0.8/kg |
| Granular activated carbon | \$1.92–2.5/kg |
| Moringa seed | \$4/kg |
| Fly ash | \$35–60/Mg |
| Perlite | \$53–119/Mg |
| Mussel shells | \$1.5–2.3/kg |
| Kaolinite | \$18–30/Mg |
| Bentonite | \$50–200/Mg |
| Alumina | \$100–220/Mg |
| Tyre granules | \$20–50/Mg |
| Rice husk | \$80–300/Mg |
| Feldspar | \$86–102/Mg |
| Ground granulated blast furnace slag | \$33–38/Mg |
| Hydrotalcite | \$0.1–1/kg |
| Silica gel | \$1–1.5/kg |
| Tea leaves | \$1–5/kg |

Alibaba (1999–2018).

## CONCLUSION AND RECOMMENDATION

Grey water contains high contents of surfactant, bleaches and other chemicals that are harmful and the quality is not similar to domestic wastewater. Therefore, guidelines and design criteria used for wastewater treatment cannot be used for grey water reclamation.

Studies show that grey water with detergents inhibits grey water reclamation process. The aerobic biological process, cloudy appearance of reclaimed water, change in colour and excessive bubble formation resulting from detergent characteristics will reduce willingness, especially for indoor uses than outdoor uses.

The chemical treatment also has an impact from public perception. Therefore physical treatment such as adsorption, filtration or ion exchange with low cost materials should be used in removing chemicals from cleaning and personal care products that are drained into grey water. This will eliminate the use of chemicals in treating grey water. Using low cost materials in grey water treatment systems will increase the public willingness towards recycling and treating grey water because the cost and the payback period are less than other treatment units.

The materials such as charcoal, coconut shell, feldspar, kaolinite, alumina, bentonite, pulverized fuel ash, zeolite and tyre granules are promising as potential sustainable materials for the reclamation of grey water.

Grey water treatment systems consists of different treatment train and they are designed according to the end use. Grey water treatment systems can incorporate treatment systems with low cost materials to remove characteristics of detergent. Those units are the adsorption unit, the filtration unit, and the ion exchange unit. Low cost materials also could be used for disinfecting microorganisms in grey water treatments. An example would be moringa seeds. Low cost materials can also be used as a medium for growth of microorganisms in biological systems for treating grey water. If the low cost materials are used in one of these units then it is a sustainable way of reclaiming grey water.

Low cost material treatment can be used in the final stage as a polishing unit. Low cost materials unit could also be incorporated as a pre-treatment unit(as an adsorption or filtration unit) for grey water treating systems with biological processes. This is because microorganisms in biological treatment can be destroyed by detergent characteristics in grey water. But when low cost materials are used as a pre-treatment (adsorption/ion exchange unit) then the detergent characteristics can be removed before they enter into the biological system, thereby protecting the microorganisms and allowing the system to work efficiently.

The treatment unit with the low cost materials cannot be installed underground because the maintenance will be difficult when the material bed needs to be replaced.

## REFERENCES

Adak, A., Bandyopadhyay, M. & Pal, A. 2005 Removal of anionic surfactant from wastewater by alumina. *Colloids and Surfaces A Physicochemical and Engineering Aspects.* **254** (1-3), 165–171.

Ahmad, J. & EL-Dessouky, H. 2008 Design of a modified low cost treatment system for the recycling and reuse of laundry waste water. *Resources, Conservation and Recycling* **52** (7), 973–978.

Alibaba (1999–2018) https://www.alibaba.com/?src=sem_ggl&cmpgn=899957934&adgrp=48934145510&fditm=&tgt=aud-362622410597:kwd-324959264110&locintrst=&locphyscl=9046172&mtchtyp=b&ntwrk=g&device=c&dvcmdl=&creative=211394277590&plcmnt=&plcmntcat=&p1=&p2=&aceid=&position=1t1&gclid=EAIaIQobChMIxpH-s6SD2QIVab7tCh3QoA8nEAAYASAAEgIetPD_BwE (accessed 30th January 2018).

Al-Jayyousi, O. R. 2003 Greywater reuse: towards sustainable water management. *Desalination* **156** (1–3), 181–192.

Ansari, R. & Khanesar, P. H. 2013 Application of spent tea leaves as an efficient low cost biosorbent for removal of anionic surfactants from aqueous solutions. *European Chemical Bulletin* **2** (5), 283–289.

Apreutesei, R.E., Catrinescu, C. & Teodosiu, C. 2008 'Surfactant-modified natural zeolites for environmental applications in water purification. *Environmental Engineering and Management Journal* **7** (2), 149–161.

Baciocchi, R., Lombardi, F. & Torella, R. 2007 Activated carbons application to remove nonionic surfactants from wastewater produced by an italian metallurgic plant. *Journal of Environmental Science and Health* **A39** (4), 1095–1106.

Bajpai, S.K. & Jain, A. 2010 Removal of copper(II) from aqueous solution using spent tea leaves (STL) as a potential sorbent. *Water SA* **36** (3).

BBC 2014 http://www.bbc.co.uk/news/magazine-26049927 (accessed 2nd May 2017).

Beltran-Heredia, J. & Sanchez-Martin, J. 2009 Removal of sodium lauryl sulphate by coagulation/flocculation with Moringa oleifera seed extract. *Journal of Hazardous Materials* **164** (2–30), 713–719.

Bondi, C. A. M., Marks, J. L., Wroblewski, L. B., Raatikainen, H. S., Lenox, S. R. & Gebhardt, K. E. 2015 Human and environmental toxicity of sodium lauryl sulfate (SLS): evidence for safe use in household cleaning products. *Environmental Health Insight* **9**, 27–32.

Braga, J. K. & Varesche, M. B. A. 2014 Commercial Laundry Water Characterisation. *American Journal of Analytical Chemistry* **5**, 8–16.

Centers for Disease Control and Prevention 2015 1, 4-dioxane. https://www.cdc.gov/niosh/ipcsneng/neng0041.html (accessed 15th April 2017).

Chin, W. H., Roddick, F. A. & Harris, J. L. 2009 Grey water treatment by UVC/H2O2. *Water Research* **43**, 3940–3947.

Chirila, E., Drăghici, C. L. & Tudor, C. A. 2008 Analytical control of the nutrients and detergents removal in municipal wastewater treatment processes. *Scientific Study and Research* **9** (3), 317–324.

Eriksson, E., Auffarth, K., Henze, M. & Ledin, A. 2002 Characteristics of grey wastewater. *Urban Water* **4**, 85–104.

Ghernaout, D. 2014 The hydrophilic/hydrophobic ratio vs. dissolved organics removal by coagulation – a review. *Journal of King Saud University - Science* **26** (3), 169–180.

Ghunmi, L. A., Zeeman, G., Lier, J. V. & Fayyed, F. 2008 Quantitative and qualitative characteristics of grey water for reuse requirements and treatment alternatives: the case of Jordan. *Water Science and Technology* **58** (7), 1385–1396.

Glennie, E. B., Littlejohn, C., Gendebien, A., Hayes, A., Palfrey, R., Sivil, D. & Wright, K. 2002 *Phosphates and alternative detergent builders – final report*. EU Environment Directorate Wiltshire, UK.

Gross, A., Kaplan, D. & Baker, K. 2007a Removal of chemical and microbial contaminant from domestic greywater by using recycled vertical flow bioreactor. *Ecological Engineering* **31**, 107–114.

Gross, A., Shmueli, O., Ronen, Z. & Raveh, E. 2007b Recycled vertical flow constructed wetland (RVFCW) – a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere* **66** (5), 916–923.

Habeeb, G. A. & Mahmud, H. B. 2010 Study on properties of rice husk ash and its use as cement replacement material. *Material Research* **13** (2), 185–190.

Harutyunyan, L. R. & Pirumyan, G. P. 2015 Purification of waters from anionic and cationic surfactants by natural zeolites. *Proceedings of the Yerevan State University*, pp. 21–28.

Hosseinnia, A., Harshtroudi, M. S., Pazouki, M. & Banifatemi, M. 2006 Removel of surfactant from wastewater by rice husk. *Iranian Journal of Chemical Engineering* **3** (3), 44–50.

Ifelebuegu, A. O. & Johnson, A. 2017 Nonconventional low-cost cellulose-and keratin-based biopolymeric sorbents for oil/water separation and spill cleanup: A review. *Critical Reviews in Environmental Science and Technology* **47** (11), 964–1001.

Ismadji, S., Soetaredjo, F. E. & Ayucitra, A. 2015 *Clay Materials for Environmental Remediation*. Springer International Publishing, Berlin, Germany.

James, D. T. K., Surendran, S., Ifelebuegu, A. O., Ganjian, E. & Kinuthia, J. 2016 Grey water reclamation for urban non-potable reuse – challenges and solutions: a review. In: *Conference Proceedings, 7th International Conference on Sustainable Built Environment*, Sri Lanka.

Jefferson, B., Palmer, A., Jeffrey, P., Stuetz, R. & Judd, S. 2004 Grey water characterization and its impact on the selection and operation of technologies for urban reuse. *Water Science and Technology* **50** (2), 157–164.

Jones, M. I., Wang, L. Y., Abeynaike, A. & Patterson, D. A. 2011 Utilisation of waste material for environmental applications: calcination of mussel shells for waste water treatment. *Advances in Applied Ceramics* **110** (5), 280–286.

Kamal, S., Kamal, A., Shahzad, T., Rehman, S., Azeem, M. & Bibi, I. 2017 Potential of kaolinite as adsorbent to remove anionic surfactant from simulated industrial wastewater. *Desalination and Water Treatment* **88** (2017), 85–92.

Karimi, B., Ehrampoush, M. H. & Jabary, H. 2014 Indicator pathogens, organic matter and LAS detergent removal from wastewater by constructed subsurface wetlands. *Journal of Environmental Health Science and Engineering* **12** (52).

Ketola, A. 2016 Determination of surfactants in industrial waters of paper- and board mills. Unpublished Masters thesis, University of Jväskylä, Finland.

Leal, L. H., Soeter, A. M., Kools, S. A. E., Kraak, M. H. S., Parsons, J. R., Temmink, H., Zeeman, G. & Buisman, C. J. N. 2012 Ecotoxicological assessment of grey water treatment systems with *Daphnia magna* and *Chironomus riparius*. *Water Research* **46**, 1038–1044.

Li, F., Behrendt, J., Wichmann, K. & Otterpohl, R 2008 Resources and nutrients oriented grey water treatment for non-potable reuses. *Water Science and Technology* **57** (12), 1901–1907.

Li, L., Yao, J., Fang, X., Huang, Y. & Mu, Y. 2017 Electrolytic ammonia removal and current efficiency by a vermiculite-packed electrochemical reactor. *Scientific Reports* **7**.

Mahvi, A. H., Melaki, A. & Roshani, B. 2004 Removal of anionic surfactants in detergent wastewater by chemical coagulation. *Pakistan Journal of Biological Sciences* **7** (12), 2222–2226.

Mercola 2011 *Are You Poisoning Your Household With this Chore?* http://articles.mercola.com/sites/articles/archive/2011/12/21/are-you-slowly-killing-your-family-with-hidden-dioxane-in-your-laundry-detergent.aspx (accessed 10th June 2017).

Met Office 2013 *England and Wales drought 2010–2012*. http://www.metoffice.gov.uk/climate/uk/interesting/2012-drought (accessed 10th January 2017).

Mimanne, G., Sennour, R., Benghalem, A., Taleb, S. & Benhabib, K. 2012 Use of the geomaterial for the elimination of surfactant dodecylbenzene sulfonic acid from aqueous solutions. *Journal of Material Environment Science* **3** (4), 712–725.

Mi-na, Z., Xue-pin, L. & Bi, S. 2006 Adsorption of surfactants on chromium leather waste. *Journal Society of Leather Technologists and Chemists* **90**.

Narkis, N. & Weinberg, H. 1989 Removal of surfactants from effluents. *Environment*, 400–405.

Ojo, O. A. & Oso, B. A. 2009 Biodegradation of synthetic detergents in wastewater. *African Journal of Biotechnology* **8** (6), 1090–1109.

Ottoson, J. & Stenstrom, T. H. 2003 Faecal contamination of greywater and associated microbial risks. *Water Research* **37**, 645–655.

Pidou, M., Avery, L., Stephenson, T., Jeffrey, P., Parsons, S. A., Liu, S., Memon, F. A. & Jefferson, B. 2008 Chemical solutions for greywater recycling. *Chemosphere* **71**, 147–155.

Priyantha, N. & Perera, S. 2000 Removal of sulfate, phosphate and colored substances in wastewater effluents using feldspar. *Water Resources Management* **14**, 417–433.

Purakayastha, P. D., Pal, A. & Bandgopadhyay, M., 2005 Adsorbent selection for anionic surfactant removal from waste water. *Indian Journal of Chemical Technology* **12**, 281–284.

Ragheb, S. M. 2013 Phosphate removal from aqueous solution using slag and fly ash. *Housing and Building National Research Center Journal* **9** (3), 270–275.

Rashed, M.N. 2013 *Organic Pollutants – Monitoring, Risk and Treatment*. Intech, London, UK.

Rayen, J., V, J. & Venkatsubramanian, S. G. 2015 Surfactants removal from grey water by soap solidification using $CaCl_2$. *Discovery* **41** (188), 67–78.

Rowe, D.R. & Abdel-Magid, I.M. 1995 *Handbook of Wastewater Reclamation & Reuse*. Lewis Publishers, Boca Raton, FL, USA.

Sabharwal, J. 2015 Health issues and environmental impact of cleaning agents. *International Journal of Research in Life Sciences* **2** (2), 31–38.

Salager, J. 2002 *Surfactants: Types and uses no. 2*. Universidad de las Andes, Venezuela.

Sawadogo, B., Sou, M., Hijikata, N., Sangare, D., Maiga, A. H. & Funamizu, N. 2014 Effect of detergents from greywater on irrigated plants: case of okra. *Journal of Arid Land Studies*. **24** (2), 117–120.

Schouten, N. 2009 Reuse of laundry rinsing water by low cost adsorption technology. Unpublished PhD thesis, Eindhoven University of Technology, Eindhoven, The Netherlands.

Scott, M. J. & Jones, M. N. 2000 The biodegradation of surfactants in the environment. *Biochimica et Biophysica Acta (BBA) – Biomembranes* **1508** (1–2), 235–251.

Sherief, M., Hanna, A. A & Aboelenin, R.M.M. 2015 Removal of phosphate ions from aqueous solutions by using modified diatomaceous earth. *Research Journal of Pharmaceutical, Biological and Chemical Sciences* **6** (2), 583–588.

Smith, E. & Bani-Melhem, K. 2012 Grey water characterization and treatment for reuse in an arid environment. *Water Science and Technology* **66** (1), 72–78.

Sotheeswaren, S., Nand, V., Matakita, M. & Kanayathu, K. 2011 *Moringa oleifera* and other local seeds in water purification in developing countries. *Research Journal of Chemistry and Environment* **15** (2).

Sweeney, M. F., Hasan, N., Soto, A. M. & Sonnenschein, C. 2015 Environmental endocrine disruptors: effects on the human male reproductive system. *Reviews in Endocrine and Metabolism Disorders* **16** (4), 341–357.

Taghizadeh, M. M. & Vahdati, R. 2015 Study about efficiency of nitrate removal from water by activated carbon prepared by pistachio, walnut and almond shells. *International Journal of Biosciences* **6** (2), 375–379.

Tsai, W., Lai, C. & Su, T. 2006 Adsorption of bisphenol-A from aqueous solution onto minerals and carbon adsorbents. *Journal of Hazardous Materials* **134** (1–3), 169–175.

Uta Linke, G. 2014 *Experiment Instruction*. Gant, Hamburg, Germany.

Verma, C., Sar, S. K. & Mathew, J. 2013 Natural adsorbent: removal of anionic surfactant from grey water and its comparison with chemical adsorbent. *Journal of Energy Technologies and Policy* **3** (11).

Vitosh, M. L., Warncke, D. D. & Lucas, R. E. 1994 *Secondary and micronutrients for vegetables and field crops*. Michigan State University, East Lansing, MI, USA.

Wang, S. & Peng, Y. 2010 Natural zeolites as effective adsorbents in water and wastewater treatment. *Chemical Engineering Journal* **156** (1), 11–24.

Weston, R. F. 1998 *Environmental fate and effects of cleaning product ingredients in graywater*. The Soap and Detergent Association, New York, NY, USA.

WHO 2006 *Overview of grey water management health considerations*. WHO, Cairo, Egypt.

Widiastuti, N., Wu, H., Ang, M. & Zhang, D. 2008 The potential application of natural zeolite for greywater treatment. *Desalination* **218**, 271–280.

Yahaya, S., Jikan, S. S., Badarulzaman, N. A. & Adamu, A. D 2017 Chemical composition and particle size analysis of kaolin. *Path of Science* **3** (10).

Yaper, S. & Yilmaz, M. 2005 Removal of phenol by using montmorillonite, clinoptilolite and hydrotalcite. *Adsorption* **10** (4), 287–298.

First received 14 August 2017; accepted in revised form 9 May 2018. Available online 22 May 2018