ICSBE2016-186

GREY WATER RECLAMATION FOR URBAN NON-POTABLE REUSE - CHALLENGES AND SOLUTIONS: A REVIEW

D. T. K. James[1*], S. Surendran[1], A. O. Ifelebuegu[1] , E. Ganjian[1] and J. Kinuthia[2]

[1]Coventry University, Coventry, UK
[2]University of South Wales, Pontypridd, UK
**E-Mail: jamesd19@uni.coventry.ac.uk, TP: +447470496184*

Abstract: The study shows the sustainable and effective way of managing growing water and wastewater problem is to reclaim and use greywater from bath/shower, hand basin and washing machine for outdoor and indoor non-potable purposes. A detail wastewater characterisation study by the past researchers indicates that grey water is polluted, but the quality is not similar to the domestic wastewater and therefore the traditional design criteria cannot be used for greywater reclamation. The study by the past researchers show grey water with detergent inhibit grey water reclamation process such as aerobic biological process and the appearance of reclaimed water with cloudiness, colour and excessive bubble formation reduce willingness especially for in-house uses than outdoor uses. Partially or untreated soapy grey water are useful for outdoor use and has useful nutrients, but some study shows excess detergent and other cleaning materials may cause harmful effects to the growth of plants and degrades soil structure. It may cause risk to the environment and human who makes close contact with grey water or inhale the spray. Currently most of the grey water reclamation systems are based on traditional wastewater and/or water treatment design and some have no proper design at all. In addition, due to the public perception ("yuck effect"), it is not acceptable for using reclaimed grey water for direct potable use. Also, globally there are standards for potable water quality and regulated widely, whereas only a few countries have non-potable water quality or grey water reuse standards and regulated properly. Therefore, when designing grey water reclamation, the above challenges needed to be considered. This paper presents review on grey water characteristics, health and environmental risks, public acceptability, regulatory requirement for non-potable use and on current grey water reclamation processes, particularly about the treatment of detergent and other cleaning materials and also identify natural geo or waste material for synthetic detergent removal from grey water.

Keywords: Detergent and surfactants; Grey water characteristics; Natural or waste material; Non-potable uses; Treatment systems.

Abbreviations: BOD - Biological oxygen demand, COD - Chemical oxygen demand, TSS - Total suspended solids, TDS - Total dissolved solids, TOC - Total organic carbon, WHO - World health organisation, WC- Water closet flushing

1. Introduction

The United Nation Office for Disaster Risk Reduction [1] reports that during 2005-15 due to over 4016 natural hazard events, 0.8 million people were killed worldwide and another 1831 million people affected, with $1.7 trillion damage. About 84% of the hazards are related to flood, storm, heatwaves and drought events led to 43% of fatality and 95% of people were affected. The UN's Intergovernmental Panel on Climate Change [2] has stated that climate change has accelerated faster than predicted, with the consequence of dryer summers and wetter winters with frequent droughts and floods with associated pollutions. WWAP (World water assessment programme) [3] indicates more than 50% of the world population are living in cities and 30% of them are in slums.

Urban populations are expected to increase, particularly 93% of people in the developing countries will live in urban areas by 2050 and half of them will be in the urban slum. Climate Change and demographic changes due to mass urbanisation are the most urgent challenges of the 21st century and these are the key drivers for all water shortage and wastewater (flooding & pollution) problems.

Therefore, there is a need to manage the above water and wastewater problems by considering alternatives to conventional methods. The study carried out in Loughborough University during 1994-98 shows planned direct grey water from bath, shower, hand basin and washing machine with or without storm water from roof could be reclaimed and used for non-potable indoor (WC) and outdoor (gardening) purposes as a suitable additional option to solve the problem [4,5,6].

2. Grey water characteristics

In order to design the degree and type of greywater treatment, studying the grey water quality characteristics are very important. Surendran et al [4,5,6] collected grey water from a student accommodation hall in Loughborough University analysed for 17 parameters (Table 1)

Table 1: Characteristics of grey water / wastewater

Micro-biological, Physical & Chemical Parameters	Typical Greywater Quality			Domestic Waste-water Quality (See Key)
	Surendran et al [4,5,6]		Others (See Key for Ref)	
	No of Samples	Typical		
Thermo-tolerant Coliform (cfu/100ml)	221	320 - 1485	2022 (10)	10^7 (6)
Total Coliform (cfu/100ml)	73	$1.6x10^5$-$5.2x10^6$	1.9 $x10^5$-$19.2x10^6$ (1,9)	10^{12} (6)
Turbidity (NTU)	272	25-72.8	8.8-184 (1,2,3,4,5)	70 (6)
Tot Suspended Solids (mg/l)	303	24-53.7	19-397 (1,2)	1- 400 (6,7,8)
Tot Dissolved Solids (mg/l)	139	364-442.9	175 -397 (1,2)	540-800 (7)
Total Volatile Solid (mg/l)	139	145.8 - 251.3		320 (6)
Temperature - °C	123	20.4-22.4	19.7-24.4 (1,2,3,4)	
Conductivity - µS/cm³	137	557-599.5	351-1225 (1,4)	
pH	142	7.3-7.72	6.6-10 (1,3,4)	6.6 - 7.9 (6,7,8)
BOD - mg/l	175	60.5-110.4	22 -149 (2,3,5)	12 - 360 (6,7,8)
COD - mg/l	31	138.4 - 173.2	23- 655 (1,2,3,5,9)	94-750 (6,7,8)
Tot. Org. Car (TOC)- mg/l	255	37.6-57	72.6 -181 (3,9,10)	29 (6)
Inorganic Carbon - mg/l	225	26.1-29.6		
Phosphate (PO_4) as P-	62	1.6-	0.29– 8.1	7.7-

mg/l		3.6	(1,4,5)	26.4 (6,7)
Nitrate (NO_3) as N-mg/l	62	0.81-1.21	0 – 5.5 (1,2,5)	2.8 – 25 (6,7,8)
Ammoniacal Nitrogen (mg/l)	9	1.6	0 – 8.2 (4,5)	45 (6)
Ammonia (mg/l)			5.43-13.23 (1,3,4)	
Dissolved Oxygen (mg/l)	37	5-7.6 (83%)	0.92 - 3.26 (1)	(54%) (6)
Anionic surfactant (mg/l)			143 (3)	1.1(6)
Sodium (mg/l)			141 (3)	
Cholride (mg/l)			23.6 (2)	400 (6)
Sulphate (mg/l)			43.6 (2)	0.5 (6)

Key: 1[7]; 2[8]; 3[9]; 4[10]; 5[11]; 6[12] ; 7[13]; 8[14], 9[15], 10[16].

The term "greywater" is defined as; "*untreated wastewater from wash basins, baths, showers and laundry facilities, that excludes WC, urinal, bidets, soiled laundry water, cleaner's sinks, kitchen sinks and dishwashers or other wastewater which are of non-domestic origin*". The grey water quality results from the Surendran et al [4,5,6] were compared with other grey water results found in the literature and shows that all of this results were almost similar and the grey water is polluted and cannot be used without some treatment.

There are small variations of greywater characteristics from different authors, this is due to nature of users and uses; e.g. Smith and Bani-Melhem [7] and Ghunmi et al [9] samples had higher suspended solids than Piduo et al [11] and Chin et al [8]. The variation is mainly due to the laundry activities done by the students in the hall, involved in sports [9] and from cleaning and hand basin activities in domestic household [7]. Suspended solids found in all the authors' samples were lesser than the domestic waste water. TDS concentration from Surendran [5] and Smith [7] was higher than Chin[8]. TDS has resulted from usage of soap and detergent from bathing, cleaning and laundry activities in all authors but sampling (grab/composite/continuous) techniques and the laboratory testing procedures are different. The TDS found in waste water is much higher than grey water samples and TDS in Surendran [5] sample was 44% lower than Final effluent. Similarly, Li [10], Ghunmi [9] and Smith [7] studies had the higher turbid grey water due to shower, laundry and cleaning activities.

Organic contents (BOD_5) and total coliform in grey water from Surendran [6], Winward [15] and Ghunmi [9] all were higher than others and the final effluent of waste water treatment plant [5]. This is due to University students taking part in sporting activities and showering afterwards. In addition of this, students in accommodation use their hand basin for washing food items and regular cleaning of student halls. BOD in Ghunmi's sample was about 58% lower than the domestic waste water. Even though the grey water does not include toilet waste, the fecal coliform in Jefferson [16] grey water results are bit high. This variation is due to washing diapers or children in the shower/bath or hand basin.

All most all the detergent and cleaning products used for cleaning or personal hygiene contain anionic surfactant. They also contain other element/compounds such as boron, sodium, ammonium, sulphate and sulfonates in them. Anionic surfactant in grey water are higher than waste water since the dilution is less in grey water. The ammonium content in grey water is higher in Li [10] than Ghunmi [9] and Piduo [11] that has been resulted from shower. Even though Smith [7] sample which is collected from an office building that has no bathing and washing diapers but still it shows a higher ammonia content. This ammonia content may be resulted from anionic surfactant (alcyl amino acids), Cationic surfactant (linear akylamines and alkyl ammonium) or Amphoteric surfactant (Amino propionic acid) from cleaning and washing activities [17]. The ammonium and nitrates in wastewater are far higher than in grey water. This is because waste water includes toilet waste. Nitrogen is useful for plants but in nitrates form. Therefore, these ammonium content should be converted to nitrates for it to be useful for the plant as a fertilizer.

Phosphate concentration in domestic waste water is 7.7 - 26.4mg/l and was higher than the grey water samples. Surendran [5] and Li [10] experiments reported higher level of phosphate than others. These phosphates are mainly from the shower creams, cleaning liquids and detergents from bathing and cleaning activities (from the Sink and wash basins). Ghunmi [9] had more chloride in the sample than Smith [7] and Chin [8]. This variation was contributed from the bleaches in detergent from laundry activities that can harm the plants if they are found in large amounts [9]. Except for chin [8], the pH in grey water ranges from 7 to 8 in all the authors' experiments, had pH of 10. This variation can be due to higher detergent concentration since Chin collected the first discharge from the washing machine.

The results from Surendran [6] shows that organic and microbial qualities of greywaters are comparable with settled domestic wastewater. In some cases, the Grab grey water sample had higher values of BOD, COD and TOC than average settled domestic wastewater. The ammonia and bacterial content in the university greywater was lower than average domestic wastewater or the greywater from the household with young, old and disabled members where the Faecal Coliforms value could be as high as 3.2x105 per 100ml. The comparison of greywater quality with domestic wastewater shows that the quality is not similar and therefore the traditional design criteria cannot be used for greywater reclamation.

2.1 Health and Environmental risk

Pollutants from grey water can produce adverse effect if it accidently comes in contact or ingested by people during WC flushing or spraying during gardening. Microorganisms in grey water could contribute to health risk such as skin or eye infection [18]. Inhalation of aerosol during non-potable uses can cause severe breathing problem [19,20]. Un-treated greywater use (by close contact or spray) also may cause risk to the environment.

Partially or untreated soapy grey water are useful for outdoor use and has useful nutrients. Nitrogen, phosphorus and potassium from grey water are useful for the plant growth but not in excess amounts [18,19]. Therefore, if grey water with these parameters are used in gardening, it could reduce the fertilisers need. But the following studies shows excess detergent and other cleaning materials may cause harm to plants growth and degrades soil structure. Therefore, this concertation should be treated before watering the plants.

The most concerned parameters from grey water that could destroy the plants and environment are sodium, boron and Chlorine from detergents, surfactant and bleaches [18,19]. High levels of these contaminants could contribute to discoloration, burning of leaves, leaf cupping, can contribute to the alkalinity of the soil, prevents calcium ions reaching the plants, it also disturbs the soil's ability to absorb water by disrupting the osmotic pressure [19]. Ottoson [21] believes that untreated grey water with chemicals (Sodium) from detergent and surfactants can lead to harmful consequences such as soil degradation and WHO [19] reasons that this consequence is due to the reduced permeability and aeration due to high amount of sodium adsorption (Sodium from detergents). Ultimately not allowing the soil to support the plant. Boron is needed to 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 in excess to the plant that is toxic and will cause severe damages [19].

Chin [8], Surendran [5,6], Eriksson and Christova-boal [8] studies addresses the other effects of un-treated grey water usage on treatment and pipework. Suspended solids in grey water can clog up pipework that transport grey water. Surendran [5] claims that high level of Total dissolved solids can cause corrosion and scaling on bathroom fixture when used directly for toilet flushing.

The study show grey water with detergent inhibit grey water reclamation process such as aerobic biological process and the appearance of reclaimed water with cloudiness, colour and excessive bubble formation reduce willingness especially for in-house uses than outdoor uses. High turbidity in grey water can make the treatment processes such as disinfection treatments inefficient [5] and the turbidity of non-potable water should be between 2 to 5 NTU according to the standards used in many countries [22]. Therefor the detergent should be removed to the quality acceptable to the users, regulators and other stakeholders.

2.2 Public acceptability to the greywater use

Surendran [5] says successful outcome of the development of water reclamation system would depend on the public attitudes, acceptability, affordability and willingness to pay for water recycling and related water and environmental benefits. The expected non-potable water quality depends on the legal requirements and public perception. This institutional survey [5] showed that over 95% of people questioned would accept and are willing to consider using the reclaimed water for toilet flushing, 97.3% for lawn irrigation and 98.4% for golf course irrigation, if the water was clear, colourless, odour free, carried negligible risk and gave cost-benefits. About 70% would invest an additional 9.8% of their water bill-equivalent to water management devices for long term benefit. In commercial terms this may also enhance the company or institution's reputation. Further, Surendran [4,5,6] studied public attitude prior to demonstration of recycling system at Royce hall. The major for the opposition of reclaimed water reuse are: (1) psychological repugnant and personal preference – 38%; (2) fear or worry about the water quality such as lack of purity & physical quality - 28%; (3) undesirable for bodily contact & cause diseases - 22%; (4) undesirable chemical added - 8%. (5) Operation & maintenance including corrosion & scaling - 2%; and (6) cost for treatment - 2%.

In a survey conducted by Jefferson [16] turbidity, colour, suspended solids and odour influence the public perception of reusing of grey water and reveals that turbidity is the parameter that mostly limits the reuse of grey water and willingness to reuse greywater for toilet flushing was more than watering the garden. Boyjoo [23] reasons the above statement that people oppose more to reuse of grey water when the grey water comes in close contact with them.

2.3 Requirements for non-potable use

The legal requirements are in practice to protect from associated risks of grey water (as stated above), exposed to human and environment [18] and the standards varies according to the end use. There is at present no official guidance on quality criteria for reclaimed greywater in the UK. In order to develop and evaluate the effectiveness of reclamation plants the following alternative sets of water quality guidelines were used in the UK (Table 2):

Table 2: Non-potable water quality standards

	WHO guidelines	UK/EU bathing water standards	EPA reclaimed water standard for WC flushing
Faecal Coliform (F_Coli)	Recreational waters: ≤100 for 50% sample and ≤1000 for 90% sample Irrigation of crops eaten uncooked, Sports fields, public parks and lawns: ≤1000 (all samples)	100(g)/ 2000(m) (g: guidance m: mandatory value)	≤14 for any sample 0 for median of samples from over 7 days monitoring Monitoring 1/day
Total coliform cfu/100ml		500(g)/10000(m)	
Faecal streptococci per 100ml	≤100 for 50% sample and ≤1000 for 90% sample	100(g)	
Enteric Viruses		0(m)	None
BOD_5 - mg/l			≤10 Monitor 1/week
Total suspended solid (TSS) - mg/l		Visibly absent	None
Turbidity (Tur)- NTU		Transparency in M -2(g) / 1(m)	≤2 NTU continuous monitor
Cl_2 residual -mg/l			>1 after 30 min contact Continuous monitoring
pH		6-9(m)	6-9 (monitor 1/month)

3.0 Current process for detergent s removal

Although there are limited guidelines for grey water reuse, reclaimed grey water should fulfil four main criteria for reuse namely; hygienic safety, aesthetics, environmental tolerance and economics [9,10,24].

To meet these criteria, various technologies have been assessed for the treatment of grey water. Treatment varies in both performance and complexities depending on the various target pollutants and the purpose of reuse. They vary from very simple treatment processes like filtration to advances processes like reverse osmosis. The various methods that has been utilised and the pollutants (Detergent characteristics and characteristics that affect public perception) treated are listed in table 3 below and they can be divided into physical, biological and chemical treatment processes.

Physical filtration involving sand and other coarse media are only able to remove large suspended solids and are not able to remove chemicals from detergent / cleaning material and microbiological parameters to levels required for potable reuse. To achieve potable reuse criteria more advances filtration involving nano filtration and reverse osmosis are required. Micro and ultra-filtration membranes can achieve excellent removal of solids, turbidity but not good removal of dissolved salts / Surfactant characteristics and organics. Adsorption, distillation and Reverse osmosis are the main physical methods used in the removal of surfactant characteristics from wastewater / grey water [25, 26].

Chemical processes including coagulation, Ozonation and ion exchanges have also been used for grey water treatment specially in the removal of detergent characteristics [27]. These chemical methods are usually able to reduce organic substances (Surfactants) and turbidity to certain degree but usually not to levels that allows for potable reuse for high strength grey water [11,28]. To achieve potable reuse standards, chemical processes are usually combined with physical processes like filtration or membranes as a further polishing step [11].

Grey water has also been treated using biological processes including aerobic and anaerobic processes. Aerobic processes are usually good in achieving organic matter and turbidity removal while anaerobic process do not achieve good removal results [10,28]. Biological processes are not effective in removing microbiological parameters hence there is usually need for further filtration before potable reuse and also it is not effective in removal of detergent from grey water since the detergent characteristics will destroy the microorganism used in biological process.

Table 3: Treatment Process for different quality

Detergent characteristics DE - Detergent FO - Foam SU-Surfactant C/BL - chloride & bleaches BO - Boron SO – Sodium / its compounds A - Ammonium NI – Nitrates P – Phosphates	SE – Sulphate TDS – Total Dissolved Solids O/G – Oil / Grease (Oil attached to surfactant) **Public perception characteristics** CO - Colour OD - Odour TU - Turbidity TSS -Total suspended solids
Physical treatments	
Screening & grit removal	TSS
Dilution	A, P, NI, SU
Storage	FO, TSS
Sedimentation	FO, TSS
Aeration	OD
Floatation	DE, O/G, TSS
Slow filtration	DE, O/G, TU, TDS, TSS
Rapid filtration	DE, O/G, TU, TSS
Reverse osmosis	TDS, SU, BO, SO, SE
Distillation	SU, TDS, SO, SE
Adsorption	SU, BO, OD, CO
Biological treatments	
Suspended-growth	A, TDS, NI
Fixed-film reactor	A, TDS, NI
Bio. nutrient removal	P, NI
Reed bed	DE, TU, P, TSS, NI
Land treatment	DE, FO, C/BL, TU, P, TSS, NI
Chemical treatments	
Coagulation	DE, OD, TU, SU, TSS, BO
Chlorination	OD
Ozonation	SU
Ion exchange	TDS, SU, BO, SO, SE
Electro dialysis	TDS, SO

Source: [5], [29], [30]

3.1 Loughborough Grey Water Reclamation

Surendran [4,5,6] conducted a research and developed a bio-filter for reclaim greywater at a student accommodation in Loughborough University from 1994 to 1998. This research includes treatment process for grey water, this was a partly funded project by Anglian Water, Yorkshire Water and Entec Pollution Control.

This package unit was composed of four main stages (Fig 1) and the detail designs were given in Surendran [4,5,6]. Stage 1 was for balancing flows and buffering peak mass loads includes Screening, grit chamber, (preliminary treatment) and Stage 2 for solid separation and digestion by sedimentation, roughening filter (primary treatment) to reduce sludge yield. Stage 3 was an aerated bio-filter (a modified activated sludge process with complete mix fluidized bed and up-flow sunken media filtration, (secondary treatment) to remove most organics and Stage 4 gravity fed deep slow filtration (tertiary treatment) to generate near potable quality.

The fifth stage is further polishing by adsorption and it was an option. This unit was tested and modified during two laboratory trials (Table 4).

Table 4: Results of Loughborough experiment

Water quality Parameters, monitored at Royce-5	Project 1 - monitored up to 57 weeks		Project 2 - monitored up to 46 weeks	
	Initial Influent	Final Effluent	Initial Influent	Final Effluent
Thermo-tolerant Coliform (cfu/100 ml)	900-1485	1.0 - 3.8	900-922.6	1.6 - 3.9
T/Coliform (cfu/100 ml)	160000	50.0 - 52.9	160000	50.0 - 64.7
Turbidity (NTU)	30.0-35.1	1.2-1.5	25-33.3	1.7-2.5
TSS (mg/l)	34.5-40.2	2.0-2.7	24-28.9	1.5-1.9
TS(mg/l)	414-426.2	338.5-361.4	449-458.5	418.6 - 440
TDS (mg/l)	364-379.7	335.8-356.6	427.5-428.4	417.1-437.9
Temperature (°C)	21.0-21.9	16.3-16.5	20.4	15.5-16
PH	7.3-7.4	7.6	7.4	7.8-7.9
BOD(mg/l)	78.1-83.1	3.0-4.0	60.5-70.2	1.8-2
COD(mg/l)	ND		138.4 - 162.9	9.8-10.8
Ammoniacal N (mg/l)	1.6	0.1-0.2	ND	ND

Source: [5]

Fig 1: Greywater reclamation Plant construction in Loughborough, source: [5]

3.2 Joint Chinese / German partnership grey water recycling project

A grey water reclamation system was jointly developed by Chinese / German partnership to cater a residential area of 60 apartments. The water sources were from showers and basins and it was reclaimed and used for non-potable use such as toilet flushing. Grey water was treated using a membrane bioreactor with a capacity of 10000l/day and was operating since June 2006. The treated water parameters met the EU bathing standard (Table 5) [31].

Table 5: Results from the Chinese/German project

Parameters	Inlet	Out let	Water quality standard for flushing
pH	7.8- 7.9	8.2 -8.4	6.5 – 9.0
TSS	22 – 65	0 – 2	10
BOD	86.2 - 123	1.8 - 3	10

COD	132 -200	12.9-14.1	50
Turbidity	48-74	1-2	10
TDS			1200
Ammonia	6.41-7.72	0.52-0.86	20
Total phosphorus	4.02-5.42	2.81-5.24	-

Source: [31]

4. Natural geo / By-product material to remove detergent characteristics

All Materials such as natural material, artificial material, geo material, plant material and waste materials can be used to treat water or wastewater or grey water using the following treatment methods.

- Coagulation and flocculation (i.e. Alum from bauxite are used as coagulants in water, they bind the pollutants together to form flocks, thereby increases settlement to the bottom or they make them to float).
- Adsorption (i.e. Granular activated carbon from charcoal have surface area of 800-1500 m2/g and their pore size is 1.8 – 3.0nm [33] and the particle size range from 1.2-1.6 mm. Activated carbon uses the mechanism of physisorption to adsorb the pollutants into their pores by means of Van der Waals forces).
- Disinfectant is killing of microorganism from water or waste water (i.e. moringa seeds are effective in killing 97.5 % total coliform, in the same time they also act as coagulant and adsorbent [34]).
- ion exchange process (i.e. Zeolites), the structure of zeolites places an important role in removing cations due to their resulted negative charge from their 3D alumino silicate structure [27].
- Medium for the growth of microorganism in biological processes (In Trickling filter sand, rock and gravel are used in which the microorganism from waste water get attached to the sand / rock bed, grow and break down pollutants in waste water.

The following natural geo materials e.g. bentonite [32], Hydrotalcite: Layered double hydroxide [33], Alumina from bauxite (Adak et al 2005), Perlite can be used to remove the anionic surfactant. Zeolites (Clinoptilite) can be used to remove the cationic surfactant and the cationic modified zeolites are being used in the removal of anionic surfactant [27].

Waste materials such as activated carbon from charcoal and coconut shell [33], fly ash [36] were used in the removal of detergent. Tyre rubber granules were used to remove 96.5% of anionic surfactant and in the same experiment it confirmed that the removal efficiency of tyre granules are slightly higher than activated charcoal [25]. Mussel shells are aragonites that are being used to remove phosphates that are being resulted from surfactant and builders. When the mussel shells are heated to 800^{o}C, they are converted to lime, that uses the adsorption and precipitation property to remove phosphates from detergent containing water [26].

5. Conclusions

- Grey water characteristics are not similar to waste water characteristics therefore traditional wastewater treatment design criteria cannot be used to reclaim grey water.
- Grey water is polluted specially with the physical and chemicals properties of soap and detergents (surfactants and builders) from shampoos and washing/cleaning materials. Therefore it needs novel and a sustainable treatment for it to be used as a non-potable source and also it should achieve the quality required by the regulation and standards and also cater the public acceptability.
- Removal of detergent from the grey water is possible by using natural and/or waste or by-product. This study will lead to the development of an eco-

friendly mineral coated synthetic foam layers for effective detergent removal.

References

[1].http://www.unisdr.org/files/47804_2015disastertrendsinfographic.pdf , visited, (25th July 2015).

[2]. IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B et al (eds.)]. Cambridge University Press.

[3]. UN World Water Assessment Programme - WWAP. (2015), *World Water Development Report 2015: Water for a Sustainable World.* Paris, UNESCO.

[4]. Surendran. S, and Wheatley. A. D, (1998), Grey-water Reclamation for Non-Potable Re-use, Journal CIWEM, Vol 12, No 6 (Dec), pp 406-413. ISSN:09517359

[5]. Surendran, S. (2001) *The development of an In-house grey water reclamation system for large institutions, During 1994- 1998.* Unpublished PhD thesis. Loughborough: Loughborough University

[6]. Surendran, S. S. and Wheatley, A. W., (2007), Development and Demonstration of an in-house Water Reclamation and Reuse System for Large Institutions, NOWRA / IWA 16th Annual Conference on "Decentralise Infrastructure for Sustainable Future", Baltimore, Maryland, USA, 12th-14th Feb 2007 (http://071812c.membershipsoftware.org/store_product.asp?prodid=201)

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

[8]. Chin, W.H., Roddick, F.A. and Harris J.L. (2009) 'Greywater treatment by UVC/H2O2'. *Water Research* 43, 3940 – 3947

[9]. Ghunmi, L.A., Zeeman, G., Lier, J.V. and 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

[10]. Li, F., Behrendt, J., Wichmann, K. and Otterpohl, R (2008) 'Resources and nutrients oriented greywater treatment for non-potable reuses'. *Water Science and Technology* 57(12), 1901-1907

[11]. 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

[12].Henze M and Comeau Y (2008) Biological Wastewater Treatment: Principles Modelling and Design. IWA,. ISBN: 9781843391883.

[13]. Bai , S. , Srikantaswamy ,S. , Shivakumar , D. (2010) ' Urban Wastewater characteristics and its management in urban areas – A case study of Mysore city , Karnataka , India'. *Water resource and Protection* 2 , 717 – 726

[14]. Karimi, B. , Ehrampoush , M.H., and Jabary , H.(2014) 'Indicator pathogens, organic matter and LAS detergent removal from wastewater by constructed subsurface wetlands' J of Environmental health science and engineering

[15]. Winward, G.P., Avery, L.M., Stephenson, T. and Jefferson, B. (2008) 'Essential oils for the disinfection of grey water'. *Water Research* 42, 2260 – 2268

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

[17]. Salager , J . (2002) Surfactants: Types and uses no.2. Venezuela : Universidad de las Andes.

[18]. Rowe, D.R. and Abdel-Magid, I.M. (1995) *Handbook of wastewater reclamation & reuse.* Florida: Lewis

[19]. WHO (2006) *Overview of grey water management Health considerations.* Cairo: WHO

[20].http://caice.ucsd.edu/index.php/education/clear/learning-with-clear/aerosols-and-health/ ,visited, (31st March 2015)

[21].Ottoson , J. and Stenstrom, T.H. (2003) 'Faecal contamination of greywater and associated microbial risks'. *Water Research* 37, 645 – 655

[22].http://www.public.health.wa.gov.au/cproot/2280/2/Guidelines%20for%20the%20Non-potable%20Uses%20of%20Recycled%20Water%20in%20WA_140620.pdf , visited, (25th March 2016)

[23].Boyjoo, Y., Pareek, V.K and Ang, M. (2013) 'A review of greywater characteristics and treatment processes'. *Water Science and Technology* 67(7), 1403 – 1423

[24]. Nolde, E., 2005. Greywater recycling systems in Germany—results, experiences and guidelines. *Water Science and Technology*, *51*(10), pp.203-210.

[25].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.

[26].Jones, M. I. , Wang, L. Y. , Abeynaike , A. and 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

[27].Widiastuti, N. , Wu, H. , Ang, M. , Zhang, D. (2008) 'The potential application of natural zeolite for greywater treatment'. Desalination 218 , 271 – 280

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

[29]. Ghavanloughaver (2015) *Use of Boron in Detergents and its Impact on Reclamation.* Unpublished dissertation. Los Angeles : University of Califonia.

[30].http://www.lenntech.com/periodic/water/sodium/sodium-and-water.htm visited (30th September 2016)

[31].http://www.dwc-water.com/technologies/grey-water-recycling/case-studies/index.html , visited , (30th September 2016)

[32]. 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

[33]. Schouten , N. (2009) ' Reuse of laundry rinsing water by low cost adsorption technology'. Unpublished PhD thesis. Eindhoven : Eindhoven University of Technology.

[34].Alfa, M. I. , Igboro, S.B. , Ajayi , S.A. , Dahunsi , S.O. and Ochigbo B.O. (2014) 'Assessment of the Antimicrobial Efficiency of Moringa oleifera Seed Extracts in the Treatment of Grey Water'. *British Journal of Applied Science & Technology* 4(3) , 558 -567

[35]. Adak, A., Bandyopadhyay, M., and Pal,A., (2005) 'Removal of anionic surfactant from wastewater by alumina: a case study'. *Colloids and Surfaces a Physicochemical and Engineering Aspects* 254 (1-3), 165-171

[36]. Witek-krowiak, A. Szatran,R.G., Modelski , S., Davice , A. (2012) 'Removal of cationic dyes from aqueous solutions using micro spherical particles of fly ash'. *Water Environmental Research* 8(2) , 162-16