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Research Article

ECONOMICAL APPROACHES FOR THE TREATMENT AND REUTILIZATION OF LAUNDRY WASTEWATER - A REVIEW

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ABSTRACT

This paper provides an elementary characterization of laundry wastewater (LWW) and treatment techniques with their installation and operation cost analysis for potential chemical removal such as surfactants i.e., linear alkylbenzene sulfonates (LAS), chemical oxygen demand (COD), nitrate, sulphates and phosphate found up to 1024, 4474, 25.7, 102.6 and 279 in mg/L, respectively. LWW also contains solids, turbidity, low levels of alkalinity, volatile acids, deodorizing agents, fabric, food, body fluids, non-biodegradables, and a few metals like Zn, Ni, Fe, Cu, Pb and xenobiotic organic compounds. The treatment techniques for LWW as physical treatments includes sedimentation and filtration for particulate matter and adsorption using granular activated carbon (GAC) or bio-char are used to reduce the COD, BOD, anionic surfactants, total solid and turbidity by 50-95%. Bio-char is more preferred than activated carbon because it is 60% more economical and facilitates E. coli removal. Chemical treatments such as coagulation integrated with GAC results in 80-95% removal of COD, BOD, total phosphorous and anionic surfactant. Biological treatment and phyto-remediation take more time but they are the most eco-friendly strategies to employ. Each technique can serve according to each project's budget, material availability and according to the desired utilization or application. In this review, the best cost effective trends are highlighted along with recommendations for further developments. This paper further highlighted the current knowledge gaps and future research directions for the application of these technologies for wastewater treatment and reuse.

INTRODUCTION

For millennia human beings have lived with the misguided notion that water is not a commodity, and it is in fact after air the second most valuable resource on this planet (Spelman, 2003; Stephen and Agouridis, 2008). Potable water is becoming scarcer with the passing of time and as the world's population grows. Water is essential for everyday basic needs as well as many industrial, production and manufacturing operations; water resource challenge accessibility and unsustainability use focus on reuse of Laundry wastewater (Textina and Svilanit, 2010; Turkay, *et al.*, 2017).

According to the World Health Organization (WHO, 2011), 700 million people currently do not have potable water and 2.4 billion still lack proper sanitation (WHO, 2016). Due to the poor water and sanitation conditions in developing countries, people suffer from various infections and tropical diseases. For this reason the World Health Organization (WHO) initiated the Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS) and United Nation with Sustainable Development Goals (SDGs), the objective being to improve water accessibility and to achieve water safety through various innovative technology and sustainable development techniques. These include, for example,

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water harvesting, wastewater treatment, recycling and reuse. Engineers, researchers and regulators are investing time and resources to alleviate the efficiency of existing technology and solving the challenge for treating the mixed contaminants of concerns. People still lack potable water sources or have much fewer reliable sources of water, which points towards the need to save clean water and reuse wastewater for other purposes in line to save potable water (WHO, 2016).

The increasing stress on fresh water resources has made it clear that societiesaround the world must urgently consider alternatives such as recycling and reuse of wastewater. Wastewater can be divided into many types according to where they are sourced from. In this paper, a comparative discussion is undertaken with reference to LWW from different sources. It can be stated that large amount of water requires daily and portion of water for laundry purpose. This paper focuses on the characterization of laundry wastewater, which is classified as grey water and evaluate the economic feasibility of existing techniques in terms of capital and operation cost to provide comparison among different techniques of reuse and recycling methods.

LWW is generated from a water-washing process that utilizes soap and detergent for the cleaning of clothes, they are first rinsed in a soap solution to remove heavy dirt, followed by a second rinse to remove the remaining dirt and finally rinse involving more diluted soap bleach or a deodorizing agent (Ahmad, 2008). The final outcome of these synergistic efforts of mechanical energy, chemical energy, thermal energy and time, results in dirt-free clothes (Sostar-Turk, et al., 2005). LWW consists of various cleaning chemical agents and dirt, which can originate from food, fabric, drink, body fluids and atmospheric dust, bleach, oil, paints, solvents and non-biodegradables on clothes, etc. (Ramcharan and Bissessur, 2016; Yadav, et al., 2013).

For composition of LWW of concern constitute surfactants, which are major part of cleaning agent. Surfactants possess harm and difficulty to treatment technology. Surfactants are employed in a wide variety of products including pharmaceuticals, textiles, tanneries, cosmetics, detergents, agriculture, biotechnology, food, paints, microelectronics and mining (Rivera□Utrilla, *et al.*, 2012; Olmez-Hanci, *et al.*, 2010; Aboulhassan, *et al.*, 2006; Central Pollution Control Board (CPCB), 2008; Cserháti, *et al.*, 2002) It must be emphasized, however, that surfactants are harmful to human beings, fish and vegetation (Koparal, *et al.*, 2006; Kotut, *et al.*, 2001; Liu, *et al.*, 2010).

Anionic and non-ionic varieties are the mostly used as household detergents and cleaning agents (Aboulhassan, *et al.*, 2006). Linear Alkylbenzene Sulfonate (LAS) is the most commonly used household detergents, and it consists of different compounds of homologous and isomers containing aromatic rings (Ramcharan and Bissessur, 2016). Furthermore, the sulphonate ion is attached to the linear alkyl chain due to its excellent performance and low cost (The Food and Agriculture Organization (FAO), 1985; Faria, 2004; Friedler, 2004; García, *et al.*, 2005). The concentration of LAS in LWW is tested using analytical instruments HPLC-UV and UV-Spectrophotometry (Duarte, *et al.*, 2006). LAS can affect internal processes of living organisms such as human beings' reproduction and growth. In aquatic environment, this damage fish gills or increase mucus production and damages the swimming patterns of fish (Petrovic and Barceló, 2003; Hampel, *et al.*, 2012).

In Irish municipal wastewater the contribution from detergents of these metals are 31.9% for Cd, 0.24% Cu and 0.30% for Zn which is the alarming stage to alleviate the sewage disposal quality to avoid the aquatic and irrigation life cycle (Aonghusa and Gray, 2007). Therefore, Cd was most easily absorbed by crops, and different crops had different capacities to absorb Heavy Metals (HM) (Bifeng, *et al.*, 2017). The total carcinogens risks (TCRs) for children, adults, and seniors were 5.24×10^{-5}, 2.65×10^{-5}, and 2.08×10^{-5}, respectively as per the hazard quotient (HQ) of the HMs, all of which were less than the guideline value but at the alert level. Ingestion was the main pathway of carcinogen risk to human health (Bifeng, *et al.*, 2017). Nitrate and Phosphate have the significant value in LWW which can easily accumulate in onion and maize crops via irrigation from the water body of which received untreated municipal waste water disposal (Haftbaradaran, *et al.*, 2018) (Sigua, *et al.*, 2017). Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) of LWW has the alarm value to maintain the disposal of municipal sewage.

Alcohol ethoxylates (AE) are another major group of non-ionic surfactants found in cleaning agents. It does not ionize in aqueous solution and is sensitive to electrolytes, due to it being the non-dissociable hydrophilic group. Subsequently, they are used in many complex mixtures (Duarte, *et al.*, 2006; The Food and Agriculture Organization (FAO), 2016). The aggregate consumer exposure to AE has been conservatively estimated to be at maximum 6.48

μg/kg bw/day (HERA, 2009). AE also exert serious environmental impacts due to their biodegradability, in that direct and indirect skin contact from its use in laundry detergents, inhalation through the use of spray cleaners and oral ingestion derived from residues deposited on dishes and also it affects aquatic bodies through the process of bio-accumulation and can be adsorbed into solids and soils, affecting their properties (Singla, *et al*., 2009; Liu, *et al*., 2010; Lourdes, *et al*., 2008; Marian, *et al*., 2016; Marks, *et al*., 2002; Kerr, *et al*., 2001). These surfactants have antimicrobial properties leading to a more tolerant microbial strain which might pose a threat to human beings if present in drinking water or water used for irrigation (Shao, *et al*., 2005).

CHARACTERIZATION OF LAUNDRY WASTEWATER

Volatile organic acids and linear alkyl benzene sulfonates (LAS) can be examined by high performance liquid chromatography (HPLC). UV-Spectrophotometry is also ideal for the analysis of anionic surfactants (Jamrah, *et al*., 2011; Jamrah, *et al*., 2008; Jurado, *et al*., 2006; Akyuz and Roberts, 2006; Al-Mughalles, *et al*., 2012; Chen, *et al*., 2008; Udayakumar, 2015; Wangkarn, *et al*., 2005). Nitrate, nitrite, phosphate, fluoride and bromide can be tested by ion chromatography. Similarly, alcohols can be quantified by gas chromatography.

(Ramcharan, *et al*., 2016) worked on Linear Alkylbenzene Sulfonates (LAS) specifically which is found upto 30% of total detergent (Ramcharan, *et al*., 2016). LWW were sampled from a domestic washing machine which program comprised of one wash cycle (rinse 1) followed by two sequential rinse cycles (rinse 1 and 2). The results of the analysis of LAS are summarized in Table 1. It is found that the amount of LAS is reduced by 41% after rinse 1 and 25% after rinse 2 (Table 1), respectively, when the UV method was used. Similarly, in the case of HPLC, LAS was reduced by 55% initially, and then by 38% later on. These results show that with each rinse the amount of LAS declines.

(Ramcharan, *et al*., 2016) also reported impact of temperature on LAS reduction and biodegradation under aerobic condition. When rinse one stored at 4°C for a period of 5 days with no added preservative showed a decrease in concentration of LAS by 31.84% while a 9.07% decrease was observed for samples stored in 15% methanol at the same temperature. Under aerobic condition LAS is biodegraded into acetoacitic acid and fumaric acid (Ramcharan, *et al*., 2016).

The amount of LWW may vary according to the user's mechanical efficiency and availability of water etc. Table 2 documents a typical example of LWW flow rates from various sources such as apartments, bars, hotels, hospitals and prisons in Hong Kong, China. The flow rate varies from 132-2460 l/day.

Table 3 gives the details of other chemicals of concern which are found in LWW. Significant amounts of ethanol were reported, whereas the amounts of butyric acid were found to be the highest for all acids. These significant contaminants need special treatment in order to make this water reusable.

(Braga, *et al*., 2014) conducted an extensive testing of xenobiotic organic compounds in LWW. They identified 33 xenobiotic organic compounds, which included cleaning agents, fragrances, insect repellents, and antioxidants (Table 4). This certainly confirms that cleaning agents as well as other chemicals used for deodorizing constitute complex compounds, resulting in the release of a high concentration and wide variety of pollutants into the environment. Consequently, there is a need for well-considered innovative recycling and treatment techniques (Braga, *et al*., 2014).

Compliance limit of LWW reuse

The comparative data analysis shown in Table 5, has been done employing various recommendations emanating from various international standards for drinking water, irrigation water, water course discharge, cattle drinking water and construction water quality along with the laundry wastewater characteristics noted by the authors. As indicated in the Table 5, all the parameters present in LWW are under the permissible limit of water courses. However, the excessive presence of COD and LAS results in the unacceptable limits passing. Thus only treating COD and LAS can make LWW water disposable to water courses.

Table 5 demonstrates that the permissible limit of water quality for irrigation and cattle feeding is to be easily achieved after specifically treating LAS, COD, TSS and total alkalinity. Water permissible limit for construction is achieved easily after initial stage of treatment of LWW as per the Table 5. There is daily use of water which needs low permissible limit to utilise it such as flash in toilet does not require good quality of water therefore LWW can be used directly. The acceptable limits for drinking water parameters are significantly high due to health impact. Although the effects of all kinds of chemicals present in LWW

Table 1. Reproducibility analysis of LAS over a time period for UV-VIS and HPLC-UV; Source: (Ramcharan, *et al.*, 2016).

Method	Period	Rinse 1 (mg L^{-1})	Rinse 2 (mg L^{-1})	Rinse 3 (mg L^{-1})
UV-VIS	Day 1	357.2 ± 0.14[a]	217.6 ± 2.54[a]	159.2 ± 5.02[a]
	Day 2	353.5 ± 0.13[a]	208.9 ± 4.82[a]	153.0 ± 4.97[a]
	Day 5	339.3 ± 4.20[a]	192.6 ± 4.77[a]	151.8 ± 2.62[a]
HPLC-UV	Day 1	454.5 ± 0.48[a]	200.9 ± 3.89[a]	125.9 ± 2.07[a]
	Day 2	447.6 ± 1.32[a]	198.0 ± 4.95[a]	118.9 ± 3.54[a]
	Day 5	413.2 ± 1.37[a]	184.8 ± 3.73[a]	116.1 ± 3.19[a]
Rinse 1=Wastewater disposed after 1st wash cycle, Rinse 2=Wastewater disposed after 1st rinse cycle, Rinse 3=Wastewater disposed after 2nd rinse cycle, [a]Average of triplicate analysis				

Table 2. Average LWW produced from various facilities; source: (HKSAR, 2001).

Source	Flow rate (l/day)	
	Range	Typical
High rise apartments	132-283	189
Low rise apartments	189-302	246
Individual residences **113-567 278**	113-567	278
Bars	1040-1520	1280
Hotels	1700-2460	2080
Hospitals	473-908	624
Prisons	284-567	435

Table 3. Other chemical characteristics of LWW, Source: (Braga, *et al.*, 2014).

Parameters (mgL^{-1})		VSS	NKT*	Ethanol	Citric	Malic	Succinic	Latic	Formic	Acetic	Propionic	Isobutyric	Butyric	Isovaleric	Valeric	Caproic
Value	Min	10	1.2	38.9	8.3	4.6	7.4	11.8	3.2	7.8	10.7	10.9	10.9	11.2	10	10.9
	Max	260	136	384.6	307.5	183.7	193.7	406.7	172	329.2	279.7	287.2	292	35.2	251	273.5
	Average	70 ± 50	32.4 ± 26.2	148.6 ± 94.6	50.9 ± 95.2	34.6 ± 52.7	63.5 ± 82.9	92.2 ± 103.4	15.6 ± 35.8	24.2 ± 61.9	44.6 ± 65.9	46 ± 67.4	121.6 ± 140.6	16.4 ± 7.4	40.5 ± 85.1	97 ± 122.5

Table 4. Xenobiotic organic compounds found in LWW, source: (Braga, *et al.*, 2014).

Compounds			
Headspace analysis	%A	Liquid analysis	% A
Butilcicloexil acetate	3.2	Octadecanoic acid	0.61
Butanol	70.96	Palmitic acid	1.67
Cis-dimetilciclohexanol	0.4	Etil citrate	5.88
Decamethylcyclopentassiloxane	1.5	Cholesterol	1.2
Dimetilciclohexanol	0.89	Cicloexenodimetiletil	0.13
Dodecametilciclohexassiloxano	0.92	Dimetilpentadecilamina	0.62
Ethanol	5.49	Diglicidilbisphenol A ether	0.4
Diphenyleter	0.52	Etilhexilftalato	4.97
Octilfenileter	0.35	Phenoxi ethanol	0.39
Etilhexanol	2.14	Heptadecanol	1.37
Isobornilformate	1.18	Hexadecanol	1.8
Limonene	1.82	Isobutilphtalato	0.22
Linalool	3.04	Metilmetóxietiloctadecanamina	3.15
Mercaptomethane	2.04	Nonylphenolethoxilado	8.85
Octametilciclotetrassiloxano	0.47	Terpineol	0.16
Metil sulfite	0.6	Tetrametilbutilphenoxiethoxilado	3.48
Terpineol	0.93		
Tetradecene	0.37		
% A=Area percentage, which indicates the normalized relative distribution of the compounds in the sample			

are uncertain with reference to health, it is not advisable to reuse wastewater for drinking purposes without extensive treatment of LWW (WHO, 2017).

Characterization of LWW by country

Theuse of surfactant and duration of rinsing changes with people's culture, lifestyle, geographical location and the climate they live in. Table 6 lists the physio-chemical and biological characterization of eight different countries.

Table 6 demonstrates that TDS is more than 2000 NTU except China and Bangladesh. Turbidity is also in the hundreds except Amman and Oman 2. BOD and COD are quite high in India and Kenya. pH is nearer to the permissible limit whereas electrical conductivity needs treatment in order to reach its permissible limit. Microbiological character has also been shown to require special treatment to make it reusable.

Characterization of LWW by source type

Laundry wastewater quality changes with sources type and consequently the treatment techniques. Extensive characterizations of LWW from difference sources are displayed in Table 7. The concentration of chemicals of concern present in the LWW that derive from hospitals needs more attention than other sources as demonstrated in Table 7. Physical parameters such as odor and color are found objectionable in LWW generated from hostel, India. Chemical parameters, in particular, heavy metal such as lead has been found to need special treatment so that the allowable limit can be achieved. COD need to be treated and reduced by 95% to make it reusable for further daily use purposes. Although electric conductivity (EC) of LWW generated from beauty parlour and girls hostel are significantly high whereas pH and TDS from beauty parlour need to treat well to make it reclaimable. COD and nitrate from beauty parlour are easy to treat for reuse of water for daily purpose with low permissible limit. The turbidity and BOD need special treatment to be in the limit for reclamation of LWW of only white sheet only of dormitory, Finland. This shows that white sheet has more light intermittent object and carelessly used. The industrial laundry participating in this study from Turin, Italy is specialised in wet washing of textiles made of vegetable fibres, animal fibres, man-made fibres and their mixtures with 22 tons of textiles each day, using both conventional washer–extractors and continuous-batch washers. The production cycle requires a total of 400 m^3/day

Table 5. Screening values of physico-chemical parameters of LWW using international permissible limits sources: for characterization, (Braga, *et al.*, 2014; NEAS, 2016; FAO, 2016; FAO, 1985; Stephen, *et al.*, 2008; ProBCguide, 2016; WHO, 2011; CPCB, 2008).

Parameters (mgL^{-1})	[a]Values			Permissible Limit					
	Min	Max	Average	[b]Irrigation	[c]Cattle Drinking water	[d]Construction	[e]Water Course	[f]Drinking water
pH	3.3	6.8	5.6 ± 0.9	6.5 - 8.4	5.0-9.0	-	6.0-9.0	6.5-8.5
Total Alkalinity	0	82.1	25.9 ± 20.2	1.5-8.5	-	-	200	-
COD filtered	415	4474	1471 ± 917	-	-	-	100	-
LAS	12.2	1024	163.6 ± 247.9	-	-	-	15	-
TSS	10	290	80 ± 60	-	-	2000	-	-
Sulphate	1.4	102.6	21.1 ± 19.1	0-20.0	< 500	400	500	400
Sulphide	0.04	0.8	0.2 ± 0.1	-	0.0-0.33	-	0.2	10.1
Nitrate (as NO_3^-)	1.03	25.7	8.4 ± 6.8	5.0-30.0	45-132	-	-	50
Nitrite (as NO_2^-)	1.1	3.3	2.1 ± 0.8	-	-	-	-	1.5
N-ammoniacal	0.3	54.8	7 ± 10.8	-	-	-	-	3
Phosphate	9.8	279	94.6 ± 75.4	0.0-2.0	0.0-1.0	-	<10	-
Zinc	0.03	3.59	0.56 ± 0.8	2	24	-	1	5
Lead	<0.01	0.17	0.06 ± 0.05	-	0.1	-	0.1	0.01
Cadmium	<0.0006	0.08	0.02 ± 0.02	0.01	0.05	-	0.1	0.005
Nickel	<0.008	0.08	0.04 ± 0.02	0.2	-	-	1	0.02
Iron	0.037	0.72	0.22 ± 0.2	-	<0.3	-	20	1
Manganese	<0.003	2	0.04 ± 0.05	0.2	0.05	-	5	0.4
Copper	<0.003	0.09	0.03 ± 0.03	0.2	0.5		<2	1.3
Chromium	<0.005	0.06	0.02 ± 0.01	0.1	1		<1	0.1

*NKT=Nitrogen Kjeldahl Total.

Table 6. Characteristics of LWW in eight countries. Sources: (Jamrah, *et al.*, 2011; Kim, *et al.*, 2014; Abedin and Rakib, 2013; Friedler, *et al.*, 2004; Udaya, *et al.*, 2015; Kotut, *et al.*, 2001; Prathapar, *et al.*, 2005; Jamrah, *et al.*, 2008; Sostar-Turka, *et al.*, 2005).

Parameters (mg/L)		**[a]Amman**	**[b]China**	**[c]Bangladesh**	**[d]Israel**	**[e]India**	**[f]Kenya**	**[g]Oman 1**	**[h]Oman 2**	**[i]Slovenia**
Physical	Temperature (°C)	-	40 ± 1.0	-	-	30.7	24	-	-	62
	Turbidity (NTU)*	42	858 ± 111	395.7	-	390	-	444	32.8	-
	TS	2653	-	-	2021	-	-	2700	2384	-
	TSS	209	359 ± 82	1203	188	-	-	315	244	35
	TDS	2444	357 ± 52	1120	-	-	-	2385	2140	-
Chemical	pH (unit less)	8.98	12.5 ± 0.5	7.4	7.5	7.3	7.3-10.3	8.3	8.5	9.6
	EC (mS/m)	7.03	124	-	2457	9000	1526	2.9	3.5	-
	TOC	-	-	-	361	-	-	174	170	-
	Salinity	-	-	-	-	-	0.6	28.3	32.7	-
	Nitrate	-	-	-	-	22	-	25.8	-	-
	Tot. N	14.2	-	-	4.9	-	-	-	-	2.75
	Tot. P	51	22 ± 4	-	169	4.2	-	-	-	9.9
	Ca	24	-	-	-	-	-	18.7	18.7	-
	Mg	15	-	-	-	22	-	60.8	60.8	-
	Na	302	-	-	530	-	-	667	667	-
	BOD	44.3	-	73.7	462	-	6250	179.9	296	195
	COD	58	1138 ± 58	1253.3	1339	4200	-	231	471	280
	Zeta Potential (mV)	-	minus 57.4 ± 8.5	-	-	-	-	-	-	-
	Sulphate	-	-	-	-	-	-	-	-	-
	Chlorine	205	-	-	450	1800	-	-	-	< 0.1
	Nitrogen (Ammonia)	14.2	-	-	-	-	-	-	-	2.45
	Mineral oil (mL)	-	-	-	181	-	-	-	-	4.8
	Anionic Surfactant	-	-	-	-	-	-	118.3	101	10.1
	DO	8.3	-	-	-	-	3.7	2.9	3.4	-
	Phenol	-	-	-	-	225	-	-	-	-
Biological	TC (MPN)	303	-	-	-	-	4.2	-	-	-
	FC (MPN)	13	-	1400	4	-	2.1	> 200	> 200	-
	E. coli (MPN)	-	-	-	-	-	-	> 200	> 200	-

*NTU: Nephlometric Turbidity Unit

of water. This has 8.78 mg/L of surfactant, 1342 mS/cm of EC and 602 mg/L of COD which attracts the potential treatment to make it reusable. Train laundry wastewater discharged from the washing process of the beddings on train in China shows the significant need of treating for 500 mg/L and 15 mg/L of COD and LAS respectively.

A detailed study has been conducted on nitrate, phosphorous, lead, sulphate, pH, electrical conductivity and COD of LWW generated from Girls' hostel, hospital and beauty parlor as depicted in (Fig. 1). Results of this analysis demonstrated that the girl's hostel in India achieved a score for higher quality than the other sources, whilst the *beauty parlour*in Ghana reveals almost lesser quality than other sources.

PHYSICAL AND CHEMICAL TREATMENT TECHNIQUES

Sedimentation Vs Filtration of particulate matter

Laundry wastewaters have potential physio-chemical value and various techniques need to be implemented to remove them. Sedimentation and filtration as first stage should be used to make LWW reusable.

Table 7. Characterization of LWW from different sources. Sources: (Udayakumar, *et al.*, 2015; Turkay *et al.*, 2017; Kumarathilakal, *et al.*, 2015; Lourdes, *et al.*, 2008; Nkansah, *et al.*, 2016; Ciabattia, *et al.*, 2009; Liu and Bi, 2012; Turkay, *et al.*, 2017).

Parameter (mg/L)	**[a]Hostel (India)**		**[b]Dormitory (Finland)**	**[c]Hospital (Sri Lanka)**	**[d]Hospital (Brazil)**	**[e]Beauty parlour (Ghana)**	**[f]Industrial laundry (Italy)**	**[g]Train LWW (China)**
	Girls	**Boys**						
Color	Clear	Murky Yellow	-	-	-	-	-	-
Odor	Objectionable	Objectionable	-	-	-	-	-	-
Temperature (°C)	31.1	31	-	-	-	-	-	-
Turbidity (NTU)*	100	90	145	-	87.0-9.0	20.29	110	90-102
pH (unit less)	6.2	6.5	7.7	6.0-8.5	8.0-9.0	9.55	7.2	8.5-9.0
Electrical Conductivity (mS/m)	4960	3080	0.27 (mS/cm)	110-1120	-	1404.89	1342 (mS/cm)	-
Chlorine	1600	2600	-	-	-	-	-	-
BOD	-	-	484	416	305	-	-	-
COD	6600	6400	1355.50	130.0-1183.0	477	60.04	602	500-580
Sulphate	18	25	0.70	-	-	30.03	-	-
Nitrate	22	24	0.73	12.0-3696.0	-	5.42	-	-
Phenol	10	105	-	-	-	-	-	-
Phosphorous	5.24	4.2	64.76	1.5 -100	2.53	-	1.9	3.8-6.0
Copper	3	0.4	-	-	-	-	-	-
Lead	12	6.7	-	0.1	-	-	-	-
Magnasium	28.2	30.4	-	-	-	-	-	-
Cromium	0	0	-	0.01-0.22	-	-	-	-
Zinc	5.3	2.3	-	-	-	-	-	-
TDS	-	-	-	50-560 mg/L	-	1150.25	-	-
Total surfactant	-	-	-	-	-	-	8.78	-
LAS	-	-	-	-	-	-	-	13.2-15.0

*NTU: Nephlometric Turbidity Unit

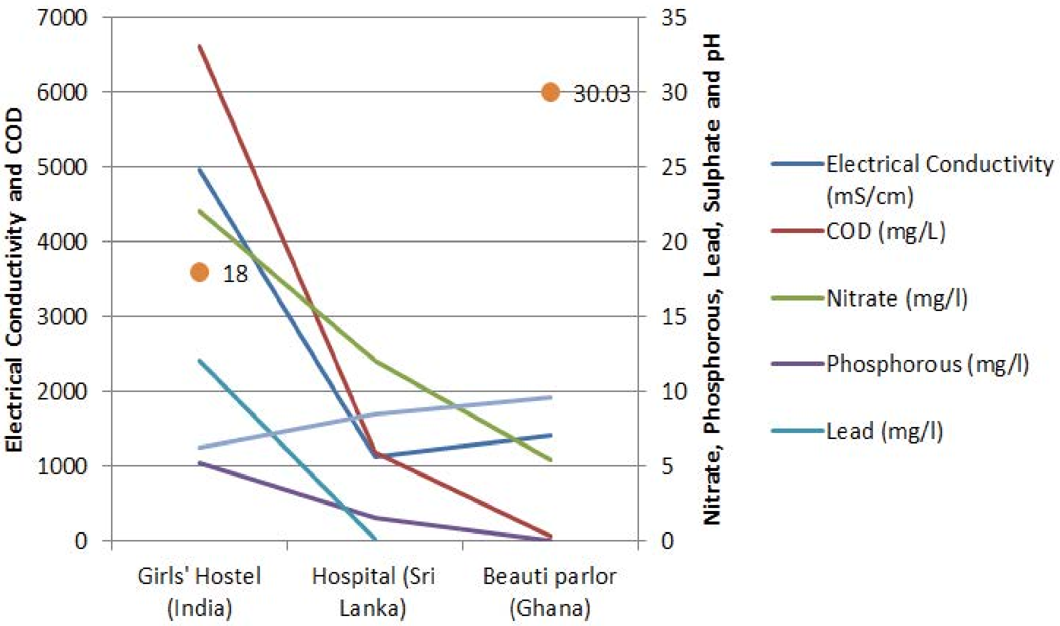

Fig. 1 Chemical characterization of three different sources. Sources: For Ghana, (Nkansah, *et al.*, 2016); for India, (Udaya, *et al.*, 2015); for Sri Lanka, (Kumarathilakal, *et al.*, 2015).

(Ahmad, *et al.*, 2008) demonstrated a filtration chamber with aspecific sand size (0.00125m) and two different sizes of gravel (0.0125 and 0.025m) with a depth of 0.1 m each layer has been constructed. Following sedimentation and filtration, the level of pH was reduced from 8.02 to 7.71, TSS from 380 to 40ppm, TDS from 540 to 380ppm, turbidity from 10.27 to 2.40 NTU, and total hardness from 240 to 150 ppm. There was no change in COD and BOD values whereas iron content increased from 0.40 to 6 ppm. As per the above-mentioned authors' research this water can be reused for first rinse of dirty clothes. The total capital and operating cost were 1343 US$ per year and saved 1.80 m^3 water daily (Ahmad, *et al.*, 2008).

(March, *et al.*, 2004) reported the use of wastewater from bathtubs and hand-washing basins located in hotel rooms to reuse in flush toilets. The authors used a nylon sock type filter of 0.3 mm mesh and 1 m^2 surface area for filtration, sedimentation and disinfection consecutively. The pH changed from 7.6 to 7.5, suspended solid from 44 to 18.6 mg/L, turbidity from 20 to 16.5 NTU, TOC from 58 to 39.9 mg/L, COD from 171 to 78 mg/L, and total nitrogen from 11 to 7.1 mg/L. Although the water cannot be used for drinking purposes it can be used in flushing tanks, provided that the water has residual chlorine greater than 1 mg/L and should not be stored for more than 48 hours. The total capital cost and operating cost were 17000 € and 0.75 €/m^3 and saved 1.09 €/m^3 (March, *et al.*, 2004).

According to the experiments undertaken by (Itayama, *et al.*, 2004) a slanted soil treatment system with plastic foam tray and kanuma soil containing alumina and hydrated silica with a soil layer of 12.5 cm resulted in environmentally friendly outcomes. The removal ratio percentages for SS, BOD, COD, total nitrogen and total phosphorous were 78%, 83%, 85%, 78% and 86%, respectively. Removal of nitrogen was due to micro-organisms present in soil, and in the upstream water saturated anaerobic zone in the slanted system. This system was able to remove detergent with a removal ratio of 60% under a high concentration of detergent during summer. This slanted soil system is inexpensive enough for application in developing countries with zero maintenance cost for approximately more than 3 years (Itayama, *et al.*, 2004).

Coagulation

Colloidal particles do not agglomerate naturally. To do this they need specific chemicals and agglomeration can be achieved by various mechanisms, for instance ionic layer compression, adsorption and charge neutralization, and entrapment in flocculent mass and inter-particle bridging (HKSAR, 2001; Peay, *et al.*, 1985).

(Sostar-Turk, *et al.*, 2005) reported their use of $Al_2(SO_4).18H_2O$ as a coagulant for 20 min in a filter. The filter was made of silicic sand of 0.5-2 mm in size, 1 m in height with a velocity of filtration was 10 m/hr and granular activated carbon (GAC) column with a diameter of 3.2 cm, height of 1 m and velocity of filtration was 5m/hr with 12 minutes of contact time. According to their analysis coagulation followed by filtration is essential for obtaining good results. After coagulation, the removals of COD and BOD increased by 36% and 51%, respectively. The GAC filtration score for COD removal was 93%, while both BOD and anionic surfactant removal were 95%. Similarly, the total amount of phosphorous removed was 89% in coagulation and there was no further reduction shown in GAC. They found that coagulation and the GAC method were cost effective, with capital cost of 0.11 €/m^3 and operating cost of 0.4 €/m^3 (Sostar-Turk, *et al.*, 2005).

PHYSICAL AND CHEMICAL OF CONCERN

Granular Activated Carbon (GAC)

Various adsorbents are available for the removal of anionic surfactants but most of them are expensive except natural adsorbents. The adsorbents should have high adsorption capacity when working on various mechanisms like ion exchange, ion pairing, hydrophobic interactions and aromatic interactions and adsorption by dispersion (NEAS, 2016; Kumarathilaka, *et al.*, 2015; Paria and Khilar, 2004; Prathapar, *et al.*, 2005; Professional Building Construction Guide (PROBCGUIDE), 2016). Activated carbon is one of the low cost options and it can be produced using waste wood, bagasse fly ash, coconut-haycarb and peat (Gupta, *et al.*, 2000; Eremina, *et al.*, 2004).

(Eremina, *et al.*, 2004) reported that activated carbon produced from wood waste birch and aspen wood are used as low-cost adsorbent. The charcoal was produced on a UVP-5B installation. Further, the charcoal was subjected to steam-gas activation in a fluidized-bed reactor at 850°C for 0.5 h; the content of oxygen and steam in the steam-gas mixture was 5 and 35%, respectively. The commercial fraction of the activated carbon with a particle size of 40 mm in diameter and 450 mm long was isolated from the overall activated product. Commercial LWW has been introduced in filter column which contained anionic surfactants (52-130) mg/L, phenols (0-5) mg/L, COD (1020-1200) mg/L and after filtration, anionic surfactants (0.5-2) mg/L, phenols (0-0.01) mg/L, and COD (510-560) mg/L reach to the permission limit with minor treatment for disposal in municipal sewer line (Eremina, *et al.*, 2004).

(Schouten, *et al.*, 2007) described a very good evaluation of adsorbents to remove LAS and alpha olefin sulfonate (AOS) which was 92%wt of both. Two types of adsorbents have been selected, first was synthesised in laboratory such as inorganic anion exchanger which are layered double hydroxide (LDH) and Syntal. These both have high value of adsorption capacity respectively 1.3 and 1.5 g LAS/g for LDH and Syntal. While activated carbons (Norit SAE2 and SAE Super) is possible to use due to their relatively low costs as shown in Table 8.

Various activated carbons with their detailed information were selected by (Schouten, *et al.*, 2007) who referred to the surface area, pore volume, pore size and cost as shown in Table 8. C Gran indicated the maximum surface area with more pore volume and subsequently showed the most promising activated carbon for removing contaminants.

The adsorbent with a smaller pore size will achieve maximum removal. The evidence as shown in Table 8 reveals that C Gran has maximum adsorption (qm) 0.53 and SAE2 and SAE super have almost the same qm values of 0.3 and 0.32, respectively, for LAS. For AOS, SAE super works very well with qm of 0.4 whereas Haycarb does not show promise in both cases. The maximum adsorption capacity (qm) depends on the amount of surface area, pore diameter and pore size. Since the critical micelle concentration (CMC) for LAS and AOS is 2mM, all of the adsorbents will achieve removal to some extent (Abed, *et al.*, 2004).

Authors have used the Langmuir model to find correlation coefficients (R^2) and make their design simple, and easily incorporable as shown in Table 9 and (Fig. 2). This figure describes the co-relationship details of the Langmuir isotherm for LAS and AOS with various adsorbents - preferably activated carbon. Norit SAE 2 and Norit SAE Super show the highest LAS adsorption values, while Norit SAE super and Haycarb GC indicate good adsorption values for AOS. These activated carbons are cheap, easily available and have promising removal capacity.

(Fig. 2) illustrates the Langmuir model curve between capacity (g LAS/g) and Equilibrium concentration (g

Table 8. Characterization of the adsorbents, source: (Schouten, *et al.*, 2007).

Activated carbons	Raw material	Activated method	BET surface area (m^2/g)	Pore volume (cm^3/g) at p/p_0=0.99	Average pore size (nm)	Cost ($/kg)	Supplier
PK1-3	Peat	Steam	827 875*	0.55	2.7	3.0	Norit
SAE2	Peat/wood	Steam	928 875*	0.67	2.9	2.0	Norit
SAE Super	Peat/wood	Steam	1363 1300*	0.88	2.6	2.1	Norit
C Gran	Wood	Phosphoric acid	1423 1400*	1.06	3.0	3.7	Norit
Haycarb GAC Bagasse fly ash	Coconut Bagasse	Steam hydrogen peroxide	1270 106	0.58 0.06	1.8 2.4	1.5	Hycarb (Gupta and Ali, 2000)

BET surface area, pore volume and average pore size are measured using the Tristar 3000. The total pore volume is measured at a relative pressure of 0.99. BET and pore size data marked with * are obtained from suppliers

Table 9. Parameters obtained from correlation with the Langmuir isotherm model for LAS and AOS adsorption.

Activated Carbon	LAS adsorption	qm (gLAS/g)	b (kg/g)	R^2 (-)	q at C=0.1 g/kg (gLAS/g)
	Norit PK 1-3	0.15	42	0.995	0.12
	Norit SAE 2	0.3	336	0.864	0.29
	Norit SAE Super	0.32	71	0.929	0.28
	Norit C Gran	0.53	2.7	0.908	0.11
	Haycarb GAC	0.15	1043	0.936	0.15
	Bagasse fly ash	0.27	11	0.963	0.01
	AOS adsorption	**qm (gAOS/g)**	**b (kg/g)**	**R^2 (-)**	**q at C=0.1 g/kg (gLAS/g)**
	Norit SAE Super	0.4	29	0.927	0.3
	Haycarb GAC	0.13	28	0.975	0.1

LAS/kg) of different activated carbons with varied adsorption techniques such as LAS and AOS.

Bio-char

(Wiley, 2005) revealed adsorption is a physical phenomenon which could be reinforced by managing the surface area and pore size of adsorbent and adsorbate (Wiley, 2005). Biochar is a good adsorbent for anionic organic compounds using H-bonding because it induces adsorption (Teixidó, 2011). Biochar is available in various types, based on their method of production (Wiley, 2005). (IBI, 2012) was defined a few years ago as "a solid material obtained from the thermochemical conversion of biomass in an oxygen-limited environment (Hyun-Chul, *et al.*, 2014; IBI, 2014). A temperature of 700°C in an oxygen-limited environment leads to the production of potential adsorbent for removing anionic compounds. The most popular feed stocks used to produce biochar for anionic compound removal are shown in Table 10. Peanut shell is shown to have the maximum surface area with potential pore volume compared to pinewood and pine needles.

(Ahmad, *et al.*, 2012) have reported that biochar is an eco-friendly sorbent and reveals good anionic surfactant removal qualities. Activated biochar could replace activated carbon because it is 60% less expensive. The cost of activated biochar is US $246 per ton whereas activated carbon cost is US $1500 per ton (Ahmad, *et al.*, 2012).

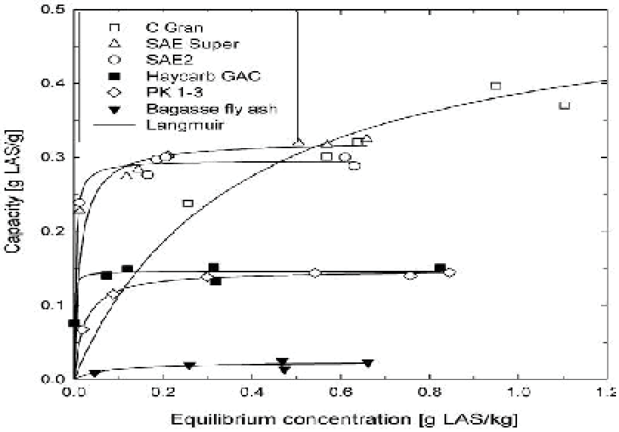

Fig. 2 Adsorption isotherms of LAS and activated carbons. Source: (Schouten, *et al.*, 2007).

According to (Moges, *et al.*, 2015) to treat grey water biochar can be used because as an adsorbent it possesses a particle size ranging from 2 mm to 5 mm in diameter. Authors have illustrated the various significant changes in characteristics like pH improved from 6.99 to 7.71, EC (μS/cm) increased from 260 to 323, turbidity (NTU) decreased from 75.5 to 0.86, COD_t (mg/L) also going down from 320 to 11.90, Part-PO_4 (mg/L) from 0.55 to 0.18, P_{tot} (mg/L) from 1.49 to 0.21,NH_4-N (mg/L) from 8.52 to 2.07, NO_3-N (mg/L) changed 0.16 to 0.30,N_{total} (mg/L) from 17.90 to 3.16, totalcoliform bacteria (TCB) (MPN/100mL) from 2.97E+ 06 to 6.40E +02 and *E. coli* (MPN/100mL) from 8.51E+ 05 to 1.46E +02 (Moges, *et al.*, 2015).

BIOLOGICAL TREATMENT

Biological treatment is preferred to chemical treatment since the former method is environmentally friendly. This is despite the fact it needs more space and more processing time. The wastewater requires proper adjustment in its pH and other parameters before treatment.

Sodium dodecyl benzene sulfonate (SDS) and sodium silicate are commonly found chemicals in detergents. An investigation was conducted by (Quality of water for construction purpose, 2008; Ramcharan, *et al.*, 2016) using 50 mL of the *Bacillus* strain poured into 1 L of LWW with the required quantity of bio-spinners. As per another publication SDS can be decreased under proper aerated conduction without the bacterial presence generated by oxidative degradation (Scott and Jones, 2000; Abedin and Rakib, 2013). (Ramcharan, *et al.*, 2016) found that 49.19%, 64.55% and 67.02% increases in the TDS occurred for the 1st wash cycle (W1), 1st rinse cycle (R1) and 2nd rinse cycle (R2), respectively, due to the slowly settling mass formation. SDS concentration fell by 40% in 12 hrs in W1. COD increased for W1 but there was a 32.51% decrease for R1 while not much change was reported in R2 (Ramcharan, *et al.*, 2016).

Phytoremediation

A comparative study was done by (Ng and Chan, 2017) which revealed the phytoremediation

Table 10. Characterization of biochar production using different kinds of feed stocks, Sources: for Peanut shell, (Ahmad, *et al.*, 2012); for Pinewood, (Liu, *et al.*, 2010); for Pine needles, (Chen, *et al.*, 2008).

Feedstock	Pyrolysis Temperature (°C)	C%	Surface area (m^2 g^{-1})	Pore Volume (cm^3 g^{-1})
Pinewood	700	95.3	29	0.13
Pine needles	700	86.51	430.8	0.186
Peanut shell	700	83.76	448.2	0.2

Capabilities of *Spirodela polyrhiza*, *Salvinia molesta* and *Lemna sp*. on synthetic grey water and the result demonstrated that ammonia removal was rapid, significant for *S. polyrhiza* and *Lemna sp*., with efficiency of 60% and 41% respectively within 2 days. *S. polyrhiza* was capable of reducing 30% of the nitrate. *Lemna sp.* achieved the highest phosphate reduction of 86% at day 12 to mere 1.07 mg/L PO4 3− -P. Correlation was found between COD and TC, suggesting the release of organic substances by macrophytes into the medium (Ng and Chan, 2017). (Ng and Chan, 2017) have also revealed in their results that *S. molesta* achieved a high efficiency of 95% phosphate removal from wastewater, lowering the concentration to 0.17 mg/l. Nitrate concentration was determined to be at 0.50 mg/l. Ammonia concentration showed a dynamic fluctuation trend with an average value of 2.62 mg/l. For water quality assessment, turbidity reduced from 7.56 NTU to 0.94 NTU in 2 days and COD removal efficiency was 39%. This study indicates that *S. molesta* plants have the potential to be used in the phytoremediation of waste water (Ng and Chan, 2017).

(Kumar and Chopra, 2017) reported that maximum removal of total dissolved solids (TDS), electrical conductivity (EC), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), phosphate ($PO4^{3-}$), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), cadmium (Cd), chromium (Cr), copper (Cu) were obtained at 60 days of the phytoremediation experiments by water caltrop (*Trapa natans L.*) on municipal wastewater but the removal rate of these parameters were gradually increased from 15 days to 45 days and it was slightly decreased at 60 days. The most contents of Cd, Cu, Fe, Mn and Zn were translocated in the leaves of T. natans while the most contents of Cr and Pb were accumulated in the root of T. natans after phytoremediation experiments. The contents of different biochemical components were recorded in the order of total sugar > crude protein > total ash > crude fiber > total fat in T. natans after phytoremediation of municipal wastewater. Therefore, T. natans was found to be effective for the removal of different parameters of municipal wastewater and can be used effectively to reduce the pollution load of municipal wastewater drained from the activated sludge process based treatment plants (Kumar and Chopra, 2018).

Potential re-use of LLW

Re-using water should be made compulsory given the stresses on the planet's existing water resources. The comparative treatment-analysis of LWW shows that a potential amount of wastewater can be economically reclaimed for everyday use for various purposes. These include flushing, irrigation, gardening, recreation and construction because after treatment the quality of wastewaters can reach their permissible limit, and remain eco-friendly and economically viable. Fortunately, there are different economical wastewater treatment techniques which can recycle wastewater and make it reusable. If the LWW is treated by sedimentation and followed by filtration then it can be reused for first rinse of dirty clothes which can save huge amounts of water daily; this has good implications for localities experiencing water shortages. If the previous process is improved by adding disinfection process the wastewater can be reused for flushing tanks. Utilizing recycled water in place of fresh water can decrease the stress on water resources. Chemical coagulation and activated carbon can be very efficient in that after treatment, it can be used for irrigation and gardening. Electro-coagulation significantly improves the LWW quality. The treated wastewater can be reused for construction purposes because for construction the water quality requirement is very low and the demand for water in the construction industry is high. Usage of low cost adsorbents and bio-char can drastically reinvigorate LWW quality, making it worthwhile for irrigational purposes. It may be possible to make the water potable if we combine other techniques with it. Phytoremediation and use of microbes have resulted in promising outcomes for improving the quality of wastewater to the desirable limits for irrigation and construction.

CONCLUSION

Elementary characterization of LWW highlights that it contains nearly to permissible limits. Surfactants (such as LAS), COD, BOD, nitrate, sulphates, phosphate, solids and turbidity are the major pollutant. There are also small amounts of alkalinity, volatile acids, deodorizing agents, fabric, food, body fluids, non-biodegradables, a few metals like Cd, Zn, Fe, Cu, and different xenobiotic organic compounds especially Butanol, Nonyl phenolethoxilado, Etil citrate and Etilhexilftalato. In particular bio-char is 60% less expensive than GAC and has the potential to adsorb physico-chemical pollutants. Furthermore to some extent it has biological properties that can reduce the pollutants. Coagulation coupled with GAC and elctro-coagulation (aluminium hydroxyl species electrode) revealed the astounding ability to remove different potential pollutants found in LWW. A few biological activities involving *Spirodela polyrhiza*, *Salvinia molesta*, *Lemna sp* and *Trapa natans*

L. were integrated into conventional treatment methods and they illustrated the possibilities to reach the permissible limits set by international institutions for the daily purposes such as gardening, flushing and construction apart from drinking and cooking. LWW has the potential to be recycled and reused especially in water deficient and developing countries using economical wastewater treatment techniques. The review also suggests that there is a need for deeper experimental analyses of LWW and its innovative integrated treatment process to reduce the retention time within budget and still remain eco-friendly.

On this theme, it is evident that more research in the field is required, especially the possibility of merging one or more techniques to achieve better results. Multi-barrier approaches can generate superior results where integrated procedures, tools and techniques are used. Research in this area needs to be more problem-oriented and utilize natural and local products; in other words more localized problem-solving research is required to make the solutions viable, economical, eco-friendly and acceptable to the general public. The main cost effective trends have been highlighted in this paper along with recommendations for further developments and future research directions related to the application of these technologies for wastewater treatment and reuse.

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