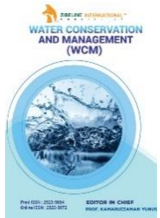
ZIBELINE INTERNATIONAL™ PUBLISHING
ISSN: 2523-5664 (Print)
ISSN: 2523-5672 (Online)
CODEN: WCMABD

Water Conservation & Management (WCM)

DOI: http://doi.org/10.26480/wcm.02.2022.89.94



RESEARCH ARTICLE

THE PROGRESS IN USING GREYWATER AS A SOLUTION TO WATER SCARCITY IN A DEVELOPING COUNTRY

Joan Nyika*, Megersa Dinka

University of Johannesburg, Cnr Kingsway & University Road, Auckland Park, Johannesburg, 2092, South Africa.
****Corresponding Author E-mail: joashmada2011@gmail.com***

ARTICLE DETAILS

Article History:

Received 01 July 2022
Accepted 03 August 2022
Available online 08 August 2022

ABSTRACT

Increased production of greywater prompted by the rise of urbanization and increased population in the industrial era is a growing environmental concern exacerbating the apparent water insecurity. Treatment and reuse of greywater is a promising solution to this problem since it will divert the use of limited freshwater resources to unavoidable consumptive uses. This study reviewed the various methods used to treat greywater and the progress made in taking up the practice in Kenya. Findings showed a variety of physicochemical treatment methods such as filtration, adsorption, coagulation and photocatalytic oxidation used to decontaminate greywater. Biological approaches such as the use of reactors and constructed wetland systems were discussed. Case study applications of the treatment approaches in Kenya to manage greywater were also highlighted. However, it was noted that appropriate policies, adequate funding and better designing of greywater treatment systems should be adopted to support the enhanced practices in Kenya.

KEYWORDS

Biological Treatment; Contaminants; Domestic Wastewater; Effluent; Kenya; Physicochemical Treatment

1. INTRODUCTION

The global supply of freshwater outweighs existent demands. Approximately 97% of water supply in the world is from oceans while 3% is available for direct consumption. Of the 3%, only one-hundredth can be accessed for human use (Oteng-Peprah et al., 2018). The temporal and spatial distribution of these water resources is uneven and so is the use where some areas are deprived off the resource (Nyika, 2020). Currently, many parts of the world are facing chronic water shortages, destruction, and over-exploitation of these resources by anthropogenic activities, which result to their pollution. More than 800 million people live under water stress conditions and the number is expected to rise to 3 billion by 2025 considering the pressure on these resources due to climate variability and change (Oteng-Peprah et al., 2018). 2.7 billion people will be water insecure by 2050 and consequently, 33-50% of the population will be affected (Juan et al., 2016).

In another study, it is projected that 2.3 to 3.2 billion people translating to 42-95 % of the global population will live in areas that are water scarce by 2050 (Boretti and Rosa, 2019). This is an upward trend from 1.9 billion people (27% of the global population) who lived in such areas in 2010. With the rise in population growth, industrialisation and urbanisation the demand for water is expected to ever-rise and extra quantities will be required to sustain these human activities (Juan et al., 2016). Worldwide, the demand for water for all uses stands at 4,600 km^3 annually and the figure is expected to rise to between 5,500 and 6,000 km^3 by 2050, which is a 20-30 % rise (Boretti and Rosa, 2019). The demand for agricultural water will grow by 60% while that of domestic water will rise by 22-32 % (Alexandratos and Bruinsma, 2012). Exponential growth in the water demand will be predominant in Africa and Asia.

To manage the growing demand for water resources, greywater reuse is the promising solution to this problem. Greywater is any wastewater generated from washing toilets, laundry and bathing without the inclusion of toilet water (black water). The water has low strength, high volume and high reuse potential and its composition depends on climatic conditions, fixtures and lifestyles of producers (Katukiza et al., 2015). Greywater constitutes 60-70% of total domestic water consumption although its reuse has the potential to reduce this consumption rate from 50 to 70% (López Zavala et al., 2016). A group researchers shared the same views claiming that greywater reuse is not a novelty though it has immense potential to supplement depleting resources amidst acute water shortage and climate variability conditions especially in arid areas (Oteng-Peprah et al., 2018). In a study by incorporating simulations, it was found that reuse of greywater for flushing toilets and in hot showers and sinks resulted to 55-58 % energy and water savings (Knutsson and Knutsson, 2021).

In Kenya for instance, grey water contributed to more than 70% of domestic water use and the magnitude could be quite enormous considering that greywater is a non-point pollution source when directed to freshwater resources (Raude et al., 2009). The major concerns in reference to greywater reuse is the acceptability of the practice by the public and technologies used to process it (Katukiza et al., 2015). Although many technologies including membrane filtration screening, chemical processes including resin-based ion exchange and coagulation-flocculation and biological systems such as bioreactors and constructed wetlands have been explored to reuse greywater, developing countries do not know them. In addition, application of the technologies is hampered by low-cost investments in them. developing countries have limited knowledge on the characteristics of greywater, methods of treating it and its usability potential (Kotut et al., 2011). This is especially so in Kenya where specific studies on such aspects are limited. To bridge this gap, the current study reviewed existent literature on the technologies used in

Quick Response Code	Access this article online	
	Website: www.watconman.org	**DOI:** 10.26480/wcm.02.2022.89.94

Cite the Article: Joan Nyika, Megersa Dinka (2022). The Progress in Using Greywater as A Solution to Water Scarcity in A Developing Country. *Water Conservation & Management, 6(2): 89-94.*

greywater processing before reuse, the progress made in taking up the practice in Kenya and made recommendations on the way forward. The aim was to improve understanding on the usability of greywater resources and the prerequisites needed.

2. Technologies to Treat Greywater for Reuse

Grey water comprises of different components at varied quantities as shown in Table 1 (Rakesh et al., 2019). The composition of greywater is influenced by the chemical choices used for bathing, cleaning and laundry, the lifestyle of the original freshwater users and local water quality (Rakesh et al., 2019). A group researchers noted that greywater composition depends on the population structure and availability of water resources (Filali et al., 2022). The factors vary temporally and spatially. The characteristics of greywater also vary based on the habitat found, sanitary state of producers, volumes and sources of greywater collected, initial water quality, storage and treatment approaches applied (Oteng-Peprah et al., 2018). Prior to reuse or recycling, characterizing the physicochemical, microbiological, and biological aspects of greywater is imperative. Usually, the standards used to assess treated effluent quality are applied to assay greywater since the latter has no specific standards.

Greywater comprises of pathogenic organisms, synthetic chemicals, heavy metals, oil and grease, fats, dissolved and suspended solids and alkaline and acidic contaminants. The contaminants vary in levels and result from various kitchen, laundry and bathing activities using carbon and phosphate containing detergents and soaps (Filali et al., 2017). A large portion of these components are biodegradable substances such as nutrients and organic fractions at 9-20 % and 30 % of the total components, respectively (Rakesh et al., 2019). Organic matter in greywater includes hydro-chemical constituents, biological microbes, phosphorous and nitrogen nutrients and their derivatives though xenobiotic compounds also occur (Fatta-Kassinos et al., 2011). Another study found that greywater had pigments, aerosols, beauty and health products, pharmaceuticals and toxic heavy metals (lead, nickel, cadmium, copper, mercury and chromium) (Eriksson et al., 2010).

A group researchers reported that greywater is slightly alkaline, has heterogenous turbidity and suspended solids and high levels of nutrients, chemical and biological oxygen demand (Filali et al., 2022). These components depict the complexity of greywater, which necessitates its treatment prior to reuse. The treatment techniques used range from simple to complex methods whose aim is to reduce the contaminant levels before using greywater and prior to its final disposal. A common aspect of these techniques is their processing, which occurs in a similar sequence just as wastewater treatment beginning with pre-treatment, primary, secondary, and tertiary treatment stages in respective order (Oteng-Peprah et al., 2018). The treatment methods are categorised as either physicochemical or biological systems.

Table 1: Components of Greywater and Their Estimated Levels (Rakesh et al., 2019)

Component	Average Levels
pH	5-9
Electrical Conductivity (EC)	14-3000 µS/cm
Suspended Solids (SS)	15-800 mg/l
Dissolved Solids (DS)	712-6888 mg/l
Total Dissolved Solids (TDS)	190-537 mg/l
Biochemical Oxygen Demand	5-431 mg/l
Chemical Oxygen Demand	38-4800 mg/l
Pathogens Colony Forming Units (CFU)	3×10^3 -2.4×10^7 CFU/100 ml
Bacteria	*Pseudomonas aeruginosa, Legionella pneumophila, Escherichia coli, Salmonella, Campylobacter*
Protozoa	*Cryptosporidium* sp.
Oil and Grease	50-100 mg/l
Other Compounds	Xenobiotics, phosphates, nitrates, halogenated organic compounds (XOCs)

2.1 Physicochemical Treatment Methods

Physicochemical methods apply simple physical and chemical techniques such as reverse osmosis, adsorption and filtration among others to treat water. Filtration involves the use of fine mesh, sand, gravel, pebbles, charcoal, pine bark, polyurethane foam, bricks, coconut shell, coarse sawdust, tuff filter and mulch to pass greywater (Juan et al., 2016). Filtration using sand and activated carbon have been used to remove coarse materials from greywater (Filali et al., 2022; Nyika and Dinka, 2022). Similarly, gravel, sand and cotton have been used to filter greywater at varied results (Samayamanthula et al., 2019). These methods are cost efficient and practical but only provide limited decontamination of greywater. Average removal of turbidity, suspended solids and chemical oxygen demand from these techniques is 49, 56 and 70 %, respectively (Pidou et al., 2007). In another study, filtration was shown to eliminate only 15% of suspended solids and 25% of COD from greywater (Gual et al., 2008). Another comparative study found sand filters superior in removal of phosphates and dissolved solids from greywater compared to charcoal and sawdust filters (Adonadaga et al., 2020). Filtration can be advanced to nanofiltration, membrane filtration and ultrafiltration to improve the contaminant removal efficiency but at higher costs. Nanofiltration for instance had a removal efficiency of 93% and 98% for COD and turbidity, respectively compared to ultrafiltration that had 49 and 94 % removal efficacy for the same contaminants (Filali et al., 2022).

Adsorption involves the use of flocculants such as activated carbon, iron hydroxide and aluminium hydroxide among other synthetic chemicals (resins and ion exchangers) that have tiny pores where contaminants from greywater adhere to and are consequently removed (Nyika and Dinka, 2022). Adsorptive methods have been modelled to be effective in removal of priority substances and priority hazardous substances effectively though the efficacy of the technique in removal of xenobiotic substances in greywater is unknown (Donner et al., 2010). A group researcher however differed with these views claiming that methods such as filtration and adsorption removed 50 CFU/ 100 ml of total coliform residue suggesting that the methods are suitable in treating greywater of low strength (Pidou et al., 2007). In another review study by the use of low-cost natural adsorbents such as zeolites, coconut shell, rice husks, dolochar, granite sand and granular charcoal was reported to have varied efficacies in decontaminating greywater (Shreya et al., 2021). Surfactants present in soapy greywater are difficult to remove using filtration because they have hydrophobic tails that repel water molecules. Membrane separation through reverse osmosis (RO) is a promising technique to remove such contaminants in greywater (Singh et al., 2014; Simonic, 2021). The use of RO membranes for removal of microbial contaminants of greywater is however limited and the use the technique results to fouling, which alters its operation capacity and has cost implications (Pidou et al., 2007; Singh et al., 2014; Simonic, 2021).

The use of chemical techniques such as disinfection, photocatalytic oxidation, coagulation, and electrocoagulation in greywater treatment has been reported at different efficacy rates (Filali et al., 2022). For instance, some researchers reported that electrocoagulation reduced COD, BOD, turbidity and SS by 33 mg/l, 14 mg/l, 39 NTU and 20 mg/l from their initial concentrations of 55 mg/l, 23 mg/l, 43 NTU and 29 mg/l, respectively (Lin et al., 2005). Using electrocoagulation, 87% of total organic carbon and 95% COD was eliminated from greywater (Barzegar et al., 2019). More than 90 % removal efficiency of organic matter and total coliforms was realized using photocatalytic oxidation combined with ultraviolet light and titanium oxide treatment (Parsons et al., 2000). Through photocatalytic treatment, greywater was cleansed off 58% of its total organic carbon (Poulopoulos et al., 2019). More than 80 % removal efficacy for BOD, orthophosphates, turbidity, total coliforms, *E. coli* and enterococci from greywater was reported using optimized coagulation in combination with ion exchange resins (Pidou et al., 2007). Ghaitidak and Yadav had a contrary opinion where they found ion exchange resins in combination with coagulation ineffective in removal of total nitrogen and phosphates (Ghaitidak and Yadav, 2015). The authors just like found the technologies effective in removal of *E. coli*, BOD and turbidity from greywater with 99, 77 and 88 % efficacy rates, respectively (Pidou et al., 2007). Therefore, chemical techniques have relative effectiveness in greywater treatment.

2.2 Biological Treatment Systems

Biological methods use a combination of oxygen, sunlight and microbial manipulations such as rotating biological contactors, sequence batch reactors, membrane bioreactors and up flow anaerobic sludge blanket to treat greywater (Oteng-Peprah et al., 2018; Pidou et al., 2007). Rotating biological contactors (RBCs) comprise of revolving disks and fixed bioreactors, which are mounted on a horizontal shaft and are partially submerged on greywater. Treatment of contaminated water is done by microbes, which are exposed to the atmosphere to aerate them, enhance nutrient degradation and assimilation of dissolved organic pollutants (Oteng-Peprah et al., 2018). A review by Mizyed highlighted that RBCs are effective in greywater decontamination at laboratory scale and considerations of upscaling such applications are underway (Mizyed, 2021).

This technique has been used to remove heterotrophic bacteria, faecal coliforms and specific pathogens including *Staphylococcus aureus* and *P. aeruginosa* in greywater and reported 88-99.9% effectiveness (Friedler et al., 2011). Similarly, Giloba and Friedler assessed the performance of RBCs combined with sedimentation in removal of *Clostridium perfringens* pathogens and faecal coliforms in greywater and reported 99% effectiveness (Giloba and Friedler, 2008). The technique was reported as effective in cleansing greywater off microbial contents, COD and BOD with up to 99% efficacy though removal of nutrients and suspended solids was lower at about 85% effectiveness (Oteng-Peprah et al., 2018). RBCs are effective in laboratory experiments though their application to decontaminate greywater at field scale is limited (Rakesh et al., 2019; Mizyed, 2021).

Sequence batch reactors (SBRs) are fill-draw activated sludge systems used in both greywater and blackwater treatment. Using a reactor tank, batches of greywater are released for treatment through a time-set sequence and optimised in processes of equalisation, biological processing and secondary cleansing (Juan et al., 2016). The technique was successfully used to cleanse greywater from ammonium-nitrogen, total nitrogen and COD to levels below the Tunisian drinking water standards (Lamine et al., 2007). Using SBRs, greywater was cleansed off ammonia, surfactants, phosphates, BOD and COD with 81.68, 92, 72, 97.38 and 96.62 % efficacy, respectively (Priyanka et al., 2020). Two studies investigated the use of SBRs in decontaminating greywater from Malaysian and Netherlands houses (Krishnan et al., 2008; Hernandez et al., 2010).

The two studies reported approximately 80, 98 and 99 % effectiveness of the method in cleansing total nitrogen, oxygenation demand (COD and BOD) and ammonium-nitrogen from greywater in respective order. SBRs also cleansed greywater off 71.4 % total nitrogen, 98.4 % ammonium and 86.5 % COD (Tombola et al., 2019). A group researchers reported that SBRs were effective in greywater treatment and reduced the levels of SS, BOD, COD, nitrates and phosphates by 94, 86, 95, 88 and 100 %, respectively (Elmitwalli et al., 2007). The technique however experienced disadvantages of nitrification and operated on the basis of varied hydraulic retention times, which resulted to different water qualities (Scheumann and Kraume, 2009). Hydraulic retention time optimisation is difficult to realise in this technique (Hernandez et al., 2010). Additionally, the technique requires constant supply of energy and highly skilled operators.

Membrane bioreactors (MBRs) combine ultrafiltration, microfiltration and biological treatment systems to perm-treat greywater selectively (Pidou et al., 2007). The compact nature of MBRs systems makes them suitable for areas that have space limitations such as urban and peri-urban areas. A study assessed the performance of the technique in treating greywater from Spanish hotels (Atanasova et al., 2017). The study reported 80-95 % and 80.5-85 % removal of COD and ammonium-nitrogen from the contaminated samples, respectively and resultant water was below the maximum permissible limits on water quality in the country (Atanasova et al., 2017). The procedure was successfully used to treat greywater from Japanese and Korean households and the recovered effluent was not polluted compared to the permissible water quality limits (Jong et al., 2010; Pidou et al., 2007).

The three studies used a pore size of 0.1 μm that is known to be efficient in filtering faecal coliforms (Pidou et al., 2007). A group researcher also reported more than 90% treatment efficacy for BOD, anionic surfactants and BOD using MBRs (Lin et al., 2005). In another study, confirmed that MBRs resulted to 94 and 97 % clearance of ammonium and COD from greywater, respectively (Liberman et al., 2016). The up-flow anaerobic sludge blanket (UASB) is a greywater treatment system that operates anaerobically to form a granular sludge blanket suspended in a reactor tank. Anaerobic microorganisms are used to process and degrade the greywater that flows up via the blanket (Katukiza et al., 2015). Gravitational action and upward flow of water and the use of flocculants enhances the suspension of contaminants on the blanket (Oteng-Peprah et al., 2018). The technique was used to treat greywater in Netherlands and Egypt (Hernandez et al., 2010; Abdel-Shafy et al., 2015). Removal efficacies in the latter study were estimated at 83, 68, 58 and 19 % for grease/oil, BOD, COD and suspended solids, respectively. A much lower efficacy was reported by using UASB, where reductions of phosphates, nitrates and COD from greywater were rated at 17, 30 and 35 %, respectively (Elmitwalli et al., 2007).

Biological filters have also been used in greywater treatment owing to their cost effective and environmentally friendly nature (Filali et al., 2022). In cleansing greywater BOD and SS, the filters were found to be 96 and 89 % effective while in removal of total coliforms, an efficiency rate of 6 log 10 was reported (Travis et al., 2010). Although these biological treatment systems require maintenance to remove accumulated sludge in their lagoons, they can be easily integrated into the landscape for positive contribution to diversification of flora and fauna (Filali et al., 2022). Biological systems can also be hybridized with physicochemical processes to improve greywater treatment efficacy as recommended (Bani-Melhem and Smith, 2012). A study by showed that hybrid systems combining biological and physicochemical treatment approaches had better efficacy in decontaminating greywater compared to individual methods (Srivastava et al., 2021).

2.3 Advanced Extensive Greywater Treatment Technologies

The use of extensive technologies for greywater treatment is on the rise in modern day green chemistry as noted (Pidou et al., 2007). These technologies use artificially constructed wetlands such as ponds and reed beds, whose design mimics ecological conditions of natural wetlands (Oteng-Peprah et al., 2018). Using microorganisms, soil, flora and fauna, various contaminants of greywater are removed through these techniques. The wetlands adopt floating, surface flow or subsurface flow treatment systems though the latter is widely used in two technologies; vertical and horizontal flow constructed wetland designs (Juan et al., 2016). Using a combination of biological and physicochemical processes, the two methods treat greywater, and the efficacy of the process is dependent on electron acceptor availability and their loading rates.

However, there efficacy to remove nutrients such as nitrogen and phosphorous is low at 26 and 4 %, respectively (Oteng-Peprah et al., 2018). A study by recommended the method for cleansing suspended solids, chlorides, BOD, grease, oil, nitrates, phosphorous, microbial contents, Ca and Mg in greywater, where the efficacy was beyond 90% (Travis et al., 2010). A combination of vertical and horizontal flow constructed wetlands cleansed 94.6, 65, 87.9 and 82.4 % of suspended solids, phosphates, nitrogen, and COD from greywater in respective order (Otieno et al., 2017). In this case, hybridization proved more effective in wastewater treatment compared to individual vertical or horizontal systems. In addition, the method is inexpensive and environmentally friendly (Pidou et al., 2007).

3. Uptake of Greywater Treatment Systems in Kenya

In Kenya, greywater reuse is common among the poor and in informal settlement areas but on ad hoc basis. The data to support greywater use is unavailable as noted (Mungai, 2008). 50% of greywater that was generated in Nairobi slums in 2006-2007 was reused to irrigate more than 720 ha of land under cultivation while the other half was diverted to treatment facilities (Kaluli et al., 2011). The study focused on informal settlements of Nairobi such as Kariobangi South, Maringo, Mailisaba, Kibera, Soweto and Kahawa. This water usually does not undergo any formal treatment and if present, treatment is limited, although according to the Kenyan laws, it is illegal to use greywater owing to its associated composition of noxious elements. More than 75% of the produce from greywater irrigation mainly vegetables were sold while the rest, consumed at home.

Mungai made similar observations in Waruku slum of Nairobi, where greywater was used to cultivate tomatoes, leafy vegetables and cabbage for domestic and commercial consumption (Mungai, 2008). Furthermore, Kenya lacks a national wastewater reuse policy to support efforts of the poor to use the resource in bridging the water scarcity gap. With the recognition of greywater reuse practices as efforts towards sustainability of freshwater resources, a number of initiatives have begun in the country to promote uptake of the practice. Treatment of greywater using physicochemical treatment onsite is being practiced in Nakuru County of Kenya though the designs are expensive to maintain (Raude et al., 2009). In their argument, the authors noted the need to improve on greywater treatment planning and designing through pilot testing of different treatment systems (Raude et al., 2009). A group researchers designed such a treatment pilot system that was used to treat greywater from kitchen and student hostels at Kenyatta University in Kenya (Kariuki et al., 2011).

The design consisted of separate barrel units to disinfect, sediment, flocculate and filter greywater. The design, which was cost-efficient, resulted to water whose electrical conductivity and pH levels were within the permissible limits by World Health Organisation (WHO) for agricultural use and reduced the total number of coliforms and *Salmonella* species. A group researcher also documented another greywater treatment pilot-test in secondary schools of a Nakuru County that was funded by the European Union (EU) (Muchiri et al., 2010). Greywater sourced from food preparation, washing of dishes and handwashing was passed through a horizontal sub-surface flow constructed wetland system for polishing. Although the capital and maintenance expenses of the project were found to be high, the system improved the quality of water by decontaminating its physical and some microbial contents making it suitable for agricultural use (Muchiri et al., 2011).

The use of constructed wetlands to cleanse greywater has also been reported in the country. Constructed wetlands in tropical Africa and in particular, Kenya is a relatively new concept and therefore, uptake is still limited (Raymer, 2006). In 2001, six privately owned constructed wetlands were found to effectively treat greywater before release for disposal or reuse in Kenya's Nairobi, Nakuru and Nandi counties (Raymar, 2006). Another two constructed wetlands at Chemelil and Nairobi based on horizontal subsurface flow designs reduced COD, TSS, nitrogen and phosphorus by 37, 96, 29 and 74 %, respectively from greywater (Oketch, 2006). Another study on wastewater treatment using constructed wetlands in Nairobi, reported the clearance efficacy for BOD, COD and TSS to be between 96 and 99 % (Nzengy'a and Wishitemi, 2001). A recent pilot study in Gusii wastewater treatment plant of Kisii County, Kenya, used a hybrid (vertical and horizontal) subsurface flow system of constructed wetland to polish greywater (Otieno et al., 2017).

The system removed 94, 88 and 82 % of suspended solids, total nitrogen and COD, respectively. Despite the reported high efficiency of constructed wetlands in cleansing contaminants from greywater, the uptake of such systems in Kenya was limited to small-scale and by private rather than public entities. A group researchers noted that Kenya's hospitality industry (resorts, game lodges and hotels) is taking up subsurface and surface flow constructed wetlands to polish and reuse their greywater (Makopondo et al., 2020). Challenges such as limited financial and technical inputs, poor institutional management, lack of supportive policies and awareness creation on the importance and potential of constructed wetlands limit uptake of the technology for greywater treatment in Kenya (Oketch, 2006). Negative perceptions on the reuse of greywater in the hospitality industry, limited land space and low supply of greywater during off-seasons limited the application of constructed wetlands in Kenya's hospitality industry (Makopondo et al., 2020).

A number of privately owned companies are also operating in Kenya to supply low chemicals and equipment for treatment of greywater. These include Enviro Tech and WASP systems based in Nairobi as well as Biokube A/S based in Kenya's Mombasa County (Environment XPRT, 2019). The companies supply a number of biological greywater treatment equipment including MBRs, filtration systems and RBCs. Through the companies, greywater has been diverted for irrigation purposes. A case example is at Kibera informal settlements where land belonging to Kenya's national social security fund has been given to residents on informal arrangements where they irrigate vegetables in 60 by 20 metre plots using greywater treated with EnviroTech RBCs system installed nearby (Environment XPRT, 2019).

Greywater is therefore a potential perennial water source considering that it is a product of 70% domestic water consumption in Kenya. Its treatment and reuse though not considered a priority in the country due to institutional and cultural barriers as well as policy constraints could save the limited freshwater resources as noted (Kariuki et al., 2011). A group researcher also noted that the reuse of greywater through cost effective and environmentally friendly methods such as constructed wetlands could be a source of livelihood for youths in the country who suffer from unemployment (Raude et al., 2009). Some researchers noted that greywater treatment in Kenya was not only a wastewater management strategy but also a conservation strategy, which prevented potential harm on flora and fauna once exposed to contaminants in the resource (Makopondo et al., 2020). Some researchers who conducted a greywater treatment pilot-test using constructed wetlands supported these sentiments (Muchiri et al., 2011).

Optimized benefits of greywater as a resource in Kenya could be realised with introduction of supportive legislations on the standards, procedures for handling, using, processing, and assessing the quality of greywater in the near future (Kaluli et al., 2009). This recommendation comes in the wake of safety concerns on the use of greywater for irrigation where some plants grown using the resource in Nairobi's informal settlements have been found with elevated levels of trace metals, which is an environmental and human-health risk (Githuku, 2009). Investment on proper designing of greywater treatment systems is imperative as it improves the uptake of the practice since the implementation cost of the technology is lowered (Kariuki et al., 2011). In design selection, decentralized or clustered treatment systems are preferred and recommended compared to centralized ones since such an approach reduces the energy and transport costs incurred in transporting greywater to a common plant (Oh et al., 2018).

It also decentralizes the management of greywater to the producers, which is key in regulating production tendencies. The Kenyan government can offer financial assistance by providing rebates and subsidies following new installation of greywater systems as successfully implemented in Malaysia to encourage decontamination of municipal effluents prior to reuse (Oh et al., 2018). Such financial inputs will lower the capital costs incurred in setting up greywater treatment systems in addition to encouraging safe reuse of the resource. Additional improvement on greywater treatment technologies by the government and non-governmental organisations as well as a public perception change on the uptake of the practice are requisite considerations to leverage its benefits and improve uptake of the technology (Pidou et al., 2007).

Perception change can be realized via extensive education and community awareness on the importance of treating greywater prior to its reuse for enhanced public safety and health (Radingoana et al., 2020). With improved technology, better planning, designing and implementation of greywater appropriate treatment technologies leading to enhanced contaminant cleaning will be realized (Makopondo et al., 2020). Intensified research using empirical studies is therefore needed to validate the findings of this study that relies on literature to report on the progress in up-taking greywater treatment and reuse in Kenya.

4. Conclusions

Greywater reuse is a promising solution to water stressed developing countries including Kenya. The uptake of the practice in Kenya is slow at pilot testing and in most cases by private entities and in small-scale. This trend is attributable to cultural barriers that result to negative perceptions of using greywater among the public, limited technical knowhow and financial inputs on operations of greywater treatment systems. Additionally, limited policy and institutional support of greywater treatment undertakings make its development sluggish. A number of pilot studies using constructed wetland technologies, MBRs and physicochemical treatment techniques are underway in the country as detailed in this study but mostly in informal settlements for greywater reuse in agriculture and in the hotel industry to reuse water for sanitation purposes. To fast track the uptake of greywater reuse as a water resource in Kenya, future prospects should focus on increased investments on planning and technical designing for greywater treatment systems and policy enactment to support institutions dealing with wastewater handling, use and treatment.

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