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Greywater Reuse Review and Framework for Assessing Greywater Treatment Technologies for Toilet Flushing

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Authors' contributions

This work was carried out in collaboration between the two authors. Both authors were involved in the literature review, design of the questionnaires, survey and development of the framework. The two authors read and approved the final manuscript.

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ABSTRACT

Increasing impacts of climate change, development and urbanisation on water resource availability have promoted increased water reuse and recycling. This paper achieves two objectives: Firstly, it presents an extensive review of greywater characteristics, treatment technologies and risks, and secondly, it presents the development of a framework for holistically assessing different greywater treatment technologies in order to select the most appropriate for a specific greywater reuse (GWR) application. Addressing these objectives is particularly valuable for South Africa due to the growing interest in greywater reuse (especially for irrigation, toilet flushing and a variety of non-domestic applications), the scarcity of guideline documents to facilitate optimal GWR, and the proliferation of package plants purporting to treat grey/waste water to acceptable quality for use in certain non-potable applications. The developed framework was employed to assess 10 commercially available greywater treatment systems in South Africa using sustainability criteria (social, environmental and economical) and thus mitigated the risks associated with choosing an inappropriate system for

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toilet flushing at 2 GWR pilot sites. Three of the 10 package plants emerged with favourable scores and the preferred was selected based on simplicity of treatment technology, ease to implement, ease to maintain and cost, amongst other factors.

Keywords: Greywater; characteristics; reuse; treatment technology.

1. INTRODUCTION

South Africa is an arid to semi-arid country with its climate varying from desert and semi-desert in the west to sub-humid along the eastern coastal area. The country is water stressed with 65% of its land area receiving less than 500 mm of precipitation per annum while 21% receives less than 200 mm [1]. Stream flows in most South African rivers are at relatively low levels for most of the year, and the infrequent high flows that do occur, happen over limited and often, unpredictable periods. From the foregoing, it was projected in 1996 that the water resources supply in South Africa may be unable to cater for anticipated demands by 2030 if unchecked [2].

In a bid to efficiently managed demand, the interest in and use of appropriate qualities of non-potable water (e.g. greywater and sewage) has increased in recent times [3]. Non-potable water may be suitable for certain applications (e.g. toilet flushing, fire-fighting, and irrigation) after undergoing none to some levels of treatment. This use of non-potable water is typically referred to as water reuse. It has been proven that greywater reuse (GWR) can reduce urban potable water demand by between 30% - 70% [3,4].

Greywater (also referred to as dark greywater) is defined as urban wastewater originating from the bathroom (excluding toilet waste) and kitchen. Light greywater excludes kitchen effluent [5]. The characteristics of greywater vary considerably over time and space. There are three factors which influence that, i.e. the source water quality, the distribution network conveying the source water and generated greywater, and the water related activities within the building generating the greywater [6]. The choice/design of a GWR system should therefore depend not only on quantities of effluent to be treated, but also on the type of treatment to be employed to transform the generated greywater to a beneficial resource.

GWR conserves fresh water resources by reducing urban potable water demand, creates the opportunity to provide water services in remote locations without municipal water supply or environmentally sensitive locations, can facilitate in mitigating the rising costs of drinking water treatment for non-potable water applications, and has the potential to reduce sewage treatment costs and discharges to the environment [4]. Despite these benefits, several risks/barriers to the successful implementation of GWR include insufficient information and experience on the typical characteristics, appropriate uses and risks associated with the reuse of different greywater qualities, and the performance of various GWR treatment plants, thus making it difficult to select an appropriate treatment technology for a specific reuse purpose; long pay back periods of more than 8 years; difficulty in obtaining historical operational cost data during GWR planning; health hazards that may result from exposure to pathogens and/or chemicals in greywater; the lack of regulations and guidelines to steer GWR implementation and the unwillingness of potential users [7,8].

The objectives of this study are to firstly undertake an extensive review of greywater literature to crisply document greywater characteristics, risks and treatment technologies. Secondly, is to develop a framework for holistically evaluating different greywater treatment technologies in order to optimally select the most appropriate for a specific GWR application.

2. REVIEW OF GREYWATER REUSE LITERATURE

2.1 Greywater Application

Greywater may be used for non potable applications such as crop and landscape irrigation, toilet flushing, cooling, groundwater recharge, vehicle washing,fire fighting, laundry, bathing, ornamental lakes and streams, dust control, street washing, and snow melting [8,9]. Depending on the intended application, greywater can be treated and in some instances treatment may not be required.

2.2 Greywater Quantity

The quantity of greywater generated is dependent on the characteristics (e.g. water supply service and infrastructure, lifestyle preferences, water use patterns and age distribution) of houses which generate the effluent [10]. Quantity of greywater generated in low-income areas which experience water scarcity and/or with rudimentary water supply services (such as stand pipes or wells) can be as low as 20-30 litres per person while high-income households with reticulation pipeline may generate several hundred litres per day. These quantities may even be less in regions where rivers or lakes are used for personal hygiene. Morel and Diener [10] and Li et al. [11] determined typical greywater generation quantities of 90-120 l/p/d in houses with water pipeline. This range corresponds with that generated by Mandal et al. [12], i.e. an average greywater generation of 110 l/p/d, 80 l/p/d which is generated from bathing, cloth washing and wash basins, and 30 l/p/d from kitchen greywater. In general, greywater produced is about 69% of the total water consumption [13] and accounts for up to 75% of the wastewater volume produced by households, and over 90% if vacuum toilets are installed [14].

2.3 Physical Characteristics of Greywater

Physical parameters of relevance to GWR are temperature, colour, turbidity and suspended solids. Greywater temperature is often higher than that of the municipal water supply and within a range of 18-30ºC. These comparably higher temperatures are attributed to the use of warm water for personal hygiene and/or cooking. Although these temperatures fall within the range recommended for biological treatment (i.e. aerobic and anaerobic digestion occurs within an optimal range of 25-35ºC) [15]. The temperature range of 18-30ºC encourages bacterial growth and decreases CaCO3 solubility, thus causing precipitation in storage tanks or reticulation pipe systems in developed communities. Suspended solids in greywater range between 0-1553 mg/l with the highest concentrations typically found in dark greywater.

2.4 Chemical Characteristics of Greywater

The chemical parameters of relevance are pH, alkalinity, electrical conductivity, sodium adsorption ratio (SAR), biological and chemical oxygen demand (BOD_5, COD), nutrient content (nitrogen, phosphorous), and heavy metals, disinfectants, bleach, surfactants or organic pollutants. The pH indicates the acidity or alkalinity of a liquid. The effluent of treated greywater with the pH in a range of 6.5-8.4 is suitable for irrigation [16]. Christova-Boal et al. [17] observed a higher pH values of 9.3-10 in laundry greywater, which was partly due to the sodium hydroxide-based soaps and bleaches used. Also contrary to the range for irrigation, a lower pH value of 6-6.5 was observed by Pathan et al. [18] in Pakistan from wash hand basin and shower, which is due to some cleansing chemicals used for bathing. Greywater also contains salts which contribute to electrical conductivity (EC). EC measures salinity of all the ions dissolved in greywater which include both negatively charged ions (e.g. Cl-, NO3-) and positively charged ions (e.g.Ca++, Na+). The most common salt is sodium chloride (table salt). Other important sources of salts are sodium-based soaps, nitrates and phosphates present in detergents and washing powders. Salinity of greywater is normally not problematic but can become a hazard when untreated greywater is used for irrigation. In laundry greywater, sodium concentrations can be as high as 530 mg/l [19] (similar to the upper limits observed in the Stellenbosch samples as stated by Murphy [20], with SAR exceeding 100 for some powder detergents [21] Sodium is of a concern when applied to loamy soils, poor in calcite or calcium/magnesium as a high SAR may degrade well-structured soils, thus limiting aeration and water permeability. This high sodium problem in soils can best be avoided by using low sodium products, such as liquid laundry detergents. While European and North American countries recommend irrigation water with SAR < 15 for sensitive plants [22]. Patterson [23] observed hydraulic conductivity problems in Australian soils irrigated with a SAR as low as 3 in wastewater.

COD describes the amount of oxygen required to oxidise all organic matter found in greywater while BOD describes biological oxidation through bacteria within a certain time span (normally 5 days, BOD5). BOD and COD concentrations in greywater strongly depend on the quantity of water and products used in the household (especially detergents, soaps, oils and fats). When water consumption is low, BOD and COD concentrations are typically high. The COD/BOD ratio is also a good indicator of greywater biodegradability. A COD/BOD ratio below 2.5 typically indicates easily degradable greywater. However, some studies have shown low greywater biodegradability with COD/BOD ratios of 2.9-3.6 [5,24]. This was attributed to the fact that biodegradability of greywater primarily depends on the type of synthetic surfactants used in detergents and on the amount of oil and fat present. While many countries north west of the equator have banned and replaced non-biodegradable surfactants with biodegradable detergents, non-biodegradable resistant products (e.g. in powdered laundry detergents) are still being used in many low and middle-income countries. Greywater data collected in low and middle-income countries indicate COD/BOD ratios within the 1.6-2.9 range. Greywater with values close to the upper limit typically proceed from the laundry and/or kitchen.

Greywater normally contains low levels of nutrients compared to toilet wastewater. Nonetheless, nutrients such as nitrogen and phosphorous (typically from dish-washing and laundry detergents) are important parameters given their fertilising value for plants, their relevance for natural biological treatment processes and their potential negative impact on the aquatic environment. The high phosphorous contents often observed in greywater can lead to problems such as algae growth in receiving waters. Average phosphorous concentrations are typically within the 4-14 mg/l range in regions where non-phosphorous detergents are used [6]. However, they can be as high as 45-280 mg/l in households where phosphorous detergents are utilised, as observed for dark greywater in the UK [25] and Stellenbosch [26]. Levels of nitrogen in greywater are typically low with kitchen greywater being the main source of nitrogen. Nitrogen in greywater is derived from ammonia, ammonia-containing cleansing products, proteins in meats, vegetables, protein-containing shampoos and other household products. In some instances, the municipal water supply can be a source of ammonium nitrogen. Dark greywater contains significant quantities of vegetable oil and cooking oil and grease (O&G) which are derived mainly from kitchen sinks and dishwashers. No recommended specification for O&G were determined in the literature. However, values as high as 230 mg/l were observed in Jordan for dark greywater [5].

Surfactants are the main components of household cleaning products. Laundry and automatic dishwashing detergents are the main sources of surfactants in greywater. Other sources include personal cleansing products and household cleaners. Surfactants are usually organic compounds that are amphiphilic, meaning they contain both hydrophobic groups (their tails) and hydrophilic groups (their heads). Therefore, a surfactant contains both a water-insoluble (or oil-soluble) component and a water-soluble component. Surfactants will diffuse in water and adsorb at interfaces between air and water or at the interface between oil and water, in the case where water is mixed with oil. The water-insoluble hydrophobic group may extend out of the bulk water phase, into the air or into the oil phase, while the water-soluble head group remains in the water phase. The most common surfactants used in household cleansing chemicals are LAS (*linear alkylbenzene sulfonate*), AES (*alcohol ethersulphate*) and AE (*alcohol ethoxylate*). Other pollutants that are present in greywater include heavy metals and Xenobiotic organic compounds (XOCs). XOCs constitute a heterogeneous group of compounds that are derived from the chemical products used in household detergents, soaps and perfumes. Information about the presence and levels of XOCs is scarce and it has been recommended that further research be conducted in this regard if greywater has to be used for irrigation or groundwater infiltration [6].

2.5 Microbiological Characteristics of Greywater

Greywater may pose a public health risk when contaminated with viral, bacterial, protozoan or intestinal parasitic pathogens. In the case of light greywater, these pathogens are primarily faecal in origin (e.g. from hand washing after toilet use, washing of babies after defecation and diaper washing) while for dark greywater, these pathogens originate from both faecal and food (e.g. washing of vegetables and raw meat) contamination. Faecal contamination of greywater typically depends on the age distribution of household members i.e. higher faecal contamination of greywater is typically experienced where young children are present in a household [27]. Enteric viruses, which are known to be the most critical group of pathogens, can cause illness even at low doses and cannot be detected by routine microbial analysis. Greywater which contains at least 10^5 of potentially pathogenic microorganisms per 100 ml, typically changes in quality over time. Counts of total coliform and faecal coliform increased from 10^0-10^5/100 ml to higher than 10^5/100 ml within 48 hours in stored greywater from various sources [5]. Easily biodegradable organic compounds which are typically found in dark greywater favour the growth of microorganisms [28].

3. REVIEW OF GREYWATER TREATMENT TECHNOLOGIES

A greywater treatment system consists of different treatment steps depending on the required quality of the effluent (Fig. 1). Several treatment technologies can be used in each step. Technologies examined for treating greywater are classified based on the treatment principle, i.e. physical, biological, chemical, or a combination of these [29]. According to Jefferson et al. [23] and Holt et al. [30], greywater treatment technologies can be broadly categorised into five classes such as physical, biological, chemical, natural and hybrid. The latter refers to the utilisation of more than one of the distinct technologies listed prior to improve treatment efficiency (and hence, the quality of the final effluent). Table 1 presents an indication of the type of pollutants removed in each of the four categories. This was further re-classified by Pidou et al. [31] into the following:

1. Simple treatment system (coarse filtration and disinfection) which can be referred to as (Hybrid system)
2. Chemical (photo catalysis, electro-coagulation and coagulation).
3. physical (sand filter, adsorption and membrane)
4. Biological (biological aerated filter, rotating biological contactor and membrane bioreactor)
5. Extensive (constructed wetlands) which can also be referred to as natural system.

Pidou et al. [31] categorization was based on an extensive review of sixty-four schemes of which twenty-six reviewed schemes were pilot or bench scale for research purposes and the remaining thirty-eight systems were full scale as they were fitted in buildings. In his review, he reported that most of the treatment technologies listed above are operated with a screen or sedimentation stage before and /or a disinfection stage (UV, chorine) after. This supports the suggestion of Li et al. [10] who gave a suggestion in terms of the process for greywater treatment for restricted and unrestricted uses. Li et al. [10], suggested that unrestricted non-drinking urban reuses (including toilet flushing) typically requires four processes – pre-treatment, chemical/biological treatment, filtration and disinfection. If restricted reuse, disinfection may be excluded. It is believed that individually, these processes cannot guarantee adequate treatment. Fig. 2 shows Li et al. [10] proposed treatment flow for different qualities of greywater for urban non-drinking purposes.

Furthermore, in terms of the level of treatment provided by greywater reuse technologies, Wiltshire [32] shows that the level of treatment is dependent on the combination of the treatment technology, scale of use and reuse application i.e.,:

1. Technology based(primary secondary and tertiary)
2. Scale of Use: Single dwelling, multi-dwellings , community-dwelling
3. Greywater application: external use-garden and internal use-toilet flushing an

In the light of the review, the treatment technologies will be discussed based on the treatment processes and the combination of processes.

3.1 Simple Treatment Systems

Simple technologies used for greywater reuse are usually decentralized two-stage systems based on a coarse filtration or sedimentation stage to remove the larger solids followed by disinfection [33,34,35]. The technology represent the most common technology used in the United Kingdom till date with a number of companies supplying products based on these two stage processes. The coarse filter usually comprises of a metal strainer and disinfection is normally achieved using either chlorine or bromine [36]. A simpler system with only a coarse filter or a sedimentation tank was also reported in Western Australia where the regulation allows the reuse of greywater for subsurface irrigation [31,37].

Consequently, these systems are mostly used at small scale levels such as a single household. Moreover, they are usually used to treat low strength greywater from bath, shower and hand basin due to the limited treatment they can achieve and subsequent applications are toilet flushing and garden watering. In South Africa, Ilemobade et al. [8] and Olanrewaju [38] reported a greywater treatment unit using the two-stage basic principle as supplied by *Water Rhapsody©*.

The system was implemented in two buildings which include the School of Civil and Environmental Engineering, University of the Witwatersrand and a sixteen person residential unit at the Student Village Residence, University of Johannesburg. The system only screens and disinfects the water with the use of calcium-hypochlorite blocks in the holding tank. The cost of the system was reported to be between R7,800 and R11,800 per unit ($1,000 – $1,500) excluding the installation cost. Although the treatment system was modified to suit the research purpose, the purchase and installation costs of the treatment unit was estimated around R39, 000($3,500) due to the retrofitting and pipeline in an existing building. It was reported that the greywater system at both the pilot sites couldn't achieve a payback period within 20 years, thus making it economically unsustainable.

Similar systems reported in the United Kingdom show a variety of water saving levels ranging from 3.4 to 33.4% with a moderate cost of between £500-£1000 as installation cost, with a minimum payback period of about 8 years for a four-person household [39]. However, two other systems installed in individual households in the United Kingdom with similar capital, operational and maintenance (O & M) costs of £1195 and £50/year and £1,625 and £49/year respectively were found to be economically unsustainable as the water savings were not sufficient to cover the O & M costs [33,34]. In Spain, March et al. [32], reported that a hotel was economically viable. The system including two 300 μm nylon filters, a sedimentation tank and disinfection with sodium hypochlorite had a capital cost of 17,000 € (~£11,500) and the O & M cost were calculated at 0.75 € (~£0.50) per cubic meter. A saving of 1.09 € (~£0.74) per cubic meter was then attained and a payback period of 14 years was obtained with the system operative only 7 months per year.

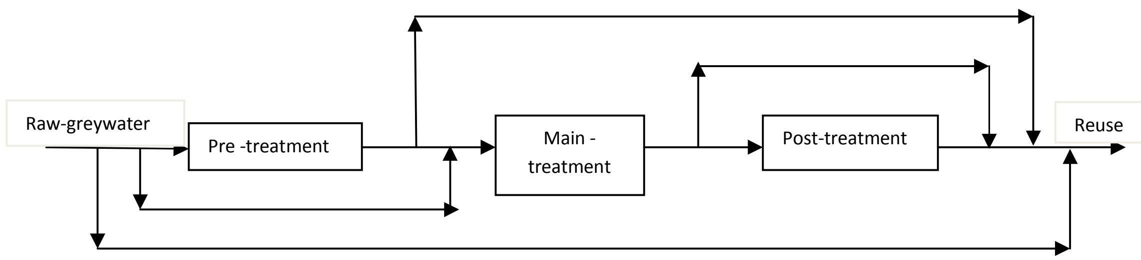

Fig. 1. Greywater recycling and treatment possible steps and tracks (Abu Ghunmi et al. [29])

Table 1. Overview of treatment technologies and their pollutant removal abilities (Holt and James [30])

Category	Sub-category	Suspended solids removal	Biodegradable organics (BOD) removal	Nutrients: nitrogen removal	Nutrients: phosphorus removal	Salts removal	Pathogen removal
Physical	Media filtration	Yes	Function of size	Limited	Limited	No	Limited
	Membrane filtration	Yes	Function of size	Function of size	Function of size	Reverse osmosis only	Function of size
Biological	Membrane bioreactor	Yes	Yes	Function of size	Function of size	No	Function of size
	Recirculating media filter	Yes	Yes	Yes	Limited	No	Limited
Chemical	Disinfection	No	No	No	No	No	Yes
Natural	Subsurface flow wetland	Yes	Yes	Yes	Yes	No	Yes

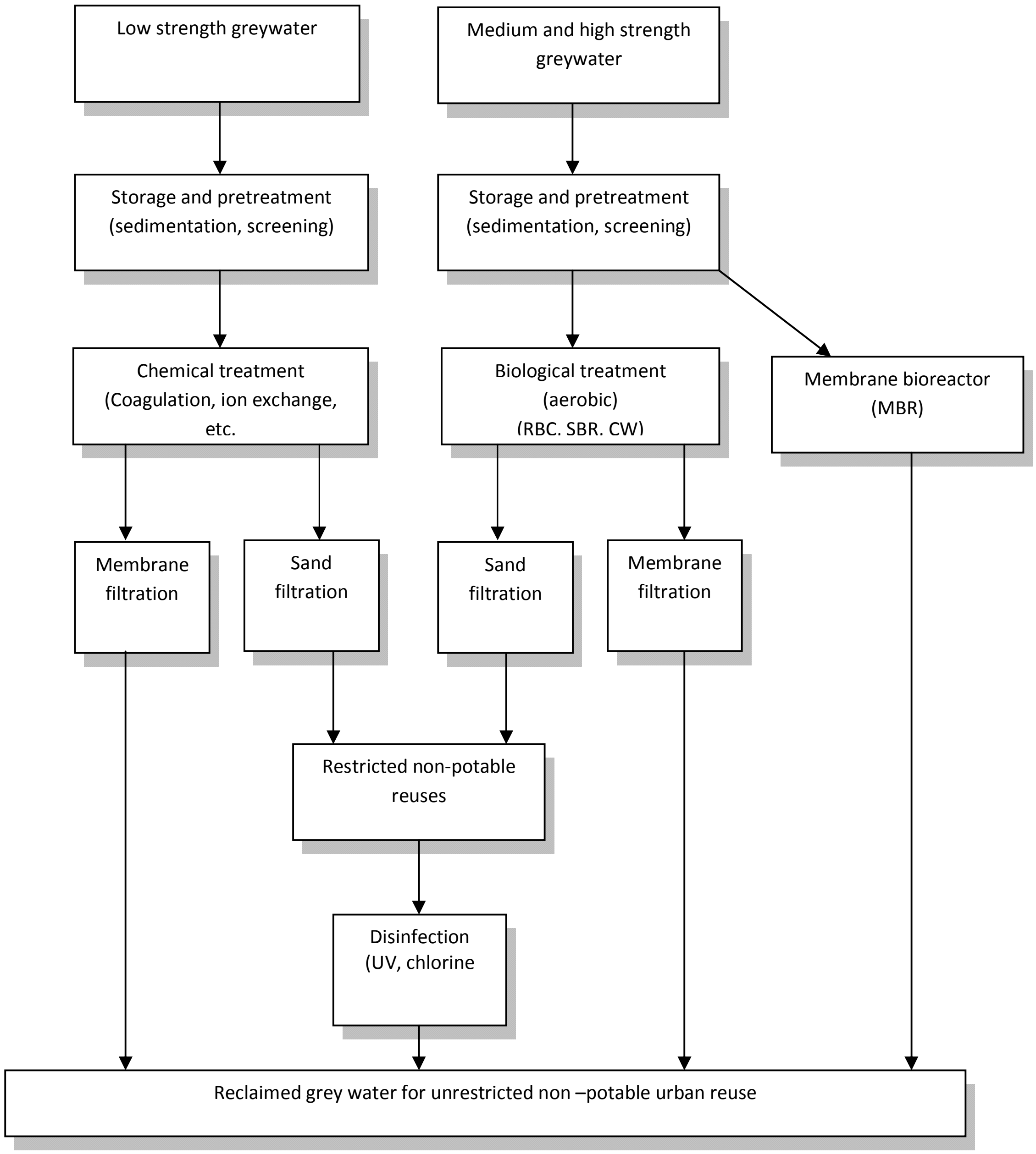

Fig. 2. Greywater treatment for non-drinking urban applications (Li et al. [11])

Because of the simple technologies, only a limited treatment of the greywater in terms of organics and solids is noticed. An average removals of 70, 56 and 49% for COD, suspended solids and turbidity have been reported in the literature [31]. However, good removals of micro-organisms due to the disinfection stage have been observed with total coliforms residuals below 50 cfu.100 mL^{-1} in the treated effluent [33,34]. Little information is available in the literature on the hydraulic performance of these systems; the hydraulic retention time (HRT) should be short as a result of their simplicity.

3.2 Physical Treatment Processes

Physical treatment processes such as filtration, sedimentation and flotation rely on the physical separation of effluent from the pollutant. Physical processes can either be a preliminary, primary or tertiary treatment process depending on the pore size of the media such as in a sand filter where it is used alone [40,41] or in combination with disinfection [42], or with activated carbon and disinfection [42,43]. If a sand filter is used as a sole treatment stage, it provides a coarse filtration of the greywater similar to the simple technologies previously reviewed. According to Pidou et al. [31], physical systems can also be divided into two sub-categories, e.g. sand filters and membranes. Since sand is not the only medium used for filtration processes, it will be preferable to referred to it as a media or macro filtration as reported by Abu Ghunmi et al. [29]. Membrane filters are more expensive and effective in physical treatment processes because of the pore sizes of the media. Abu Ghunmi et al. [29] reported that the efficiency of the filtration techniques depends on the particle size distribution of greywater pollutants and the porosity of the filters. In general, the smaller the filters' porosity, the better the effluent quality as it typically removes residual suspended solids and organic matter for more effective disinfection. In relation to the purpose of this review, physical processes are sub-categorized under the media/ macro filtration and membrane filtration processes.

3.2.1 Media/Macro filtration

The tested media/macro filtration units include a strainer series with pore size ≥0.17 mm, nylon sock-type filters, geotextile (filter sock) filters, fibrous (cloth) filters, coarse filters (CF), and sand filters (SF) [5,16,36,44]. According to Pidou et al. [31], sand filter was extensively used in most of the pilot projects reviewed. Sand filters are usually lined excavated structures filled with uniform media over an under-drain system. The untreated greywater is poured on above of the media and thereafter percolates through to the under-drain. Design variations include re-circulating sand filters where the water is collected and re-circulated through the filter. In order to achieve effective microbial control, low flow is required through the sand filter. This ensures contact between the sand media's biofilm and water. The biofilm helps to adsorb colloidal pollutants and encourages oxidation of the organic material as oxygen diffuses within the biofilm. Depth filtration is a variation of the sand filter. Depth filtration uses a granular media, typically sand or a diatomaceous earth to filter greywater. Typically, there are four layers in the filter media. The particle size decreases through the filter's layers. The coarser top layer removes larger particles and finer material is removed towards the lower layers, increasing the efficiency of the filter.

The advantage of macro filtration processes is that the filtering raw greywater reduces blockages in the recycling system through macro-filters irrespective of the quality [16,36]. However, macro-filtration units, in exception sand filters, show no absolute barrier for the suspended pollutants. The chemical nature of greywater regarding the load and turbidity remains almost unaltered, thereby promoting biological growth [16,36].

Filters face a number of operational problems such as the cleaning frequency of macro filtration units, which may vary from once after each use to once per week [16,36,44]. The effect of organic content and turbidity on the quality of effluent causes periodical failures of disinfection by halogen compounds [36] which have the affinity to react with the organic matter.

3.2.2 Membrane filtration

Membrane (or cross flow membrane) filtration systems consist of semi-permeable media that allows the removal of pollutants. There are four broad classes of membrane filtration namely- (i) micro-filtration, (ii) ultra-filtration, (iii) nano-filtration and (iv) reverse osmosis. Micro-filtration has the largest pore size, decreasing to ultra-filtration, nano-filtration and reverse osmosis. Membrane filtration systems offer a permanent barrier to suspended solid particles greater than the size of the membrane material, which can range from 0.5 µm for micro-filtration membranes to molecular dimensions for reverse osmosis. The treated water is thus generally very low in turbidity and below the limit of detection for coliforms. The key technical limitation of membrane filtration is the fouling of membrane surfaces by pollutants [23]. The prevention or reduce fouling, pre-treatment of raw greywater in storage and settling tank is highly recommended [29]. High operation time of micro-filtration results can result in anaerobic conditions of the greywater [36] and generate organic components that are less readily be rejected by the membrane [45]. A general attribute of ultra-filtration is very high energy demand [46]. This also occurs in nano-filtration and reverse osmosis because decreasing pore size results in the removal of smaller pollutants, thereby causing an increase in pressure and energy requirements. Pressure requirements, pore sizes and typical pollutant removal are summarised in Table 2.

3.3 Biological Treatment Technologies

Biological treatment is primarily used to remove dissolved and colloidal organic matter from water. Biological treatment promotes natural processes to break down high nutrient and organic loaded waters. Biological treatment alone is not usually sufficient to produce an effluent suitable for reuse and as has to be accompanied by a physical process to retain active biomass and prevent the passage of solids into the effluent [23]. Pidou et al. [31] reported that it is common that biological treatment processes were preceded by a physical pre-treatment such as sedimentation or screening and/or followed by disinfection. A biological treatment of greywater followed by disinfection guarantees a risk-free effluent [25,34,44]. Biological schemes are mostly centralized systems commonly seen in bigger buildings such as students' residence [25,34,44] multi-storey buildings [46,47] and stadia [48]. Hydraulic retention times (HRTs) for most biological treatment ranges from 0.8 hours up to 2.8 days and organic loading rates were found to vary between 0.10 and 7.49 $kg.m^3$ for COD and 2.38 $kg.m^3.day^{-1}$. Pidou et al. [31] reported that almost all the schemes reviewed in their report under biological treatment achieved excellent organic and solid removal except two that did not met the most stringent BOD standard for reuse with residual concentration below 10 mgl^{-1}. Turbidity was below 8 NTU for all the systems reviewed and all the schemes expect one) had suspended solids residual below 15 mgL^1. Membrane Bioreactor (MBR) was the only system that achieved optimal micro-organism removal without disinfection stage. The costs for a construction and installation of a buffering tank with screening, an aerated biofilter, a deep bed filter and GAC range from £3 345 [25] to £30,000 for an aerated bioreactor combined with a sand filter, GAC and disinfection with bromine for a student hostel [33]. Biological treatment can be broadly classified under two major categories (i) suspended growth systems and (ii) attached growth systems as described below:

3.3.1 Suspended growth systems

Tested suspended growth systems are (i) Sequencing Batch Reactor (SBR) [49] and (ii) Membrane Bioreactor (MBR) [50,51,52, 53,54,55]. An activated sludge process is the best-known suspended growth system. This process is most commonly used in large, centralized and small wastewater treatment plants. Activated sludge is the process whereby sewage is aerated (using atmospheric air or pure oxygen) and agitated in order to promote the growth of beneficial microorganisms that break down organic matter and produce biological floc. The process usually occurs in two distinct phases (and therefore vessels) i.e., aeration, followed by settling. Four processes are common in all activated sludge systems [56]:

- A flocculent, aerated slurry of microorganisms (which is called "mixed liquor suspended solids" or MLSS) is utilized in a bioreactor to remove soluble and particulate organic matter from the greywater;
- Quiescent settling is used to remove the MLSS from the process stream, producing an effluent that is low in organic matter and suspended solids;
- Settled solids are recycled as a concentrated slurry from the clarifier back to the bioreactor;
- Excess MLSS (sludge or biosolids) is discharged from the bioreactor in order to control the solids retention time to a desired period.

There are several process variations to the activated sludge process- the main ones are briefly described below:

a) Sequencing Batch Reactor (SBR)

The SBR process is a fill-and-draw-type reactor that acts as an aeration basin and final clarifier. Greywater and biomass are mixed and allowed to react over several hours in the presence of air. At a certain point in time, the aeration is turned off and the mixed liquor in the reactor is allowed to settle, without aid of a separate settling tank. After a short settling period, the clarified treated effluent is discharged via a specially designed decanter. Tested Sequencing Batch Reactor (SBR) operated by Shin et al. [49] produced an unstable effluent quality in terms of SS, but was stable regarding BOD. The BOD values were close to the effluent BOD of FBR, RBCs and MBR reported by Friedler et al. [52] and Hernandez et al. [57].

b) Membrane Bioreactor (MBR)

A membrane bioreactor (MBR) combines the process of a suspended growth system and membrane filtration into a single unit process. MBRs replace a separate filtration process which would be attached to a suspended growth system with a treatment process that has a small footprint and produces high quality effluent with low TSS, BOD and turbidity. There are two basic configurations for a MBR: a submerged membrane bioreactor that immerses the membrane within the suspended growth system (Fig. 3) and a bioreactor with an external membrane unit. The suitability of MBRs for GWR is strongly influenced by its capability to remove biological contaminants without the use of chemicals. MBRs have higher capital (which includes expensive membranes) and energy (chemicals required for membrane cleaning) costs than other treatment systems. It may be susceptible to shock loading of organic matter and bactericidal chemicals. As earlier mentioned, MBR can achieve a good micro-organism removal without the need for disinfection stage.

3.3.2 Fixed growth/film systems

Tested fixed growth/film systems in the literature are among others (i) Fluidized Bed Reactor (FBR) examined by Nolde [46], (ii) Submerged Aerated Filter by Laine [50], and Surendran et al. [25] (iii) Rotating Biological Contactors (RBCs) examined by Nolde [46] and Friedler et al. [52].In fixed growth/film systems, microorganisms are attached to a surface that is exposed to the water. Many locally available package plants employ a purely fixed film system or a combination of fixed film and suspended growth systems. Two variations of the fixed/film systems are briefly described below [56].

a) Rotating Biological Contactor

The Rotating Biological Contactor (RBC) (Fig. 4) supports a biologically active film, or biomass, of aerobic micro-organisms. A RBC treatment system typically comprises three units:

- Primary Zone: A settlement/sedimentation tank where wastewater enters, and the solids settle and are stored for subsequent removal. Anaerobic digestion may take place in this tank.
- RBC: This is where the biological treatment takes place. Numerous discs attached to a shaft form the RBC assembly, which is partially submerged in a trough to create an environment for an active biomass to develop on the media. The RBC is slowly rotated to bring the biomass into alternate contact with the wastewater and atmospheric oxygen.
- Final Clarification tank: Here settlement of the mixed liquor and excess biomass takes place.

Generally, partially submerged RBCs are used for carbonaceous BOD removal, combined carbon oxidation and nitrification, and nitrification of secondary effluents. Completely submerge RBCs are also used for de-nitrification [58].

b) Submerged Aerated Filter

The Submerged Aerated Filter (SAF) process can be described as follows: settled wastewater is fed from a primary tank into the first stage of a reactor at a controlled rate where it is mixed with the aerated bulk liquid already present. Air is then introduced into the reactor through a fine bubble diffuser system at the base of each chamber. A uniquely structured media is suspended over the fine bubble membrane diffuser to provide optimized contact between the oxygen-rich wastewater and the biomass.

Regarding a high surface area to volume ratio, the media supports a biologically active film of micro-organisms to treat the greywater by using oxygen from the air provided. When the oxygen-rich greywater comes into contact with the biomass attached to the surface of the media, organic pollutants are broken down by the biomass.

c) Recirculating media filters

Recirculating textile filters (RTF) are similar to trickling filters. However, the media used for the growth of the biofilms are textiles rather than plastics or rocks. RTFs are available in small compact footprint package plants suitable for decentralised treatment. The RTF and recirculating sand filters (RSF) consist of two major components. The first is the biological chamber and low-pressure distribution system. The greywater flows between and through the non-woven lightweight textile material in the RTF and through a bed of sand in the RSF. The second major component is a recirculating tank and pump which pumps typically 80% of the filtrate back to the chamber. The pump fills the chamber every 20 to 30 minutes. The remaining effluent may be diverted to a storage tank or discharged.

3.4 Chemical Treatment Technologies

Chemical treatment typically involves coagulants and disinfectants, which are used to increase the

Table 2. Key features of membrane filtration (Holt and James [30])

Filtration	Pore size	Operating pressure	Typical target pollutant
Micro-filtration	0.03 to 10 microns	100 -400 kpa	Sand silt, clay, *Giardia lamdia,crypotosporidium*
Ultra-filtration	0.002 to 0.1 microns	200-700 kpa	As above plus some viruses (not an absolute barrier) some humic substances
Nano-filtration	About 0.0001 microns	600-1000 kpa	Virtually all cysts, bacteria, viruses and humic materials
Reverse osmosis	About 4 to 8 A	300-6000 (or 13.000 kpa-13.8 bar) kPa	Nearly all inorganic contaminants. Radium, natural organic substance, pesticide, cyst, bacteria and viruses, salts (desalination)

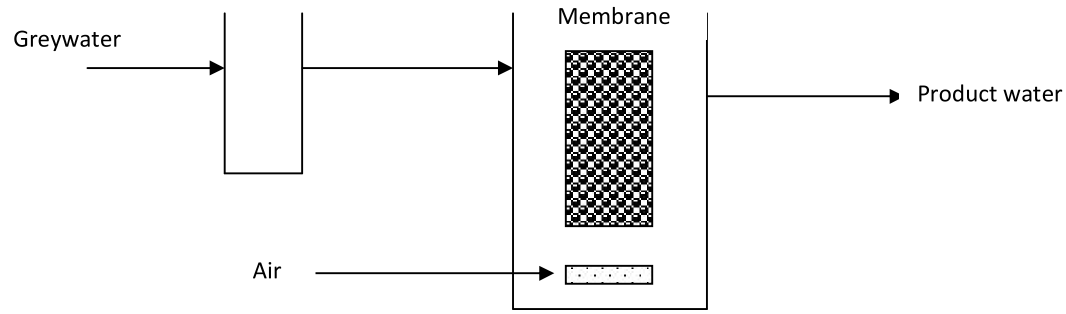

Fig. 3. An immersed membrane bioreactor (Jefferson et al. [24])

removal rate of pollutants or destroy pathogenic organisms but does not remove solids. The removal of waterborne pathogens is the most important public health concern for water treatment. The three common disinfection methods are ultraviolet radiation, chlorination and ozonation.

a) Ultraviolet (UV) radiation uses UV light to deactivate microorganisms in water. When the short UV radiation penetrates the cell of an organism, it destroys the cell's genetic material and its ability to reproduce.
   Chlorination, which involves the application of chlorine, is the most common water disinfection method. Chlorine can be added in gaseous form (Cl_2), hypochlorous acid or as hypochlorous salt, $Ca(OCl)_2$. A characteristic of chlorine is that it provides residual microbial control, i.e., it continues to disinfect water after treatment. Optimal chlorination dosage is dependent on its concentration and the water temperature and pH which exert a strong influence on chlorination performance similar to UV radiation. Chlorination destroys a microorganisms genetic material and thus, its ability to reproduce.
b) Ozonation is the most powerful of the three disinfection methods. Ozone is created by an electrical discharge in a gas containing oxygen, i.e. $3O_2 \rightarrow 2O_3$.Ozone production depends on oxygen concentration and impurities such as dust and water vapour in the gas. It achieves the same result on microorganisms as UV radiation and chlorination.

Three schemes using chemicals as the major source of greywater treatment were reported in the literature [59,60]. The first scheme used a combination of coagulation, sand filters and granular activated carbon (GAC) for the treatment of laundry greywater and achieved in the coagulation stage alone, 51% of BOD removal and 100% of suspended solids removal. The second scheme combined electro-coagulation with disinfection for the treatment of low-organic greywater (with BOD concentrations of about 23 mg/l) and achieved BOD residuals of 9 mg/l, turbidity residuals of 4 NTU and undetectable levels of E. coli. The above schemes achieved the above results in relatively short periods (i.e., 20 and 40 minutes respectively). The third scheme was based on photocatalytic oxidation with titanium dioxide and UV disinfection. This scheme achieved good results (i.e., 90% removal of organics and removal of total coliform of the magnitude of 10^6 cfu/100 ml) within 30 minutes [61].

The advantages of chemical treatment technologies include that the treatment unit can be located in well ventilated indoor spaces, have small ecological footprint, removes turbidity and organic matter, and efficiently disinfects. Disadvantages include that the technology does not remove solids and its capital cost is typically high.

3.5 Extensive /Natural Treatment Technologies

Natural treatment systems include artificial or constructed wetlands (reed beds, lagoons or ponds) which are a complex collection of water, soils, microbes, plants, organic debris, and invertebrates. Greywater is commonly treated by natural systems in areas without a public sewer system and available land space. The term “constructed wetlands” refers to a technology designed to employ ecological processes found in natural wetland ecosystems. These systems utilize wetland plants, soils, and associated microorganisms to remove contaminants from wastewater. They can remove contaminants such as BOD and suspended solids; metals, including cadmium, chromium, iron, lead, manganese, selenium, zinc and toxic organics from wastewater [61]. Removal of contaminants occurs by physical, chemical and biological processes. The rate of these processes depends on many factors like the surface loading rate and the availability of electron acceptor [58].

Constructed wetlands are classified as either Free Water Surface *(FWS)* systems or Subsurface Flow *(SSF)* systems. Any wetland, in which the surface of the water flowing through the system is exposed to the atmosphere, is classified as an FWS system. In SSF systems water is designed to flow through a granular media, without coming into contact with the atmosphere. Free water surface wetlands can be sub-classified according to their dominant type of vegetation: *Emergent macrophyte*, *Free floating macrophyte*, or *Submerged macrophyte*. Subsurface flow wetlands (which by definition must be planted with emergent macrophytes) can best be sub-classified according to their flow patterns: *Horizontal flow* or *Vertical flow* [62].

Subsurface wetlands are a proven technology used to remove organic matter and suspended solids from greywater. In subsurface flow wetlands, greywater is treated in horizontal or vertical (Fig. 5) flow reed beds where the water is below the surface of a gravel bed to minimise undesired insect breeding and odours. The soil typically has a high permeability and contains gravel and coarse sand. Some flora/plants, which are utilized in these wetlands, have bactericidal properties and are able to treat some pollutants. Common plants used include *phragmites, Bauma, water hyacinth (Eichhornia crassipes), Typha and schoenoplectus. Greywater characteristics, target effluent quality, seasonal temperature variation and flora characteristics determine the size of the pond and infiltration areas which may vary in size from 0.7 m2 [63] to 8 m2 [64] per person served by the facility.*

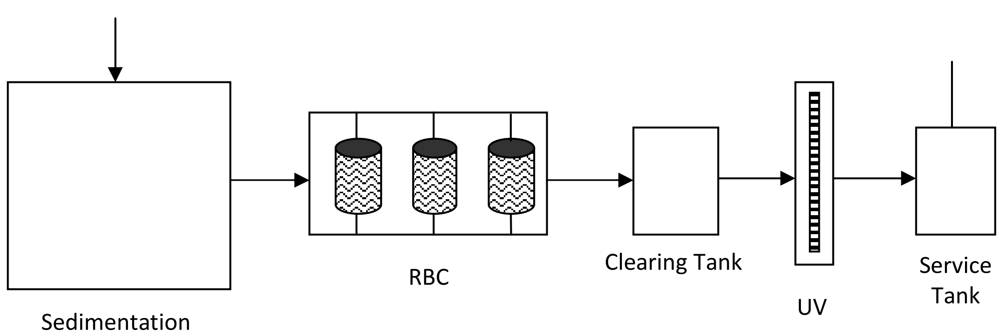

Fig. 4. A Typical flow diagram of biological technologies having a rotating biological contactor in the treatment train (Jefferson et al. [24])

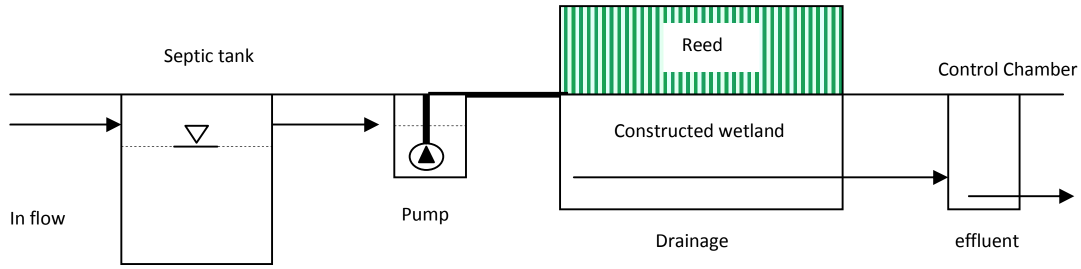

Fig. 5. A typical flow diagram showing a constructed wetland in the treatment train (Dowling [68])

Recently tested subsurface flow constructed wetlands include using a recycled vertical flow constructed wetland (RVFCW) [65,66], Horizontal flow constructed wetland (HFCW) [67]. Constructed wetland has been considered as the most environmentally friendly and cost effective technology for greywater treatment. In a study led by Gross et al. [65], a recycled vertical flow constructed wetland was applied for a high strength mixed greywater treatment. The TSS, BOD5, COD,TN,TP, anionic surfactants, baron and faecal coliform were reduced from 158mg/l, 466 mg/l, 839 mg/l, 34.3 mg/l, 22.8 mg/l, 7.9 mg/l, 1.6 mg/l and 5x 10^7/100ml in the influent to 3 mg/l, 0.7 mg/l, 157 mg/l, 10.8 mg/l, 6.6 mg/l, 0.6 mg/l, 0.6mg/l and 2x10^5/100ml respectively in the effluent. The result shows that the constructed wetland shows good treatment performance to treat greywater. In general, natural systems are typically inexpensive, energy-efficient, and do not require chemicals for treatment. However, they must be located outdoors, have a large ecological footprint, and are climate-dependent.

4. RISKS AND RISK MANAGEMENT OF GREYWATER REUSE

Despite the benefits of reuse, GWR can pose a great risk to the public health. In case of reuse for toilet flushing, the possible transmission of infectious diseases from greywater ingress (accidental or deliberate) into potable networks continues to be of great concern. Greywater may contain chemical and microbiological agents which pose a health risk to users and the accidental ingestion of contaminated greywater can cause gastrointestinal illness. In a risk assessment conducted by Ottoson and Stenstroem [28], rotaviruses pose the most significant risk to human health. Micro-organisms such as adenoviruses and enteroviruses have been found to cause respiratory illnesses as a result of the inhalation of recycled water [69]. Aerosols and droplets may also be deposited on surfaces (e.g. toilet seats) which may in turn be touched by users who may subsequently ingest through hand-to-mouth contact. There is also the possibility of dermal exposure. However, there is a lack of evidence of the health impacts through this route, and it is considered unlikely to cause significant levels of infection or illness in users. It is reasonable to also assume that children will take less care to avoid hand-to-mouth contact after touching contaminated surfaces, but there is little information available to quantify this potential route of exposure [70].

Domestic greywater on lawns and gardens is usually considered to have a low risk; the irrigation of lawns may be associated with public health risks because disease causing organisms in greywater are principally transmitted through the ingestion of greywater via contaminated hands, or indirectly through contact with contaminated items such as grass, soil, toys or garden implements. A recent research conducted in South Africa by Jackson [71] confirms that although there is a health risk related to most of the activities regarding irrigation with greywater, especially the handling of the greywater itself, the risks could be brought within the World Health Organisation guidelines of less than one case of disease per 10,000 people per year by the implementation of simple barrier interventions.

A way of preventing and controlling the risk is through risk management. Risk management is the process of controlling risks, weighing alternatives and selecting appropriate action; while risk communication is the communication of risks to managers, stakeholders, public officials and the public [72].Risk management includes identifying preventive measures to control a hazard, the establishment of monitoring programmes to ensure that preventive measures operate effectively, and the verification of the management system as it consistently provides quality recycled water that is fit for the intended use (i.e. 'fit for purpose') [69].

A process of carrying out risk management strategy is the development of an integrated risk management framework using various frameworks that have been proposed (i.e. The World Health Organisation, [72]; The United States Environmental Protection Agency, USEPA, [73]; Canada Health, [74] and the Australian guidelines, NRMMC-EPHC, [69]) in order to mitigate the risks relating to GWR. Developing this framework involved documenting the different risk management frameworks listed above and identifying the similar measures employed as applicable to different risks [38]. These strategies involved all aspects of sustainability which included social, technical, economic, legal and political issues. Part of the technical strategies proposed, is the development of a framework for the selection of appropriate treatment unit. The evaluation of available and appropriate greywater treatment package plants is imperative, especially with the increasing availability of novel, emerging or imported package plants for which little information and experience under local conditions are known.

5. DEVELOPMENT OF A FRAMEWORK FOR ASSESSING GREYWATER TREATMENT PACKAGE PLANTS FOR TOILET FLUSHING

The selection of the most appropriate technology for a GWR project plays a key role in the project's operational reliability, the suitability of recycled water quality and a reduction in the risks associated with GWR. In order to optimally facilitate this selection, a framework was developed to assess available greywater treatment package plants in South Africa. The development of the framework was preceded in the literature review (which is presented in section 3) in order to understand greywater treatment technologies typically employed in small package plants. Small package plants are used to treat greywater flows between 37.85 m^3/day and 946.25 m^3/day; and the population of a database of locally available small package plants. Details of these plants were obtained from the following sources: Swartz et al. [75], Gaydon et al. [76] and The Green Pages [77].

In each of the plants listed, detailed information was obtained from the manufacturers/suppliers using performance criteria obtained from the documents above. Manufacturers/suppliers were typically contacted as follows:

a) A letter was drafted explaining the project and requesting plant specific information using a questionnaire.

The process of assessing package plants using the framework is as follows:

- Criteria within each of the key issues are scored using a scale of 0 (low), 1 (moderate) and 2 (high);
- Each criteria's score is multiplied by the weight of the key issue in order to obtain a weighted real score;
- The weighted mean of the real scores is calculated for each key issue;
- For the framework, the aggregate of the weighted mean of the real scores is then calculated. This aggregate ranges between 0.00 (most preferred package plant) and 6.78 (the least preferred package plant)

6. RESULTS AND DISCUSSION

Table 6 represents the results of the assessment of the 10 locally available greywater treatment package plants. Many of the manufacturers/suppliers that were contacted responded by sending leaflets with little to no information on expected treated effluent quality. Hence, where no responses were given to specific criteria, the worst effluent quality, etc was assumed and the appropriate score assigned. For each plant, the final score is the aggregate of the weighted mean real score of the three key issues.

The Technical key issue refers to the treatment technology employed by the package plant. Below are the highlights of some of the technical key issues considered during the assessment:

- Plants 1, 2 and 3 scored the lowest in this key issue with the treatment employed being biological or chemical disinfection;
- Plant 7 only treated effluent produced by 35 people or less; and
- An advantage of plants 1 and 3 is that they covered a wide operating range i.e. from household level to clustered developments.

In terms of the economic key issue, life cycle cost (have to be/is) determined to ensure that a package plant was affordable. Cost are directly related to the treatment technology employed hence, the more complex the treatment process, the more expensive the package plant would be. Costs to implement plants 1, 2, 3, 4, 6 and 8 were obtained from manufacturers/suppliers. Below are some of the highlights of economic issues considered during the assessment:

- Plants 1, 2 and 4 scored the lowest in this key issue;
- Plant 2, which included a pump chamber/greywater tank, pump, sieve, plumbing retrofitting and installation, cost the least per toilet;
- Costs of greywater disinfection and electricity were not provided for the plants assessed.

b) The drafted letter and questionnaire were faxed or emailed to the relevant contact person and telephone calls were made to confirm receipt and request responses. A number of 30 manufacturers/suppliers from investigated documents were initially listed, 25 were contacted and sent questionnaires, while 10 responded. Table 5 presents the summary of the 10 locally available greywater/wastewater treatment package plants and the key elements in the selection process.

The performance criteria used in the framework for the assessment of the 10 package plants were obtained from the following documents: DWAF [78,79], Holt and James.,[30], USEPA [73], Li et al. [11], Prathapar et al. [80] and Gaydon et al. [76].The framework developed for assessing package plants for GWR for toilet flushing is shown in Table 3.

The weights employed in the framework were based on the average weights obtained by Ilemobade et al. [4]. Ilemobade et al. [4] developed these weights based on decision-makers ranking of key issues to be considered when assessing the feasibility of implementing a dual water reticulation system in South Africa (Table 4). The three key issues making up the 3 sections of the framework are technical, public health and safety, and economics.

Public health and safety was assessed using the quality of the treated effluent from each package plant. Many of the manufacturers/suppliers contacted did not however supply this information. Below are some highlights of public health and safety issues considered during the assessment:

- Plants 3,5 and 1 scored the lowest in this key issue;
- Although Plants 6 and 7 did not specifically mention that their treated effluent could be used for toilet flushing, their effluent quality parameters were within the DWAF [80] guidelines for toilet flushing;
- Plant 3 produced the best quality effluent.

6.1 Selection of the Preferred Greywater Treatment Package Plant

The trade-offs between the 3 key issues made selection of the preferred GWR plant complex. From the 10 plants assessed, plants 1, 2 and 3 achieved the lowest scores. Particular highlights of each of the 3 package plants selected included:

- Package plant 3 was (i) particularly sensitive to influent quality and changes in influent quality negatively affected effluent quality; (ii) aesthetic, compact, automated and produced effluent suitable for multiple non-potable domestic applications; (iii) triple the cost of package plants 1 and 2;
- Package plant 2 (i) was designed specifically for toilet flushing; (ii) used a 2mm sieve with disinfection tablets manually inserted into the sieve twice a week; (iii) required weekly maintenance (iv) houses a greywater tank deliberately kept small in volumes to reduce the potential for treated greywater to be stored for more than 24 hours, thereby reducing the possibility of pathogen growth; (v) cost the least to install among the three; and (vi) was made from local materials.
- Package plant 1 (i) obtained the least score in the framework; and (ii) was made from local materials.

6.2 Selected Package Plant

Package plant 2 emerged as the most appropriate system out of the three package plants for the two pilot sites (UJ and WITS). The selection was based on the fact that it was cheap, rugged, functional and easy to change/upgrade if and when necessary.

Table 3. Framework for evaluating greywater treatment plants for toilet flushing

Criteria	Scores			Weight	Literature reference
	0	1	2		
Technical key issue					
Treatment technology	Secondary and tertiary treatment	Primary Treatment only/ no info		1.00	Li et al. (2009)
Pre-treatment and storage	Yes	No / no info		1.00	Li et al. (2009)
Disinfection	Yes	No / no info		1.00	Li et al. (2009)
Operating range (kl/d)	0.5-100 (Covers a wide range 4-500 PE)	0.5-10 (household)	10-100(clustered development<= 500 PE) / no info	1.00	Holt and James (2003)
Footprint (m²)	1.2-124 (Covers a wide range 4-500 PE)	1.2 to 3 (household)	3-124(clustered development<= 500 PE) / no info	1.00	Holt and James (2003)
Life cycle (years)	>= 25	25 to 15	< 15 / no info	1.00	USEPA (2007) and Gaydon et al. (2007)
Level of operator skill	Low	Moderate	High / no info	1.00	USEPA (2007) and Gaydon et al. (2007)
Ease to upgrade	Yes	No / no info		1.00	USEPA (2007) and Gaydon et al. (2007)
Weighted mean of real scores					
Economic key issue					
Cost (Rand)	< 50 000	50 000 -100 000	> 100 000 / no info	1.26	Holt and James (2003)
Operating cost (Rand/year)	< 5000	5000 to 10 000	>10 000 / no info	1.26	Holt and James (2003)
Weighted mean of real scores					
Public safety and safety (I.E. Water quality) key issue					
BOD (mg/l)	<= 10	> 10 / no info		1.13	USEPA (2007)
COD (mg/l)	< 75	> 75 / no info		1.13	DWAF (1998); Prathapar et al. (2005)
Total Suspended Solids (mg/l)	< 30	> 30 / no info		1.13	German Standard (DIN 38404-4:1976-12)
Turbidity (NTU)	<= 2	> 2 / no info		1.13	USEPA (2007)
Free chlorine (mg/l)	>= 1	<1 / no info		1.13	USEPA (2007)
pH	6 to 9	no info		1.13	DWAF (1998); USEPA (2007)
Total Coliform	Non detected	Detected / no info		1.13	USEPA (2007)
E. coli	Non detected	Detected / no info		1.13	DWAF (1998); USEPA (2007)
Weighted mean of real scores					
Aggregate of the weighted mean of real scores					

Table 4. Key issues in order of priority to be considered when assessing the feasibility of implementing a dual water reticulation system (Ilemobade et al., 2009)

Key issues	Decision-makers ranking	Weight
Technical	1	1.00
Public health and safety	2	1.13
Economics	3	1.26
Social acceptance	4	1.93
Legislation	5	2.13
Organisational capacity	6	2.40
Public education	7	2.43

Table 5. Summaries of the 10 locally available greywater/wastewater package plants and the key elements in the selection process

Plant Number	Treatment processes	Features of package planet (e.g. treatment technology)	Operating range in L/hour or	Cost of purchasing the plant	approximate cost of operating the	Energy consumption	Footprint	Level of skill required for operation	Ease to upgrade	Water quality is suitable for
1	physical+ tertiary treatment (chlorine)	Greywater is collected and channelled through a two 2 mm sieves in series (which are housed within a cylindrical pipe) and disinfected using 200g Sanni tabs4a (chlorine + bromine tablets) which were inserted into the sieves once a week. The greywater was then stored within a 200 litre greywater tank which houses 2 submersible pumps (each pump was connected to a toilet). When the bell-push is push is pushed and held, filtered and disinfected greywater is pump directly into the toilet pan for flushing without the need for a toilet cistern. As soon as bell-push is released, the flushing stop	No restriction to flow rate	R8000 to R12000 per unit this exclude the installation cost	R1200 per year	360 watts	1m2	Moderate	Yes	Irrigation toilet flushing car wash
2	Biological treatment (Aerobic –combination of suspended growth and Fixed film method) tertiary treatment (chlorine, ozone, UF or activated carbon)	The system is based on a submerged fixed-film Aeration technology where bacteria are supplied with air (oxygen) and food (sewage) and thus perform biochemical breakdown of the effluent. It consist of two bioreactors, clarifier and chlorine disinfection	1500 to 3000 l/day	Above R100,000	Not specified	Not specified	Not specified	Low	Yes	Irrigation toilet flushing
3	Per-treatment + biological treatment	The system of fully automated. The treatment unit consist of (1) a filter which removes the coarse particles	500-3000kL/d	AUS $6,680 above	High	Approx 2.5 kWh/day	2m2-100m2	High	No	Irrigation toilet

	(Aerobic- two stages of suspended growth method)+ tertiary treatment (chlorine, ozone or UV)	from the incoming gray water from the shower or bath tub. (2) then the water undergoes the first stage of biological treatment with the supply of atmospheric oxygen, microorganisms degrade the contaminants in the water. (3) in the second stage of biological treatment, the process of the first stage is repeated.(4)in the final stage, the water in disinfected by using an UV lamp and stored in		R100,000						flushing
4	Biological treatment (Anaerobic)+ biological treatment (Aerobic-suspended growth method)+Tertiary	The treatment process involves an activated sludge process, which involve four major processes: 1. Collection and anaerobic storage 2. Aeration of the sludge 3. Settling of sludge removing all solids 4. Chlorination to bring the final effluent up to the required standard	Not specified	R27,000 for the unit only	5000 per month including electricity	Not specified	Not specified	High	Moderate	Irrigation
5	Physical+ tertiary treatment (ozone)	Ozone disinfection. For a gray water system, it can be a combination of a 50 liter jojo tank for storing bathing water and can be connected to an ozone generator while the effluents are later stored in another Jojo tank before it is pumped out.	751/day	R20,000carbon filter +ozone generator only	Not specified	60amps	3m2	Low	Yes	Irrigation toilet flushing
6	Biological treatment (Aerobic-combination of suspended growth and Fixed film method)+ tertiary treatment (chlorine, ozone, UF or activated carbon)	The operation process of the treatment planet is mainly extended Aeration Activated sludge or submerged aerated fixed film both utilizing ozone... Ultra UF and activated carbon dosing system for disinfection and for pH correction and phosphorus removal	15000 l/day to 2Ml/day	R350,000	R15,000p/a	20kw/hrs	40-60m2	Low	Yes	Irrigation toilet flushing car wash
7	Physical + Biological treatment (Anaerobic)+ biological treatment (Aerobic-suspended growth method)+ tertiary treatment (chlorine, ozone or UV light)	Submerged Aeration media (SAM). The method of treatment comprises seven sequential treatment steps and involves: (i) solids removal by either a solid collection basket or a screening grid, (ii) an anaerobic settler, followed by (iii)an anoxic settler and (iv)an aeration chamber into which air is blow to supply the required volume of oxygen. (v)the settler, in which micro-organism and any remaining inorganic material is settled out and returned to the primary anaerobic settler by a unique efficient venture method (vi)an extended anoxic chamber after the settler that assists in the removal of nitrates (vii)a disinfection chamber that uses	10-100 l/day	Above R100,000	Not specified	2,2-5,5kw	16m2-160m2	Low	Yes	Irrigation toilet flushing car wash

		either chlorine,								
8	Physical + tertiary treatment (ozone)	Ozone disinfection. For greywater system, it can be a combination of a 50 liter Jojo tank for storing bathing water and connected to an ozone generator. The effluents are later stored in another Jojo tank before it is pumped out	Not specified	R 87,000	Not specified	Not specified	Not specified	Not specified	Not specified	Irrigation toilet flushing
9	Physical + biological treatment (anaerobic) + biological (aerobic-Fixed film method)+ Tertiary treatment (chlorine)	The operational process of the plants is simple and comprises of a primary combined settlement tank and anaerobic digester, a secondary aerobic process comprising of the bio-filter RBC fixed film reactor units, followed by a humus settlement tank and a disinfection tank	10k/day (50 persons)-500kl/day (2500)	Above R100,000	Not specified	0.5-6kw	150m2-1200m	Low	Yes	Irrigation toilet flushing car wash
10	Physical + biological treatment (anaerobic)+ biological treatment (Aerobic – suspended growth method)+ tertiary treatment (chlorine)	The treatment process consists of septic tank which acts a primary digestion. From the septic tank effluent flows to the aeration chamber of the bioreactor, in this tank compartment an aerator blows a huge volume of air into the water at an adjustable depth, in the form of micronized bubbles. It mixes with the turbulence optimizing the dissolution of air and oxygen in the water, neutralizing polluting elements. Immediately after the aeration chamber is a settling chamber which acts as a clarifier. This is where the sludge is separated and pump back to the septic tank. The effluent from the settling tank is pumped via a submersible pump through a flow meter with a pulse emitter, which activates the desired units of chlorine into the liquid, and then on to a contact tank. In order to maintain the correct balance the plant needs supplementary dosing of enzymes and bacteria monthly	500 l/day	Above R100,000	Not specified	Not specified	Not specified	Low	Yes	Irrigation

Table 6. Results of the evaluation of ten greywater/wastewater treatment package plants with effluent for toilet flushing

Criteria	Weight	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Plant 7	Plant 8	Plant 9	Plant 10
		Real Score x Weight									
Technical											
Technology	1.00	0	1	0	0	1	0	0	1	0	2
Pre-treatment and storage	1.00	1	1	0	0	1	0	0	1	0	2
Disinfection	1.00	0	0	0	0	1	0	0	0	0	2
Operating range (kl/d)	1.00	0	1	0	2	1	1	1	1	2	2
Footprint (m²)	1.00	1	1	0	2	1	2	2	2	2	2
Life cycle (years)	1.00	1	1	1	2	2	2	0	2	2	2
Level of operator skill	1.00	0	0	0	0	0	0	0	2	2	2
Ease to upgrade	1.00	0	0	0	1	0	0	0	2	2	2
	Weighted Mean	**0.38**	**0.63**	**0.13**	**0.88**	**0.88**	**0.63**	**0.38**	**1.38**	**1.25**	**2.00**
Economics											
Cost (Rand)	1.26	0	0	1.26	0	0	1.26	2.52	1.26	2.52	2.52
Operating cost (Rand/year)	1.26	0	0	1.26	0	1.26	2.52	2.52	2.52	2.52	2.52
	Weighted Mean	**0.00**	**0.00**	**1.26**	**0.00**	**0.63**	**1.89**	**2.52**	**1.89**	**2.52**	**2.52**
	Aggregate of weighted mean of real scores for Technical and Economics	**0.38**	**0.63**	**1.39**	**0.88**	**1.51**	**2.52**	**2.90**	**3.27**	**3.77**	**4.52**
	Score range	0.00				2.26					4.52
Public health and safety (i.e. water											
BOD (mg/l)	1.13	1.13	1.13	0	1.13	1.13	1.13	1.13	1.13	1.13	2.26
COD (mg/l)	1.13	0	1.13	0	1.13	1.13	0	1.13	1.13	1.13	2.26
Total Suspended Solids (mg/l)	1.13	0	1.13	0	1.13	1.13	0	1.13	1.13	1.13	2.26
Turbidity (NTU)	1.13	1.13	1.13	0	1.13	0	0	1.13	1.13	1.13	2.26
Free chlorine (mg/l)	1.13	1.13	1.13	0	1.13	1.13	0	1.13	1.13	1.13	2.26
PH	1.13	0	0	0	1.13	0	0	1.13	1.13	1.13	2.26
Total Coliform	1.13	0	0	0	1.13	0	0	1.13	0	0	2.26
E.Coli	1.13	0	0	0	1.13	0	0	1.13	0	0	2.26
	Weighted Mean	**0.42**	**0.71**	**0.00**	**1.13**	**0.57**	**0.14**	**1.13**	**0.85**	**0.85**	**2.26**
	Aggregate of weighted mean of real scores for Technical, Economics and Public health and safety	**0.80**	**1.33**	**1.39**	**2.01**	**2.07**	**2.66**	**4.03**	**4.11**	**4.62**	**6.78**
	Score range	0.00				3.39					6.78

7. CONCLUSION

GWR offers environmental and economic benefits. However, it is accompanied by risks and problems which require particular care and solutions in order to ensure a responsible use. In cases where there is high like-hood of human contact with the use of greywater for toilet flushing, disinfection is required, therefore secondary and tertiary system are more applicable. GWR in a single dwelling system are more likely to offer the greatest benefit of greywater reuse due to the possibility of gardens irrigation. However, the level of technological understanding by the reuse system operator is likely to be lower and therefore the level of sophistication of the systems on these scale would generally be low preferably, a simple treatment system. In a multi-dwelling or a community based greywater reuse system, biological treatment processes can be more effectively utilized due to high quantity and variability in the quality of greywater produced. Maintenance and operation of an efficient system may require a caretaker for the system as individuals are likely not to take ownership or responsibility of the system. The parameters for the greywater system would therefore involve large volumes storage to dilute varying greywater quality and high quality of treatment with safe application to reduce health concern.

Package plant 2 was selected after the extensive investigation into the locally available greywater technologies as shown above. The selection was based on the fact that it was cheap, rugged, functional and easy to change/upgrade if and when necessary. Although specific criteria to assess various treatment unit differs from one application to the other and are also site specific. (incomplete because you started the sentence with the word "Although". in other words, this application/exercise would affect the weighting factor for each criterion. It is highly recommended that a site/application specific framework be developed for individual greywater reuse application.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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