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Solutions for Decentralized Greywater Treatment

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Solutions for Decentralized Greywater Treatment

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environment and Natural Resources - Specialization Sustainable Water and Sanitation, Health and Development

By

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Abstract

As the world water resources continue to deplete, reuse and recycling of greywater has become an alternative potential sustainable solution to reduce the stress on fresh water resources. The objective of this thesis is to assess the different technological approaches for greywater treatments and to provide an extensive review on the application of compacted decentralized solutions to produce high quality treated water suitable for non-potable household uses. The paper reviewed various solutions of decentralised systems for greywater treatment. Various compacted treatment technologies have also been examined. Both physical, chemical and biological treatment systems and their combinations are assessed. Moreover, case studies mainly on nature-based solutions, constructed wetland, presented. The thesis revealed that these systems are effective and have the potential of treating greywater to the level of good quality for safe discharge or for non-potable fit-for-purpose uses. Constructed wetlands, green roofs and green walls are recently receiving more attention in decentralized urban greywater treatment and are proved to have high removal efficiency of suspended solids, organic matter, microorganisms and micro-pollutants. These technologies are eco-friendly, energy efficient, less expensive and easy to operate and maintain. Treating greywater is not only an important option to help manage the balance between the demand and supply of water and reduce the burden on fresh water reserves, but also it provides an opportunity to avert environmental, surface and ground water pollution.

Acknowledgement

This thesis is submitted in partial fulfilment for the requirement for the award of a Master of Science at the Department of Environment and Natural Resource Management (Sustainable Water and Sanitation, Health and Development).

The research process, though tedious, was very interesting, insightful and enlightening. Nonetheless, there were some setbacks, including the global outbreak of COVID-19, which altered the initial objective to also include laboratory work. COVID-19, declared a global pandemic by WHO, led to global lockdowns, including Norway, which restricted access to the laboratory for conducting experiments. Thus, the paper resorted to review existing literature from online sources and articles.

My utmost and profound gratitude goes to my lead supervisor, Petter D. Jenssen, and Melesse Eshetu Mogens, for their selfless and superb supervision. I am appreciative of the effort and time they spent to read, edit, comment and gather resources for this paper. Thank you.

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Timothy Boamah

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Abbreviations

BOD ____Biochemical Oxygen Demand

COD ____Chemical Oxygen Demand

CW ____ Constructed Wetland

DOC ____Dissolved Organic Compound

GROW ______________________________________GREEN Roof-top Water Technology

GWT _______________________________________Greywater Treatment

HSSF ______________________________________Horizontal subsurface flow

KIO_3 ____Potassium Iodiate

LWA _______________________________________Light Weight Aggregate

MP ____Member of Parliament

p.e ____ Population equivalent

PPCP ______________________________________Pharmaceuticals and Personal Care Products

STE ____Septic Tank Effluent

T & O ______________________________________Taste and Odour

USA____ United States of America

VF ____Vertical Flow

WHO____ World Health Organisation

WWTPS ____________________________________ Wastewater Treatment Plants

XOCs ______________________________________Xenobiotic Organic Compounds

CHAPTER ONE

1. INTRODUCTION

1.1 Challenges of water security in the world

About 71 percent of the Earth's surface is covered with water. According to Gleick (1993), the oceans contain about 97% of the total world water and fresh water constitutes the remaining 3% which is available for direct exploitation. However, only about one-hundredth of the freshwater, as shown in figure 1 below, is available as surface water (readily exploitable lakes and rivers) and accessible ground water for human consumption. The amount of fresh water actually available to people is, therefore, finite. Human life depends largely on water not only for drinking but also an extremely huge amount is used for agriculture, industry, electricity, transportation, waste disposal and recreation This amount faces extreme scarcity due to global population increase, urbanization, industrialization, improved living standards, climate change and increased pollution.

Figure 1: world water distribution (James and Stefan, 2015)

The world's population is increasing at a rate that outweighs the world's freshwater resources resulting in an uneven distribution of water globally. Currently, the world's population is estimated at 7.8 billion and growing at a rate of about 1.05%, annually (Worldometer, n.d). Most regions, especially arid regions, are faced with acute water shortage. According to Reid (2019), as of 2018, water scarcity affected 2.1 billion people globally. The growth in population coupled with economic development accounts for the excessive stress on the world water supply.

Water usage for domestic, industrial and agriculture causes withdrawal of water from diverse sources. According to AQUASTAT (2014) water withdrawal has occurred about 1.7 times above the rise in population. Additionally, Ritchie and Roser (2020) agree that the withdrawal of fresh water due to domestic, industrial and agriculture use has increased about six-fold since 1900. Ritchie and Roser (2020) states further that the highest freshwater withdrawal above 760 million cubic meters per year occurred in 2014 in India, followed by China and the United States at over 600 billion m^3 and 480-90 billion m^3, respectively. According to Ritchie and Roser (2020), agriculture accounts for an estimated 70% of freshwater withdrawal globally, whilst industrial and domestic account for 19% and 11%, respectively. Figure 2 below shows the global water withdrawal trend over the years.

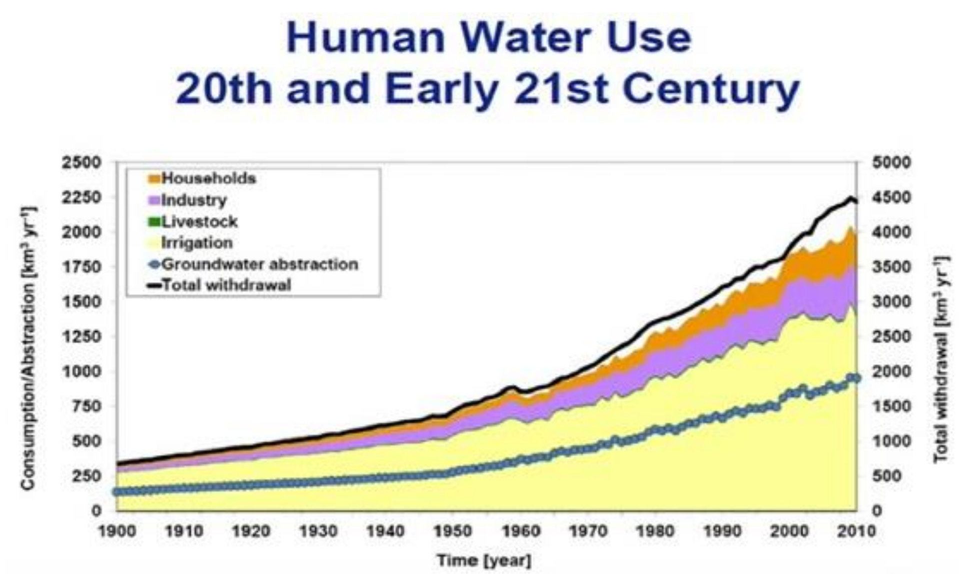


Figure 2: Global water withdrawal trend for the 20th and 21st centuries (Wada et al. 2016).

Anthropogenic uses of water, evidently, play a key role in the world water crisis and projections are that an acute scarcity is imminent. The concerns regarding water can be divided into two categories: quantitative and qualitative. Quantitative refers to issues such as whether we will have enough water to meet our needs and what will be the impacts of diverting the water from one point of cycle to another. Qualitative refers to issues, such as whether the water is polluted or has sufficient purity so as not to harm human or environmental health.

According to AQUASTAT (2014) approximately, 1800 million people will live in extreme water scarce conditions across the globe by 2025. This is alarming and threatens life on earth. Domestically, the use of freshwater just for flushing accounts for about 40%. On a daily basis, individuals excrete about 1.02.5 L of urine and 120400g of faeces and the centralized system uses around 615 times of water to flush each litre (Rauch, et al., 2003; Schouw, et al., 2002).

Urbanization poses dire challenges for water resources. Life in cities is predominantly associated with increased per capita water consumption, land use patterns and social conditions due to the increase in the usage of water and energy by the rich (Tiboris, 2016). A study conducted by Wu and Tan (2012) found that, in the last decade rapid rise in housing complexes, industrial parks and power projects in China has resulted in an increase in water consumption and demand leading to an increased pressure on freshwater resources. As cities expand, industries are likely to spring up and demand water for production causing more stress on the water supply. Ironically, though industrialisation leads to economic benefit, a study conducted by Zhou et al., (2017) found that the emergence of industrial agriculture will promote rural employment and improve standard of living but will exacerbate the outflow of water and cause mayhem between diverse consumers. Even more ironic is the fact that water scarcity will lead to inflation of products as a result of increase in the price of water.

As rapid urbanization and industrialization increase water consumption, there is a high probability of increase in both domestic and industrial wastewater. Thus, surface and groundwater will be polluted due to the discharge of effluent from septic tanks and leachate from drains and soak pits. Qin et al., (2014) investigated the causes of change in water quality in China during the rapid urbanization period and found that the rise in domestic discharge due to the rapid urbanization led to water pollution. The discharge of effluent into surface water without treatment will also result in eutrophication. Balke et al., (2018) found that wastewater discharge was the main source of phosphorus introduction into a shallow lake in the USA and rendered the lake eutrophic.

Studies also show that as demand for water increases across the globe, the availability of freshwater in many regions is likely to decrease because of climate change. Changes in climate may result in flooding, due to increased precipitation, and drought, due to less precipitation and increased atmospheric temperature. If the observed changes in climate in the last decades persist into the future, the potential impacts on water resources are likely to increase in magnitude, diversity and severity (United Nation Water, 2014). An increase in precipitation will increase surface runoffs which will transport nutrients and pathogens from nonpoint sources into surface water. Mainstone and Parr (2002) agree that agricultural fields' runoffs are a crucial nonpoint source nutrient pollution of lakes. The introduction of nutrients into water bodies will lead to eutrophication resulting from high concentrations of nitrogen and phosphorus, thereby altering the quality of the water. The impact of climate change on surface water eutrophication stems from the interaction between the meteorological factors and nutrient availability. As precipitation erodes nutrients from agricultural fields and sewage systems into the water body, drought will inhibit dilution of the received nutrient. Xia et al., (2013), adds that soil erosion resulting from floods transport a great amount of nitrogen, pathogens and other toxins into water bodies. Wang et al., (2018) found that increased precipitation caused increased streamflow leading to the transportation of NO_3-N from hillslopes into the Green Lake watershed. Added to floods and drought is the issue of atmospheric temperature. When air temperature is high, surface water temperature also increases leading to an altered physio-chemical composition and biological reaction of the water. These factors render various water bodies, which serve as sources of global drinking water, undrinkable. Fecht (2019), agrees that changes in climate will put immense stress on global drinking water.

1.2 Greywater as a potential alternative source to mitigate water insecurity

As the world water sources deplete, there is a rising need to find innovative solutions to salvage life on earth, since water is required by both living and non-living organisms to survive.

Several solutions have been proposed, including the invention of water-free toilets, a campaign to reduce water usage, wastewater treatment, amongst others. In recent times, the treatment of wastewater has, arguably, become a more plausible approach as more and more countries have taken keen interest in investing in WWTPs for the purpose of treating wastewater for reuse.

Many countries spend huge amounts of money to treat water for drinking. According to Cho (2011), billions of dollars is used to treat water in the US but only 10% is used for drinking and cooking, the rest is, mostly, flushed away. As mentioned earlier, the use of wastewater for irrigation, landscaping, toilet flushing is a historical practice. However, drinking recycled wastewater on the other hand, is not so welcomed as people are repelled by the thought of drinking toilet water. But, an acute water scarcity in Namibia around the mid 1900 led to the establishment of the Goreangab wastewater recycling plant in 1968; designed to treat 27,000 m^3/day of sewage but now treating 41,000 m^3/day at peak hours and produces 35% of all potable water used in the city daily (Wingoc, n.d; Gross, 2016; Du Pisani, 2004).According to Wingoc, (n.d), the Goreangab wastewater recycling plant treats secondary effluent from the Gammams Water Care Works and Goreangab dam via a ten step process depicted in figure 3 below:

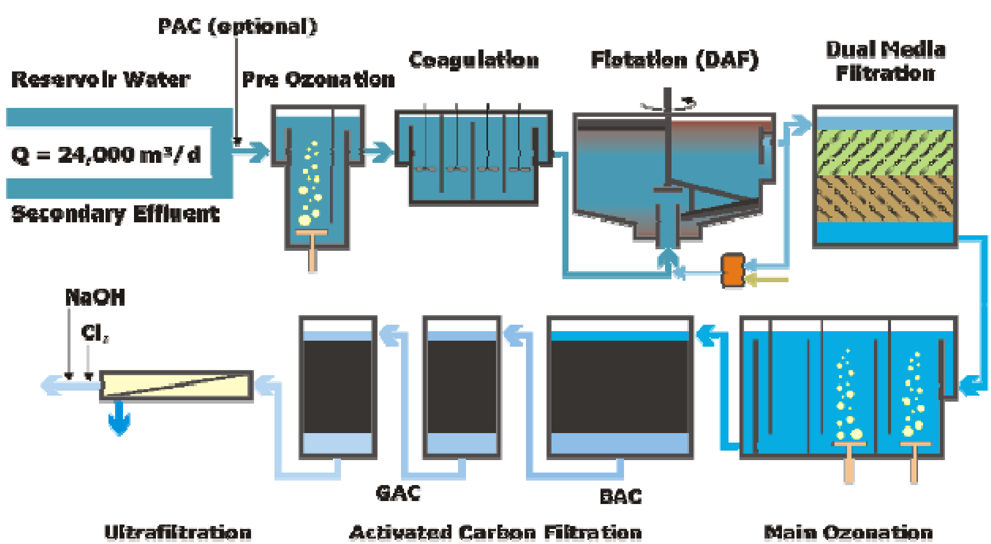


Figure 3: Flow chart of water treatment at the Goreangab wastewater recycling plant (Lahnsteiner & Lempert, n.d).

Moreover, in Singapore, the provision of water supply was a huge challenge for decades, as it has no natural aquifers and a small landmass (Cho, 2011). Since 2003, Singapore has been producing drinking water from wastewater using NEWater (use of advanced membrane techniques such as microfiltration, reverse osmosis and UV disinfection) and has passed about 65,000 scientific tests which supersedes the WHO drinking water standards (Cho, 2011). Figure 4, shows the NEWater process cycles:

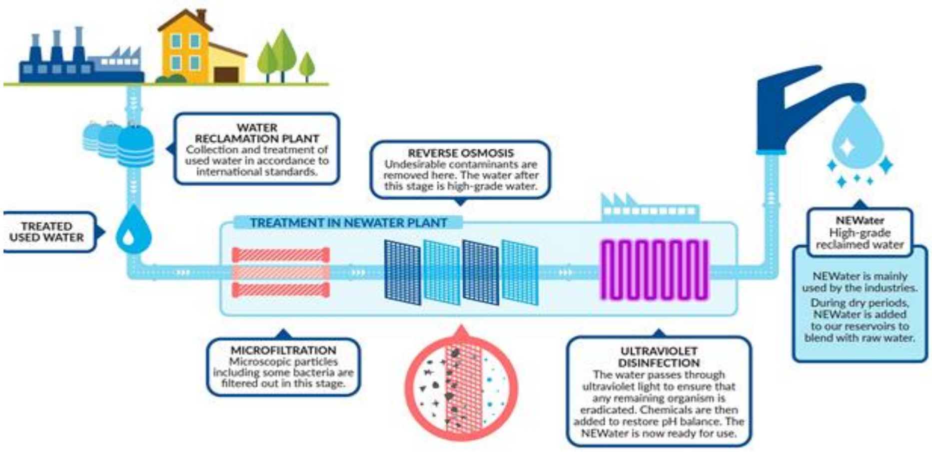


Figure 4: NEWater process cycles. (PUB, Singapore's National Water Agency.)

When it comes to drinking water, greywater is usually the preferred choice of wastewater for treatment due to the very little nutrients and pathogens it contains as compared to blackwater (water from the toilet). Internationally, the attempt to reuse and recycle waste has seen the emergence of the 3R (reduce, reuse, recycle) campaign. This campaign also captures the attempt to manage the available freshwater and to safeguard the current and imminent water scarcity. Reducing the consumption of water will translate into minimal withdrawal of water resources. According to WHO (2006), the reuse of greywater helps to conserve about 40% of fresh water supplies. Again, the option to reuse wastewater, specifically greywater, for toilet flushing, irrigation, etc will add up to the management approach to safeguard the scarce freshwater resources. Further, recycling greywater for both portable and non-portable uses is, debatably, the best solution for its management as well as to combat the stress on the world water supply. The recycling of greywater in recent times has become highly imperative, especially in arid regions. Greywater has been treated and reused in several countries for varied reasons. For

Japan, reusing greywater serves as an augment to their scarce water supply in order to meet the rapid rise in their population; in the USA, for instance, greywater is reused for irrigation, toilet flushing and groundwater recharge in a bid to guard against drought (Lazarova et al., 2003; Al-jayyousi, 2003). In countries and states like Australia, California, New Mexico, etc, wastewater is recycled for drinking.

Historically, greywater has been rationed for the purposes of irrigation, lawn watering, vehicle washing, and other non-potable uses (Chong et at., 2015) in the a bid to, locally and nationally, adapt to issues emanating from climate change, ensure food security, reduce environmental, ground and surface water pollution, and safeguard water supply (Drechsel et al, 2015). According to Monteleone et al., (2007) the use of greywater for non-potable uses was a well-known phenomenon in the water supply system of ancient Roman; and to augment freshwater supply in the Minoan civilization in ancient Crete where, dating back 5000 years, wastewater was reused for agricultural irrigation (Vigneswaran and Sundaravadivel, 2004). Vigneswaran and Sundaravadivel (2004) mentions further that, since the 16th and 18th centuries, Germany and UK, respectively, have used wastewater for agricultural purposes; likewise China and India who have long histories with the reuse of sewage for irrigation. In recent times, greywater is still being treated and used for irrigation and other purposes. For instance, in an arid country like Oman, greywater is treated, as part of the Government's policy, for irrigation and it as well constitutes 80% of water used in Omani households (Ahmed et al., 2011).

The need for greywater recycling for both potable and non-portable uses is highly necessary to help reduce the excessive reliance on the limited freshwater resources and also reduce pollution of the environment caused by the discharge of untreated greywater effluent, as well as provide a source of water supply for arid regions. However, concerns are raised regarding public health perceptions and the appropriate technology for greywater reuse options (Vigneswaran and Sundaravadivel, 2004). The reuse and recycling of greywater has become necessary because:

- It provides a supplement to the world's scarce freshwater resources
- It provides an avenue to manage water supply in-situ

- It reduces environmental and water (surface and ground) pollution.

1.3 Objectives

The objective of this thesis is to assess the different technological approaches to greywater treatment and to provide an extensive review on the application of compacted decentralized solutions to produce high quality treated water suitable for non-potable household uses.

CHAPTER TWO

2.0 Material and Methods

This thesis was first designed to assess the performance of a compacted solution for decentralized greywater treatment based on practical laboratory work. The experiment planned to use greywater from Kaja student dormitory at the Norwegian University of Life Sciences (NMBU), Ås, Norway. Unfortunately, first due to some technical problems and later due to COVID-19 access to greywater the laboratory was restricted. It was then decided that the thesis should be a Literature review based. Google scholar was used to collect different peer review articles for literature research.

2.1 Data collection and analysis

Several literatures were reviewed to write this paper. Relevant document search was carried out on the internet using the keyword "greywater", "decentralized solutions", "constructed wetlands", "biofilter systems", "green roofs", "green walls". The focus of the search was largely on greywater reuse and applications in a decentralized urban setting. A distinction was carried out to identify studies directly relating to greywater treatment and applications by systematically reviewing abstracts and in some cases conclusions of each work.

Through the search, it was identified that the term "constructed wetland" was directly related to wastewater treatment and a preferred decentralized nature based solution for greywater treatment. Different physical, chemical, biological treatment processes and technologies were assessed and reviewed. Urban green infrastructure (green roof and green wall) as alternative and an emerging nature based solution for greywater treatment were also investigated.

CHAPTER THREE

3.1 Greywater: definitions and characteristics

Greywater has been defined by various researchers. For Casanova et al., (2001), greywater is wastewater without toilet water. It is, basically, water derived from showers, laundry and the kitchen. Greywater is very voluminous and potentially suitable for reuse and application, and it provides an imperative opportunity to mitigate the world water crisis.

Lifestyle and climatic conditions define the composition and characteristics of greywater (Abedin and Rakib 2013; Katukiza et al. 2015). Again, depending on the source, grey water can be categorized into light and dark. Wastewater from the showers and the tubs is known as light greywater (Friedler and Hadari, 2006) whilst dark greywater refers to a more contaminated wastewater from the washing machine, dishwashers and the kitchen sink (Birks and Hills, 2007). Figure 5 below shows the categories of greywater:

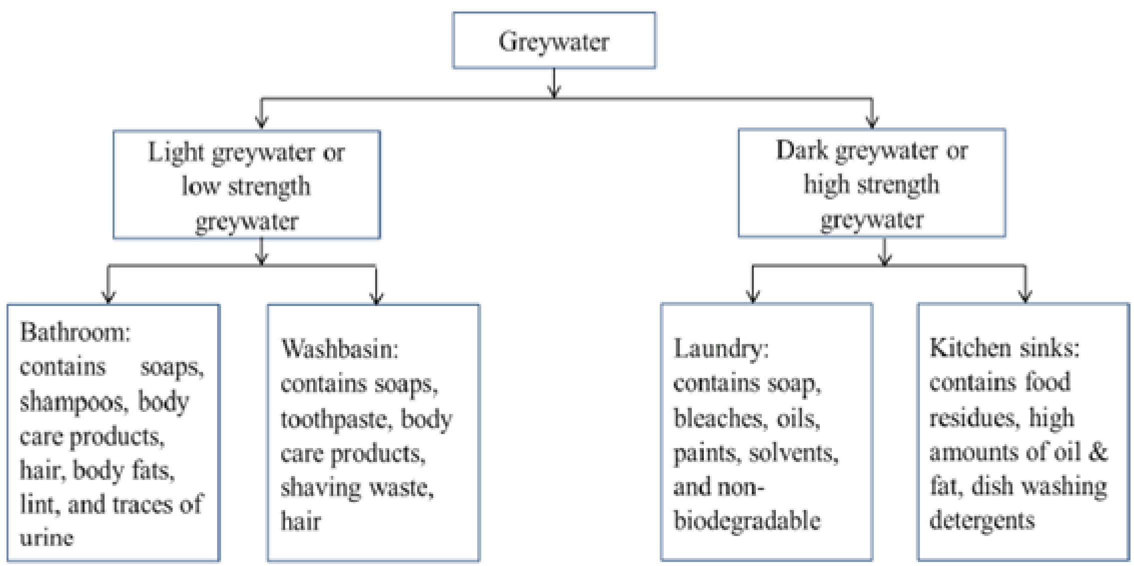


Figure 5: Greywater categories and its components. (Albalawneh et. al., 2015).

3.2. Greywater quantity

The quantity of greywater produced domestically is averaged at 15/lpd for poor areas and above 100/lpd for rich areas (Oteng-Peprah et al., 2018). The domestic use of water produces about 75% greywater of total wastewater and has less contaminants compared to blackwater (Eriksson et al., 2002). Oteng-peprah et al., (2018) posits that geographical location, lifestyle, climate conditions, type of infrastructure, culture and habit determine the quantity of greywater produced in different locations. To confirm this, Alsulaili and Homoda (2015) found that high school students produced less greywater than primary pupils because the former are mature and use water diligently. Again, greywater quantity may vary according to its source and water consumption. Greywater from the kitchen sink and dishwasher contributes 27% and wash basins, bathroom and shower produces 47% whilst the laundry and washing machine accounts for 26% (Jamrah et al., 2006; Al-Mughalles et al., 2012; Ghaytidak and Yadav, 2013). Whereas water consumption may range between 40-381 L/P/d, greywater quantity may range between 35-117 L/p/d with a ratio of 0.3-0.87, which was found to be low in high-income countries even though water consumption was high (Ghaytidak & Yadav, 2013; Alsulaili & Homoda; 2015). There is a global disparity in the amount of greywater produced around the world. Economical (i.e. developed, developing or least developed), technological and cultural orientations account for the quantity of greywater produced in various countries. In Europe, the quantity of greywater produced is minimal due to their water saving culture (Boyjoo et al., 2013). According to Morel and Diener (2006), Asia produces about 72-225 lpcd of greywater, whilst about 200 ipcd is produced in the USA (WHO, 2006). In Norway, greywater from the ecovillage project was found to be 81L/p/d whereas student dormitories in Kaja produced 112L/p/d, even though water saving showerheads where used; this could increase to 156L/p/d in the absence of showerheads (Jenssen, 2002). A typical demonstration of greywater from various sources in a Norwegian residence is illustrated in fig 6

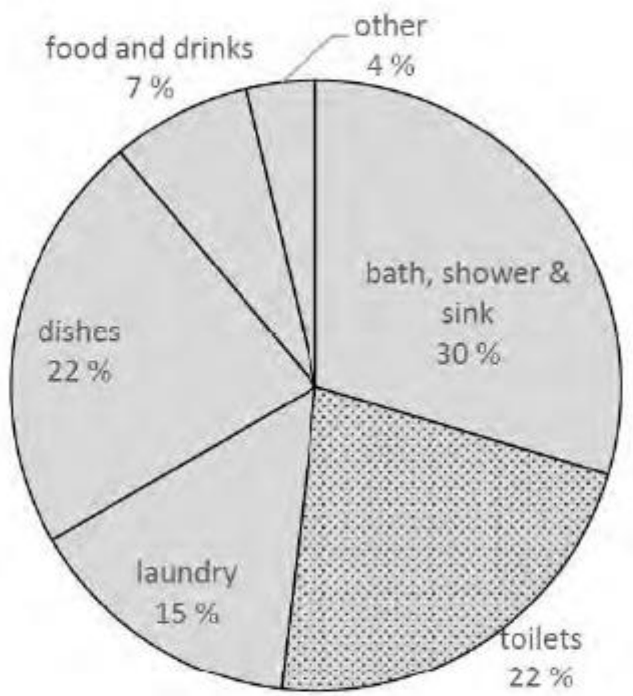


Fig 6: quantity of greywater from various sources in a Norwegian residence (Ødegaard et al., 2012).

Typically, the quantity of greywater varies from 90 to 120L/p/d but in low income nations where water scarcity is rampant, the volume can be as little as 20-30L/p/d (Morel and Diener, 2006). The disparity in greywater quantity can also be found in rural and urban areas as illustrated in figure 7.

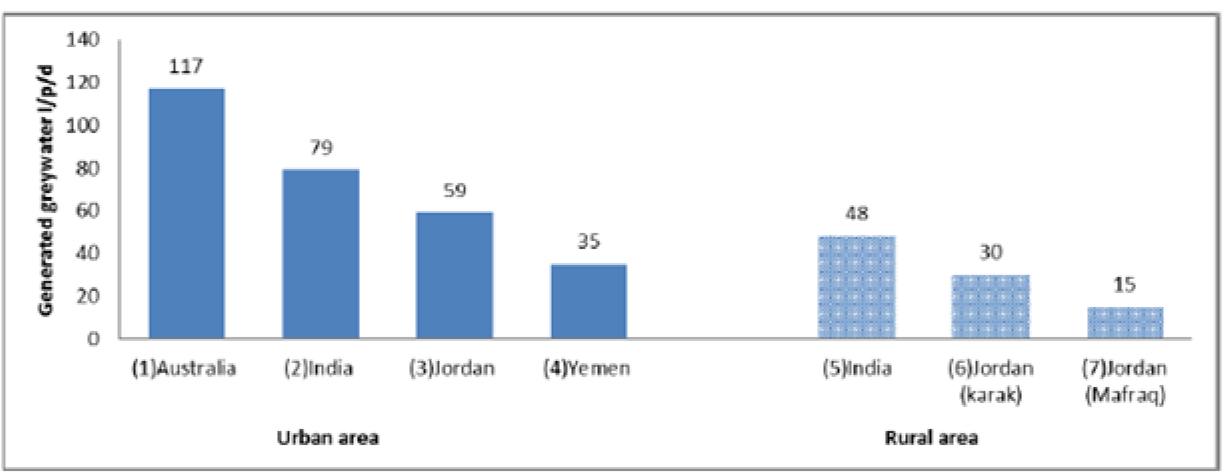


Figure 7: Quantity of greywater produced in urban and rural areas (Albalawneh and Chang, 2015).

3.3 Greywater quality

The quality of greywater vary from region to region and among individual households depending on its composition. Greywater composition depends on the quality and amount of water supply and usage, water source, plumbing system, living habits, personal hygiene of the users, and type of greywater. In addition, the cleaning products, dishwashing patterns, laundry practices, bathing habits, and disposing of household chemicals will influence the characteristics of greywater (Al-Jayyousi 2003). As a result, the physical, chemical and biological characteristics of greywater vary greatly among families. Again, the chemical and biological degradation of some compounds in the storage system contribute to the change in quality of greywater.

3.3.1 Parameters for assessment of greywater treatment

The quality of greywater, its strength and pollutant level is characterized and expressed in terms of a combination of the physical, chemical and biological parameters.

3.3.1.1. Physical Parameters

The physical parameters that determine the characteristics and quality of greywater include, total solids (TS), total suspended solids (TSS), temperature, colour, and turbidity mainly resulted from food particles, hair and fibres and electrical conductivity (EC) due to ionic concentration. The concentration of physical parameters of high strength greywater are higher compared to those of the low strength greywater due to the input from laundry and kitchen.

3.3.1.2. Chemical Parameters

The chemical parameters comprises mainly of dissolved organic matter expressed as biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC)). Moreover, pH, alkalinity, nutrients (mainly N and P), heavy metals content, residual chlorine and recalcitrant organic compounds such as xenobiotic organic compounds (XOCs) are present in greywater (Eriksson et al. 2002). Elemental concentrations will vary according to the water quality and plumbing conditions. However it is well known that laundry detergents are a source of heavy metals such as Cd, Cu, Pb, Cr and Zn (Aonghusa & Gray, 2002) mainly originate from household chemical products such as detergent, soaps and dyes. Xenobiotic organic compounds (XOCs) are synthetic organic compounds that are present in household chemicals and pharmaceuticals and personal care products. XOCs can also be formed when chemicals are partially modified via chemical/biological treatment (Fatta-Kassinos et al. 2010).

3.3.1.2. Biological Parameters

Greywater may also consists of microorganisms including bacteria, viruses, and protozoans. The most common indicators to assess faecal contamination are coliform bacteria (e.g., faecal coliforms (FC), thermotolerant coliforms), *Escherichia coli* (E. coli) and faecal streptococci (Enterococci). Skin-associated bacteria *Staphylococcus aureus* and *Pseudomonas aerugina* can also be expected in greywater (Winward et al. 2008). In some cases, enteric pathogenic bacteria such as *Salmonella* and *Campylobacter* can also be introduced by inadequate food handling in the kitchen although the individual risk is higher from direct handling of the contaminated food (Ottosson, 2003).

These physical, chemical and biological quality parameters are used as a basis for establishment the guidelines for greywater recycling. Moreover, these water quality parameters are important in selecting appropriate treatment systems and intended greywater reuse. Greywater characteristics, mainly the organic fractions, biodegradability, and biodegradation rate under aerobic and anaerobic conditions are key factors in selection, design and operation of treatment systems. Although there are variations in greywater quality from region to region and from household to household, literature review shows that the analysis of the greywater characteristics by different categories (Table 1) indicates that greywater originated from the kitchen and the laundry are higher in both organics and physical pollutants compared to the bathroom and the mixed greywater (Li et al., 2009). Greywater characteristics and their concentrations around the world in presented in table 2.

Table 1. Characteristics of different household greywater streams (Li et al., 2009)

	Bathroom	Laundry	Kitchen	Mixed
pH (—)	6.4–8.1	7.1–10	5.9–7.4	6.3–8.1,
TSS (mg/l)	7–505	68 – 465	134–1300	25–183
Turbidity (NTU)	44–375	50 – 444	298.0	29–375
COD (mg/l)	100–633	231 – 2950	26–2050	100–700
BOD (mg/l)	50–300	48 – 472	536–1460	47–466
TN (mg/l)	3.6–19.4	1.1 – 40.3	11.4–74	1.7–34.3
TP (mg/l)	0.11– >48.8	ND – >171	2.9– >74	0.11–22.8
Total coliforms (CFU/100 ml)	$10–2.4 \times 10^7$	$200.5–7 \times 10^5$	$>2.4 \times 10^8$	$56–8.03 \times 10^7$
Faecal coliforms (CFU/ 100 ml)	$0–3.4 \times 10^5$	$50–1.4 \times 10^3$	–	$0.1–1.5 \times 10^8$

Table 2. Greywater characteristics and their concentrations in some countries. (eg, Norway, Sweden, German, Australia, Israel, UK, USA)

	pH	TSS mg/L	BOD mg/L	COD mg/L	Total colifirm bacteria MPN/100ml	E. coli MPN/100ml	Reference
Norway	7.1	51-270	50-250	135-485	2.98E+05-2.42E+07	1.10E+05-4.10E+06	Melesse, et al., 2014, Eregano et al., (2017);
Sweden	7.8	-	425	890	-	-	Ghaitidak & Yadav (2013)
Germany	7.6	-	59	109	-	-	Ghaitidak & Yadav (2013)
Israel	8.2	30-298	74-890	840-1340	-	5.0E+04	Ghaitidak & Yadav (2013)
Australia	-	74	104	-	-	-	Fowder et al., (2016)
UK	6.6–7.6	37-153	8.7-155	33-587	6.4E+3–2.2E+7	10–3.9E+5	Ghaitidak & Yadav (2013); Frazer-Williams et al., (2008)
USA	6.4	17	86	-	-	5.4E+02	Ghaitidak & Yadav (2013)

Greywater contains high amounts of biodegradable organic material. According to Oteng-Peprah et al., (2018), the BOD_5/COD ratios determine the biodegradability of greywater. BOD_5/COD ratio in greywater ranges between 0.31 and 0.71 (Halalsheh et al., 2008). Greywater also contains hazardous substances such as XOCs as found by Eriksson et al., (2002) in some chemical detergents used in Denmark. Donner et al., (2010) found that about 200 xenobiotic organic compounds are present in greywater. Troiano et al., (2018) found an increased tetracycline-resistant bacterial with high resistant traits as well as antibiotics resistance in treated greywater. Benzene and 4-nitrophenol can also be found in greywater (Revitt et al., 2011).

The physical appearance of greywater is composed of suspended solids, turbidity, conductivity, and temperature. According to Oteng-Peprah et al., (2018), greywater temperature ranges between 18 and 35^oC and that, the warm temperature, which may be as a result of the hot water used for domestic purposes, may cause microbiological growth leading to the precipitation of $CaCo_3$ and other inorganic salts.

Total suspended solids account for 190-537 mg/L (Edwin et al., 2014) and conductivity ranges between 14 and 3000 µS/cm (Fatarella et al., 2009) whilst turbidity may range between 19 and 444 NTU (Oteng-Peprah et al., 2018). Greywater may be high or low in pH depending on the alkalinity of the water supply and type of detergents used domestically. According to Oteng-Peprah et al., (2018) surfactants are the major chemical constituents found in greywater due to the washing and cleaning activities. The differences and rates of constituents in greywater is largely dependent on the source of contaminants, i.e. kitchen, laundry, washroom etc. Figure 8 below illustrates the various sources of greywater contaminants:

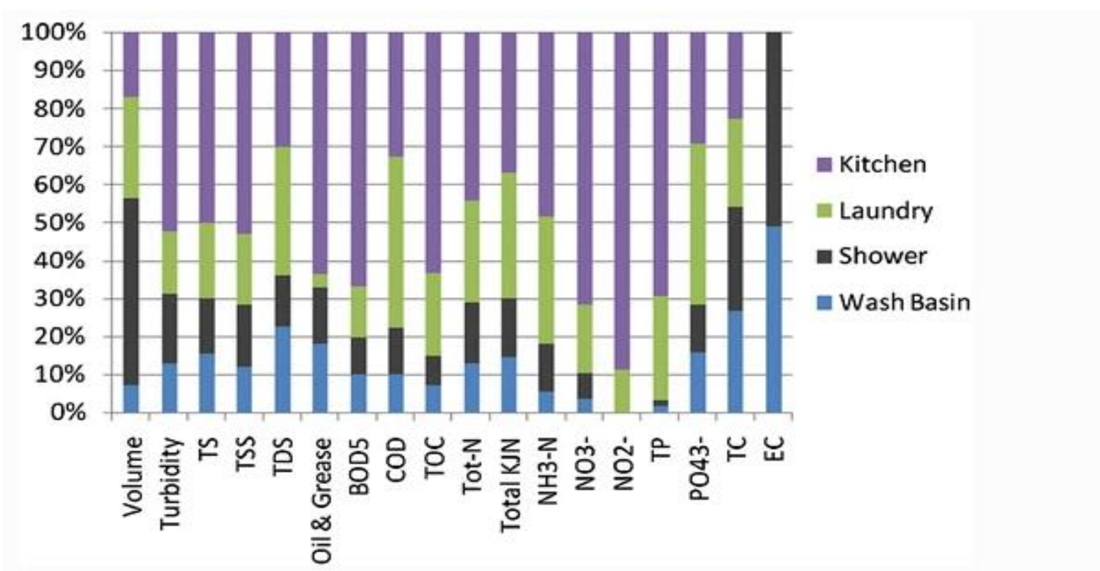


Figure 8: Sources of greywater contaminants (Fatarella et al., 2009)

3.4 Treatment Processes and Technologies employed for greywater treatment

3.4.1 Greywater treatment and discharge limits

The aim of greywater treatment is to fulfil the reuse requirement or local discharge permit level. For recycling purpose, the systems should fulfil mainly hygienic safety, aesthetics, environmental tolerance, technical and economic feasibility.

Greywater may be treated preliminary, primary, secondary, or tertiary. Each level of treatment is dependent on the organic content, the greywater quality, final application and acceptable standards. However, each level of treatment may be restricted to certain limits of nutrients and other physicochemical parameters it may remove. Table 3 shows the various level of treatment and their effluent quality:

Table 3: Treatment levels and their effluent qualities (WHO, 2006).

Parameter	Primary effluent g/m3	Secondary effluent g/m3	Advanced secondary effluent g/m3
Biological oxygen demand (BOD_5)	120–240	20	10
Total suspended solids	65–180	30	10
Thermotolerant organisms (cfu/100 mL)	Not applicable	200	10

Primary treatment systems must include a sedimentation tank for the removal of fats, grease and solids before final application (WHO, 2006). A primary diverted treatment system may be used for the irrigation of ornamental plants, fruit trees and fodder plants but, measure must be adopted to prevent leaching into groundwater, direct human and animal contact, and release of undesired substances and be sure of the exact quantity of nutrient needed for the plant and soil to avoid soil toxicity (WHO, 2006). Greywater intended to be discharged into lakes and rivers usually requires a secondary treatment. The oil/grease, solids and organic matter concentrations in greywater are usually removed with secondary treatment. Secondary treated and disinfected greywater may be used for micro-drip or irrigation and it's not harmful when in contact with humans. Largely, greywater intended for reuse is dependent on the required quality. Below is table 4 depicting greywater treatment levels and irrigation option.

Table 4: Greywater treatment level and irrigation options (WHO, 2006).

Treatment	Greywater reuse application
Untreated greywater	Bucketing (carry greywater manually)
Primary treated greywater	Subsurface irrigation
Secondary treated to a 20 mg/L BOD_5, 30 mg/L SS and possible disinfection to achieve 10 cfu thermotolerant coliforms/100 mL	Micro-drip and spray irrigation

Edwin et al., (2014) posits that there is no known globally accepted greywater treatment (GWT) method even though America and Australia have accepted standards that consider the greywater source, quality, site condition and reuse options. In Norway, for instance, pollution legislation requires a 70-90% reduction of BOD, 80% of phosphorus and 70-80% of nitrogen from urban wastewater effluent from over 100.000pe with a concentration of BOD <25 mg/L, TN < 10mg/L, TP < 1mg/L (Sagen, 2014). The WHO (2006) prescribes parameter limits for greywater reuse in table 5.

Table 5. Permitted limits for greywater reuse per final application (WHO, 2006).

Test	*Permitted limit*		
	a) Irrigation of ornamentals, fruit trees and fodder crops	b) Irrigation of vegetables likely to be eaten uncooked	c) Toilet flushing
Biological oxygen demand BOD_5 (mg/L)	≤ 240	≤ 20	≤ 10
Samples number	Sample/month	Two samples/month	Sample/week
Total suspended solids TSS (mg/L)	≤ 140	≤ 20	≤ 10
Samples number	Sample/month	Two samples/month	Sample/week
Faecal coliforms cfu/100 mL	≤ 1000	≤ 200	≤ 10
Samples number	Two samples/month	Sample/two weeks	Sample/week

Although GWT methods may differ from region to region, GWT is required to be eco-friendly with no chemical additives and toxic by-products. Harju (2010) adds that the storage time for greywater, before treatment, should be limited for the prevention of microbial growth.

3.4.2 Treatment processes and Technologies

Greywater treatment methods are, largely classified in relation to the contaminants removed and process used but each method adheres to the basic conventional wastewater treatment sequence, i.e pre-treatment, primary, secondary and tertiary. Biological treatment methods may not be appropriate for the treatment of greywater from the washbasin and bathroom due to its high concentration of soap and low concentration of biological essential macro and micronutrients. Biological treatment methods use a combination of microbes, and oxygen manipulation (Oteng-Peprah et al., 2018); and are categorized into aerobic and anaerobic. Chemical treatment methods adopt chemical processes such as electro-coagulation and photo-catalyltic oxidation for the removal of organics and coliforms (Li et al., 2019; Parsons et al., 2000). Some physical, chemical and biological treatment methods are discussed below.

3.4.2.1 Physical treatment process

Filtration

Filtration is a conventional method for the removal of turbidity, colloids and residual suspended solids. (Boano et al., 2019). Filtration is usually preceded by other methods to remove particulate matter. Filtration media could be in the form of sand, gravel, fine mesh, etc (Oteng-Peprah et al., 2018). Parjane and Sane (2011) treated greywater from bathroom, basins and laundry using sand bed, course size brick bed, charcoal bed, wooden saw dust bed and coconut shell as the filter media, shown in Figure 9. The average concentrations of the parameters used in both the raw and treated greywater is shown in Table 6

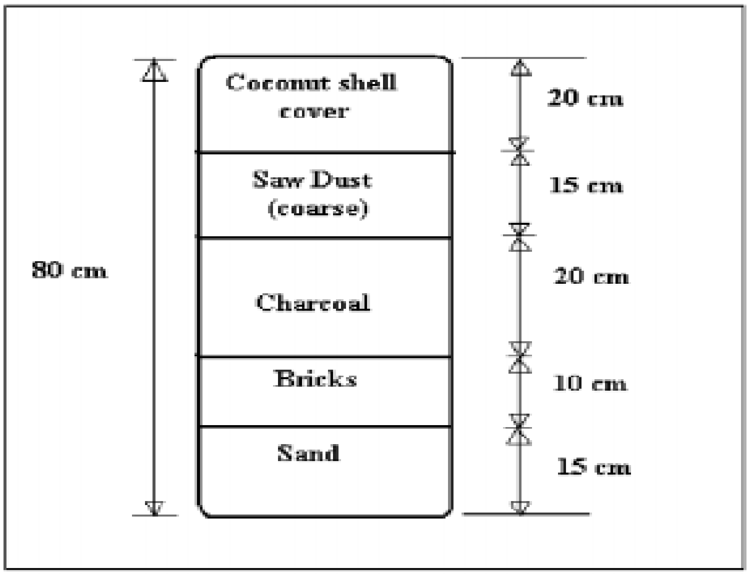


Figure 9. Arrangement of filter media in a filtration tank (Parjane & Sane, 2011)

Table 6. Average concentrations of parameters before and after filtration (Parjane & Sane, 2011)

Parameter	Raw greywater	Treated greywater
Ph	8.12	7.43
Total hardness(mg/l)	374	187
COD(mg/l)	327	58
TDS(mg/l)	573	172
TSS(mg/l)	184	32
Oil & grease(mg/l)	7.2	0.24
Florine(mg/l)	0.82	0.43
Nitrites(mg/l)	0.08	0
Nitrates(mg/l)	0.67	0.21
Phosphate(mg/l)	0.012	0
Sulphate(mg/l)	21.3	10.66
Sodium(mg/l)	32.28	17.11
Potassium(mg/l)	4.52	1.98
Magnesium(mg/l)	0.11	0
Ammonia-nitrogen(mg/l)	0.79	0.21
Calcium(mg/l)	0.13	0

Compared to the performance of other treatment methods, the filtration method used by Parjane and Sane (2011) seemed better due to its less operating and maintenance cost, lower load on fresh water, less strain on septic tank, highly effective purification, groundwater recharge and environmental friendly.

Sedimentation

Sedimentation is a physical treatment process used as a pre-treatment to remove hair, larger particles, oil & grease (Abdel -Shafy & Al-Sulaiman, 2014). Abdel –Shafy and Al-Sulaiman (2014) used two sedimentation tanks made up of polyvinyl chloride and an aeration tank consisting of dual baffled chambers of 350L (fig 10). The results following the 4.5h of settling showed effluent concentrations within average limits (Table 7).

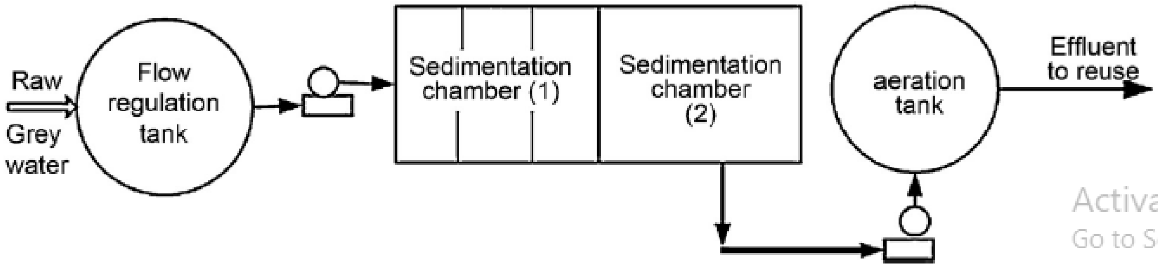


Figure 10. Schematics of a sedimentation tank (Abdel -Shafy & Al-Sulaiman 2014)

Table 7: Effluent quality after sedimentation (Abdel -Shafy & Al-Sulaiman 2014)

Parameter	Influent quality (mg/l)	% removed (mg/l)
TSS	116	66.5
COD	388	40.3
BOD	298.6	38.5
Oil & grease	128.5	50.2

3.4.2.2 Chemical treatment processes

Coagulation and flocculation

Coagulation and flocculation are the most commonly used chemical processes in the chemical treatment step of greywater treatment. Coagulation-flocculation involves the addition of compounds and/or polymers that promote the clumping of fine particles into larger floc so that they can be more easily separated from the water. Coagulation is a chemical process that involves neutralization of charge whereas flocculation is a physical process that assists in removal of colloids. Through these process suspended solids and turbidity (Sivaramakrishnan, 2008) are removed from greywater. According to Sivaramakrishnan (2008), chemical coagulation is followed by sedimentation and filtration after the water has been conditioned with various types of coagulants including, but not limited to:

- Aluminium sulphate
- Lime
- Ferrous sulphate

Pidou et al., (2008) found that coagulation with aluminium salt reduced BOD, COD, TN, Turbidity, Phosphate and bacteria from greywater from the shower. Table 8 below shows the various concentrations of contaminants before and after treatment.

Table 8: concentrations of contaminants removed from greywater from the shower using alum as coagulation (Pidou et al., 2008).

Parameter	Unit	Raw Greywater	Treated Greywater
BOD	mg/l	205	23
Total nitrogen	mg/l	18	15.7
COD	mg/l	791	287
Turbidity	NTU	46.6	4.28
E.coli	MPN/100 mL	6490	<1
$PO4^{3}$	mg/l	1.66	0.09

Adsorption

Adsorption is a surface phenomenon that is characterized by the concentration of a chemical species (adsorbate) from its vapor phase or from a solution onto or near the surfaces or pores of a solid (adsorbent). The adsorption process can be physical (if adsorption occurs due to London–van der Waals forces of the solid and adsorbate) or chemisorption (if adsorption happened due to chemical bonding forces) Adsorption therefor, depends on the solid surface characteristics (such as particle size, surface charge, surface area) the concentration and types of ions present in the liquid phase

Studies have found adsorption as a favourable technique for the removal or organic pollutants in wastewater. It is known to be cheap with less complex design and easy to operate (Rashed, 2012). The process employs the use of nut shells, seed hulls, rice husk etc as adsorbents (Veli et al., 2018). Veli et al., (2018) studied the effectiveness of adsorption as the treatment process for greywater from the laundry. Walnut shell, seed hull, hazelnut shell and rice husk were carbonized with polyaniline to synthesize the adsorbents. The parameters used for the study were turbidity, surfactants and colour.

Adsorbents produced with KIO_3 oxidation obtained a 97% efficiency. For turbidity, the adsorbent produced with KIO_3 oxidation obtained a 46% efficiency. Surfactants achieved a 95% efficiency following adsorbents produced with KIO_3 oxidation.

Advance Oxidation Process

According to Gassie and Englehardt (2019) ozone-UV advanced oxidation treatment is effective in the mineralization of total carbon organic, excluding additional chemicals. In their study Gassie and Englehardt (2019) used a $1.2m^2$p/d (320 GPD) pilot ozone-UV to treat greywater from the shower. Results showed a hydroxyl radical concentration were $\sim 10^{-10}$M. Hydroxyl radicals reacted with TOC produced (1.7-7.6) $x10^7M^{-1}S^{-1}$ which is comparable to reports on mineralization of wastewater organics.

Parson et al., (2019) used advanced oxidation process based on photo-catalytic oxidation combined with titanium dioxide and UV to treat greywater. Results showed that organic pollutants and total coliforms were removed at 90% and 6log, respectively.

3.4.2.3 Biological treatment process

Biological treatment is governed by biological processes, which involve the activity of microorganisms in aerobic or anaerobic conditions. A ratio of BOD:COD ≥ 0.5 indicates good potential for biological treatment (Palmquist & Hanæus, 2005). Biological treatment of grey water followed by disinfection have been shown to guarantee risk-free effluent with a minimal energy and maintenance (Nolde, 1999). The biological treatment systems can be categorized into: i) aerobic attached biomass growth process such as Fluidized-Bed Reactor (FBR) (Nolde, 1999) and the Rotating Biological Contactors (RBCs) (Nolde, 1999, Friedler et al. 2005). ii) aerobic suspended growth process such as Sequencing Batch Reactor (SBR) (Shin et al., 1998; Hernandez et al., 2010) and iii) Anaerobic treatment of greywater using UASB (Elmitwalli and Otterpohl 2007, Ghunmi et al. 2008, Abu-Ghunmi 2009). Moreover, the benefits of biological (microbial degradation) and physical (filtration) treatments are combined in processes such as membrane bioreactors (MBR) and biologically aerated filters (BAF), which are small footprint processes capable of producing high-quality effluents. Recent preliminary study of greywater treatment using modified Biological Aerated Filtration (BAF) at NMBU showed promising results (Rummelhoff, 2019).

CHAPTER FOUR

4.1 Treatment Technologies for greywater treatment

Decentralized solutions prove to have benefits of flexibility of capacity expansion and the elimination of water transportation over long distance (Leigh and Lee, 2019). Decentralized treatment systems provide an impressive alternative to centralized systems especially when they are source-separated. Source-separated systems provide an avenue for nutrient recovery by separating blackwater from greywater. According to Ahmed and Arora (2012) septic tank, constructed wetland and intermittent sand filter are amongst the best solutions for decentralized treatment because they are easy to operate and maintain and relatively cheap. Compared to centralized systems, decentralized systems have proved to be more eco-friendly. Constructed wetlands are considered one of the most viable solutions for decentralized treatment.

4.1.1 Constructed wetlands

Constructed wetlands (CW) are considered a nature-based solution due to the use of natural media (soil and plants) for filtration and biological degradation (Boyjoo et al., 2013). Several authors explain that CWs combine physical (use of filter media), biological (aerobic and anaerobic) and chemical precipitation and adsorption processes (Boyjoo et al., 2013; Kivaisi, 2001). CW technologies include the horizontal-flow constructed wetland (appendix A), sand filter and planted sand filters, often termed vertical flow wetlands (appendix A), anaerobic filter amongst others. CW’s are usually used as a primary or secondary treatment but depending on the final discharge disinfection may be necessary as the final application. Some studies combine other systems with CW´s in order to meet quality standards and satisfy regulatory guidelines. For instance, Jenssen and Vråle (2003) combined an aerobic biofilter and a horizontal-flow constructed wetland (fig 11) to treat greywater that met swimming water quality. The study found that the aerobic biofilter was essential for the removal of BOD in climates where plants are inactive in winter (Jenssen and Vråle, 2003).

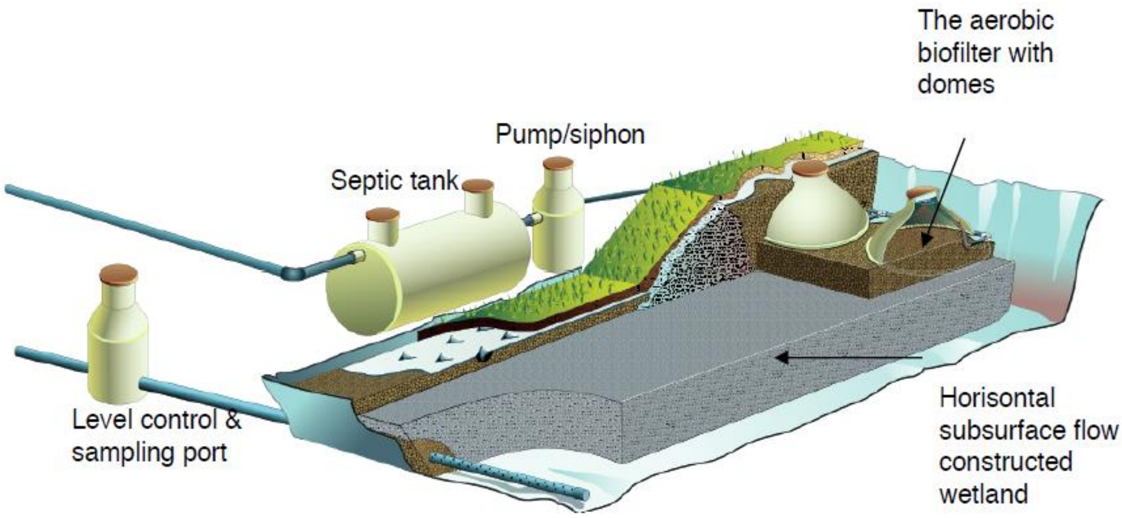


Figure 11: Biofilter/Constructed Wetland for cold climate (Jenssen and Vråle, 2003).

The biofilter/constructed wetland technology was implemented for greywater treatment at a student dormitory, Kaja, at the Norwegian University of Life Sciences in fall 1998 and spring 1999 and had the results presented in table 12.

Table 9: Average concentrations and treatment performance (%) for the Kaja greywater treatment plant, fall 1998 and spring 1999 (n = 11) (Jenssen & Vråle, 2003).

Parameter	Average concentration out of each unit				Percent removal %	Percent removal %	Total removal %
		Outlet	Outlet	Outlet			Biofilter and
	Unit	Septictank	Prefilter	Wetland	Biofilter	Wetland	Wetland
pH		6,72	6,78	7,43			
Total phosphorous	mg P/l	0,97	0,32	0,07	67,0	78,1	92,8
Ortho phosphate	mg P/l	0,56	0,10	0,04	82,1	60,0	92,9
BOD 7	mg O/l	130,7	38,2	6,90	70,8	81,9	94,7
Total nitrogen	mg N/l	8,20	5,00	2,50	39,0	50,0	69,5
Ammonium	mg N/l	3,2	2,4	2,3	25,0	4,2	28,1
Nitrate	mg N/l	<0,03	<0,03	<0,03			
Termotol. Colif. Bacteria	TCB /100 ml	106	10^3-10^5	0-10^3			

Constructed wetlands are known to successfully remove organic pollutants and suspended solids as found by Itayana et al., (2006) who also found that slugs and earthworms in the Kanuma soil they used helped to remove solid food particles from the kitchen greywater; the phosphorus concentration in the GW was removed through the soil adsorption and the biological process aided the reduction of the nitrogen concentrations. Each type of CW is unique in their performance and efficiency. The vertical-flow CW has been investigated and proven to be more efficient with pathogens removal than the horizontal-flow CW and green roof water treatment systems. (Winward et al., 2008).

4.1.2 Biofilter systems

Biofilter systems have been investigated and results show that they are essential for the removal of organic and particulate matter, bacteria and waxy substances (Jenssen & Vråle, 2003; Eshetu et al., 2017). Biofilters are categorized into macro and membrane biofilters. According to Abu Ghunmi et al., (2011) macro biofilters are further categorized into attached and suspended film systems whereas membrane biofilters are grouped into submerged and side-stream. Eshetu et al., (2017) studied the performance of a biofilter system for on-site treatment and achieved a 90% removal efficiency of the parameters sampled. The system setup included a primary settler, a fixed-film biofilter and a secondary clarifier. The authors found that the system, when combined with a soil infiltration system as a polishing step, can produce effluent quality that satisfies Norwegian requirements for discharge to sensitive areas like drinking water sources with very little environmental and health risks. See table10 for quantity of nutrients and pathogens removed. The effluent quality from the combined biofilter system and the polishing step satisfy the new EC reclaimed water quality requirement of class A (EC, 2018) which can be used for irrigating all crops using all irrigation methods.

Table 10. Average effluent quality of compacted fixed-film biofilter system followed by infiltration trench compared to present limits for discharge and agricultural reuse. (adapted from Eshetu et al., (2017)

Standards	Applicability	BOD_5 mg/L	Tot P mg/L	TSS mg/L	E.coli MPN/100 ml
Average effluent GWTP + infiltration trench	discharge to sensitive recipients	<2*	<0.1	<2	<5
Average effluent GWTP	discharge to none-sensitive recipients	12	0.6	14	10^4–10^5
Norwegian discharge limit (Miljø Blad 100, 2010)	discharge household wastewater	<20	<1	–	–
US standard (NSF/ANSI 350-2012)	reuse of greywater	10	–	10	14
Australian Guideline (2011)	reuse of greywater	<20	–	<30	<30

* Most samples had BOD5 value below the detection limit.

Though some studies have found biofilters to have challenges relating to cleaning due to suspended solids (Jefferson et al., 2000), the system used by Eshetu et al., (2017) had no issues with clogging throughout the experiment period, probably due to the infiltration system in place.

Sequencing Batch Reactor (SBR)

The sequencing batch reactor (SBR) is one of the compact solution technologies for the removal of conventional parameters in small communities due to low cost and simple operation. SBR is a type of activated sludge treatment process that occurs in batches in the reactor tank (Oteng-Peprah et al., 2018). The SBR is a cyclic fill and draw system that performs equalization, biological treatment and secondary clarification in a single tank using a time control sequence. It also offers a great flexibility of operation for effective nutrient removal. The SBR system can effectively remove nutrients and promote biodegradation of organic matter for domestic grey water.

Up flow Anaerobic Sludge Blanket (UASB)

Anaerobic digestion (AD) is a mature and core technology in wastewater treatment mainly for high strength (organic matter rich) wastewater. Anaerobic digestion process is a multi-step process governed by different groups of microorganisms. The process consists four main stages in a series: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Batstone et al. 2002, De Mes et al. 2003). Although the performance in the removal of COD in the greywater is relatively poor (Abu-Ghunmi 2009), the anaerobic step was suggested as a pre-treatment (Elmitwalli and Otterpohl 2007) to be followed by aerobic treatment. This system is known to provide better settlable sludge as compared to other treatments. The anaerobic process retain a high concentration of active suspended biomass (Oteng-Peprah et al., 2018).

Hernandez et al., (2010) combined three biological systems with the same hydraulic retention time of about 12-13 hours to treat greywater from 32 houses of the Decentralized Sanitation and Reuse project in Sneek, Netherlands. The system setup included an aerobic treatment in a sequencing batch reactor (SBR), an anaerobic treatment in an up-flow anaerobic sludge blanket reactor (UASB) and a combined aerobic - anaerobic treatment (SBR + UASB) (fig.12). The study found anaerobic pre-treatment to be less feasible whereas aerobic treatment was found to be a preferred option for greywater treatment. The effluent quality from the study is presented in table 11.

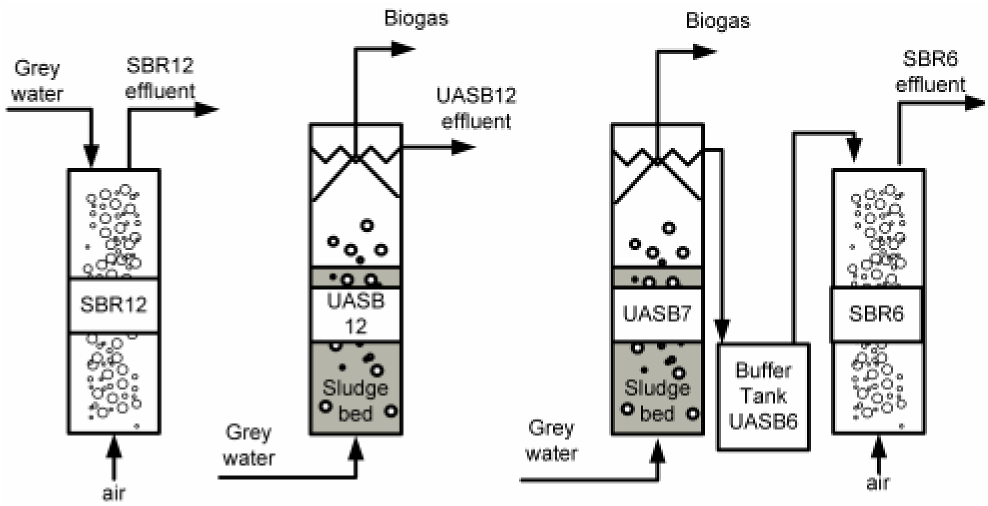


Figure 12: Combined reactors set up (Hernandez et al., 2010).

Table11. Effluent quality for the Sneek biological treatment process (adapted from Hernandez et al., 2010).

Parameter	SBR (%)	UASB (%)	SBR+UASB (%)
COD	90	51	89
TN	35	15	2
TP	28	11	3

Rotary Biological Contactor (RBC)

RBCs are fixed bed reactors with rotating disks installed on a horizontal shaft. RBCs are partially submerged in order that the microbes necessary for treatment are exposed to the atmosphere to enable aeration and assimilation of dissolved organic pollutants and nutrients for degradation (Oteng-Peprah et al., 2018). Friedler et al., (2011) treated light greywater using chlorination and UV irradiation of RBC to remove indicator bacteria (faecal coliform, heterotrophic sp.) and specific pathogen (Pseudomes aeruginosa sp., Staphylococcus aureus sp.). Results showed an 88.5% -99.9% removal of the bacteria and pathogens. Though the treatment system proved very effective as it produced effluent of high quality (Tab. 12), the microbial quality did not meet GW reuse standard. Thus, an efficient disinfection step is required.

Table 12. Effluent quality for the RCB system (Friedler et al., (2011)

Parameter	Removal Efficiency (%)
BOD	96
Turbidity	95
COD	68

4.1.3 Membrane Bioreactor

In a highly populated or urbanized area, the most appropriate solution for greywater treatment is membrane bioreactor (MBR) because it requires less space. MBR is a perm-selective process combined with biological, microfiltration and ultrafiltration system (Oteng-Peprah, 2018); it also combines activated sludge and membrane separation processes. The use of MBR allows for the avoidance of sedimentation and disinfection and is apt for the removal of biological pollutants, particulate matter, turbidity, microorganisms etc. Cornelia et al., (2007) studied the feasibility of treating greywater from a leisure and sporting club in Morocco using a 3L-lab-scale MBR consisting of an ultrafiltration membrane for non-potable reuse.

MBR is proven to provide a high quality effluent. It ensures an efficient removal of microorganisms and dissolved substances. The technology has small footprint and can be applied in decentralized treatment systems. However, the economic investment and fouling phenomenon are the main challenges presented. The quality of the treated greywater (Table 13) satisfied the basic standards for toilet flushing and other domestic uses

Table 13. Percentage removal of the treated greywater (Cornelia et al., 2007).

Parameter	% removed
Turbidity (NTU)	98
COD (mg/l)	85
BOD (mg/l)	94
Faecal Coliforms	99

4.1.4 Urban green infrastructure: green roofs and green walls

Green roofs and green walls have become a recent nature based solution for GW treatment in modern buildings around the world. According to Francis and Lorimer (2011) green roofs and green walls provide a very beneficial technology for urban reconciliation ecology and require very little space as compared to reedbeds (Masi et al., 2016). Green roofs and green walls filtrate via plants and use filter media like sand, clay, growstone, phytofoam, coconut coir and perlite (Prodanovic et al., 2017). Green roofs are usually installed on roof tops (fig. 13) and consist of a vegetated surface made up of an insulation layer, a waterproof membrane and a vegetation layer planted in a growing substrate (Francis and Lorimer, 2011).

Figure 13. Green roof installed at the Horniman Museum in London (Boano et al., 2019).

Some studies have found green roofs to be efficient in reducing suspended solids and turbidity and can remove about 80% of all parameters taking the season and hydraulic parameters into account (Frazer-Williams et al., 2008; Ramprasad et al., 2017).

In Frazer-Williams et al., (2008) the Green Roof-Top Water Technology System (GROW) was compared to other CWs (HSSF & VF). The GROW system was made up of an inclined framework of interconnected horizontal troughs and weir planted species. The authors found that, GROW system was efficient in the removal of BOD, SS, COD, and Turbidity (Table 14)

Table 14. Effluent quality for GROW (adapted from Frazer-Williams et al., 2008)

Parameter	% Removal
BOD_5 (mg/l)	95
COD (mg/l)	77
SS (mg/l)	94
Turbidity (NTU)	0.6

Green walls are vertically planted pots or vegetation installed across the vertical surface of the interior or exterior of a wall (Boano et al., 2019; Manso and Castro-Gomes, 2015). Like green roofs, the type of vegetation or plants used for green walls must be appropriate for the local weather, must require low space for root growth, the aesthetic appearance must be considered and must have good removal capacity of nutrients (Castellar da Cuncha et al., 2018). This explains why the effluent quality obtained by Masi et al., (2018) from a green wall filled with lightweight expanded clay aggregate was not satisfactory, whereas the coconut coir and perlite media used by Prondanovic et al., (2017) successfully removed the physico-chemical parameters in their study. According to Svete (2012) Norway pioneered the first vegetated wall for greywater treatment. The system, constructed in Ås (see appendix B), was dosed with about 1000L/m2/d for three months and had the results presented in table 14 below:

Table 15. Average treatment and removal performance of the Ås green wall (Svete, 2012)

Parameter	Removal %
BOD_5	95
COD	80
TSS	80
TN	30
TP	69
E.Coli	2log unit

Again, Masi et al., (2016) installed a greywater treating green wall (fig.14) in the MPs building in Pune (India) using lightweight expanded clay with sand and lightweight expanded clay with coconut fiber as the porous media. The effluent quality satisfied the Indian guidelines for irrigation and toilet flushing.

Figure 14. Green wall for greywater treatment installed at the MPs Head Office in Pune, India (Masi et al., 2018).

4. 2 Cases of greywater treatment by large-scale constructed wetlands

In the past wetlands were used in the Chinese and Egyptian civilisation for the purpose of averting water pollution (Brix, 1994). In the US, CWs were researched as a cost-effective option for conventional acid mine water treatment (Girts & Kleinmann, 1986). Today, CWs are efficiently engineered systems which are green, sustainable, cheap, robust, eco-friendly (Carvalho et al., 2017) and are mostly deployed on a large scale for greywater treatment. Some large scale CWs are discussed below.

4.2.1 Case study: Bergen

In 1991, 40 eco-friendly buildings were constructed in Bergen, Norway, with a source separation system that separates the greywater from the blackwater. A constructed wetland consisting of a light weight aggregate (LWA) filter material and a pre-treatment unit with longer pipes distributing water to the surface on the filter was installed for the building. Table 6 below presents treatment efficiency of the system.

Table 16. Treatment efficiency and effluent quality for the Bergen CW (Jenssen & Vråle, 2003)

Parameter	Effluent (mg/l)	% Efficiency
BOD	15	96
Nitrogen	2.2	60
Phosphorus	0.19	79

4.2.2 Case study: Kuching

Kuching, a city in Malaysia, had source separated systems but the greywater was discharged directly into nearby streams with little or no treatment (Jenssen, 2005). To solve this, a pilot CW was constructed in 2004 to treat greywater from 9 households (Jenssen, 2005). The CW consisted of 4 biodomes with a 2-4mm filtralite LWA media and a septic tank to treat excess grease. The CW was installed to help with the reduction of phosphorus and remove bacteria to obtain swimming water quality. The system had issues relating to clogging in the biofilter, likely due to the suboptimal dosing frequency (Jenssen, 2005). The effluent quality is present in table 17. The treatment system improved the overall sanitation and environmental challenges of the area and brought a level of awareness on the effects of untreated wastewater on water bodies (Jenssen, 2005)

Table 17. Treatment efficiency and effluent quality for the Kuching CW (Jenssen, 2005).

Parameter	Unit	Effluent	% Efficiency
BOD	mg/l	2	98
Nitrogen	mg/l	9.24	75
Phosphorus	mg/l	0.33	86
Faecal coli.	MPN/100ml	646	-

4.2.3 Case study: Klosterenga

Klosterenga is located in Oslo, Norway. In Klosterenga, an aerobic vertical-flow biofilter and a subsurface horizontal-flow constructed wetland to treat greywater from 33 ecological apartments with about 100 inhabitants to swimming water quality (Jenssen, 2002 The author explains further that the system used a space of 1.5m^2 per person where 1/3 is the area for the biofilter. The nitrogen concentration in the effluent has been found, repeatedly, to be below the WHO requirements for drinking water quality as presented in table 18.

Table 18. Effluent quality for the Klosterenga CW (adapted from Jenssen, 2002)

Parameter	Effluent quality
COD (mg/l)	19
TN (mg/l)	2.5
TP (mg/l)	0.03
Faecal coliforms	0

4.2.4 Case study: Flintenbreite

Settlements in Flintenbreite, Germany are planned with eco-friendly, landscape, energy and sanitation considerations (OtterWasser GmbH, 2009). Based on these a CW was constructed to treat effluent from 380 pe, using coarse gravel as the filter media (Sagen, 2014; OtterWasser GmbH, 2009). Table 19 below is a representation of the effluent quality.

Table 19. Treatment efficiency and effluent quality for the Flintenbrie CW (OtterWasser GmbH, 2009).

Parameter	**Effluent (mg/l)**	**% Efficiency**
BOD	14	93
Nitrogen	2.7	78
Phosphorus	5.7	29

CHAPTER FIVE DISCUSSION

5.1 Constructed wetlands

Constructed wetlands provide an attractive solution for greywater treatment in a decentralized setting. Cases of wetlands installed for decentralized and ecological buildings produced effluent of good quality. As mentioned earlier, wetlands combine a series of physical, biological and chemical processes for greywater treatment. Therefore it is imperative to understand these processes for appropriate design to serve the intended purpose. Constructed wetlands are known to successfully remove organic pollutants and suspended solids as found by Itayana et al., (2006) who also found that slugs and earthworms in the Kanuma soil they used helped to remove solid food particles from the kitchen greywater. The inlet of wastewater into the CW goes through the filter media and the plant rhizosphere. The root and rhizomes excrete oxygen which results in aerobic conditions. Organic matter is then decomposed by both aerobic and anaerobic microorganisms. Organic filter media (commonly coarse sand or gravel) and inorganic filter media (bask and charcoal) serve as a substrate for filtration, physico-chemical adsorption and microbial growth pollutant removal (Dalahmeh, 2013). However, other studies have used other mineral and plastic as the filter media, which combined with the tropical ornamental plants used, removed about 80% of suspended solid. The filter media is responsible for the removal of suspended solids present in the greywater via interception, sedimentation and filtration. When interception, sedimentation and filtration combines it traps total suspended solids (TSS) (Kadlec &Wallce, 2009). The size of filter media in CW's, globally, ranges from soil (d_{10} < 0.1mm) to coarse gravels (d_{10} > 4mm) (Kadlec & Wallace, 2009).

All forms of Nitrogen are collectively referred to as Total Nitrogen (TN). The presence of TN in wastewater will negatively affect the ecosystem and cause eutrophication if discharged without treatment. In drinking water, excess nitrate is harmful to humans as it poses dire health risks. Aquatic plants (macrophytes) present in wetlands are essential for the removal and uptake of nutrients. The transportation of oxygen to the root zone is done by the release of oxygen from the root of the plants and also provides a breeding surface for bacteria. Plants on CWs are essential for nutrient uptake even though Mæhlum & Stålnacke (1999) argue minimal effect on BOD and Phosphorus. But some studies show an increased nitrogen removal at the root zone (Kadlec and Wallace, 2009). Though plants uptake nutrients, a portion of the nutrients is also released into the water organic matter decomposes while the plant deteriorates. The released nutrients can accumulate in the soil, but may also follow the effluent.

At Klosterenga, Nitrogen concentrations, including ammonia and nitrate, in the effluent were excellent and satisfied the required limits. Ammonia and nitrate concentration were reduced at 66% and 27%, respectively. And, though the ammonia concentrations were found to be decreasing due to the lower retention time which allows for aerobic conditions leading to nitrification, nitrate on the other hand was recorded at higher concentration. Overall, the system showed efficiency with nitrogen removal at 70%, above the regulatory guidelines. The low level can also be attributed to the possibility of low faecal contaminants and E. coli. In total, the effluent value in relation to Nitrogen met greywater discharge limits and also satisfied drinking water and other non-potable uses guidelines. Figure 15 shows the total nitrogen, ammonia and nitrate levels as well as discharge limits.

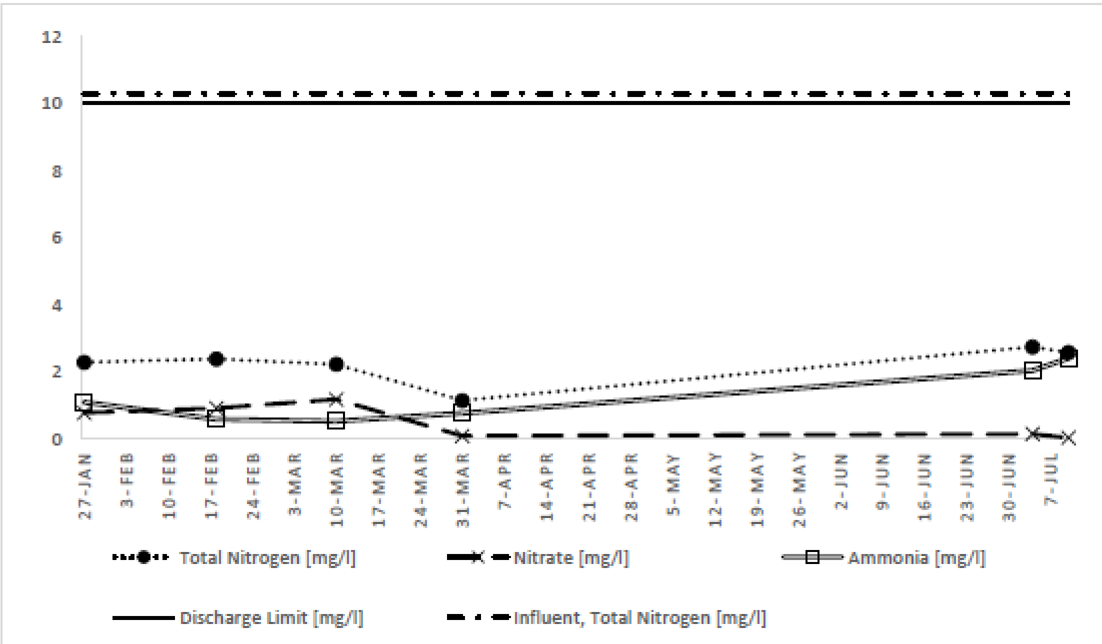


Figure 15. Total Nitrogen, Nitrate, Ammonia and discharge limit for Klosterenga (Sagen, 2014)

At Klosterenga, the phosphorus and bacteria levels recorded in the effluent were of good quality due to the light weight aggregate (Filtralite) used, which is an excellent media for phosphorus adsorption and bacteria reduction (Jenssen and Vråle, 2003). Average

Phosphorus and Nitrogen concentrations in the effluent were recorded, between 2001 and 2008, at 0.5mg/l and 3.0mg/l respectively (Fig. 16)

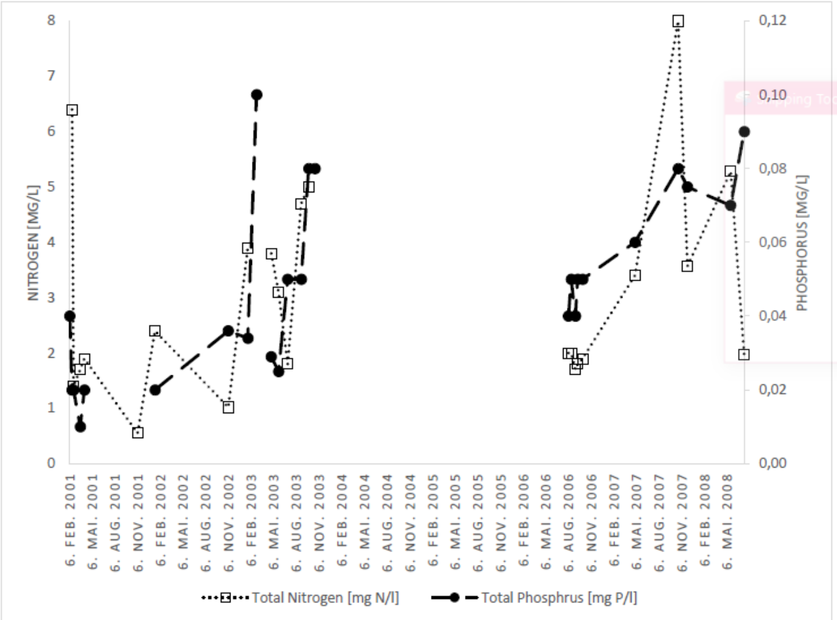


Figure 16. P and N concentration for Klosternga CW (Sagen, 2014)

The P and N concentrations in the effluent were lower than the required limits of 0.5mg/l for phosphorus and the 25mg/l for nitrogen. This makes the effluent quality excellent for irrigation and for groundwater recharge (Jenssen and Vråle, 2003).

BOD removal in CW's is aided by sedimentation. The biological processes produce soluble carbon compounds which consume the BOD. According to Kadlec and Wallace (2009) inlet of greywater with fewer or heavy concentrations of BOD into the wetland, without an outlet or additional inflow will result in a near zero plateau. This is also affected by the detention time. Figure 17 describes a near zero BOD_5 recorded for when wastewater was dosed on a CW without additional inlet nor outlet.

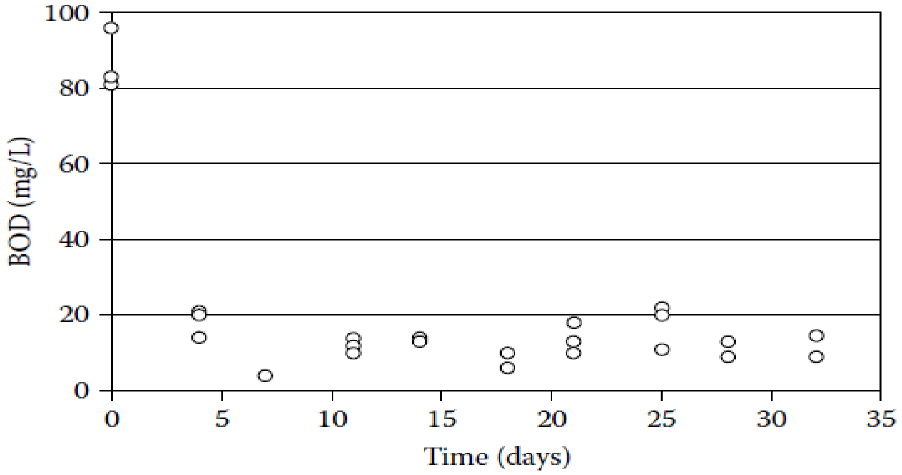


Figure 17. Five day BOD concentration in a CW without additional inflow and no outlet (Kadle & Wallace, 200)

But for Jenssen and Vråle (2003) the BOD_7 concentration recorded at the Kaja CW (see tab 9) was due to increased retention time and high temperatures recorded in the STE. Figure 18 below shows the BOD_7 concentration recorded at Kaja

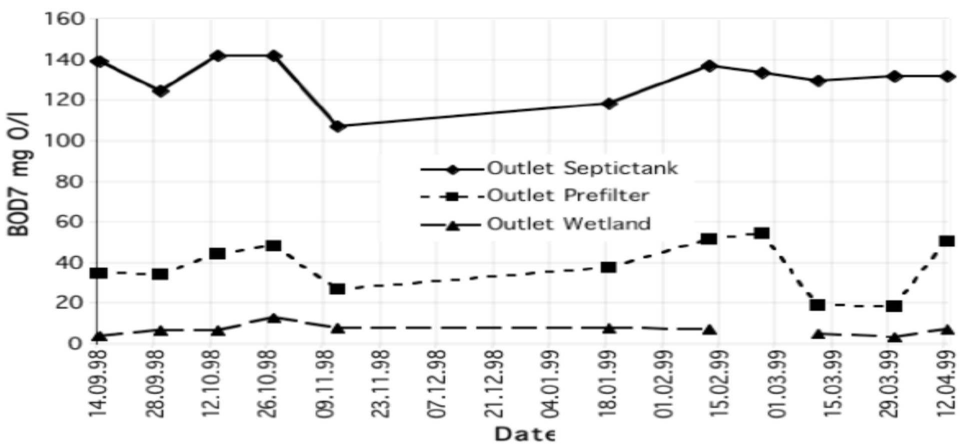


Figure 18. BOD_7 concentration and time in STE for Kaja (Sagen, 2014)

At Klosterenga, BOD influent was recorded at 225mg/l but reduced to 4.9mg/l in the effluent. In percentage terms, a total of 98% reduction was achieved indicating a good BOD treatment capacity of the system. Again, the BOD level satisfied discharge limits at less than 30% (fig. 19)

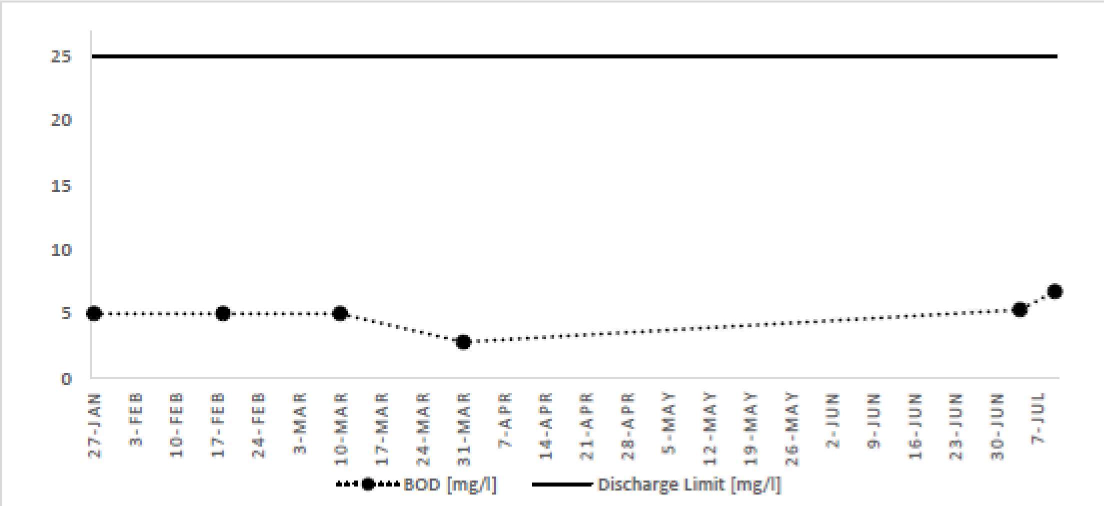


Figure 19. BOD level and discharge limit for the Klosterenga treatment plant (Sagen, 2014).

Studies have shown that constructed wetlands can be effective in the removal of pathogens from wastewater at a rate of about 99% or more (Jenssen et al., 2010). Coliform bacteria and E.coli are the most used forms of bacteria for greywater assessment.

At Klosterenga, the bacteria analysis showed that the most probable number of E. coli per 100ml was 18.9 which is below both the EU and Norwegian bathing water regulatory guidelines. Further, the effluent quality met the hygienic and safety standards for irrigation of all crops, including edible ones. Finally, the effluent also meets swimming water quality. This is basically due to the fact that directives by WHO regarding irrigation outweighs that for swimming water, hence if the effluent is suitable for irrigation then it is more than suitable for swimming

5.2 Constructed wetlands with regards to water, energy and nutrient

Water

Greywater treatment in a constructed wetland is required to satisfy set guidelines depending on the final destination or discharge as well as the quality of the greywater influent. According to Hyde (2013) kitchen greywater is sometimes excluded from other greywater due to the presence of grease & oil which may require additional treatment. Water recycled from greywater via CWs is essential to augment the growing demand on fresh water sources. Donner et al., (2010) agree that greywater can produce water which will reduce about 20-40% of water usage from existing freshwater sources. Reclaimed water have also proven to have no difference compared to water from other sources. According to Nolde (2005) studies on reclaimed greywater for laundry showed no difference from laundry done with regular water.

Nutrients

Nutrient removal in microbial wetland, especially, relies heavily on temperature. According to Kadlec and Wallace (2009) "organic, ammonia and oxidated nitrogen forms interconvert in the wetland environment, with the net effect of reduction in virtually all cases". For continuous flow wetland, the biogeochemical cycling of nitrogen form an integral part of its processing network (Kadlec & Wallace, 2009). Plants uptake nitrate and ammonia for growth and release nitrogen when they decay. Total nitrogen may decrease with detention time and denitrification can be facilitated by BOD in the wetland. The reduction of nitrogen in wastewater can be attributed to the inflow concentrations, chemical form of the nitrogen, water temperature, season, organic carbon and dissolved oxygen (Kadlec & Wallace, 2009).

The effective recycling of nutrients in CWs can be attributed to the implementation of source separation systems. Jenssen et al., (2006) says that separating wastewater into blackwater and greywater, theoretically, allows for a 70% and a 90% recycling of phosphorus and nitrogen, respectively when the blackwater is treated and recycled. Phosphorus and nitrogen are essential for food production. According to Cordell et al., (2009) global reserves or phosphate rocks, from which phosphorus is mined, is estimated to deplete in 50-100 years. Meanwhile, phosphorus and nitrogen are treated as organic pollutants in greywater. Therefore, it is imperative to for future treatment systems to maximise the recycling of these nutrients. Source separation also opens to separate faeces from urine. Urine needs only storage and dilution before fertilizer application (Cordell et al., 2009). Esrey (2011) proposed a combined treatment system that will treat both the nutrient in human excreta and produce fertilizer, then transport via a single conduit to the soil for fertilization

Energy

Solar radiation influences the water temperature and determines evaporative losses or gains. Plants utilize incoming energy solar radiation and transport part to the water column.

The difference in the air temperature and the wetland water temperature leads to convection and diffusion and is responsible for the transportation of heat from the air to the wetland. Although the wetland radiates heat, some studies claim that heat may also be transferred from the soil to the wetland. The figure (20) below illustrates the energy balance in wetlands.

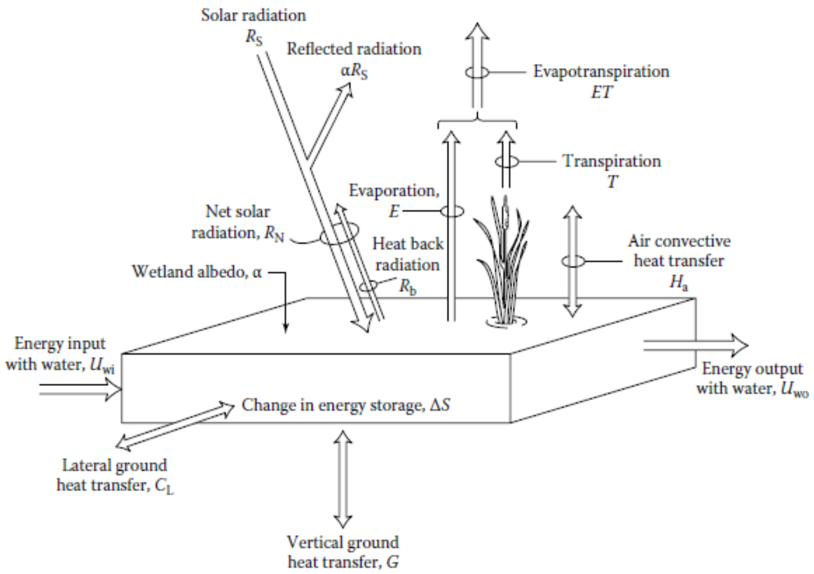


Figure 20. Energy balance in wetland (Kadlec and Knight, 1996).

5.3 Biofilter Systems

Biofilters support biofilm growth due to its large surface. The characteristics as well as aeration enhances BOD reduction. Biofilter can remove up to 70% of BOD and a 2-5log reduction in bacteria (Jenssen et al., 2006). Biofilter systems can serve as an aerobic pretreatment capable of removing 40% of TN (Jenssen et al, 2006) biofilter systems are also able have significant influence on nitrification i.e oxygen supply, temperature and pH rates (Laber et al., 2003). Combining biofilter systems with CWs, will produce effluent of swimming standard quality as studied by Jenssen and Vråle (2003). In a combined biofilter/constructed wetland system, the biofilter is responsible for the removal of the majority of the BOD whilst phosphorus and other microorganisms are removed in the CW (fig. 21). Moreover, biofilter system have been found to remove organic pollutants to discharge limits (Eshetu et al., 2017). Thus, further treatment is required if intended for reuse purposes, swimming or drinking. But, in Jenssen and Vråle (2003) the aerobic biofilter presents a simple technology for greywater treatment that allows reuse and that meet European requirements. The aerobic biofilter, like previously mentioned, reduced BOD_7 by

70% at a loading rate for greywater up to 115cm/d. It can be deducted from these two studies that aerobic treatment processes can significantly influence the indicator bacteria in greywater.

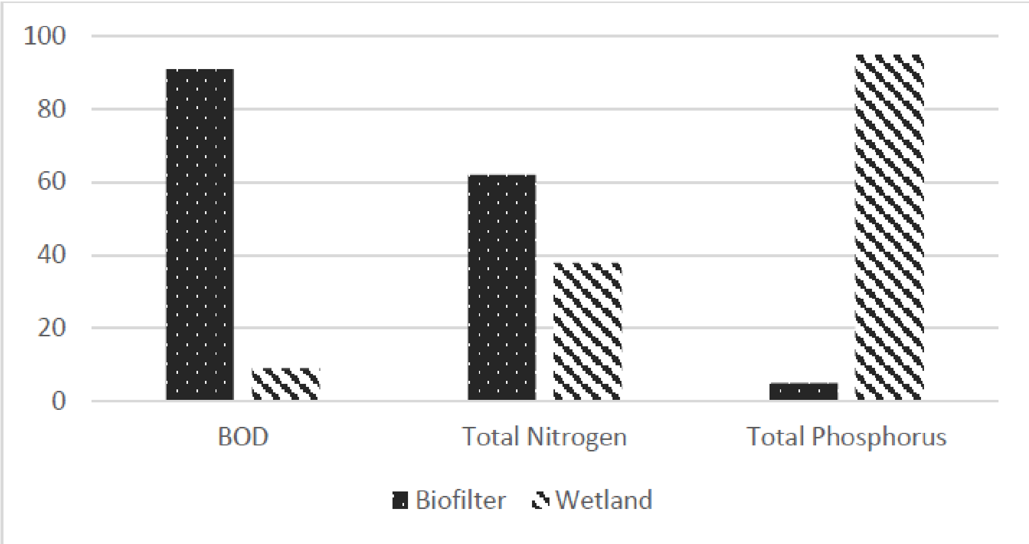


Figure 21. Treatment efficiency for biofilters and constructed wetlands (adapted from Jenssen et. al, 2006).

5.4 Membrane Bioreactors (MBR)

Membrane Bioreactors have been found to be useful where space is of critical concern. MBR treating greywater can produce effluent quality of non-potable reuse. MBR uses biodegradation and membrane filtration to separate solids from liquid. In Lie et al., (2005) a submerged MBR was employed to treat low strength greywater. Results for COD, NH_4-N, and BOD_5 showed a reduction from 322mg/l to 18mg/l, 0.6-1.0mg/l to below 0.5mg/l, 221mg/l to below 5mg/l, respectively. For anionic surfactants, the levels achieved were 3.5-89mg/l to below 0.5mg/l. At the end of the study, the effluent obtained was colourless and odourless. Suspended solids and faecal coliforms were equally reduced to meet regulatory guidelines.

It can be deduced that due to the biological degradation characteristic of MBR most micro pollutants were removed (Li et al., 2005). Also, it is true to say that the membrane separation unit of the system is effective in the removal of other pollutants found in the influent. The combination of these characteristics or properties of the system results in the provision of high quality effluent suitable for non-potable use as found by Li et al., (2009). Again, in Cornelia et al., (2007) results from the submerged MBR (see Table 14) proved that MBR was effective with biological treatment of greywater. Like Li et al., (2009), Cornelia et al., (2007) achieved a colourless and odourless effluent. Both studies achieved a permeate flux of less than $15L/m^2h$ and between $8\text{-}10L/m^2h$, respectively.

5.5 Urban green infrastructure: green roof and walls

Green roofs are similar to reed beds. In green roofs, greywater percolates via planted pots with filter materials (Boano et al., 2019).

BOD removal was influenced by an increase in the aeration time from 1hour to 24hours. The GROW's performance for the removal of suspended solids was attributed to the sedimentation and filtration unit of the system. The gravel and optiroc used as filter media for the system was found to be very efficient. Again, the system incorporated baffles, well and weirs as an additional barrier for sedimentation of finer particles. For turbidity removal, the GROW met regulatory standards even though the influent GW was very turbid. Here again, turbidity reduction was achieved via filtration and sedimentation.

Svete's study on green walls showed excellent removal rates of the parameters used (see tab. 14). The study found that COD and solids were removed at the upper 15cm of the filter. Nitrate levels were found to have increased at 100cm depth sampling outlet probably because increased organic loading limits nitrification at the filter surface.

5.6 The challenges and prospects of greywater treatment

Greywater treatment guidelines provide a framework for the treatment of GW to a higher standard to avert health risk and environmental effects. The optimal goal of greywater treatment and reclamation is to remove suspended solids, the organic matter and micro-organisms while adhering to legislative requirements (Li et al., 2009). Some studies have found public support for non-potable reuse (Dolnicar and Sauders, 2006; Marks, 2004; Kantanonleon et al., 2007). Parkinson (2008) found that inadequate information and cultural practices adds to the challenges of greywater reuse. The use of greywater for potable uses faces a huge challenge due to the fact that people associate greywater with toilet water and are repelled by the thought of sewage running through their pipes (Desena, 2006; Meehan et al., 2003; Hurliman and Dolnicar, 2003). Several studies conducted to seek responses from users around the world support the use of greywater to avert pollution. In the UK, Jeffery (2001) found that there was support for reusing greywater from users' own homes but not from other homes. Alhmoud and Madzikanda (2010) found responses from respondents in arid areas in favour of reusing recycled greywater.

5.7 Potential of small-scale greywater systems in a decentralised urban application

Implementation of small-scale treatment technologies is increasingly becoming a necessity to guard against the inevitable need to manage water in urban dwellings. Urbanization, and its attendant increased population rate, increased water consumption and demand as well as land and site scarcity, requires treatment systems that can sustainably address these issues. Decentralised systems provide an opportunity to reduce the burden on centralised systems as well as save cost for transportation. Septic tank, constructed wetland and intermittent sand filter are some decentralised systems apt for deployment domestically. These systems are easy to operate, maintain and relatively cheap. Of all the systems reviewed in this paper the nature-based technologies, constructed wetland and urban green infrastructure, prove to be a much more appropriate technology small-scale, taking into account the final discharge or reuses purposes.

Potentially, urban green infrastructure system have proven to have the capabilities to recycle greywater for irrigation as seen in Masi et al., (2016). The system require minimal space since it can be designed as part of the architecture. According to Boano et al., (2019) green roofs and green walls are incorporated in modern buildings in some countries and are a perfect technique for urban reconciliation ecology (Francis and Lorimer, 2011). The infrastructure has equally proven to be efficient with organic pollutant removal (BOD) as found by Svete (2012) and require minimum energy for operation. Again, there is no cost involved with regard to transportation.

The biofilters/constructed wetland is also a potential technology for decentralized application. Like the green roof and wall, the system is eco-friendly, requires less space and is energy efficient. Effluent quality, as seen in cases studied, is suitable for non-potable uses, irrigation and swimming. There is an emerging need for the use of nature-based technologies for greywater treatment and this has necessitated a revision in the German guidelines for design, construction and operation of CWs for both domestic and municipal wastewater treatment (Nivala et al., 2018). Boano et al., (2019) suggests that CWs should be critically considered as a mature technology for greywater treatment and reuse.

5.8 Economic and environmental benefits between biofilters/constructed wetland and other systems

Constructed wetlands, in general, are arguably a better alternative for the treatment of greywater. When combined with biofilters system as found in Jenssen and Vrale (2003) it can produce effluent of swimming water quality. Like earlier mentioned, this is done with little space and money. They are eco-friendly and some CWs use waste material as filter medium. Plants on wetland provide a habitat for aquatic and other organisms (Brix, 2003). Wetlands have green blue surfaces which contribute to a cool atmosphere and environment (Sagen, 2014). Again, since plants inhale carbon and exhale oxygen, carbon emissions from anthropogenic activities is absorbed by the plants on wetlands. In a nutshell, CWs add to the ecological improvement of the environment.

In addition to augmenting the world water supply, biofilters/constructed wetland is cheap to install compared to other conventional centralised systems (Nolde, 2005). In terms of energy, the system is very efficient. Whilst other treatment systems consume large amounts of energy (Esrey, 2001) the CW’s energy consumption is rather minimal. Less consumption of energy translates into less pressure on the national grid and less funds for operation and maintenance of the equipment for power production. Again, conventional treatment system require the construction and maintenance of very complex transportation system for wastewater which is not needed for the biofilters/constructed wetland.

5.9 CONCLUSION

Treating greywater is an important option to help manage the demand and consumption of water and reduce the burden on fresh water reserves. Reusse of greywater can reduce water consumption by at least 20-40 %. Reclaimed water have also proven to have no different quality compared to water from other sources when for non-potable use as laundry.

Constructed wetlands, green roofs and green walls have high removal efficiency of suspended solids, the organic strength, microorganisms and provide suitable decentralized technologies for greywater treatment that renders water quality for a variety of non-potable use. These technologies are eco-friendly, energy efficient, cost efficient and easy to operate and maintain. Greywater treatment (and recycling) provides an opportunity to avert environmental, surface and ground water pollution.

In Norway, the biofilters/constructed wetland successfully treat greywater to swimming quality whereas green walls proved good for treatment for other non-potable uses. However, the effluent quality from these systems do not satisfy drinking water guidelines. Regarding public acceptance, studies showed reservations towards reusing greywater from other people's homes, i.e. individuals would prefer to reuse their own greywater. This calls for more, research into decentralized, eco-friendly, energy-efficient and cost-effective systems for individual homes rather than for entire apartment building.

6. References

Abdalrahman Alsulaili & Mohamed Homoda, (2015). Quantification and characterization of greywater from schools. *Water Science & Technology: a journal of the International Association on Water Pollution Research*, 72(11), 1973-1980.

Abedin SB, Rakib ZB. (2013). Generation and quality analysis of greywater at Dhaka City. Available online: https://www.researchgate.net/publication/272702500_Generation_and_Quality_Analysis_of_Greywater_at_Dhaka_City (accessed on 4th March 2020).

Abeer Albalawneh, Tsun-Kuo Chang, (2015). Review of the greywater and proposed greywater recycling scheme for agricultural irrigation reuses. *International Journal of Research - GRANTHAALAYAH* · 3(120). Available online: **https://www.researchgate.net/publication/307866723** (accessed on 4th March 2020).

H.I. Abdel-Shafy, A. M. Al-Sulaiman (2014). Assessment of physico-chemical processes for treatment and reuse of greywater. *Egypt. J. Chem*. 57, No. 3, pp. 215-231.

Abu-Ghunmi, L. 2009. Characterization and treatment of greywater: option for (re) use. PhD Thesis. Wageningen University, ISBN 978-90-8585-393-0. Wageningen, The Netherlands.

Alhumoud J. M, Madzikanda D (2010) Public perceptions on water reuse options: the case of Sulaibiya wastewater treatment plant in Kuwait International Business and Economics Research Journal Vol 9(1).

Al-jayyousi, O. (2003). Greywater reuse: towards sustainable water management. *Desalination*, 156, 181-192.

Al-Mughalles, M.H., Rahman, R.A., Suja, F.B., Mahmud, M., Jalil, N., (2012). Household greywater quantity and quality in Sana'a, Yemen. EJGE 17, 1025-1034.

AQUASTAT, (2014). Infographics on water resources and use. FAO. Available online: http://www.fao.org/aquastat/en/

Atasoy, E., Murat, S., Baban, A. & Tiris, M. (2007). Membrane bioreactor (MBR) treatment of segregated household wastewater for reuse. CLEAN–Soil, Air,Water 35 (5), 465–472. bioreactors and their role in wastewater reuse. *Water Sci. Technol.*, 41, 197–204.

Batstone, D. J., J. Keller, I. Angelidaki, S. Kalyuzhnyi, S. Pavlostathis, A. Rozzi, W. Sanders, H. Siegrist, and V. Vavilin. 2002. The IWA anaerobic digestion model no 1 (ADM1). Water Science and Technology 45:65-73.

Birks R, Hills S. (2007). Characterisation of indicator organisms and pathogens in domestic greywater for recycling. Environmental Monitoring and Assessment; 129:61–69

Boyjoo, Y.,Pareek, V., ANG, M. (2013). A review of greywater characteristics and treatment processes. *Water Science Technology* 67, 1403-1424.

Burrows, W. D., Schmidt, M.D., Carnevale, R. M., Schaub, S.A.. (1991) Non Potable Reuse: Development of Health Criteria and Technologies for Shower Water Recycle. Wat. Sci. Tech. 24(9), 81.

C.N Sivaramakrishnan (2008). Effluent treatment: coagulation.available online: https://www.fibre2fashion.com/industry-article/3095/effluent-treatments-coagulation (accessed on 18 April 2020).

Caitrion Nic Aonghusa, Nicholas F. Gray (2002). Laundry detergents as a source of heavy metals in Irish domestic wastewater. Journal of Environmental Science and Health Part A 37(1): 1-6

Chong M.N., ChoY.J., Poh P.E., Jin B., (2015). Evaluation of titanium dioxide photocatalytic technology for the treatment of reactive black 5 dye in synthetic and real greywater effluents. *Journal of Cleaner Production* 89, 196-202.

Cordell, D., Drangert, J.-O. & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change*, 19 (2): 292-305.

D. Fatta-Kassinos, I.K. Kalavrouziotis, P.H Koukoulakis, M.I Vasquez (2011). The risks associated with wastewater reuse and xenobiotics in the agroecological environment. *Science of the Total Environment*; 409(19):3555–3563. Available online: https://doi.org/10.1016/j.scitotenv.2010.03.036

D.M. Ghaytidak, K.D. Yadav (2013). Characteristics and treatment of greywater—a review. *Environ. Sci. Pollution.* Res: 2795-2809

Daniel Gross, (2016). Recycling sewage into drinking water is no big deal. They've been doing it in Namibia for 50 years. Available online: https://www.pri.org/stories/2016-12-15/recycling-sewage-drinking-water-no-big-deal-theyve-been-doing-it-namibia-50-years (accessed on 9 March 2020)

De Mes, T., A. Stams, J. Reith, and G. Zeeman. 2003. Methane production by anaerobic digestion of wastewater and solid wastes. Bio-methane & Biohydrogen: 58-102.

De Sena N., (2006) Public opposition sidelines indirect potable reuse projects. *Water and Environment Technology*; 1999:11–16.

Donner, E., Eriksson, E., Revitt, D. M., Scholes, L., Lutzhoft, H. C. H. & Ledin, A. (2010). Presence and fate of priority substances in domestic greywater treatment and reuse systems. *Science of the Total Environment*, 408 (12): 2444-2451.

Drechsel, P., Mahjoub, O., Keraita, B., (2015). Social and cultural dimensions in wastewater use. *Wastewater. Springer*: 75-92.

Edwin G.A, Gopalsamy P, Muthu N (2014). Characterization of domestic greywater from point source to determine the potential for urban residential reuse: a short review. *Applied Water Science*. 4 (1), 39–49. Available online: https://link.springer.com/article/10.1007/s13201-013-0128-8 (accessed on 11 April 2020)

Eleonora Troiano, Luciano Beneduce, Amit Gross, Zeev Ronen, (2018). Antibiotics-resistance in greywater and greywater-irrigated soils. *Front Microbiol*, 9: 2666. Available online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6232274/ (accessed on 5 April 2020).

Elmitwalli, T. A., & Otterpohl, R. (2007). Anaerobic biodegradability and treatment of grey water in upflow anaerobic sludge blanket (UASB) reactor. Water research, 41(6), 1379-1387.

Eran Friedler, Anat Yardeni, Yael Gilboa, Yuval Alfiya (2011). Disinfection of greywater effluent and regrowth potential of selected bacteria. *Water Sci Technol*, 63(5):931-40. Available online: https://pdfs.semanticscholar.org/c03a/5e821519a718dfc4d73b2df0f67a84fc8f6c.pdf (accessed on 23 May 2020).

Eriksson E, Auffarth K, Henze M, Ledin G (2002). Characteristics of wastewater. *Urban Water*; 4 (1):85–104.

Eriksson, E., Donner, E., (2009). Metals in greywater: sources, presence and removal efficiencies. *Desalination*, 248, 271-278.

Esrey, S. A. (2001). Towards a recycling society: ecological sanitation-closing the loop to food security. *Water Science & Technology*, 43 (4): 177-187.

European Commission (2018). Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse. Proposal for a regulation - COM(2018)337

Fabio Masi, Riccardo Bresciani, Anacleto Rizzo, Ajith Edathoot (2016). Green walls for greywater treatment and recycling in dense urban areas: a case-study in Pune. *Journal of Water Sanitation and Hygiene for Development*; (6)2, 342-347 Available online: https://www.researchgate.net/publication/303716406_Green_walls_for_greywater_treatment_and_recycling_in_dense_urban_areas_A_case-study_in_Pune (accessed on 28 April 2020).

Fangyue Li , Knut Wichmann , Ralf Otterpohl, (2009). Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment* 407, 3439–3449.

Fasil Ejigu Eregno, Melesse Eshetu Moges, Arve Heistad (2017). Treated greywater reuse for hydroponic lettuce production in a Green Wall System: Quantitative Health Risk Assessment. *Water*, 9, 454.

Fatarella E, Tognotti F. Ciabatti I, Cesaro F, Faralli L, (2009). Demonstration System for purification and reuse of laundry wastewater. *Desalination*, 245:451–459.

Francis, R.A., Lorimer, J., (2011). Urban reconciliation ecology: the potential of living roofs and walls. *J. Environ. Manage.* 1429–1437 Available online: https://www.academia.edu/25481415/Urban_reconciliation_ecology_the_potential_of_living_roofs_and_walls (access on 8 March 2020).

Frazer-Williams, R., Avery, L., Jeffrey, P., Shirley-Smith, C., Liu, S. & Jefferson, B. (2008) Constructed wetlands for urban grey water recycling. *Int. J. Environ. Pollut.* 33(1), 93–109.

Friedler, E., Hadari, M., (2006). Economic feasibility of on-site greywater reuse in multi-storey buildings. *Desalination* 190, 221-234.

Fulvio Boano, Alice Carusoa, Elisa Costamagna, Luca Ridolfi, Silvia Fiore, Francesca Demichelis, Ana Galvao, Joana Pisoeiro Anacleto Rizzo, Fabio Masi, (2019). A review of nature based solutions for greywater treatment: application, hydraulic design and environmental benefits. *Science of the Total Environment*, 711. Available online: https://www.sciencedirect.com/science/article/pii/S0048969719347229#b0790 (accessed on 18 April 2020).

Ghaytidak, D.M, Yadav K.D, (2013). Characteristics and treatment of greywater - a review. *Environmental Science Pollution Research*, 20(5), 2795-2809.

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

Giæver, H. (2003). Experience and results from the northernmost constructed wetland in Norway. Advances in Ecological Sciences, 11: 215-236.

Girts, M.A.; Kleinmann, R.L.P. (1986). Constructed Wetlands for Treatment of Acid Mine Drainage: A Preliminary Review. In Proceedings of the 1986 Symposium on Mining, Hydrology, Sedimentology and Reclamation, Lexington, KY, USA, Office of Engineering Services: Lexington, KY, USA, 1986.; pp. 165–171.

Halalsheh, M., Dalahmeh, S., Sayed, M., Suleiman, W., Shareef, M., Mansour, M., Safi, M., (2008). Grey water characteristics and treatment options for rural areas in Jordan. Bioresource technology 99, 6635-6641.

Hannah Ritchie and Max Roser (2020). Water use and stress. Available online:: **https://ourworldindata.org/water-use-stress (accessed on 1 March 2020)**

Hans Brix, (2003). Plants used in constructed wetlands and their functions. Ministerio das Cidades, Ordenamento do Territ¢rio E Ambiente, pp.81-109. Available online: https://www.researchgate.net/publication/230563384_Plants_used_in_constructed_wetlands_and_their_functions (accessed on 10 May 2020).

Hans Brix. (1994). Use of constructed wetlands in water-pollution control—Historical development, present status, and future perspectives. Water Sci. Technol. 30, 209–223.

Harju V. (2010). Assembling and testing of laboratory scale greywater treatment system. Degree Thesis, Tampere University of Applied Science, Finland. Available online: https://www.theseus.fi/bitstream/handle/10024/17433/Harju_Vilhelmiina.pdf?sequence=1&isAllowed=y

Hernández Leal, L., H. Temmink, G. Zeeman, and C. J. Buisman. 2010. Comparison of three systems for biological greywater treatment. Water 2:155-169.

Harsha Fowdar, Belinda Hatt, Peter Breen, Perran L. M. Cook (2017). Designing living walls for greywater treatment. *Water Research*, 110, pp. 218-232.

Hiley, P. (2003). Performance of wastewater treatment and nutrient removal wetlands (reedbeds) in cold temperate Climates. In Mander, Û. & Jenssen, P. D. (eds) Advances in Ecological Sciences,Constructed Wetlands for Wastewater Treatment in Cold Climates, pp. 1-18. Southampton, UK: WIT Press.

Hua-peng Qin, Qiong Su, Soon-Thiam Khu, Nv Tang, (2014). Water Quality Changes during Rapid Urbanization in the Shenzhen River Catchment: An Integrated View of Socio-Economic and Infrastructure Development. *Sustainability*, 6, 7433-7451.

Hurliman A, Dolnicar S., (2013). When public opposition defeats alternative water projects—the case of Toowoomba Australia. *Water Resources;* 44:287–297.

Husein I. Abdul-Shafy, Ahmed Makki Al-Sulaiman, Mona S.M Mansour (2014). Greywater treatment via hybrid integrated systems for unrestricted use in Egypt. *Water Process Engineering*, 1, 101-107.

Hyde, K. (2013). An evaluation of the theoretical potential and practical opportunity for using recycled greywater for domestic purposes in Ghana. Journal of Cleaner Production, 60: 195-200.

Itayama, T., Kiji, M., Suetsugu, A., Tanaka, N., Saito, T., Iwami, N., Mizuochi, M. & Inamori, Y. On site experiments of the slanted soil treatment systems for domestic greywater. Water Science and Technology: A Journal of the International Association on Water Pollution Research 53 (9), 193.

J. Lahnsteiner and G. Lempert (n.d). Water management in Windhoek/Namibia. VA TECH WABAG GmbH, Siemensstrasse 89, 1210 Vienna, Austria . Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.551.4370&rep=rep1&type=pdf (accessed on 1 March 2020).

James J. & Sarah Stefan V. (2015). What amount of water on earth is drinkable? Available online: https://socratic.org/questions/what-amount-of-water-on-earth-is-drinkable#159502 (accessed on 1 March, 2020).

Jamrah, A., Al-Omari, A., Al-Qasem, L., Ghani, N.A., (2006). Assessment of availability and characteristics of greywater in Amman. *Water international* 31, 210-220.

Jaime Nivala; Manfred van Afferden; Ralf Hasselbach; Guenter Langergraber; Pascal Molle; Heribert Rustige; Jens Nowak (2018). The new German standard on constructed wetland systems for treatment of domestic and municipal wastewater. Water Sci Technol., 78 (11): 2414–2426

Jefferson, B., Laine, A., Parsons, S., Stephenson, T., and Judd, S. (2000). Membrane bioreactors and their role in wastewater reuse. Water Sci. Technol., 41, 197–204.

Jeffery P. Understanding public receptivity issues regarding ‘in-house’ water recycling. Cranfield UK: Results from a UK survey; 2001.

Joana America Castellar da Cunha, Carlos A. Arias, Pedro Carvalho , Martina Rysulova , Joan Montserrat Canals , Gabriel Pérez, Montserrat Bosch Gonzalez , Jordi Farreras Morató, (2018). ‘‘WETWALL”: an innovative design concept for the treatment of wastewater at an urban scale. *Desalination and Water Treatment*, pp. 205–220.

Kadlec RH, Axler R, McCarthy B & Henneck J. (2003). Subsurface treatment wetlands in the cold climate of Minnesota. In: Mander U & Jenssen PD. (Eds.) Constructed wetlands for wastewater treatment in cold climates: Advances in Ecological Sciences. 11: 215-235.

Kantanonleon N, Zampetakis L, Manios T.(2007). Public perception towards wastewater reuse in a medium size, seaside Mediterranean city: a pilot survey. *Resources Conservation and Recycling*;50:282–292

Kathryn Reid (2019). Global water crisis: Facts, FAQs, and how to help. Available online:https://www.worldvision.org/clean-water-news-stories/global-water-crisis-facts (accessed on 1 March, 2020).

Katukiza A.Y, Ronteltap M, Niwagaba CB, Kansiime F, Lens PNL. (2015). Grey water characterisation and pollutant loads in an urban slum. *International journal of Environmental Science and Technology* 12(2), 423-436. Available online: https://www.researchgate.net/publication/278648604_Grey_water_characterisation_and_pollutant_loads_in_an_urban_slum (accessed on 4 March, 2020).

Kivaisi, A. K. (2001). The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. *Ecological Engineering*, 16 (4), 545–560.

L.M Casanova, Charles P. Gerba & Martin Karpiscak (2001). Chemical and microbial characterization of household greywater. *Journal of environmental science and health*, 36(4), 395 – 401. Available online: https://www.tandfonline.com/doi/abs/10.1081/ESE-100103471 (accessed on 4 March, 2020).

Laber, J., Haberl, R. & Perfler, R. (2003). Enhanced nitrogen elimination in vertical-flow constructed wetlands in cold climates. *Advances in Ecological Sciences*, 11: 107-122.

Lazarova, V., hills, S. & birks, R. (2003). Using recycled water for non-potable, urban uses: a review with particular reference to toilet flushing. *Water Science Technology*: Water Supply, 3, 69-77.

Lena Westhof, Stephan Köster, Margrit Reich (2016). Occurrence of micropollutants in the wastewater streams of cruise ships. *Emerging Contaminants*, 2(4), 178-184. Available online: https://www.sciencedirect.com/science/article/pii/S2405665016300324 (accessed on 21 May 2020).

Lili Wang, Dennis C. Flanagan, Zhonggen Wang, Keith A. Cherkauer (2018). Climate change impacts on nutrient losses of two watersheds in the great lakes region. *Water*, 10(4), 44. Available online: **https://doi.org/10.3390/w10040442** (accessed on 4 March, 2020).

Lina Abu Ghunmi , Grietje Zeeman , Manar Fayyad & Jules B. van Lier (2011). Grey water treatment systems: A Review, Critical Reviews in *Environmental Science and Technology*, 41:7, 657-698 Available online: **DOI: 10.1080/10643380903048443**

Lindsey E. Svete, (2012). Vegetated greywater treatment walls: design modifications for intermittent media filters. Master Thesis. As: Department of Mathematical Sciences and Technology (IMT) Norwegian University of Life Sciences (UMB). Available online: https://nmbu.brage.unit.no/nmbu-xmlui/bitstream/handle/11250/188977/Svete2012.pdf?sequence=1&isAllowed=y (accessed on 10 May 2020).

Liu R, Huang H, Chen L, Wen X, Qian Y. Operational performance of a submerged membrane bioreactor for reclamation of bath wastewater. Process Biochem 2005;40(1):125–30.

Lucien W. Gassie, James D. Englehardt (2019). Mineralization of greywater organics by the ozone-UV advanced oxidation process: kinetic modeling and efficiency. *Environ. Sci.: Water Res. Technol.*,5, 1956-1970

M. Hu, T. Zhang, J. Stansbury, M. Dahab, J. Shi, J. Neal, M. Alahmad, C. Berryman, H. Li, A. Schwer, Z. Shen (2011). Treatment of greywater with shredded-tire biofilters and membrane bioreactors. World Environmental and Water Resources Congress: bearing knowledge for sustainability, ASCE: 1877–1887.

M. Lafforgue & V. Lenouvel, (2015). Closing the urban water loop: lessons from Singapore and Windhoek. Environmental Science: Water Research & Technology, 1(5), 622-631. Available online: https://www.researchgate.net/publication/281571252_Closing_the_urban_water_loop_Lessons_from_Singapore_and_Windhoek (accessed on 9 March 2020).

M.C. Mesquita, A.Albuquerque, L. Amaral, Nogueira (2017). Seasonal variation of nutrient removal in full-scale horizontal constructed wetland. Energy Procedia, 136, pp. 225-232. Available online: https://www.sciencedirect.com/science/article/pii/S1876610217351962 (accessed on 14 May 2020).

M. Weinmaster (2009). Are green walls as "green" as they look? an introduction to the various technologies and ecological benefits of green walls. *J. Green Build.*, 4 (4), pp. 1-18

Mæhlum, T. & Jenssen, P. (2003). Design and performance of integrated subsurface flow wetlands in a cold climate. Computational Mechanics Inc, 2003.: 69-86.

Mæhlum, T. & Stålnacke, P. (1999). Removal efficiency of three cold-climate constructed wetlands treating domestic wastewater: effects of temperature, seasons, loading rates and input concentrations. Wat. Sci. Tech. 40(3), pp. 273-281.

Mainstone, C.P., & Parr, W., (2002). Phosphorus in rivers-ecology and management. *The Science of the Total Environment*, 282-283, 25-47. Available online: https://www.sciencedirect.com/science/article/pii/S0048969701009378?via%3Dihub (accessed on 4 March, 2020).

Maria Manso., João Castro-Gomes, J., 2015. Green wall systems: a review of their characteristics. Renewable Sustainable Energy Rev., 863–871. Available online: https://www.academia.edu/21403128/Green_wall_systems_A_review_of_their_characteristics (accessed on 10 May 2020).

Marie R. Sagen, (2014). Long term performance of an urban decentralised greywater treatment system in Oslo, Norway. Master Thesis. As: Faculty of Environmental Science and Technology, Department of Environmental Sciences Norwegian University of Life Sciences (NMBU)

Marks M. (2004). Advancing community acceptance of reclaimed water. *Water Journal of the Australian Water Association;*31:46–51.

Meehan, K., Ormerod, K. J., Moore S. (2013) Remaking waste as water: the governance of recycled effluent for potable water supply. *Water Alternative*; 67–85.

Melesse Eshetu, Daniel Todt, Fasil Ejigu Eregano, Arve Heistad (2017). Performance study of biofilter system for on-site greywater at cottages and small households. *Eco. Eng. 105, 118-124*

Merz Cornelia, Scheumann Rene, El Hamouri Bouchaib, Kraume Matthia, (2007), Membrane bioreactor technology for the treatment of greywater from a sports and leisure club. *Water and Urban Wastewater Management in the Mediterranean area*. 215: 37-42

Michael Oteng-Peprah, Mike Agbesi-Acheampong, Nanne K. deVries (2018). Greywater characteristics, treatment systems, reuse strategies and user perception - a review. *Water Air Technology*, 229(8): 255. Available online: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6133124/#CR91 (accessed on 9 March, 2020).

Michael Tiboris (2016). Water scarcity, urbanization, and climate change are a combined threat to supply chains in the developing world. The Chicago Council on Global Affairs. Available online: https://www.thechicagocouncil.org/blog/global-food-thought/water-scarcity-urbanization-and-climate-change-are-combined-threat-supply (accessed on 30 April 2020).

Mohamed Nageeb Rashed (2012). Adsorption technique for the removal of organic pollutants from water and wastewater. Available online: https://www.intechopen.com/books/organic-pollutants-monitoring-risk-and-treatment/adsorption-technique-for-the-removal-of-organic-pollutants-from-water-and-wastewater (accesses on 21 May 2020)

Monteleone, M.C., Yeung, H., Smith, R., (2007). A review of ancient Roman water supply exploring techniques of pressure reduction. *Water Science & Technology: Water Supply*, 7(1), 113-120

Morel, A., Diener, S., (2006). Greywater management in low an [ie And] middle-income countries: review of different treatment systems for households or neighbourhoods. Sandec at Eawag.

Musfique Ahmed, Meenakshi Arora (2012). Suitability of greywater recycling as decentralised alternative water supply option for integrated urban management. *Journal of Engineering*, 2, pp. 31-35. Available online: ww.researchgate.net/publication/256492815_Suitability_of_Grey_Water_Recycling_as_decentralized_alternative_water_supply_option_for_Integrated_Urban_Water_Management (accessed on 5 May 2020)

N.G. Leigh, H. Lee, (2019). Sustainable and resilient urban water systems: the role of decentralization and planning. Sustainability, 11 (2019), p. 918.

Nolde, E. (1999). Greywater reuse systems for toilet flushing in multistory buildings-over ten years experiences in Berlin. Urban water 1 (4), 275-284.

Nolde, E. (2005). Greywater recycling systems in Germany results, experiences and guidelines. *Water Science & Technology*, 51 (10): 203-210.

Ødegaard, H., Lindholm, O., Mosevoll, G.,Thorolfsson, S., Sægrov, S., Østerhus, S. & Heistad, A. (2012).Vann-og Avløpsteknikk (Water-and Wastewater Engineering). Norsk Vann: Hamar, Norway.

OtterWasser GmbH. (2009). Ecological housing estate, Flintenbreite, Lübeck, Germany: Sustainable Sanitation Alliance (SuSanA). Available at: https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/59 (accessed on 18 May 2020).

Palmquist, H., & Hanæus, J. (2005). Hazardous substances in separately collected grey-and blackwater from ordinary Swedish households. Science of the Total Environment, 348(1-3), 151-163.

Parsons S.A, Bedel C, Jefferson B. (2000). Chemical vs. biological treatment of domestic greywater. Proceedings of the 9th Intl. Gothenburg Symposium on Chemical Treatment, 2-4th October 2000, Istanbul, Turkey.

Pedro N. Carvalho, Carlos A. Arias, Hans Brix (2017). constructed wetlands for water treatment: new development. Water 2017, 9,397. Available online: https://www.mdpi.com/2073-4441/9/6/397 (accesses on 15 May 2020).

Peilin Wu, Minghong Tan, (2012). Challenges for sustainable urbanization: a case study of water shortage and water environment changes in Shandong, China. Procedia Environmental Sciences 13, 919 – 927.

Peter H. Gleick. (1993). Water in crisis: a guide to the world's fresh water resources. Oxford: Oxford University Press

Petrus L. Du Pisani, (2004). Surviving in an arid land: direct reclamation of potable water at Windhoek's Goreangab reclamation plant. Available online: https://cals.arizona.edu/OALS/ALN/aln56/dupisani.html (accessed 9 March, 2020).

Petter D. Jenssen (2002). Design and performance of ecological sanitation systems in Norway. Available online: http://www.ecosanres.org/pdf_files/Nanning_PDFs/Eng/Jenssen%2052_E41.pdf (accessed on 10 March, 2020).

Petter D. Jenssen, & Vråle, Lasse. (2003). Greywater treatment in combined biofilter/constructed wetlands in cold climate. Ecosan – closing the loop. Proc. 2nd int. symp. ecological sanitation, Lübeck, Germany, pp. 875-881: GTZ, Germany.

Petter D. Jenssen, (2005). A complete recycling (ecosan) system at student dormitories in Norway. In van Bohemen, H. (ed.) Ecological Engineering: Bridging Between Ecology and Civil Engineering, pp. 81-83: Æneas, Technical Publishers.

Petter D. Jenssen, Jonasson, S. A. & Heistad, A. (2006). Naturbasert rensing av avløpsvann. VA-Forsk Rapport, Nr 2006-20.

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

PUB (n.d). Singapore's National Water Agency. Available online: "PUB, Singapore's National Water Agency" (accessed on 17 November 2019).

Qing Zhou, Xiangzheng Deng, Feng Wu, (2017). Impacts of water scarcity on socio-economic development: A case study of Gaotai County, China. Physics and Chemistry of the Earth, Parts A/B/C , 101,204-213. Available online: https://www.sciencedirect.com/science/article/pii/S1474706516302285 (accessed on 1st may 2020).

Ramprasad, C., Smith, C.S., Memon, F.A., Philip, L., 2017. Removal of chemical and microbial contaminants from greywater using a novel constructed wetland: GROW. Ecol. Eng. 106, 55–65.

Rauch, W., Brockmann, D., Peters, I., Larsen, T. A., & Gujer, W. (2003). Combining urine separation with waste design: an analysis using a stochastic model for urine production. *Science of the Total Environment*, 37 (3), 681-689.

Rebecca Balke, Cathrine Owen Koning, Ben Lundsted (2018). Watershed model identifies historic wastewater discharge to wetlands as a major phosphorus source to a eutrophic lake, NH USA. *Lake and Reservoir Management*, 34:4, 349-364, available online: DOI: 10.1080/10402381.2018.1462869 (accessed on 1 May 2020).

Renee Cho, (2011). From wastewater to drinking water. Available online: https://blogs.ei.columbia.edu/2011/04/04/from-wastewater-to-drinking-water/ (accessed on 8 March 2020)

Revitt DM, Eriksson E, Donner E. (2011). The implications of household greywater treatment and reuse for municipal wastewater flows and micropollutant loads. Water Research. ;45:1549–1560. doi: 10.1016/j.watres.2010.11.027.

Robert H. Kadlec, Knight R.L (1996). Treatment wetlands. Lewis Publishers, Boca Raton, p. 893.

Robert H. Kadlec, Scott Wallace, (2009). Treatment wetlands: second edition. CRC Press, Boca Raton, London

Rummelhoff, S. B. (2019). Evaluering av en kompakt enhet for primær og sekundær rensing av gråvann (Master's thesis, Norwegian University of Life Sciences, Ås).

Sahar Dalahmeh (2013). Bark and charcoal filters for greywater treatment: pollutant removal and recycling opportunities. Doctoral Thesis. Swedish University of Agricultural Sciences. Available online: https://core.ac.uk/download/pdf/11699079.pdf (accessed on 23 May 2020)

Sara Dolnicar, Saunders, C. (2006). Recycled water for consumer markets—a marketing research review and agenda. *Desalination*, 187 (1-3), 203-214.

Sarah Fecht, (2019). How climate change impacts our water. Available online: https://blogs.ei.columbia.edu/2019/09/23/climate-change-impacts-water/ (accessed on 3 March, 2020).

Saroj B. Parjane, Mukund G. Sane, (2011). Performance of greywater treatment plant by economical way for Indian rural development. *International Journal of Chem Tech*, 3(4):1808–1815.

Sergio Zamora , J. Luis Marín-Muñíz, Carlos Nakase-Rodríguez, Gregorio Fernández-Lambert, Luis Sandoval, (2019). Wastewater treatment by constructed wetland eco-technology: influence of mineral and plastic materials as filter media and tropical ornamental plants. Water, 11, 2344. Available online: https://www.mdpi.com/2073-4441/11/11/2344 (accessed on 23 May 2020).

Sevil Veli, Ayla Arstan, Eylem Topkaya, Hatice Kurtkulak (2018). Investigating of greywater treatment by adsorption process using polymeric composites supported with activated carbon. Conference: 3rd International Conference on Civil and Environmental Engineering (ICOCEE), At Izmir/Turkey. Available online: https://www.researchgate.net/publication/329567044_Investigation_of_Greywater_Treatment_by_Adsorption_Process_Using_Polymeric_Composites_Supported_with_Activated_Carbon (accessed 21 May 2020)

Schouw, W., Danteravanich, S., Mosbaek, H., & Tjell, J. (2002). Composition of human excreta: a case study from southern Thailand. *Science of the Total Environment*, 286 (1-3), 155-166.

Shin, H. S., Lee, S. M., Seo, I. S., Kim, G. O., Lim, K. H., & Song, J. S. (1998). Pilot-scale SBR and MF operation for the removal of organic and nitrogen compounds from greywater. Water science and technology, 38(6), 80-88.

United Nations Water. Facts and Figures Water and Energy, The United Nations World Water Development Report 2014. Available online: http://unesdoc.unesco.org/images/0022/002269/226961E.pdf (accessed on 13 January 2015).

Veljko Prodanovic, Belinda Hatt, David Mccharthy, Kefeng Zhang, (2017). Green walls for greywater reuse: understanding the role of media on pollutant removal. Eco. Eng. 102:625-635. Available online: https://www.researchgate.net/publication/314565230_Green_walls_for_greywater_reuse_Understanding_the_role_of_media_on_pollutant_removal (accessed on 9 May 2020).

Vigneswaran S, Sundaravadivel M. (2004). Recycle and reuse of domestic wastewater in wastewater recycle, reuse and reclamation. Oxford: EOLSS. Available online: http://www.eolss.net/ebooks/sample%20chapters/c07/e2-14-01.pdf (accessed on 5 April 2020).

WHO, Regional Office for the Eastern Mediterranean. (2006). Overview of greywater management health considerations. Available online: https://apps.who.int/iris/handle/10665/116516 (accessed on 7 March 2020).

Wingoc, (n.d). Water reclamation plant: sustainable supply of drinking water: our history. Available online: https://www.wingoc.com.na/our-history (accessed on 9 March 2020).

Winward, G.P., Avery, L.M., Frazer-Williams, R., Pidou, M., Jeffrey, P., Stephenson, T., Jefferson, B., (2008). A study of the microbial quality of grey water and an evaluation of treatment technologies for reuse. *Ecological engineering* 32, 187-197.

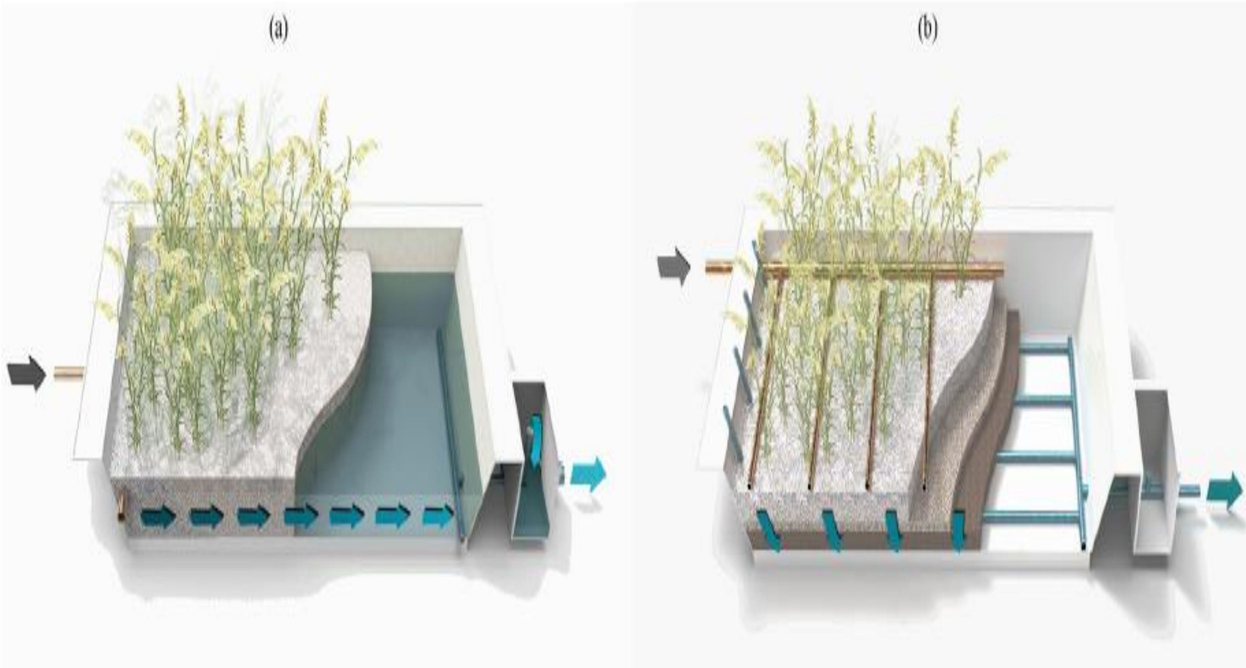
Worldometer (n.d). Current world population. Available online: https://www.worldometers.info/world-population/ (accessed on 3 March 2020).

X. H. Xia, Q. Wu, X. L. Mou,, Y. J. Lai (2013). Potential impacts of climate change on the water quality of different water bodies. *Journal of Environmental Informatics* 25(2):85-98. Available online: https://www.researchgate.net/publication/281993861_Potential_Impacts_of_Climate_Change_on_the_Water_Quality_of_Different_Water_Bodies (accessed on 4 March 2020).

Yiri, A., Hensel, G. R., Aasen, R. & Mæhlum, T. (2007). Examination of smaller sewage treatment plants in normal operation. BioSerach Report. Ås

Yoshihide Wada, Inge E. M. de Graaf, Ludovicus P. H. van Beek (2016). High-resolution modeling of human and climate impacts on global water resources. Available online:https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2015MS000618 (accessed on 1 March 2020)

APPENDIX
Appendix A



Schematics of horizontal-flow CW (a) and vertical-flow CW (b) (Boano et al., 2019)

Appendix B

Completed filter wall (left) and details of planter shelves with felt strip irrigation system (right) (Svete, 2012).

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