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Conceptual planning and designing of a greywater recycling system for a nursery house and a daycare centre in Karagwe, Tanzania

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Engineers without Borders (EWB) Finland started a project to plan, conceptualize and design a nursery centre and a daycare centre in Kayanga, Tanzania. During the planning phase, EWB Finland was informed about inconsistent water supply in the area of the site. Hence, this thesis was designed to overcome the insufficiency of water in the site location.

The presumed value of water consumption for the site indicated a large percentage of greywater generation that are usually drained down the drainage along with the blackwater. Therefore, the main objective of this thesis was to study the feasibility of recycling greywater generated in the nursery to be used for non-potable uses. The report provides a design of a conceptual treatment system that aims at recycling greywater generated from only hand basin to be used for toilet flushing. The system is designed to treat the greywater through the method of sand filtration in addition with activated carbon filter. The treatment system in the design comprises of collection tank, sand filter tank, activated carbon filter tank and storage tank in the same order.

The design of the treatment system is approached by providing detailed background, specifications and calculations for each unit of the system. The calculations and design are based on the literature review and desktop study.

Keywords	greywater, wastewater, recycling, sand filtration, activated carbon

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I would like to dedicate this thesis to my parents, Nikunj and my sister Samanta for always supporting my career choice and believing in me. Lastly I would like to thank all of my friends and family for their constant support.

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BOD	Biological oxygen demand
CAWST	Centre for Affordable Water and Sanitation Technology
cm	Centimetre
COD	Carbon oxygen demand
DS	Dissolved Solids
d	Day
EBCT	Empty bed contact time
EWB	Engineer without Border
GAC	Granular Activated Carbon
HLR	Hydraulic loading rate
h	Hour
l	litre
LAS	linear alkylbenzene sulfonates
l/p/d	litre per person per day
m	metre
m^3	cubic metre
mg	milligram
mm	millimetre
min	minute
PAC	Powdered Activated Carbon
RBC	Rotating Biological Contractor
TN	Total nitrogen
TOC	Total organic compounds
TP	Total phosphorus
TS	Total solids
UC	Uniformity Coefficient
UN	United Nations
µS	micro Siemens
VS	Volatile solids
VSS	Volatile suspended solids

Contents

1 Introduction

Water scarcity is the main and most common problem of 21st century. A total of 700 million people in 43 countries suffer from water scarcity today. UN estimates that by 2025, 1.8 billion people will be living in countries or regions with absolute water scarcity. (United Nations, 2014). Water is vital to sustain human life, other living things and the environment. There is adequate amount of fresh water sources, but due to several environmental and climate impacts, the sources are drying out. Rapid growth in population and urbanization has added fuel to this burning issue. Inadequate amount of water has arisen various problem of diseases and pollution around the globe.

The increasing rate of population growth and the scarcity and pollution of water source could initiate the world war. To overcome this issue, there has been increased amount of attention drawn towards water recycling and reusing. Water reuse and recycling and reusing is seen as an important step towards sustainable water conservation and clean environment. Greywater recycling and reusing is one of the alternative approaches to ensure water availability, reducing water stress and minimizing the cost of fresh water supply. Greywater recycling and reusing has gained substantial attention and is practiced in different part of the world as a sustainable option.

Tanzania is one of the nations in Africa facing serious issues regarding the water even though having three big lakes, one of them being Lake Victoria, the second largest in the world by surface area (Deborah M. Aller, 2013). As much as 44 percentage of Tanzania's population do not have access to clean and safe water (Water.org, 2017). Serious actions and steps are taken by different international and local organizations to reduce this problem. Greywater recycling would be a vital effort for maintaining the sustainable water environment in the country.

This thesis focuses on designing a sustainable greywater recycling and reuse in the Nursery. This thesis provides detailed information on the performance of simple and low-cost alternatives for on-site treatment of greywater. The recycled greywater is designed to be used for toilet flushing, as well as further more for irrigation if needed.

2 Background

2.1 Geographical and climatic features of the site

United Republic of Tanzania (Figure 1) is located on the south-east coast of African continent. Kayanga town (Figure 2) lies in the Karagwe district, which is one of the districts of Kagera region of Tanzania. Kagera region is located on the west shore of Lake Victoria and bordering with the Republics of Uganda and Rwanda (Malocho, 1998). Karagwe is a mountainous district with attitudes ranging between 1500 -1800 meters above sea level, where people have inhabited the hill tops. The Karagwe district is characterized with fractured ancient rock, which allows the rainwater to pass through leaving only little surface water and forming a deep groundwater table. (Simonds, 1993) The surface water lying on the deep valley, women and children have to walk a long distance to fetch water from the valleys, which are usually of poor quality. This has led to adoption of rainwater harvesting in the Karagwe district.

Figure 1 Location of Tanzania on African continent (Google , 2017)

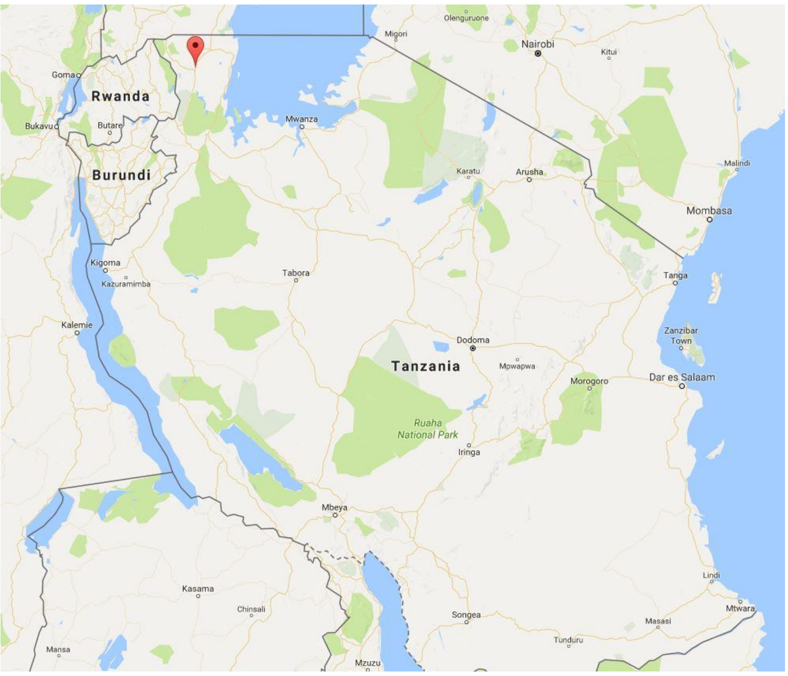

Figure 2 Location of Kayanga town in Tanzania (Google , 2017)

The Kayanga town of the Karagwe district has a tropical climate with a yearly temperature ranging from 20-22°C. From the Figure 3, it could be concluded that on year 2016 Kayanga town experienced the highest rainfall in November with an average of 178.5 mm, whereas August received the least amount of rainfall of 0.3 mm. June July and August were the driest months of all.

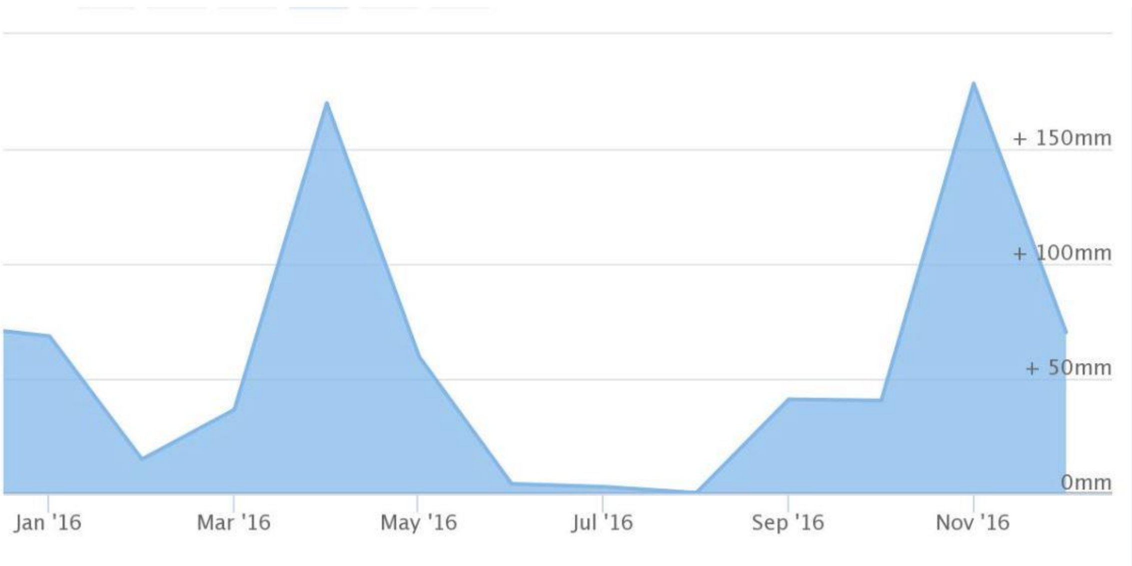

Figure 3 Average rainfall amount (mm) in Kayanga, Kagera in 2016 (World weather Online, 2017)

The town does not have access to water body such as lake, sea and river and depends upon rainfall and municipality connection for water. Although rainwater harvesting is adopted as one of the main source of water, it is not feasible for all the year around.

2.2 Water Problems in Tanzania

Surface sources such as boreholes, springs, rivers and lakes are the major source of water supply in Tanzania (The United Republic of Tanzania Ministry of Water and Irrigation, 2016). Surface water being dried due to climate change and groundwater being contaminated with various toxics, rainwater is used as supplement water supply. Large scale rainwater harvesting has been used for water supply in Tanzania from as early as 1960s (The United Republic of Tanzania Ministry of Water and Irrigation, 2016). However, small scale rainwater harvesting has been flourished especially in rural areas where only 53 % of the households have access to safe drinking water as compared to 73 % for urban households. (Marobhe, 2008). On average, rural households spend 27.1 minutes to collect water for domestic use, whereas the data seemed to be quite low down to 5.9 minutes for rural households (Reserach and Analysis Working Group,United Republic of Tanzania, 2007).

In Tanzania, most of the urban populations have systematic, protected and piped water system, while rural populations still have to travel a distance greater than 1 km to find protected drinking water source (Chuwa, 2015). Mostly in rural sectors, women and especially children often walk hours per day to fetch water from various sources which are either contaminated or insufficient. The time consumed for fetching water makes children unable to attend school and women unable to engage in other activities.

Table 1 below demonstrates the water connection in the rural, urban and mainland Tanzania by different source types. The rural sector seems to have 25 % of the water connections through unprotected dug wells while only 9 % have connection via piped system. Likewise, urban sectors have 22.2 % of connection through piped water into their households and while 7.2 % depends on unprotected wells. In other hand, Tanzania Mainland have fairly similar shares of water connection through public tap/stand pipe and unprotected dug well.

Table 1 Percentage distribution of water connection by location and main source of drinking water (Chuwa, 2015)

Source Type	Rural	Urban	Tanzania Mainland
Piped Water into Dweling	5.7	22.2	11.1
Piped Water to yard/plot	3.1	16.9	7.7
Public Tap/stand pipe	16.1	18.8	17.0
Tube well/bore hale	7.0	10.0	8.0
Protected dug well	7.0	8.9	7.6
Unprotected dug well	25.2	7.2	19.3
Protected Spring	2.8	1.2	2.2
Unprotected Spring	14.3	2.4	10.4
Rain water collection	1.5	0.7	1.2
Bottled water	0.1	0.6	0.3
Cart with small tank/drum	1.5	4.9	2.6
Tanker truck	0.4	3.4	1.4
Surface water (river, dam, lake)	15.3	2.9	11.2
Total	**100.0**	**100.0**	**100.0**

The Kagera region has adequate amount of water source and good rainfall but access to safe, clean water within reasonable distance is a big issue. However, access to drinking water facilities in the Karagwe district of Kagera is less widespread than anywhere else in the region which can be observed from figure 4. More than 50 % of the household in the district are located at more than a 30-minute travel from the nearest source of drinking water. (Kagera Rural CWIQ, 2004)

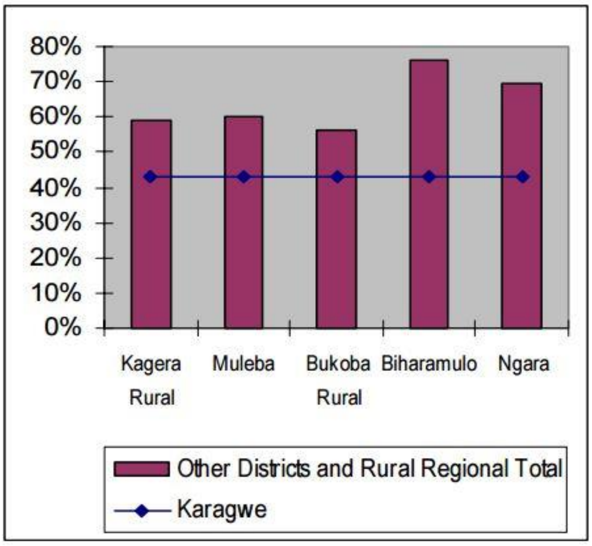

Figure 4 Percentage of households that have access to drinking water facilities in the Karagwe district and other regions (Kagera Rural CWIQ, 2004)

3 Objective

The objective of thesis was to design an onsite treatment system that recycles the greywater generated from the hand basins of the nursery and daycare premises. The treatment system is composed of sand and activated carbon filtration units. The focus of the thesis was on the conceptual planning and designing of the system. This thesis is an attempt to overcome the water scarcity in a sustainable way by utilising greywater recycling and reuse.

4 EWB Finland's Study

Engineers without Borders (EWB) Finland is a non-profit, non-governmental organisation with a mission of providing solutions related to engineering, science and technology. EWB Finland began its new non-profit project in the Kayanga town of Tanzania for the conceptual and architectural designing of sustainable, hygienic and low-cost nursery house and daycare centre. In this particular project, EWB Finland is helping in planning, conceptualizing and designing the structure of the entire premises building along with necessary utilities.

5 Concept

The author of the thesis is part of the research and designing team of Engineers without Borders (EWB) Finland for the Tanzania case study. Each sector of the designing was assigned to different individual. Sustainable water supply was the key point of the project. Therefore, the author created the concept of greywater recycling and reusing, which would help reduce the water stress of the site.

5.1 Planning

The main idea of the thesis was to create a conceptual design of the system that would recycle the water generated from the hand basin to be reused for flushing the toilet in the facility. The site of the project does not have access to a proper water supply system. The municipal city network supplies minimal water into the facility. Rainwater harvesting, even though it is very popular in the area, is not viable for all the year around as there are months with very minimal or no rainfall. Greywater recycling was seen as a viable option to solve this issue as greywater will never be exhausted but is available throughout the year and in all seasons. Greywater reuse utilises onsite resources to contribute to the sustainability of water supply which would be wasted otherwise.

This thesis was conducted in different stages, such as designing and development of the framework for the study, planning, data gathering and assembling, literature review and, finally designing of the prototype system.

5.2 Statistical data

The data required for the planning and designing was collected from the literature review of documents as well as the reports issued by EWB Finland. The statistical data on water consumption that was required for the planning and designing of the system in this thesis was adopted from the design phase 0 report of EWB Finland (Yin, 2016).

Table 2 Average household water consumption (l/d/p) of European countries (European Environment Agency, 2001)

	Denmark-1997	Sweden-1995	England and Wales-	Norway-1981	Finland- 1998
Personal Hygiene	49	57	32	40	57
Toilet flushing	37	38	53	30	17
Washing clothes	18	28	22	25	16
Dishwashing	14	38	0	20	18
Drinking and cooking	10	9	5	8	4
Other uses	19	19	48	7	3
Total	136	189	160	130	116

Yin(2016) adapted the water consumption from European standards by recalculating and remodelling. Table 2 was used by Yin(2016) to estimate the base case for water consumption. The water consumption of Norway (1981) was used for the assumption of the water needs. The value was, however, reduced from the values of Norway standard. The toilet flushing was estimated as 20 l/day by reducing the average Norwegian value. The personal hygiene is very important for the daycare centre. It was not designed to home a shower and bath facility, but wet cleaning in was important for daycare students. Therefore, the hand/face washing consumption was reduced to half of the Norway value of 40 l/day. A reduction of 10 l/day was also done for dishwashing. The water consumption for laundry was assumed to be 16 l/day since the clothes in the daycare will be less as compared to the household. All in all, the water consumption was assumed to be 74 litres per person for the base study case. The assumptions were considered to have a deviation of +/- 20 % based on the methods and ways water would be used in a real-life scenario.

Table 3 Water consumption values assumed for the design phase for the project(modified from (Yin, 2016))

Water consumption breakdown	Volume of water consumed (l/p/d)	Greywater source of interest for the thesis
Flushing/washroom	20	No
Hand basin	20	Yes
House cleaning	4	No
Dishwashing	10	No
Laundry	16	No
Drinking	2	No
Cooking	2	No
Total	74	

l/p/d = litres per person per day

Water generated from the hand basin is the only greywater source considered for recycling. From table 3 it can be observed that the total of 20 l/p/d is the volume of greywater generated from the source, and it is also the volume designed to be used for flushing the toilet. Initially, the nursery house and daycare centre are designed to hold 250 children and 30 teachers under normal conditions with a maximum design criteria of 300 children. The daycare centre is designed to run 6 days/week and 12 hours/day and be open for 10 months a year. (Yin, 2016)

6 Greywater

Domestic wastewater can usually be divided into two categories: blackwater and greywater. Blackwater is the wastewater generated from toilets that has high concentrations of organic matter and huge number of coliform contaminations which are passed into the sewage system. Greywater is termed as the wastewater originated from bathroom, laundries, showers, bathtubs, washing machines, kitchen sinks, hand basin and house cleaning. However, for this thesis only water generated from wash/hand basin sink is considered as greywater and studied for recycling and reusing purposes

Greywater is usually low in organic matter and coliform contaminants as compared to blackwater. The definitions and/or source of greywater varies from country to country. Some greywater may not include the wastewater from the kitchen sink and the dishwasher as they are high in the organic loading.

6.1 Quantity of Greywater

The amount of greywater varies vastly depending upon the dynamics of the household and is influenced by factors such as. Number of Occupants, Age Group of Occupants, Lifestyle Characteristics, Water Usage Pattern, Cost of Water and Climate (NSW Health, 2000)

Greywater volume vary greatly from low income countries to developed countries. According to (Morel & Diener, 2006), "the volume of greywater in richer area with piped tap system generates 90-120 liter per person per day whereas areas with lower income which depends on the rivers or lakes for washing clothes and personal hygiene generate very low greywater of 20-30 liter per person per day". Greywater is estimated to account for 60 % of total wastewater generated in the household. (NSW Health, 2000) (World Health Organisation, 2006). A little less than 50 % of the total greywater is generated from the bath and shower (Figure 5).

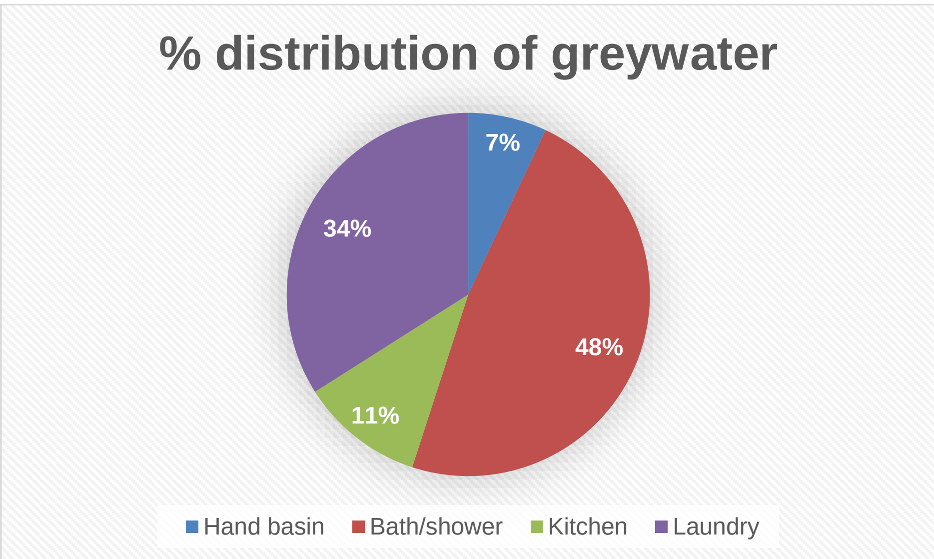

Figure 5 Percentage distribution of greywater generated in the households(Modified from (NSW Health, 2000)

6.2 Quality of greywater

The quality of greywater depends on factors such as Cooking Habits, Type of Detergents Used, Available Water Supply and Household Activities (Morel & Diener, 2006). Greywater contains lower concentrations of organic matter, microorganisms and some nutrients than blackwater, however the concentrations of heavy metals and xenobiotic organic pollutants are approximately at same level (Imhof & MÜHLEMANN, 2005). Even though the quality of greywater is not as depreciated as that of black water, suitable treatment is required before its reuse. Table 4 explains the sources of greywater in a typical household along with its constituent particles and contaminants.

Table 4 Greywater division based on three sources and its content Modified from (Imhof & MÜHLEMANN, 2005) and (Center for the study of the Built Environment, 2003))

sources	content
laundry/washing machine	bleaches, oil, grease, paints, non-biodegradable fibres from clothing, high concentration of chemicals such as sodium, phosphorus, surfactants and nitrogen from soap
Bathroom (shower, bathtub and washbasin)	bacteria, hair, organic material and suspended solids (skin, particles and lint), oil, grease, chemicals from soaps, toothpaste and other body care products
kitchen sink/dishwashing	food residue, high amount of oil and fats, dish washing detergents, bacteria

Greywater generated from bathroom is generally termed as light greywater due to its lower strength of waste and contamination, whereas greywater generated from laundry and kitchen are termed dark greywater as they include higher loads of waste (Albalawneh & Chang, 2015).

Table 5 Qualitative characteristics of greywater in general (Noutsopoulos, et al., 2016)

Greywater Source/type	pH	conductivity (μS/cm)	TS (mg/L)	COD_t (mg/L)	COD_5 (mg/L)	BOD_5 (mg/L)	LAS (mg/L)	TN (mg/L)	TP (mg/L)
Bath/ Shower	7.5±0.1	318±29.9	325±55.3	390±125	193±113	263±83.9	78±34	2.7±2.2	0.10±0.14
Hand basin	7.6±0.2	318±26.8	373±96.0	427±192	272±203	305±129	42±26	2.5±1.9	1.3±2.0
Kitchen	6.9±0.44	449±341	883±426	1119±476	518±225	831±358	87±76	6.5±5.0	2.7±3.1
Laundry	8.3±0.8	653±423	1085±608	2072±1401	1165±920	1363±950	436±288	6.2±5.3	1.2±0.81
Dishwasher	10±0.2	2199±752.62	2535±1053.4	411±59	307±2.9	184.6±24.8	7±5.6	<0.5	187.1±51.4

Different countries have different parameters of contaminants and organisms in greywater. The average hand basin ranks lowest among all the greywater sources in terms of various parameter levels. The hand basin also contains the least amount of organic and chemicals contaminants among other sources. This makes greywater generated from hand basin the least polluted and easy to recycle. Table 5 shows the qualitative characteristics of greywater generated from different sources. The ± sign in table 5 denotes the range of possible values obtained from the experimental results. It can be clearly observed that greywater generated from the hand basin has low values in all of the parameters as compared to those of other sources.

Table 6 Comparison of qualitative characteristics of greywater generated from hand basin

Parameters	(Friedler, 2004)	(Jefferson, et al., 2004)	(Surendran & Wheatley, 1998)	(Almeida, et al., 1999)	(Edwin, et al., 2014)	(Noutsopoulos, et al., 2016)
BOD_5(mg/L)	205	155			138.7	305±129
COD(mg/L)	386	451		298	340.5	427±192
TOC(mg/L)	119	99	40		60.8	
Suspended Solids (mg/L)		153	40			
pH	7	7.32	8.1		7.2	7.6±0.2
Turbidity		164	102			
Total suspended solids (mg/L)	259			181	89.2	90.5±68.3
TS (mg/L)	835		558		450.3	373±96.0
VSS (mg/L)	86			72		
DS (mg/L)			520			
VS(mg/L)			240			
E.coli (cfu/100ml)		10				
Total coliform (number/100ml)		9420				
fecal coliform (cfu/100ml)	$3.5*10^3$	1710				

Table 6 compares the parametric values of greywater generated from hand basin reported in six different literature studies. The composition of the greywater generated from a hand basin varies greatly depending on factors such as Economic Status of Household, Chemical Restrictions and Regulations in Different Countries, and Source of Raw Water. The parameter values of greywater generated from a hand basin are lower than those of other greywater sources; however, the former greywater cannot be used without any treatment. Various researches have been conducted to study the characteristics of greywater originated from a hand basin, and the results differ from each other.

7 Treatment technologies

Different treatment technologies have been used for recycling and reusing of greywater. Some have been fairly successful and used widely, while others are still under investigation. The selection of right treatment technologies depends on (but is not limited to) the following factors:

- Raw water characteristics
- Greywater characteristics
- Water quality standard and end use purposes
- Budget and financial conditions
- Available resources
- Geographic and geological conditions of place

According to the requirements of the above-mentioned factors, various treatment technologies have been used for greywater treatment. The need of specific treatment systems depends upon the usage ranging from single household to large- scale reuse. The technologies vary greatly depending upon the complexity and performance. Greywater recycling technologies involve physical, chemical and biological processes. These processes are usually combined depending upon the required quality of water and end reuse preferences. The following sections present some of the common recycling technologies and process used.

7.1 Filtration

Filtration has been widely used for greywater recycling throughout the world. The complexity of the filtration method range from simple coarse filter to gravel and sand filter. The coarse filtration method can be used to reduce a significant number of solids in the greywater for further treatment steps, but it cannot be used as the main treatment process as it does not remove enough pollution load (Morel & Diener, 2006). The basic sand and gravel filtration are mostly used alone. However sometimes, they are used in combination with activated carbon filter or disinfection or both. The basic sand and gravel filtration is suitable for filtration of greywater having low concentration of pollutants. The high concentration loads of greywater tend to clog the sand and gravel filtration resulting in inefficient performance. The sand and gravel filter system is advised to be used for greywater generated from wash basins, bath tubs, showers, dishwashers and washing machines. Greywater from the kitchen sinks due to its high organic load should be pre-treated before using in the sand and gravel filter. (Huhn, 2015)

7.2 Constructed wetlands

Physical, chemical and biological process are jointly used in this system to remove pollutants from the greywater (FBR, n.d.). This system is usually used as a secondary treatment system for wastewater and greywater. The system consists of bed linen made from either solid clay particle, concrete or plastic foils and then filled with a filter layer of sand or gravel (Morel & Diener, 2006). Plants are grown on the filter especially reed bed that soaks up the organic load from the greywater. Plants helps to provide favourable environment for the microbial growth in the filter media (Morel & Diener, 2006). Proper designing and usage of this system prevents mosquito breeding and fouling odour in the site. Compared to other systems, constructed wetlands seem to be simple, inexpensive, convenient to use and environmental friendly.

7.3 Rotating Biological Contactor (RBC)

RBC is a biological treatment system consisting of closely spaced, stacks of rotating discs mounted on a horizontal shaft. (Spuhler, n.d.). The stacked disc rotates slowly through greywater; biofilms grow on its surface. The bacteria in the biofilm digest the biodegradable organic pollutant from the water. (Ministry of Urban Development , 2008). These are usually used as a secondary treatment system preceded by the sedimentation stage and the final stage of clarification. RBC can be applicable to be used for high removal of BOD and COD from the polluted water. These are preferred for its low space requirement, low sludge production, low energy consumption and easy operation. However, it has high maintenance and operation cost, and the system can be planned and implemented by experts. (Spuhler, n.d.)

8 Recycling and Reuse of greywater

International as well as local level greywater reuse has been one of the main alternative water source to overcome the world’s main problem of water scarcity and disasters. It is emerging as a primary source of water conservation and preservation. Greywater can replace the large part of water usage in sectors such as irrigation, carwash, toilet flushing, if managed and treated in an appropriate, hygienic and sustainable manner. The standard of treated greywater quality varies greatly on the type of treatment process used. The standard value for greywater reuse vary by country. Some of countries use the standard value set by the international organization such as WHO, EU and EPA, while some of them have established their specialized standard value. Nevertheless, all the reclaimed greywater should fulfil criteria of hygienic safety, aesthetics, environmental tolerance, and economical feasibility (Albalawneh & Chang, 2015).

Concerning the recycling and reusing of greywater, proper attention should be paid and proper measures should be taken in order to prevent the spread of diseases. The greywater pipe network should be designed to prevent blackwater from entering the greywater system. All equipment, pipe networks and tanks that are used in the treatment of greywater recycling should be labelled and be kept clearly separate from other systems of the household. The system should be designed to ensure that the raw greywater reaches the system as soon as possible to ensure minimum bacterial growth. Greywater collection and treatment tanks should be designed in such a way that they are suitably sealed, protected against corrosion and lightproof. To prevent from harmful diseases, the tanks should also be mosquito-proof. Greywater overflow should always be diverted towards the sewer system. The untreated greywater should not be stored in the collection tank for more than 24 hours. All the system should be properly maintained, checked and cleaned accordingly. (Water Supplies Department, 2015)

The parameters of reclaimed water obtained after suitable treatment technology determines its end use purposes. Out of all the end use purposes, toilet flushing is one of the main sector where maximum supply of water is needed. Reclaimed water for flushing toilet, reduces the water stress of any household, school or building. Appropriate treatment technologies and proper maintenance of the system should be ensured to use reclaimed water for flushing. Human contact should be avoided and reclaimed water should not be used for other purposes such as bathing and hand washing. All of the end use purposes comply with certain standard parametric values. The treatment system designed to treat and recycle greywater for flushing toilet should comply with its parametric values.

Table 7 Parameters of reclaimed water for flushing toilet

parameters	UK (Environment Agency, 2011)	Japan (Maeda, et al., 1996)	China (Rodrigues, ei pvm)	(World Health Organisation, 2006)	United States (U.S Enviornmental Protection Agency, 2004)	Canada (Working Group on Domestic Reclaimed Water , 2010)	Singapore (Public utilities Board Singapore, 2014)
Turbidity (NTU)	<10	unpleasant	5		≤2	≤ 5	<2
pH	5-9.5	5.8-8.6	6-9		6-9		6-9
residual chlorine (mg/L)	<2				1	≥ 0.5	0.5-2
BOD_5(mg/L)		≤ 20	10	≤ 10	≤ 10	≤ 20	<5
COD							
Total suspended solids (mg/L)				≤10		≤20	
E. coli (number/100 ml)	250		0.3			≤ 200	

faecal coliforms (number/100ml)				≤10	no detectable	≤200	
Total Coliform (number/100ml)	10	≤1000	3				<10
Intestinal enterococci (number/100ml)	100						

From Table 7 it can be observed that the parametric standard value for reclaimed water vary by country and organizations. Some parametric values such as Turbidity, pH, BOD_5 seemed to be approximately same for all. On the other hand, some parametric values such as total coliform number and total suspended solids differ by a huge margin.

9 Water filtration with sand and activated carbon

9.1 Sand filter

Rapid sand filter and slow sand filter are two major types of sand filtration method widely used. Slow sand filters are the oldest water treatment system known. The first publicly known slow sand filter used was in the year 1802 in Paisley, Scotland by John Gibb. He used the filter for his bleaching business and later sold the surplus water to the public. In 1829, James Simpson designed the modern slow sand filter to treat water from the River Thames supplied by the Chelsea Water Company in London. (Baker & Taras, 1981) Then after slow sand filter has been one of the most adopted method used for treating water around the world.

Slow sand filter is a suitable treatment technology especially for developing and rural communities, due to its low cost, simple operation, requirement of less technical components and no chemicals. The structure of slow sand filter is usually made from steel shells or concrete. The use of specific material depends upon the types of operating module used which are pressure filter and gravitational filter. Pressure filter are usually carried out in closed vessel made up of steel shells and containing bed of sand and granular media. The mechanisms in pressure filter involves forcing of water under high pressure into the filter media. Gravity filters are operated in an open concrete box consisting of drain at bottom and partly filled with clean sand as filtering medium. As raw water is added on top of the sand, it flows through the media as a result of the mechanism of gravity.

(Huisman & Wood, 1974) These filters adopt physical and microbiological processes to remove the organic pollutant and dirt from the water. During the process, raw water slowly penetrates through a bed of porous fine sand, with the raw water introduced over the surface of the filter, and then drained from the bottom. (National drinking water clearinghouse, 2000)

Slow sand filter contains four basic elements (Figure 6) i.e. supernatant, filter bed, under drainage system and flow control valves. Supernatant is a layer of water which provides constant head to push the water to pass through the filter media. (Huisman & Wood, 1974) The filter bed contains a layer of fine sand grains of uniform size that filter out the raw water. This is main layer in the system as most of the filtration process occurs in this bed. A microbiological layer forms on the top layer of the sand where a complex network of ecosystem occurs. The space between sand grains traps the remaining organisms that escape the ecological system. An underdrain system supports the filter medium, providing minimum obstruction to the treated water as it flows down through the under-drain system (Huisman & Wood, 1974). The underdrain system consists of gravel medium that prevent sand from clogging the underdrain pipes. The valves control the flow velocity of water though the bed by maintaining constant head of the system.

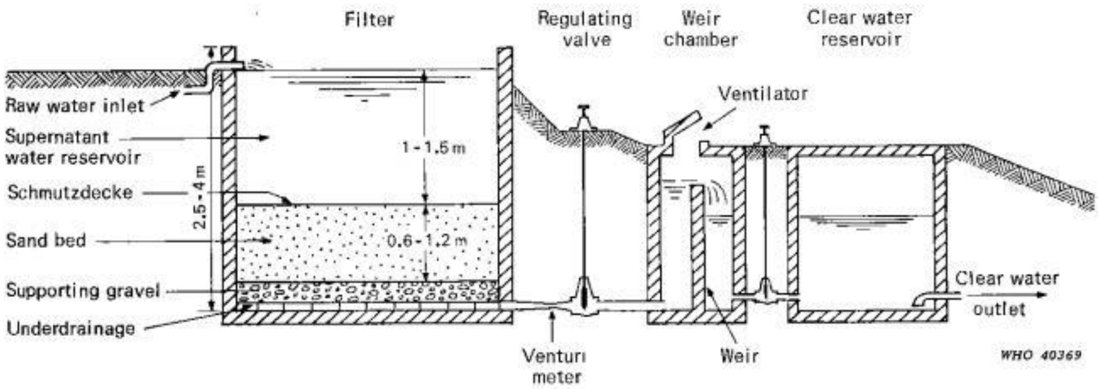

Figure 6 Slow sand filter (reprinted from (Huisman & Wood, 1974))

The slow sand filter removes biological particles such as cysts, oocysts, algae, bacteria, viruses, parasite eggs, nematode eggs and amorphous organic debris (Barrett, et al., 1991). Literature shows some variation in typical characteristics of the design. Huisman & Wood (1974) recom-mended a supernatant layer of 1-1.5 m and a sand depth of 1.2 m with an effective sand size of 0.15-0.35 mm. Hydraulic loading rate was suggested to be 0.1-0.4 $m^3/(m^2 \times h)$. Pescod OBE(n.d.) recommended a supernatant layer of 1-1.5 m, a sand bed depth of 0.8-1.4 m with an effective size of 0.15-0.3 mm and a hydraulic loading rate of 0.1-0.2 $m^3/2(m^2 \times h)$. Visscher et al.(1987) suggested a supernatant layer of 1 m, a sand bed depth of 0.9 m with an effective media of 0.15-0.3 mm and a hydraulic loading rate of 0.1-0.3 $m^3/(m^2 \times h)$. Slow sand filters are designed to serve municipalities or communities having populations of 1000 -2000 persons or maximum of 5000 persons (Barrett, et al., 1991).

9.2 Biosand filter

Biosand filter is a modern adaptation of slow sand filter which are usually adopted to use in household scale for the treatment of water for drinking purposes. Slow sand filter and biosand filter both use the mechanisms of the same sand filtration method to filter the water. Also, these have active biofilm layer on top of the sand and use gravity to push water through the filter (CAWST, 2012). Even though the technology for filtration is same for both filters, they differ in design.

Biosand filters are usually much smaller in size than slow sand filter and designed to have intermittent flow. The flow of water through media in the biosand filter is not controlled with a flow control device like in the slow sand filter. The biosand filter was developed by Dr. David Manz in 1990s at the University of Calgary, Canada. Centre for Affordable Water and Sanitation(CAWST) was founded by Dr. Manz in 2001 and since then has developed the concept of the modern Biosand filter and distributed it worldwide to different nations. A total of 650,000 bio sand filter are used in over 55 countries around the world, and they are helping more than 4 million people. (CAWST, 2009)

Biosand filters are designed to work under similar mechanisms as the slow sand filter. They are designed to have a maximum filtration rate of 0.4 $m^3/(m^2 \times h)$, filtering 12-18 litres of water per batch volume as per CAWST Version 10 concrete bio sand. Considering the recommended pause period of 6 to 12 hours with a minimum of 1 hour to maximum of 48 hours the biosand can filter out 24-72 litres of water daily per family. Even though outer structure of a standard biosand filter is made from concrete, the use of metal oil drums, plastic bin or pre-fabricated or readymade plastic filter is also possible (Biosandfilter.org, 2004). Some of the important components of a biosand filter required for its efficient run are lid, diffuser, filtration medium, underdrainage layer, and outlet tube. The lid is one of the important elements as it prevents the foreign objects and contaminants from entering into the filter. The diffuser prevents the poured water from disturbing the biolayer that forms on the top layer of the sand. The filtration layer consists of a layer of fine sand that removes the contaminants and pathogens from the water and is the most crucial part of the filter. The under layer consists two layers of gravel, separating gravel and drainage layer. The separating layer supports the filtration sand and prevents it from getting into the outlet tube, which could be clogged. The drainage gravel layer supports the separating gravel and helps the water to finally flow through the outlet tube. The outlet tube transfers the filtered water from the base of the filter to the storing tank. (CAWST, 2009) A typical biosand filter of CAWST(2009) with its design specifications can be seen in figure 7.

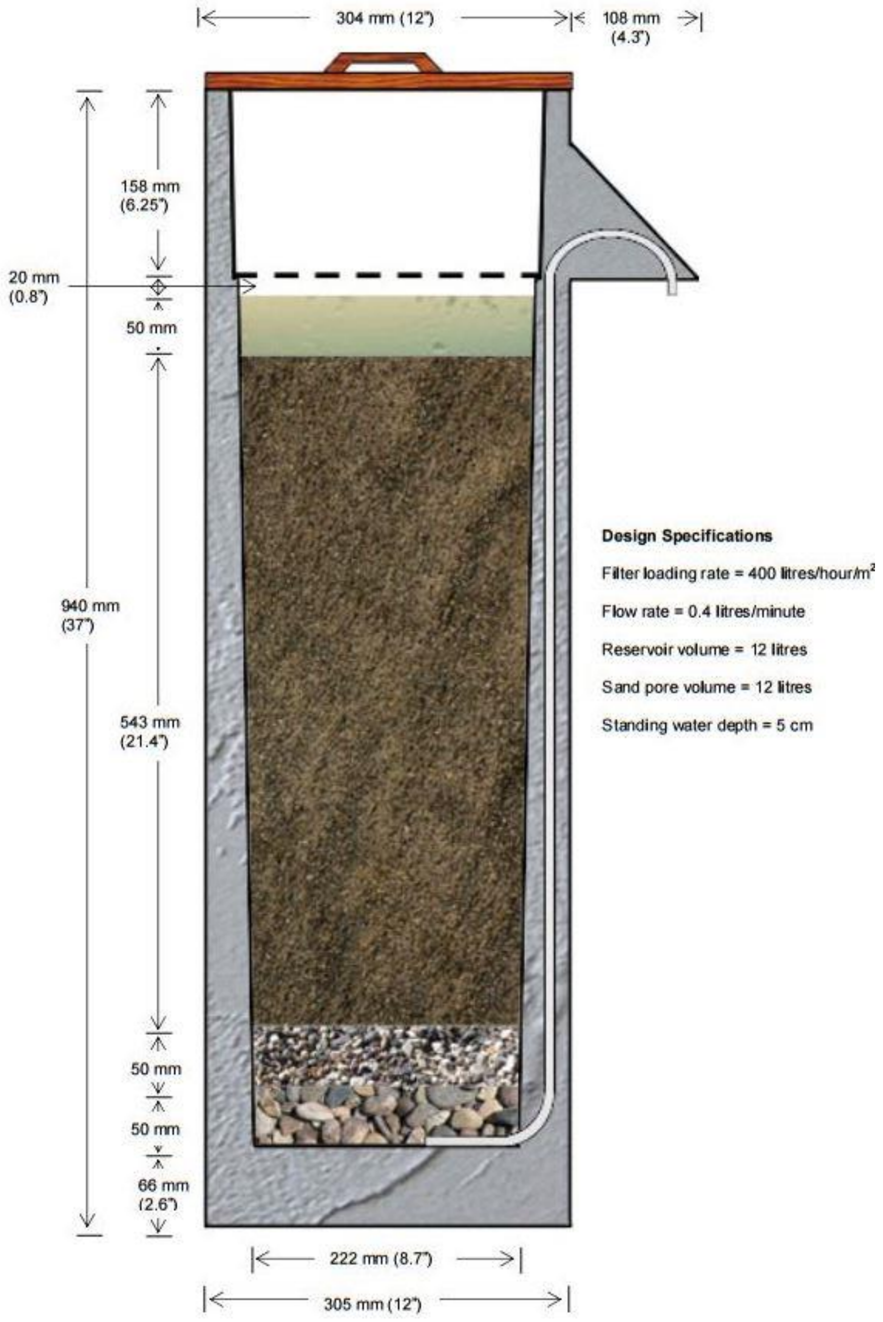

Figure 7Typical biosand filter with its design specifications (CAWST, 2009)

9.3 Activated carbon

Humans have had an intimate relationship with activated carbon from the beginning of the civilization. The use of carbon cannot be traced back exactly, but it is believed to be used long before the history was written. However, activated carbon was first recorded to be used by ancient Egyptian and Sumerians in 3750 BC, for reduction of copper, zinc and tin ores in the manufacture of bronze, and also as a smokeless fuel. According to Hindu mythology, sand and activated carbon filters were used for purification of drinking water. In 1794, activated carbon was used for the first time in industrial sector as a decolorizing agent in sugar production industry in England. The first world war was the turning point for the development of activated carbon. (Menendez-Diaz & Martin-Gullon, 2006). The usage of activated carbon is growing in recent years as they are preferred material in all various sectors such air filters, medical purposes, teeth whitening and water treatment. (General Carbon Corporation, 2017)

Water treatment is one of the main industry where activated activated carbon is found to be used abundantly. Granular activated carbon(GAC)and powdered activated carbon (PAC) are the two main types widely used in water treatment industry. PACs are less preferred than GACs due to their small size as they tend to clog easily. (US Environmental Protection Agency, n.d.) GACs are favoured as they have multifunctional properties and they do not break down easily into water leaving its residue. GACs are commonly used to remove organic materials, odour and taste from the water by the process of adsorption and catalytic reduction. (DeSilva, 2000).

In 1881, the term adsorption was first used by Kayser to explain the uptake of gases by chars. (Menendez-Diaz & Martin-Gullon, 2006). Adsorption is the physical and chemical process by which the contaminated and substances present in the water get accumulated and absorbed onto the carbon surface. The contaminants that are adsorbed is termed as adsorbate, and the surface to which the contaminants gets adsorbed is termed as adsorbent. (Baquero, n.d.). Activated carbon is very efficient adsorbent due to its high porosity and large surface area. GAC are usually made from organic materials which have high carbon contents such as wood, lignite and coal. (US Environmental Protection Agency, n.d.). The characteristics such as particle and pore size, surface area, surface chemistry, density and hardness of granular activated carbon vary depending upon the raw material used to produce them. However, the typical surface area for granular activated carbon is 1,000 square meters per gram (m^2/g). (DeSilva, 2000)

10 Prototype of the system

10.1 Predesign

As mentioned earlier, a slow sand filter is designed to treat for municipal need, whereas a biosand filter is used for household purposes. The design population for the system was assumed to be maximum of 330 people inclusive of all the children and staff members in the nursery house and daycare centre. A typical biosand filter seemed to be small for treating water for a large population as they are designed to fulfil the water need of a small household. On the other hand, typical slow sand filters are large in size as the typical slow sand filters are built to serve a large population of as many as 5000 people and also demands experienced staff to operate and maintain it. Therefore, the sand filter designed for the treatment system in this thesis is adapted partially from both the biosand filter and the slow sand filter.

Various factors and conditions were considered while designing the model of the system. The main aim of the design work was to make the filter easy and convenient to use and able to recycle a reasonable amount of water to reduce the overall water stress of the site. The system designed is to be fairly simple and requires low energy use.

Sand filters have been used in the treatment of water and wastewater in large scale as well as in household scale for a long time. Sand filters are mostly used as a treatment system to treat water for drinking purposes. Proper design, operation and maintenance of sand filters produces very high quality effluent (Al-Mughalles, et al., 2012). However, using a sand filter for the treatment of grey-water would not provide a satisfactory result to match the standard water quality criteria for end use purposes. The addition of granulated activated carbon would help to improve the quality of water. Adsorption mechanism of activated carbon has proven to be an efficient method for removing pollutants from water and wastewater, (Al-Mughalles, et al., 2012) Thus, the conceptual design of the treatment system incorporated a sand filter and granulated activated carbon to filter the greywater.

Two design alternatives were considered for the treatment system:

1 A one container system that would contain a layer of granulated activated carbon under the fine sand layer in a typical sand filtration tank. This system would contain layers of media in the following order: fine sand, granulated activated carbon, and supporting gravel.

2 A two-container system that would incorporate fine sand and the granular activated system in different containers. One container would run as a simple sand filtration system container with layers of fine sand and supporting gravel, while another container would incorporate a layer of granulated activated carbon and supporting gravel.

The latter design (2nd) was chosen from the above alternatives. Both sand and activated carbon have different cleaning procedures, sand can be cleaned either by removing a few centimetres of sand or by using simple methods, while the activated carbon needs to be replaced with a new one when it gets exhausted. Sand being on the top of the filtration system would be easy to clean, while the replacement of activated carbon would disturb the biolayer formed at the top layer of sand if the 1st alternative is considered. The 2nd alternative would allow easy cleaning and operating of both the filtering systems.

10.2 Components of the system

The designed system will have 4 tanks in the system as shown in Figure 8. Tank 1 collects grey-water from all generation points (all hand basins for this case). The collection tank is elevated to provide gravitational flow of water to Tank 2. Tank 2 is for sand filter. The water filtered through the sand filter passes through the activated carbon filter (Tank 3). Finally, the water is stored in the storage tank (Tank 4) and can be used for toilet flushing or for other non-potable uses.

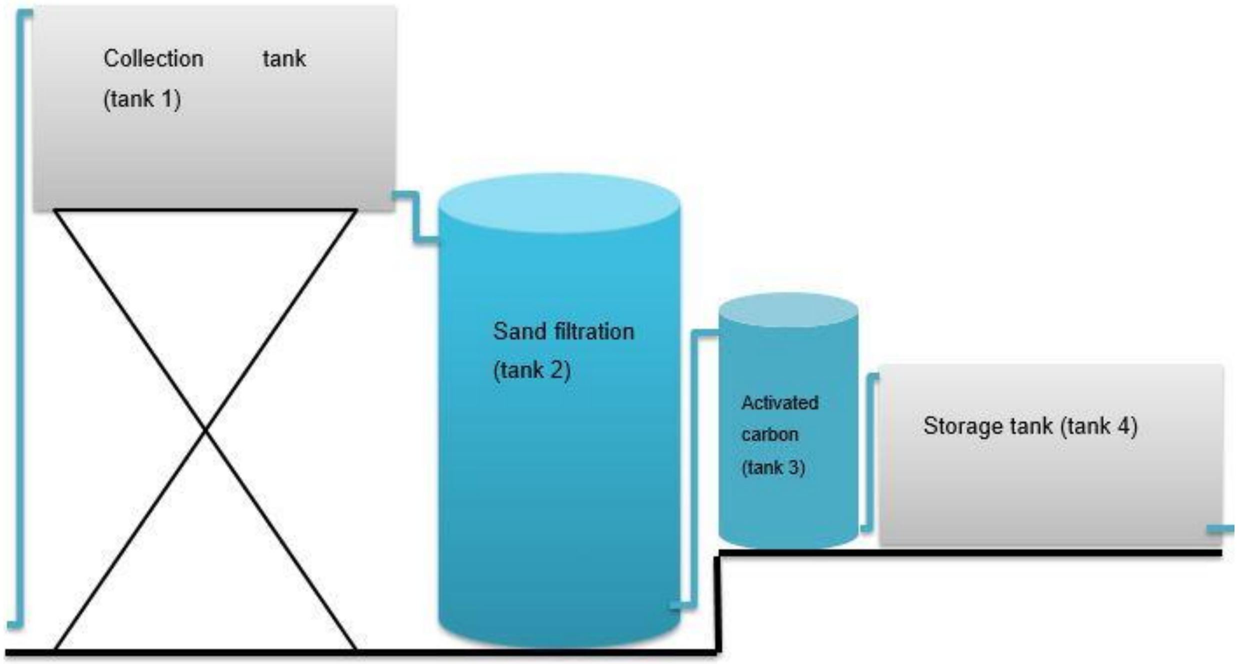

Figure 8 Conceptual design of the greywater treatment system

11 Collection tank

According to the water consumption figures presented in Table 3, the daycare centre was estimated to generate 20 l/p/d of greywater. Also, the same volume of water would be needed for flushing the toilet. Hence, the size dimensions for the collection and the storage tank will be the same for the initial design phase. The daycare centre is assumed to open for 12 hours a day. Considering the maximum design requirements for a system serving 336 people, including 300 children and 36 teachers, the daily greywater generation (Q_D) was calculated as follows:

$Q_{\mathrm{D}} = \frac{N \times Q_{\mathrm{S}}}{1000}$ (Ecosan Services Foundation, n.d.),

where Q_D is the daily greywater production [m³/d], *N* is the number of people contributing to greywater production [people/d], Q_S.is the specific greywater production per person per day [l/p/d] and 1,000 is the conversion factor. Thus, inserting the values in the formula gives the following result:

$$Q_{\mathrm{D}} = \frac{336 * 20\ \mathrm{l/p/d}}{1000}$$

$$Q_{\mathrm{D}} = 6.72\ \mathrm{m^3/d}$$

Mean greywater production per hour is calculated as follows:

$Q_{\mathrm{mean}} = \frac{Q_{\mathrm{D}}}{T}$ (Ecosan Services Foundation, n.d.),

where Q_{Mean} is the hourly mean greywater production [m³/h], Q_D is the daily greywater production [m³/d] and *T* is the duration of greywater production [h/d]. Inserting the values in the formula yields the following result

$$Q_{mean} = \frac{6.72\ \mathrm{m^3/d}}{12\ \mathrm{h/d}}$$

$$Q_{mean} = 0.56\ \mathrm{m^3/h}$$

Now, the volume of the collection tank can be can be calculated using following formula:

$V_{\mathrm{CT}} = Q_{\mathrm{D}} * T$ (Ecosan Services Foundation, n.d.),

where V_{CT} is the net volume of collection tank [m³], Q_D is the daily greywater production [m³/d] and *T* is the desired storage time [d].

$$V_{CT} = 6.72\ \mathrm{m^3/d} * 12\mathrm{h}$$

$$V_{CT} = 6.72\ \mathrm{m^3/d} * 0.5\mathrm{d}$$

$$V_{CT} = 3.36\ \mathrm{m^3}$$

The net volume of the collection tank is calculated to be 3.36 m^3

Planning the tank to be rectangular, so the tank height can be assumed to be 1 m,

$$A = \frac{V}{h},$$

where *A* is the area of the tank [m^2], *V* is the volume of the tank [m^3] and *h* is the height of the tank [m].

$$A = \frac{3.36\ \mathrm{m}^3}{1\ \mathrm{m}}$$

$$A = 3.36\ \mathrm{m}^2$$

Area of collection tank is calculated to be 3.36 m^2

Planning the tank to be rectangular, the dimensions would be

length (*l*) = 2.60 m

width (*w*)= 1.30 m

height (*h*) = 1 m

The volume of the selected collection tank is 3360 l. This tank can be constructed using concrete and local sand, or a plastic water tank could be bought at the store.

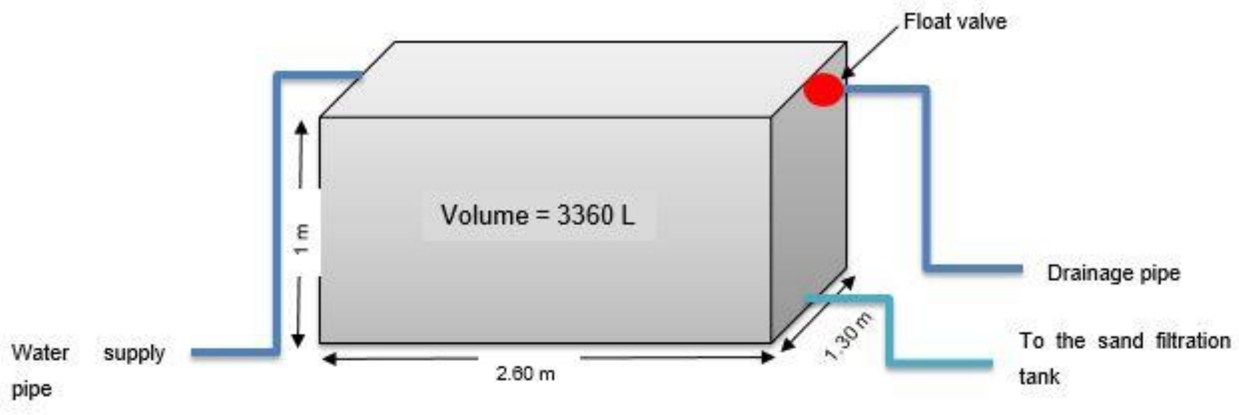

Figure 9 Specifications of tank size for collection of water

The collection tank has three pipe line connections (Figure 9), i.e. water supply, drainage and connection to the sand filtration unit. The 1st pipe supplies the water to the tank from the point of generation, the 2nd pipe works as a drainage pipe that will be connected to a float valve, and the 3rd pipe transfers the water to the sand filtration tank. The supply pipe placed at the height of 1 m and connected to the tank through its top. The supply pipe is placed at the mentioned height for undisturbed flow of water to the tank. The drainage pipe is placed at a lower height than the supply pipe in order to discharge the overflow water through it without being disturbed by the supply pipe. Float valve connected to the drainage pipe controls the water level of the system. The valve is turned on when the water in tank overflows, draining the water out of the tank through the drainage pipe. The pipe placed on the bottom of the tank transfers the water to the sand filtration tank.

12 Sand filtration tank

12.1 Functioning of a sand filter

The sand filtration tank is designed to have layers of fine sand supported by the layer of gravels. The main element of the filter is biolayer which are formed in the upper layer of sand also termed as Schmutzdecke. These layers usually consist of bacteria, fungi, protozoa, algae rotifer and a range of aquatic insect larvae, they also contain dissolved oxygen and nutrients. (Itacanet, 2005). According to CAWST, the biolayer is fully matured only after 30 days of operation. However, the formation of a biolayer depends upon temperature and biological content of the raw water. (Omills, 2011). The layer operates by mechanical trapping, predation, adsorption and natural death. When the water flows down through the filter, the top layer of the sand traps organic material and microorganisms. After being trapped, they develop into an intensely active and complex food chain, and the diseases causing pathogens are consumed by other organisms. The pathogens which escape this process get trapped in between the tiny grains of the sand or gets attached to the sand. Any remaining pathogens moving through the sand die a natural death due to lack of food and oxygen. (CAWST, 2009)

12.2 Components of Bio-sand filtration

Several factors affect the efficiency of the biosand filter. The factors which were considered when designing the sand filtration process are explained below.

12.2.1 Standing water

Standing water layer is the layer of water above the sand. This is important as it provides enough oxygen for the biolayer when the raw water stops flowing. The standard depth of this layer should be 5 cm above the sand. Depth lower than 5 cm may cause filtration sand to dry out due to evaporation of water in hot and dry climate, whereas a depth higher than 5 cm may create a thinner biolayer due to lower oxygen diffusion. (CAWST, 2009). The sand filter is designed to operate at a constant head controlled by the float valve. However, it will also function during the pause period when the daycare centre is not operated. But the pause period should not exceed more than 48 hours. (CAWST, 2009).

12.2.2 Hydraulic loading rate

Hydraulic loading rate or filtration rate is the rate at which the water flows through the filter medium. (CAWST, n.d.). Slow sand filters are designed to have a hydraulic loading rate of 0.1-0.4 $m^3/(m^2 \times h)$ (Huisman & Wood, 1974; Visscher , et al., 1987; Pescod OBE, n.d.) while the modern biosand filter is designed to run at a hydraulic loading rate of 0.4 $m^3/(m^2 \times h)$ (CAWST, 2012). Research by Bellamy et al.(1985) showed an increase in the removal efficiency of coliforms when decreasing the hydraulic loading rate from 0.40 $m^3/(m^2 \times h)$ to 0.04 $m^3/(m^2 \times h)$. CAWST advised that the sand filter with a constant head should only run at 0.2 $m^3/(m^2 \times h)$. The hydraulic loading rate is inversely proportional to the effectiveness of the filter. The higher hydraulic loading rate results in a low quality of water by the filter. (CAWST, n.d.) . Hahn (2016) suggested to use a hydraulic loading rate of 0.2 $m^3/(m^2 \times h)$ for a community-size sand filter. The hydraulic loading rate assumed for the sand filter was 0.2 $m^3/(m^2 \times h)$.

12.2.3 Tank size specifications

The sand filtration system is assumed and planned to have a tank size of volume 1000 l (Figure 10). A cylindrical plastic water tank is considered for this system, but concrete could also be used depending on the cost of the construction. The planned specifications for tank would be

Volume(V)= 1 m^3

Area(A)= 0.66 m^2

Height(h) = 1.5 m

Diameter(*d*)=0.92 m

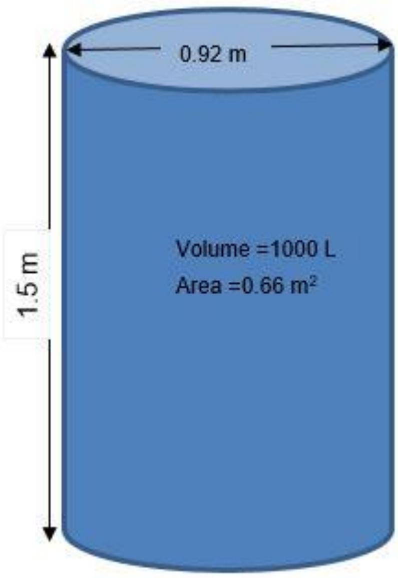

Figure 10 Tank specifications for sand filtration

12.2.4 Gravel characteristics and depth

The gravel layer lies below the sand layer at the bottom of the tank. There are two types of gravel layer; separating gravel and underdrain gravel that acts also as a supporting layer to the filter media. Separating gravel prevents the fine sand from sipping through them and getting clogged in the drainage pipe by holding them in place and also providing support for them. And underdrain gravel helps the drainage pipe by providing support and allowing proper water flow and preventing the pipe from being clogged. The minimum recommended depth for the separation gravel and for the underdrain gravel is 5 cm. The size ranges of the separating gravel and underdrain gravel are 0.7 mm-6 mm and 6 mm-12 mm, respectively. (CAWST, 2009) For this design, the separating gravel height is chosen to be 6 cm, and the drainage gravel height is chosen to be 12 cm.

12.2.5 Sand characteristics and depth

Crushed rock is the best filtration sand as it has less chances of being contaminated, but it is not viable in all the places as it is expensive and difficult to find. CAWST recommends sand from the river banks as the other options. However, the sand should be sieved to get the required size, washed and disinfected properly before use. (CAWST, 2009)

Sand composition means the detailed specifications of the type of sand used for the filtration. Maximum grain size(d_{max}), effective size (d_{10}) and uniformity coefficient (*UC*) are the important considerations for using the right sand type. Effective size(d_{10}) of the sand is defined as the size of sieve opening through which 10 percent by weight of the particle will just pass, and 90 percent of the sample is retained on the screen. It is symbolised as $d_{10.}$ D_{60} is the size of sieve opening through which 60 percent by weight of particles will just pass through. Uniformity coefficient is the ratio of d_{60} by d_{10}. A uniformity coefficient of 4 or less is recommended for all types of filter media. (Eliasson, 2011)

The maximum grain size of 0.7 mm, effective size range of 0.15 mm to 0.20 mm and uniformity coefficient range of 1.5 to 2.5 were chosen as recommended by CAWST (2009) for community slow sand filter. However, Abudi (2011) achieved a better effluent result by sand with the effective size of 0.35 mm and uniformity coefficient of 2.2. For the design criteria, sand with the maximum grain size of 0.7 mm, with the effective size of 0.35 mm, and the uniformity coefficient of 2.2 is presumed.

The total height for a 1000 l tank determined in the sector 12.2.3 is 1.5 m, which is the total working height for the filter. For the target, a hydraulic loading rate of 0.2 $m^3/(m^2 \times h)$, the height of sand bed should be approximately 6 times the height of the reservoir. The height of the sand bed is calculated by Hahn (2016) as

$$h_s = 6 * h_r,$$

where h_s is the height of sand bed and h_r is the height of reservoir.

Some of the assumed value are listed below:

- Height of standing water (h_{St})= 5 cm [from section 12.2.1]
- Height of the tank (h_t)= 1.5 m [from text above]
- Height of gravel(h_g) = height of supporting gravel + Height of drainage gravel = 18 cm [from section 12.2.4]
- [1 m = 100 cm]

These values are inserted to the formula as follows:

$$h_t = h_r + h_{st} + h_s + h_g$$

$$1.5 \text{ m} = h_r + 5 \text{ cm} + 6 * h_r + 18 \text{ cm}$$

$$1.5 * 100 \text{ cm} = 7 * h_r + 23 \text{ cm}$$

$$150 \text{ cm} - 23 \text{ cm} = 7 * h_r$$

$$h_r = \frac{127 \text{ cm}}{7}$$

$$h_r = 18.14 \text{ cm}$$

The height of sand column is calculated to be approx. 18 cm

Thus, the sand bed height can be calculated in the following way:

$$height\ of\ sand\ bed = 6 * height\ of\ reservoir$$

$$height\ of\ sand\ bed = 6 * 18 \text{ cm}$$

$$height\ of\ sand\ bed = 108 \text{ cm}$$

The required sand bed height is 108 cm.

CAWST (2012) recommends the depth of the sand layer in the biosand filter to be a minimum of 0.5 m, which is also the minimum depth at which a slow sand filter can operate. Visscher, et al. (1987) commends the minimum height of sand layer to be 0.6 mm if sand filtration is the only treatment, whereas Huisman & Wood (1974) recommended the depth of at least 0.5-0.8 m. The maximum depth allows and ensures the removal and deactivations of all the pathogens from the raw water (CAWST, 2009). Bellamy, et al. (1985) have observed that the removal efficiency increased from 95 percent to 97 percentage when the sand bed depth was increased from 0.5 cm to 1 m. Thus, on the basis of calculations and previous studies,1 m is considered to be the sand height for the design.

12.2.6 Reservoir Volume

Reservoir volume provides the hydraulic head to the sand filter. The constant hydraulic head to deliver the designed hydraulic loading rate of 0.2 $m^3/(m^2 \times h)$ for the filter is maintained by the float valve. The float valve is used to shut off the flow of water from the collection tank at the pre/deter-mined level and control the water flow in the filter sand. The float valve contains three parts: valve, lever and float device. The valve uses a long lever attached to its float device called ballcock. When the water level rises to the pre-determined level, it lifts the ball cock, which then lifts the lever, closing the valve. As the water level drops, the ballcock and the level falls, reopening the valve and allowing more water to flow into the tank. (McMahon, 2017). On the basis of the calculations in section 12.2.5, the height of the reservoir is calculated to be 18 cm.

12.2.7 Flow rate

The flow rate of the sand is directly proportional to the surface area and the hydraulic loading of the water. (Barrett, et al., 1991)

$$Q = HLR * A,$$

where Q is the flow rate of filter bed[m^3/h], HLR is the hydraulic loading rate [$m^3/(m^2 \times h)$] and A is the area of the filter bed[m^2].

From section 12.2.2, HLR is assumed to be 0.2 $m^3/(m^2 \times h)$ and from the section 12.2.5, the area of filter bed is calculated to be 0.66 m^2.

These values are inserted to the formula as follows:

$$Q = 0.2 \, \frac{\mathrm{m}^3}{\mathrm{m}^2 * \mathrm{h}} * 0.66 \, \mathrm{m}^2$$

$$Q = 0.13 \, \mathrm{m}^3/\mathrm{h}$$

The design flowrate is calculated to be 0.13 m^3/h. This is the target flowrate during the first instal-lation of the filter. The flow rate is adjusted later in the operation period if the filtration rate is signif-icantly minimal.

12.2.8 Pipe specifications for sand filter

The most important thing that should be considered while choosing the underdrain pipe is that they should be non-corrosive and robust. The clay pipe was used traditionally in the old sand filters however the plastics PVC pipes are used widely nowadays. Barrett, et al.(1991) and Thames water and University of Surrey (2005) recommended to use several sections of the pipe in the underdrain system if the filter diameter is relatively large (e.g. >0.3 m). When using a perforated pipe, proper care should be taken as they influence the performance and the capacity of under-drainage system (Thames water and University of Surrey, 2005). For a community-size filter, the drainage pipe of diameter 60 mm with 10-20 holes of approx. 6 mm in size is recommended due to its tendency of bearing loads of the filter medium. (Hahn, 2016)

For the design criteria, 60 mm diameter PVC pipe is chosen. The diameter for the hole of drainage pipe should be so, that the gravel does not enter the opening of the hole and block the water flow. Since, the drainage gravel size was 6 mm-12 mm, the diameter of hole is chosen to be 5 mm approximately. The spacing between the hole should be set to be 10 mm apart for initial design phase. Four pipes of the chosen specifications should be joined together to form x-shape and placed at the bottom of filter under the gravel layer. as shown in the figure 11.

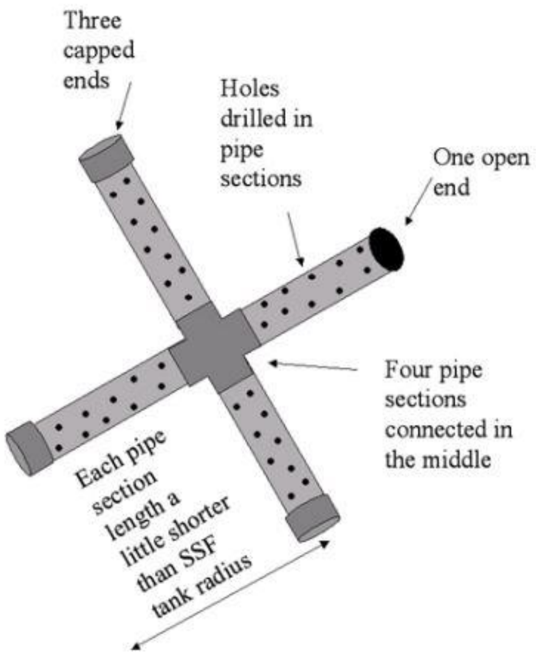

Figure 11 Detailed specification of underdrain pipe (Thames water and University of Surrey, 2005)

12.2.9 Cleaning of sand filter

In order for the sand filter to function in an optimum manner, the filter should be cleaned in an appropriate interval. The cleanout valve should be attached to the cleanout pipe (Figure 12) and should be turned on when the water filtration rate becomes slow and the filter needs to be cleaned. The method of wet harrowing, which is also called as swirl and dump should be used to clean the sand layer. (Biosandfilter.org, n.d.). For cleaning of the filter, the water level in the filter should be dropped to the standing water layer. The top layer of the sand should then be swirled lightly causing a minimal interruption to the biolayer. When the water turns cloudy, the cleanout valve should be opened and the dirty water should be drained down to the drainage. After the filter is cleaned; the float valve should be turned on in order to raise the water level to a pre-determined reservoir level.

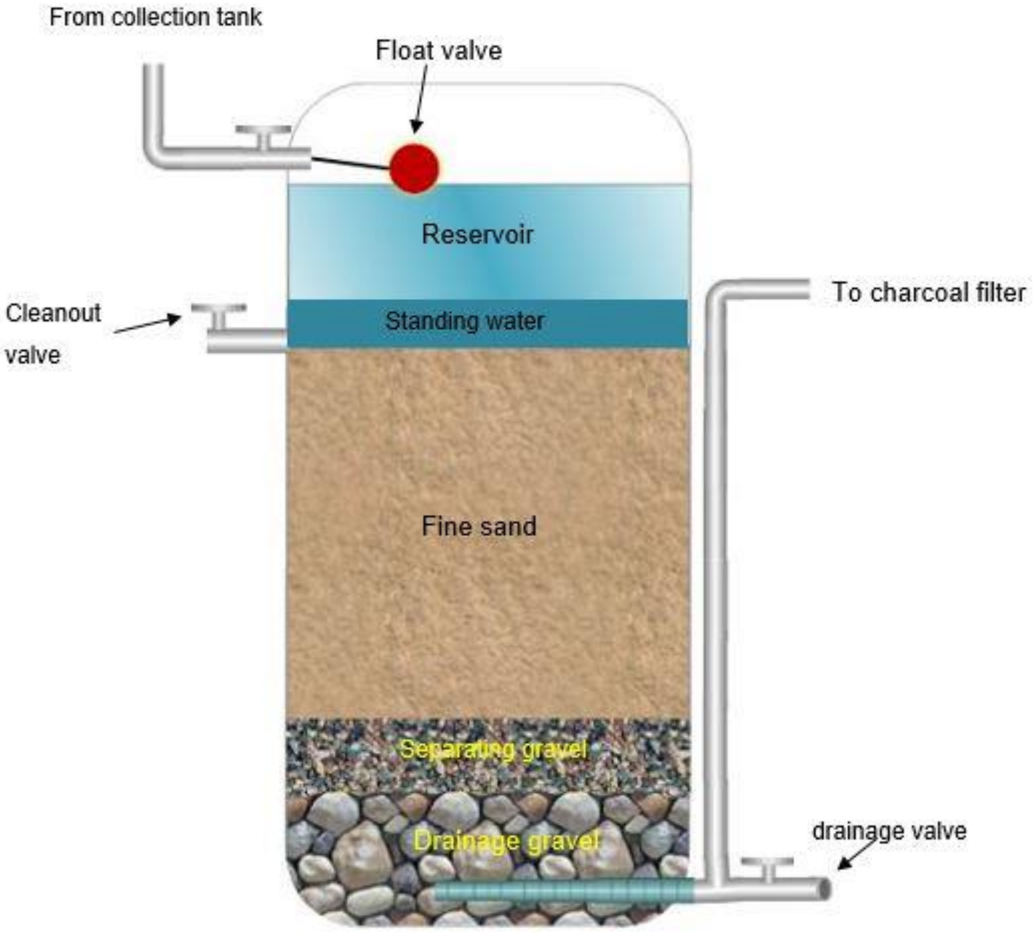

Figure 12 Conceptual design of sand filter

13 Activated carbon filter

13.1 Characteristics of activated carbon

Activated carbon is a material with a high degree of porosity and a large surface area, which makes it versatile adsorbents effective in adsorption of contaminants and pollutants from aqueous solutions (Bansal & Goyal, 2005). Adsorption mechanism of the activated carbon to remove pollutants from the water is considered an important process in water and wastewater treatment plant. (Lopes, et al., 2015). The activated carbon filter is placed after the sand filter to remove odours, bad taste, turbidity, and other organic compounds that the sand filters are unable to remove.

There is various particle size of the activated carbon available and used in the water treatment industries. Some commonly available activated carbon are 8 by 30 mesh, 12 by 40 mesh and 20 by 51 mesh. The finer mesh gives the best removal rate and contact time but there is a higher risk of clogging of the filter. 12 by 40 mesh activated carbon are usually used for drinking water filtration and food grade applications. They are easily available and also allow limited pressure drop (DeSilva, 2000) . Among different GACs type filtrasorb F400 has the highest adsorption capacity for adsorbing organic compounds from the water (Vahala, 2002). Filtrasorb are produced by steam activation of selected grades of a bituminous coal (Baquero, n.d.). They are typically applied for downflow packed bed operations using either pressure or gravity systems. Filtrasorb 400 is desired carbon type for the activated carbon filter and table 8 below specifies it's the typical feature.

Table 8 Characteristics of filtrasorb 400. (12x40 mesh)

Parameters	unit	Value from (Calgon carbon, 2017)
Iodine Number	mg/g	1000(min)
Moisture as packed	%	2(max)
Effective size	mm	0.55-0.75
Uniformity Coefficient		1.9 (max)
Abrasion number	Min	75
surface area	m^2	1050
Moisture content (as packed)	% max	4

13.2 System design Specifications

The granular activated carbon beds are usually designed to be 1 to 10 metres deep and 0.3 to 0.4 metres in diameter. However, the diameter is scaled down to 50 mm for laboratory researches. The ratio of the activated carbon bed to the column diameter should be approximately 10 (Baquero, n.d.). The average effective size of the activated carbon is 0.60 mm as mentioned in the table 8. Therefore, the diameter of column is chosen to be 0.55 m from the above-mentioned considerations (i.e. at least 50 times the size of effective size of activated carbon) and the height of the carbon bed is considered to be 0.45 m.

The area of the filter column is expected to be approx. 0.24 m^2(considering the chosen column diameter).

One of the main design parameter to be considered for the activated activated carbon filter is an empty bed contact time and a hydraulic loading rate, (Baquero, n.d.)for which the formula is mentioned below as:

$$\text{Hydraulic loading rate}(\frac{\text{m}}{\text{h}}) = \frac{\text{Flow rate } (\frac{\text{m}^3}{\text{h}})}{\text{surface area } (\text{m}^2)}$$

$$\text{empty bed contact time} = \frac{\text{carbon volume } (\text{ m}^3) * 60 \ (\frac{\text{min}}{\text{h}})}{\text{Flow rate } (\frac{\text{m}^3}{\text{h}})}$$

An empty bed contact time(EBCT) is the rate of how much contact occurs between the activated carbon and the water as the water flows though the filter bed column. The increase in EBCT increases the contact time for contaminants to adsorb on to the carbon surface (Water treatment guide, 2007) . The longer empty bed contact time is achieved by increasing the bed volume or reducing the flow rate through the filter. The carbon volume is the volume of total carbon used in the filter. (US Environmental Protection Agency, n.d.)

For the down flow carbon column, a hydraulic loading rate range of approx. 8 $m^3/(m^2 \times h)$ to 12 $m^3/(m^2 \times h)$ are used (United states Enviornmental Protection Agency, 2000) . Creek & Davidson (n.d.) suggested a hydraulic loading rate for the granulated activated carbon to be 5 $m^3/(m^2 \times h)$ to

15 m^3/(m^2 × h). The literature by Baquero (n.d.) suggested a hydraulic loading rate of 10 m^3/(m^2 × h). For the design calculations, a hydraulic loading rate of 10 m^3/(m^2 × h). is considered.

The flowrate of the activated carbon filter is calculated by the formula mentioned below:

$$Q = HLR * A,$$

where Q is the flow rate of the filter column[m^3/h], HLR is the hydraulic loading rate [m^3/(m^2 × h)] and A is the area of the filter column[m^2].

The values are inserted in the formula as:

$$Q = 10 \frac{\mathrm{m}^3}{\mathrm{m}^2 * \mathrm{h}} * 0.24 \ \mathrm{m}^2$$

$$Q = 2.37 \ \mathrm{m}^3/\mathrm{h}$$

The obtained result is the maximum design flowrate for the activated carbon filter column. However, the activated carbon filter will adopt the flowrate of the sand filter as they are interconnected, which is 0.13 m^3/h for an initial design phase.

The volume of activated carbon is calculated by the formula mentioned below:

$$C_{\mathrm{v}} = A * h,$$

where C_v is the carbon volume[m^3], A is the surface area of the filter column [m^2], which is calculated to be 0.24 m^2 and h is the height of the filter column[m] which is assumed to be 0.45 m.

These values are inserted in the formula as follows:

$$C_{\mathrm{v}} = 0.24 \ \mathrm{m}^2 * 0.45 \ \mathrm{m}$$

$$C_{\mathrm{v}} = 1.07 \ \mathrm{m}^3$$

The carbon volume of 1.07 m^3 is required for the carbon filter.

The empty bed contact time is obtained by formula mentioned as:

$$EBCT = \frac{C_v * 60 \ (\frac{\mathrm{min}}{\mathrm{h}})}{Q},$$

where *EBCT* is the empty bed contact time[min], C_v is the carbon volume[m^3], calculated to be 1.07 m^3 and *Q* is the flow rate of the filter column[m^3/h], which is supposed to be equal as the flowrate of the sand filter value of 0.13 m^3/h.

These values are inserted in the formula as follows:

$$EBCT = \frac{1.07\ \mathrm{m}^3 * 60\ (\frac{\mathrm{min}}{\mathrm{h}})}{0.13\ \mathrm{m}^3/\mathrm{h}}$$

$$EBCT = 50\ \mathrm{min}$$

Therefore, the empty bed contact time between the water and the carbon is calculated to be 50 min for an initial design phase.

13.3 Activated carbon tank

The activated carbon filter tank is designed to contain a layer of granulated activated carbon along with the layer of supporting gravel (Figure 13). The height and the specifications of the supporting and the gravel used for this tank is identical as of the sand filtration tank. Hence, the size of the separating gravel and the underdrain gravel are 0.7 mm-6 mm and 6 mm-12 mm respectively. For the design, the separating gravel height is chosen to be 6 cm and the drainage gravel height to be 12 cm.

The height of the activated carbon column is assumed to be 0.45 m. The reservoir volume is adjusted to 0.30 m. Therefore, the total height of the activated carbon filter tank is approximately 0.93 m. And the diameter of the tank is same as diameter of the filter column, which is 0.55 m. The tank volume is premeditated to be 0.22 m^3 or 220 l.

The tank is made up of either concrete or a plastics drum depending on the viability of the material. However, the filtration tank should be chosen in a manner that the light does not enter the tank, increasing the chance of algae growth.

The drainage pipe should be of a smaller diameter for the activated carbon filter tank as compared to the sand filter. The perforated pipe diameter of 30 mm is desirable for drainage pipe in activated carbon filter with the holes of diameter 5mm; with a spacing of 10 mm between each hole. Two pipes are connected together with a tee and placed at the bottom of the tank.

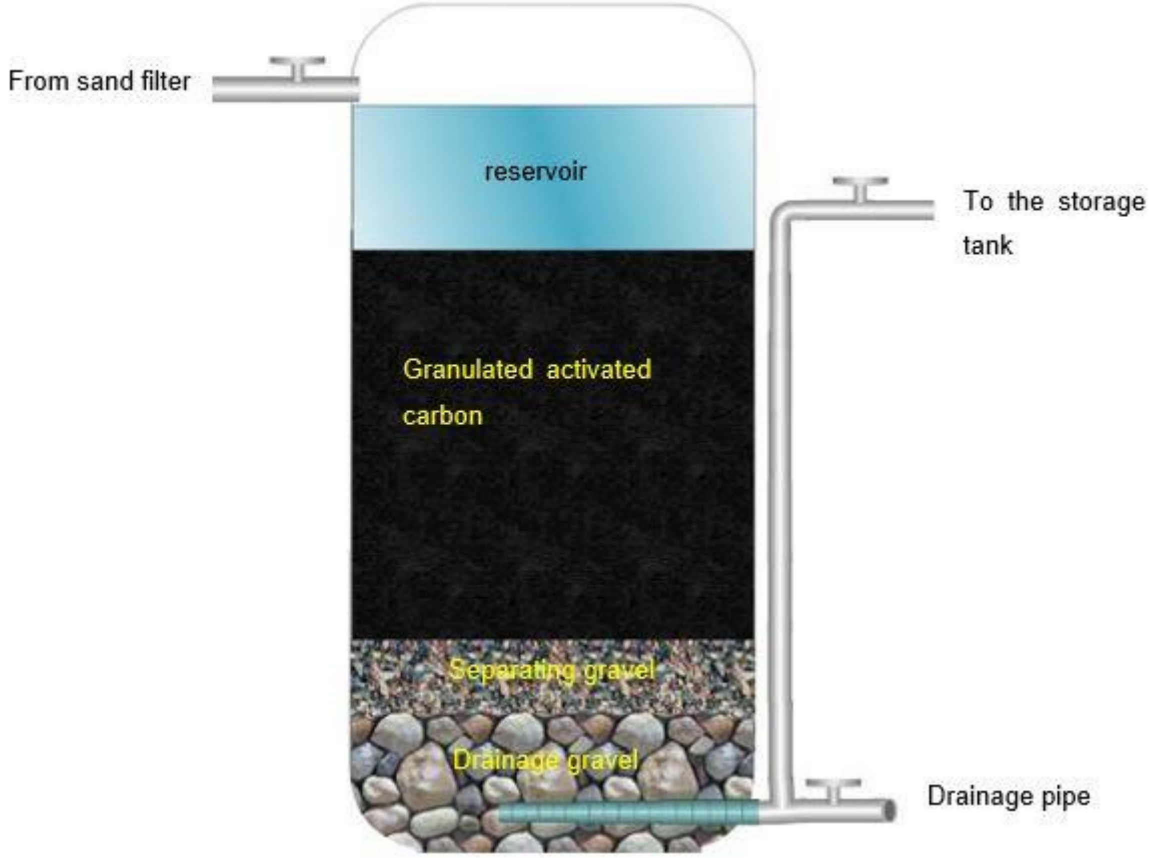

Figure 13 Activated carbon tank specifications

14 Storage tank

The filtered water is finally stored in the storage tank and distributed for non-potable uses. The dimension of the storage tank is assumed to be identical as the collection tank. From the calculation on section 11,

- Volume of tank =3360 l
- length of tank = 2.60 m
- width of tank = 1.30 m
- height of tank = 1 m

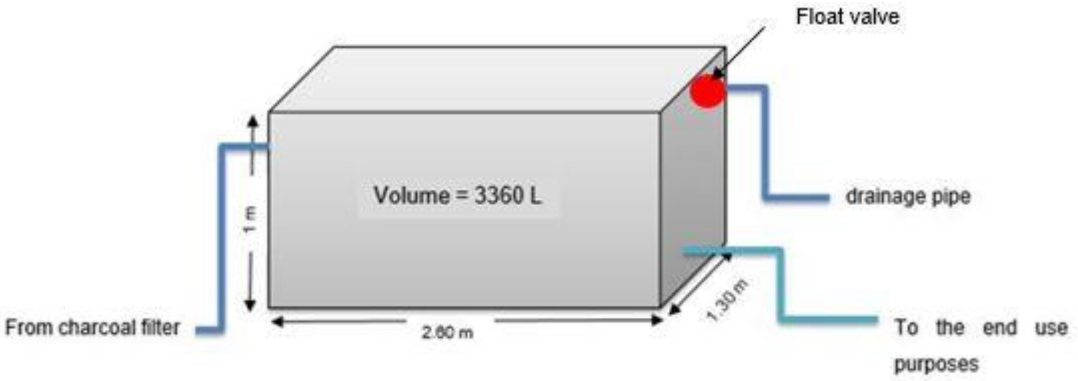

Figure 14 Specifications of storage tank

Figure 14 above reveals the features of the designed storage tank. The distractive figure above highlights the three pipes that are connected to the storage tank. Each pipe connected holds a significant purpose.as shown in the figure. The float valve is connected to the drainage pipe and is turned on when the water in the tank. The runoff water is drained into to the sewer system through the drainage pipe.

15 Servicing and Cleaning of the treatment system

Each unit of the system needs different servicing and cleaning technique. When the flow of water from the system starts to decrease, there is a possibility of filter clogging. The sand filter should be cleaned by the process of swirl and dump as mentioned in section 12.2.9. The top layer of the activated carbon should be replaced if the flow of water is slow. In every two months, clean fresh water should be run into the collection and the storage tank for some basic cleaning. The dirty water obtained after cleaning of the tank should be passed into the sewer system.

Once a year, the sand, the gravel and the activated carbon should be replaced. The storage and the collection tank needs to cleaned systematically in an appropriate interval to prevent fouling odour and microorganism’s growth. All the pipes and the valves should be checked and serviced in a regular interval to ensure proper functioning of the treatment system.

16 Limitations and further study

This thesis provides a base case design for planning of the greywater treatment system in a community-scale. The structure and the content of the design is done through literature reviews and desktop studies. Therefore, further studies regarding the system should be done for implementation of this design in the practicality. The designed system is planned to run with a constant flow of the water. Under the abnormal conditions such as too little flow of the water or generation of too much greywater load, the system is planned to run without disturbance. The standing water in the sand filter provides the nutrient for the biofilms to survive when there is little or no flow of the water. Under the conditions of higher load of the greywater, the float valve in the collection tank diverts the overflow water to the drain maintaining the same water flow to the sand filtration tank. Many parameters and factors needs to be considered when planning a proper working system. The sector such as pipe specifications for the inlet pipe and the outlet pipe, material selection for the tank construction, performance of the filter medium and finding out the optimal flow rate are few areas that needs further studies and experiments.

The design mentioned should be tested first in laboratory scale to know its efficiency and to find out the optimal result. The result from laboratory experiment should be measured to know the physical, chemical and biological characteristics of effluent water. The effluent value should meet the standard value established for the reclaimed water. Modifications could be done if the filter performance does not provide a better result in terms of effluent quality. The studies related to the cost analysis for the implementation and the installation of the filter design needs to be done after the final blueprint of the system is made.

17 Conclusion

Greywater recycling utilizes the water that would otherwise be dumped to the drainage and encourages for a sustainable environment. This thesis is based on the ideas of reutilizing water produced from the hand basin of nursery house and daycare centre in Kayanga, Tanzania. The conceptual designed system focuses on treating the greywater by the methods of sand filtration and activated carbon filtration. The recycled water is designed to be used for non-potable uses particularly toilet flushing.

The presumed value of the greywater produced in the facility comprises of approximately 30 % of total water need. Recycling and reusing of the greywater would thus save the freshwater supply of equivalent quantity. Flushing toilet being the main sector where the maximum amount of water is required; implementation of the design from this thesis will ensure in reducing the water stress of the facility. This system is chosen to recycle the greywater only from hand basin as they are the least polluted and would be treated using simple system to obtain standard water quality. The greywater from other sector of facility such as dishwashing, laundry and cleaning would need advanced treatment system as they rank high in pollutant and organic load and cannot be treated with a simple system. With further enhancement of the proposed design there is a possibility of recycling of total greywater produced from the facility.

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