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Production of Drinking Water from Greywater

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Saksham Mainali

Abstract

Potable water is becoming an increasingly scarce in parts of the world due to population increase and the effects of climate change. Reuse of wastewater as alternative source for non-potable use has been advocated and researched in the last decades to curb water scarcity problem. The NEWater project in Singapore, however, demonstrated the advances in treatment technology to treat wastewater to a level of drinking water quality with great success. Source-separated greywater (water from showers, washing and kitchen) constitutes 60-90% of the total volume of wastewater. Greywater has lower nutrient content and less pathogens than the combined wastewater (wastewater including Blackwater or toilet waste), hence, it should be easier to treat and recycle. This study was initiated to contribute to the SiEUGreen project. One of the goals of SiEUGreen project is to demonstrate and realize about 90% reduction in total water consumption through improved water use efficiencies and on-site treatment and recycling and reusing of the greywater stream of the domestic wastewater. The main objective of this thesis is, therefore, to study the combined treatment efficiency of constructed wetland as pre-treatment step and activated carbon and nano filtration of the effluent as post treatment source-separated greywater to achieve a drinking water quality standard. For this purpose a constructed wetland treated greywater effluent was taken from Nesodden and the efficiency of nano filtration (using Nerox 0.2 nm pore filter) alone or in combination with granular activated carbon was tested. The laboratory analysis results showed that the effluent from the constructed wetland had E. coli below the detection limit, whereas the total coliform bacteria was 226 MPN/100 ml indicating high treatment performance. Moreover, total COD, turbidity, total nitrogen (tot N), ammonium, pH and phosphate for this effluent were 22 mg/l, 4.55 NTU, 7.65 mg/l, 6.218 mg/l, 7.96, and <0.1 mg/l, respectively. Nano filter in combination with activated carbon column filtration in different sequences further improved the quality of the effluent to a drinking water quality except the ammonium concentration which exceeded the WHO and Norwegian drinking water quality guidelines. Greywater may contain organic micro pollutants like pharmaceuticals and personal care products (PPCPs). Examination of PPCPs was not included in this study and further investigation on the removal efficiencies of the above mentioned treatment systems on PPCPs is necessary to satisfy the use of treated greywater as alternative drinking water source.

Abbreviation

AS: Activated Sludge

BOD: Biological Oxygen Demand

cfu: coliform forming units

COD: Chemical Oxygen Demand

DO: Dissolved Oxygen

DOC: Dissolved Organic Carbon

GAC: Granular Activated carbon

GW: Greywater

HRT: Hydraulic Retention Time

Lpcd: liters per capita per day

MBR: Membrane Bio- Reactor

MF: Micro- filtration

MIB: Methylisoborneol

MW: Molecular Weight

NOM: Natural Organic Material

PAC: Powered Activated Carbon

PPCP: Pharmaceutical and Personal Care Products

PUB: Public Utility Board

RO: Reverse Osmosis

SBR: Sequential Batch Reactor

SPAC: Super-fine Powered Activated Carbon

TDS: Total Dissolved Solids

TN: Total Nitrogen

TP: Total Phosphorus

TSS: Total Suspended Solids

T&O: Taste and Odor

UASB: Up-flow Anaerobic Sludge Blanket

USEPA: United States Environment Protection Agency

UV: Ultraviolet

WHO: World Health Organization

WWTP: Waste Water Treatment Plant

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1. Introduction

1.1 Water scarcity and need of greywater treatment

In today's world, we are in a threat of having shortage of clean drinking water. It could be because of lack of proper access to the source (mostly occurring in poor countries) or over-consumption and human activities in water sources like creating dams, diversion etc. (mostly occurring in developed countries) (Postel, 2014). Water use is constantly growing in global scale at a rate twice more than population increase in the last century. Population growth and economic development is pressuring on renewable but finite sources of drinking water, mostly in arid and dry regions, according to FAO's global water information system (AQUASTAT, 2014). Figure below shows how the water withdrawal has been done over a period of century. According to AQUASTAT, water has been withdrawn 1.7 times faster than population growth.

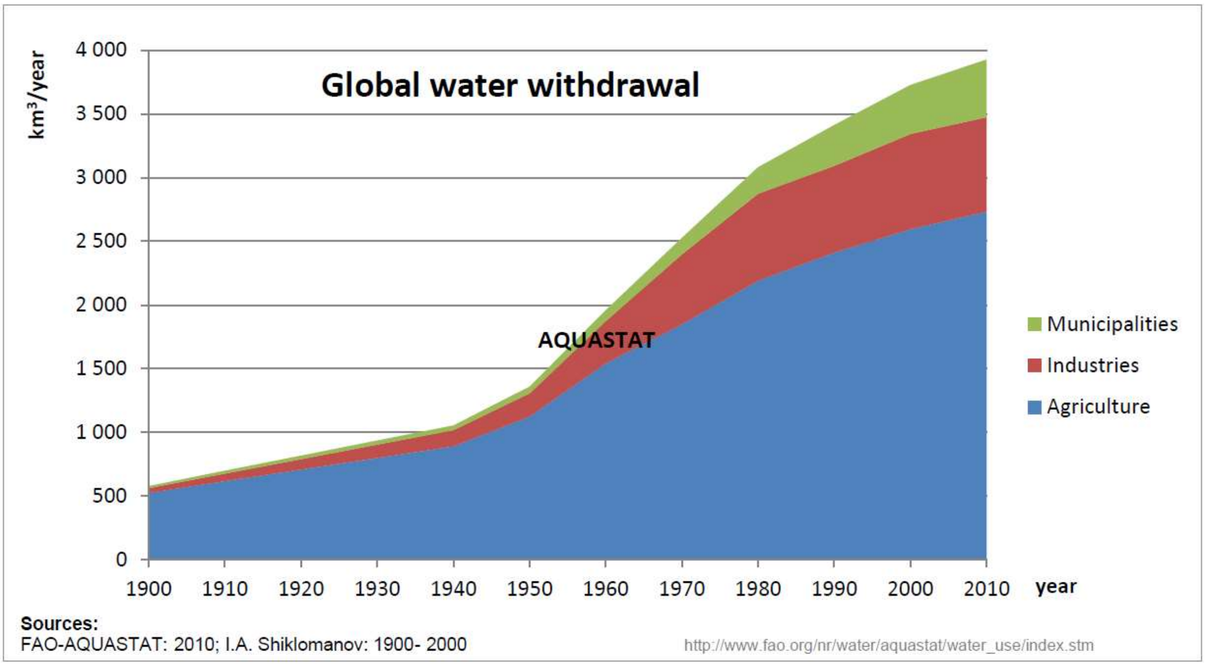


Figure 1: global water withdrawal for various aspects from 1900 to 2010 (AQUASTAT, 2014)

The fresh water that had been used traditionally for purpose of drinking will be less available for use because of climate change, limitations to cope the demand and concerns about environment and sustainability (Surendran and Wheatley, 2007). More than 1 billion of population in the world don't have ready access to an adequate and safe drinking water (Kumar and Puri, 2012). Water stress can be caused by three main factors: population growth, climate change and excessive water withdrawal. By 2025, 1800 million people are expected to be living in ‘absolute’ water scarce countries (<500m^3 per capital per year) and 2/3rd will be living in countries under ‘stressed’ conditions (between 500 and 1000 cubic m per capita per year). (AQUASTAT, 2014). In the whole globe, just 25% of water is fresh water and out of those few, only 1/3rd is accessible fresh water that is being used by around 7.7 billion people and billions of other creatures. Even just for toilet flushing, about 40% of total fresh water is consumed. According to a research from China (Jiang, 2009), by 2050, China will have shortage of 400 billion m^3 of water. Only from 2001 to 2005, China suffered 1.62% of total annual GDP solely due to water scarcity. Our today’s world is also facing a problem with climate change. Effect of climate change on water is mainly flood or drought along with decrease in quality of surface water. Drought or flood might change the concentration of certain compounds by dilution or concentration. This will lead to limitation in available drinking water (Delpla et al., 2009). In addition, temperature increase will also affect the physio-chemical characteristics and biological reaction in water. This shows how much limited water resources we have and how much water consumption rate is being increased due to population growth, climate change and various other factors. So, measures have to be established to reduce these problems and innovations are necessary especially in dry and arid places.

An environmental slogan of 3 R’s has been established as ‘reduce, reuse and recycle’ in order to counteract water scarcity problem. By reducing water consumption, water withdrawal will be automatically decreased. Second R represents Reusing household greywater for instance ‘greywater’ in toilet flushing, gardening and irrigation. Third R stands for Recycling. Recycling might sound similar to Reuse. Recycling refers to recycling the waste water and using it as fresh water for non-potable use since it will be cheaper than potable water (O’Neill, 2010).

Out of few measures to overcome this problem, one is treatment of greywater in dry and arid places where there is scarcity of water. Greywater is wastewater excluding faeces and urine (Ridderstolpe, 2004). The first ever greywater treatment ever recorded was on 1975 by NASA (Chaillou et al., 2011). It is interesting to treat greywater because it constituents large amount of volume in wastewater but with less contaminants compared to black water. Recycling greywater is not so common as compared to reusing greywater for municipal uses like public parks, schools or golf courses (Zaidi, 2007). Reuse of recycled water can be seen in countries like Nepal in agricultural aspects where water is less available and reusing of recycled water is much economic. However reuse has been done without proper treatment. Greywater comprises of 60-80% of total water consumption according to various literatures. But this number increases more than 90% if water saving/ vacuum toilets are endorsed. Treatment of greywater could be a huge step to countermeasure the worldwide water scarcity. Greywater includes water coming from washbasin, kitchen, garden, showers and laundries. The variation of wastewater coming from each source of greywater could vary from place to place which shall be discussed later in other sections.

1.2 Greywater management and reuse

Many governments allocate a huge sum of money in order to treat and transport water and wastewater. So to avoid such costly management, small scale or local treatment option should be prioritized (Mujeriego and Asano, 1999). Managing of greywater includes technical factors like designing and dimensioning as well as running and maintaining. Planning should be done considering from the point of source to recipients (Ridderstolpe, 2004). Different countries go for Greywater treatment for various reasons. For instance, Japan reuse greywater to cope with growing population demand and land scarcity. Countries like Australia, USA, Saudi Arabia and Jordan try greywater recycling to countermeasure drought conditions for purposes like toilet flushing, irrigation, groundwater recharge and plant growth (Al-Jayyousi, 2003, Zhang et al., 2010, Lazarova et al., 2003, Al-Wabel, 2011). There are some benefits as well as drawbacks of reusing greywater. Some of the advantages and disadvantages of reusing greywater are as follows:

Table 1: advantages and disadvantages of reusing greywater (Sadashiva et al., 2016)

Advantages	Disadvantages
Reduction in water demand	Cannot be stored for more than 24 hours since nutrients breakdown and gives bad odor
Reduction of organic and hydraulic load in the sewage	If it is to be used in irrigation, biodegradable soaps and detergents could be a problem
Reduction in water demand leads to reduction in water tariff	Quality and health issue could be a main issue
Less exploitation of the ground water	Contains various chemicals
Lakes and various other surface water will be protected	Sometimes utilization of treated greywater is not profitable due to various factors like no land for irrigation (for areas mostly covered with snow)

Greywater has been recycled for mainly non-potable use. Water for toilet flushing, irrigation, gardening, car wash etc. are the most common application of greywater recycling. Some local authorities do not allow reuse of greywater in various fields in many places because of some pathogens that can cause gastrointestinal diseases (Casanova et al., 2001).

Greywater treatment has been a hot topic in recent years because of the following reasons:

- Wastewater management is becoming a problem especially in a crowded urban area
- The availability of fresh water is diminishing
- Fresh water is being polluted because of human activities
- Disturbance in a natural ecosystem due to discharge of wastewater into fresh water
- Prevention of eutrophication

1.3 Examples of production of drinking water from waste water

One of the notable examples in producing of drinking water from wastewater could be taken as NEWater from Singapore. Singapore is a densely populated state with 5.5 million population living across 718km^2 area. Although they have a plenty of rainfall of about 2.4m annually, they have problem with collecting rainwater because of limited catchment area. In 2015 World Resources Institute (WRI) had kept Singapore in one of the water stressed countries. Singapore are forced to import water from Malaysian river Joho of about 250million gallon per day as per 1964 water agreement (PUB, 2016) between Malaysia and Singapore. Water reuse was done by utilization of two products, i.e. industrial water and NEWater. Industrial water was introduced in 1966 to use in industries in order to increase potable water for domestic utilization. But since the NEWater surpassed the drinking water standards (WHO and USEPA), it came on focus than industrial water despite being 1.88 times more expensive than industrial water. Today there are five NEWater projects supplying 40% of total water demand. This is predicted to reach 50% by the year 2060 (Lee and Tan, 2016). An activated sludge process is done using conventional treatment which produces secondary effluent. This secondary effluent is then treated further by NEWater treatment process. The treatment is done in following steps: micro screening (0,3mm), Micro filtration (0,3 μm) to remove fine solids and particles, followed by Reverse osmosis (RO) in order to demineralize the effluent and finally disinfection by Ultraviolet (UV) method as shown in figure 2. Chlorine is added before and after MF process for controlling biofouling on the membranes (Panel, 2002). The final effluent of the system had characteristics as in table 2.

Table 2: characteristics of final effluent of NEWater (Panel, 2002)

Parameters	Unit	value
E. coli	cfu/100ml	<1
Turbidity	NTU	<5
pH	-	7-8.5
TDS	mg/l	<150
Ammonia	mg/l	<1.0
Nitrate	mg/l	<11

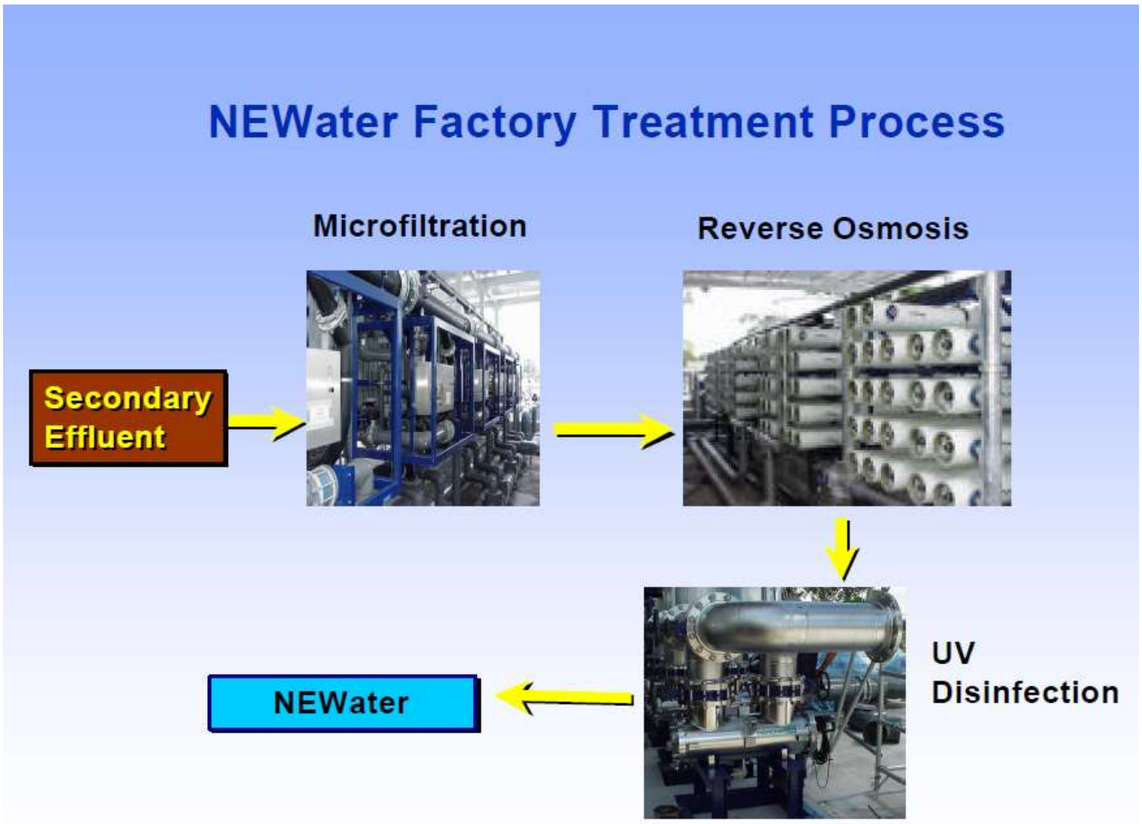


Figure 2: production of high grade drinking water in Singapore (Lee and Tan, 2016)

One main thing that can be learned from this project is that if combined wastewater can be treated into water with drinking quality, there is a huge possibility of production of drinking water from greywater since greywater is comparatively less contaminated than wastewater.

2. Objective

The main goal of SiEUGreen project is to demonstrate that 90% of reduction in total water consumption can be done by reusing greywater. The main objective of this thesis is to test methods for converting greywater into drinking water. It is assumed that if nano filter and activated granular filter are used after constructed wetland, it is possible to produce drinking water from greywater.

3. Greywater

3.1 Quality of Greywater

Greywater consists of various contaminants: organic matter, microorganisms, Pharmaceuticals and Personal Care Products (PPCPs) and taste and odor (T&O) compounds (Eriksson et al., 2002) (Butkovskyi et al., 2016) and physiochemical parameters like chemical oxygen demand (COD) and biological oxygen demand (BOD). COD concentrations could be in hundreds of mg/l. 5-15 mg/l of nutrients (Nitrogen and phosphorus), noticeable concentration of detergent and salts (boron, sodium and salts). Faecal coliform could range from zero to 10^6-10^7 cfu per 100ml (Friedler et al., 2006). Some writers have also characterized greywater into low strength (excluding kitchen and laundry) and high strength greywater (including kitchen and laundry).

Table 3: characteristics of greywater. (Winward et al., 2008) a- (Surendran and Wheatley, 1998), b- (Rose et al., 1991)

Parameters	low strength greywater	high strength greywater	(B,S,W)[a]	(B,S,W,L)[b]
BOD (mg/l)	20	164	216-252	NA
COD (mg/l)	87	495	424-433	NA
TSS (mg/l)	29	93	NA	NA
Turbidity (NTU)	19,6	67,4	57	20-140
Total nitrogen (mg/l)	NA	NA	NA	0,6-5,2
Total phosphorus (mg/l)	NA	NA	1,6-45,5	4-35
total coliform log10 CFU/100ml	5.4±0.8	7.4±0.8	4,7-6,77	6,78
E. coli log10 CFU/100ml	2.8±0.8	3.8±0.8	1,51-2,77	4,25-6,9

B- Bath, S-shower, w- washbasin, l- laundry, NA- not available

Another literature from Germany boasts greywater to have following characteristics:

Table 4: greywater composition in Germany by (Li et al., 2008)

Parameters↓	values
temperature (°C)	20±3
pH	7.5±0.5
Turbidity (NTU)	140±12
TOC (mg/l)	161±20
TN (mg/l)	16.5±2.3
NH4-N (mg/l)	10.1±2.5
TP (mg/l)	9.7±0.9

Edwin et al. made a breakdown table of greywater from its various sources i.e. shower, wash basin, kitchen and laundary and compared with characterstices of combined greywater and tap water as shown in table 5.

Table 5: breakdown of greywater from various sources and their composition (Edwin et al., 2014).

parameter	unit	tap water	Shower	Wash basin	kitchen	laundry	Combined GW
turbidity	NTU	ND	122,67	84,3	347,2	108,6	167,9
TSS	mg/l	21,1	122,7	89,2	398,7	141,2	190,4
pH	mg/l	7,1	7,4	7,2	6,9	9,1	7,7
COD	mg/l	ND	357,9	340,5	1122,8	1545,8	911,9
BOD	mg/l	226,6	135	138,7	932,4	186,5	290,6
total N	mg/l	2,1	11,3	9	31,2	18,9	17,8
total P	mg/l	ND	1,2	1,1	48,3	19	17,6

Greywater from kitchen and dishwasher contributes about 50% of total COD. Comparing COD and BOD in greywater, COD:BOD is nearly to the ratio of 3-4:1 which can also be demonstrated by above tables 3 and 5. Most of the nutrients are also contributed from kitchen greywater. This is why in some cases, greywater from these sources are excluded and is proposed to be treated separately using better technology (Edwin et al., 2014). Very less amounts of nutrients are present in Greywater 10% of nitrogen, 20% of phosphorus and 30%

of potassium (Jenssen, 2005). The major chemical contaminants in greywater could be surfactants from laundry and bathroom. The nitrogen level in greywater is less since there is no contamination of urine compared to combined waste water. Nitrogen normally appears in greywater from proteins in food residuals in sink, house hold cleaning products and personal care products (Li et al., 2008). There can also be presence of either cationic or anionic surfactants. These surfactants are major contaminants from bathroom and laundry. Along with surfactants, fabric softeners, laundry disinfecting agents and detergent builders are also used to increase effectiveness of detergent formulation (Widiastuti et al., 2008). In case of Norway, use of phosphorus free detergents are encouraged (Cullen and Forsberg, 1988).But, there could be more than 50% of total organic matter in greywater. Presence of easily degradable organic compounds might favor the growth of bacteria such as faecal coliforms (Ottoson and Stenström, 2003). Greywater usually has very high amount of organic matter like cooking oil and fats, xenobiotic compounds and residues of soap and detergents. These xenobiotic compounds and detergents may limit the biological activity and therefore hinder biological treatment efficiency. Pathogens enters in greywater through washing of faeces containing diapers and anal cleansing (Ottoson and Stenström, 2003). Greywater from houses having children are likely to have higher number of coliforms compared to houses without children (Edwin et al., 2014). Number of pathogens in greywater also depends upon the locality and ethnicity. For example, countries like Nepal are not so used to of using toilet papers. So anal cleansing is done by hand and later it is washed in the sink. This might increase the number of pathogens in greywater more than in parts of world were toilet paper is used. These are the primary source of pathogens in greywater.

3.2 Quantity of greywater

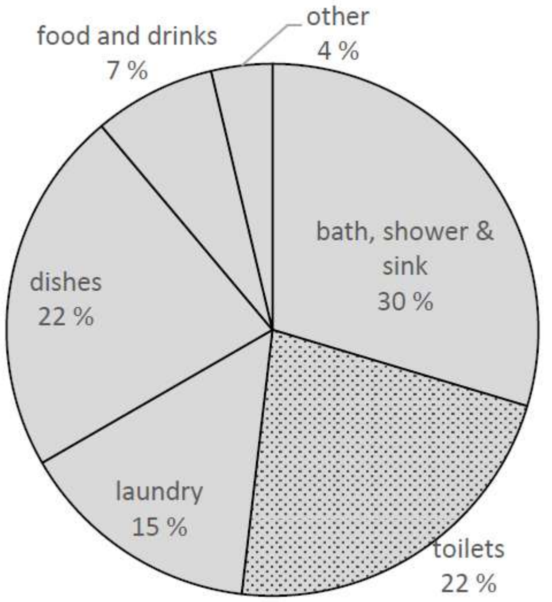


Figure 3: typical composition of greywater from a Norwegian household (Ødegaard et al., 2012a)

Figure 3 shows typical composition of greywater. Composition of greywater varies, depending upon various factors like living life style, number of consumers and number of children, water usage pattern, and health status. Amount of greywater could be just 20-30 liters per persons in poor countries but could be hundreds of liters in richer areas (Ridderstolpe, 2004). The composition of greywater depends on usage of detergents, cosmetics and personal habit of users. Greywater constituents of around 50-80 of total domestic wastewater (Sadashiva et al., 2016), (Widiastuti et al., 2008). The greywater production varies spatially. Greywater is produced 72-225 lpcd in Asia (Morel, 2006), 33-150 lpcd in Europe while 200lpcd in the USA (WHO, 2006). But in some European countries who tend to save water, are having less greywater production(Boyjoo et al., 2013)

The average household greywater as per interview with the users was 94lcpd in Syrian rural area (Mourad et al., 2011). Greywater production in rural areas of Jordan is 14±2.7lpcd, which very low compared to capital city of same country, Amman 59lpcd (Halalsheh et al., 2008). If this is compared to some European cities like 88.6lpcd in Amsterdam (Edwin et al., 2014). Table 6 below shows the difference in greywater production in rural and urban areas of India with water consumption in Netherlands.

Table 6: difference in greywater production in different locations (all units are in lpcd)

SOURCE	Rural areas of India[a]	Urban areas of India[b]	Dutch water Consumption[c]
Total water consumption	114	91.56	127.5
Drinking and cooking use	3.5	6.59	1.8
Toilet flushing	30	18.31	37.1
Gardening /irrigation	2.5	2.2	-
Washing and cleaning of house	7	6.68	-
Total greywater production	71	57.77	88.6
Shower and bath	35	25.82	52.3
Hand basin	5	NIL	5.3
Laundry	19	17.03	17.2
Kitchen/ dishwashing	12	14.92	13.8

a- (Edwin et al., 2014), b- study conducted in 7 cities in India (Delhi, Mumbai, Kolkata, Hyderabad, Kanpur, Ahmadabad, Madurai) (Shaban and Sharma, 2007), c- (Foekema et al., 2008)

4. Standards of reusing Greywater

To reuse greywater, there are some standards that needs to be met. Most of the standards are made for reuse as toilet flushing, irrigation purpose or environmental purposes as in table 8 and table 9. Various papers have been established to categorize the standards (Li, Wichmann, & Otterpohl, 2009) (Edwin et al., 2014). As seen all the regulations had pH range from 5-9. TSS were not prioritized but TDS should be within range so as to be reused. To reuse greywater in China, TDS should be less than 1000 mg/l for irrigation purpose however TDS more than 1000 mg/l is allowed to reuse greywater as washing purpose. TN and TP were of concern in case of impounded lakes according to Chinese regulation. But, ammonia was also taken in consideration for toilet flushing, irrigation and washing purposes. This could be because of foul smell produced by ammonia. The most restriction for total coliform and faecal coliform can be seen as ≤ 50/ml for landscape irrigation and environmental purposes by Japanese standards and

<3/100ml for toilet flushing, irrigation purpose and washing purpose according to Chinese act. A detail tabular form of standards under different organizations can be seen in table 7.

Table 7: standards of reusing greywater (Li, Wichmann, & Otterpohl, 2009)

	pH	TSS (mg/l)	TDS (mg/l)	Turbidity (NTU)	BOD_5 (mg/l)	Detergent (anionic) (mg/l)	TN (mg/l)	NH_4-N (mg/l)	TP (mg/l)	Dissolved O_2 (mg/l)	Residual Cl (mg/l)	Total coliform	Faecal coliform	Reuse application
Nolde, 1999, Germany	–	–	–	–	5 mg/l (BOD_7)	–		–	–	>50%	–	<100/ml	<10/ml	Toilet flushing
Ernst et al., 2006, China	6–9	–	<1500	<5	<10	1	–	<10	–		>1 mg/l after 30 min. >0.2 mg/l at point of use	–	<3/100 ml	Toilet flushing
	6–9	–	<1000	<20	<20	1	–	<20	–	>1	>1 mg/l after 30 min. >0.2 mg/l at point of use	–	<3/100 ml	Irrigation purpose
	6–9	–	>1000	<5	<6	0.5	–	<10	–	–	>1 mg/l after 30 min. >0.2 mg/l at point of use	–	<3/100 ml	Washing purpose
	6–9	–	–	–	<6	0.5	15	<5	<0.5	>1.5	–	–	<10000/ 100 ml	Restricted impoundments and lakes
	6–9	–	–	<5	<6	0.5	15	<5	<0.5	>2	–	–	<500/100 ml	Unrestricted impoundments and lakes
Asano, 2007, USA	6–9	–	–	<2	10	–	–	–	–	–	1 mg/l	–	ND /100 ml	Unrestricted reuses *
	6–9	30	–		30	–	–	–	–	–	1 mg/l	–	<200 / 100 ml	Restricted reuses **
Maeda et al., 1996, Japan	5.8–8.6	–	–	Not unpleasant	≤20	–	–	–	–	–	Retained	≤1000/ml	-	Toilet flushing
	5.8–8.6	–	–	Not unpleasant	≤20	–	–	–	–	–	≥0.4	≤50/ml	-	Landscape irrigation
	5.8–8.6	–	–	≤10	≤10	–	–	–	–	–	–	≤1000/ml	-	Environmental (aesthetic settling)
	5.8–8.6	–	–	≤5	≤3	–	–	–	–	–	–	≤50/ml	-	Environmental (limited public contact)
Australia, Queensland (2003)	–	30	–	–								<100/ 100 ml		

ND: non-detectable *Toilet flushing, landscape irrigation, car washing and agricultural irrigation.
**Irrigation of areas where public access is infrequent and controlled golf courses, cemeteries, residential, greenbelt.

Table 8 is a literature review done by Edwin et al. for greywater reusing standards by WHO, USEPA, and CPCB(Central Pollution Control Board) India. WHO has restrictions on total coliforms for reusing greywater in either of restricted or non-restricted irrigation. In case of drinking water, WHO has established 50 mg/l Nitrogen as threshold level as well as pH 6.5-8.5 and turbidity 5 NTU (Edwin et al., 2014). USEPA has determined permissible amounts for reuse as unrestricted use and restricted use as in table 9. The major criteria to be passed are 0 cfu/ 100 ml FC for unrestricted use and ≤200 cfu/100ml FC for restricted use. CPCB India have established regulations for quality of treated wastewater and for the discharge of effluent to a water source. According to CPCB India, if the water source is does not undergo any conventional treatment but only disinfection, the permissible total coliforms is ≤ 50 MPN/100ml while permissible total coliforms is ≤ 500 MPN/ 100ml if the drinking water source is further treated by conventional system followed by disinfection.

Table 8: greywater reusing standards according to WHO, USEPA, CPCB- India (Edwin et al., 2014)

Standards		pH	Turbidity (NTU)	SS mg/L	DO mg/L	BOD mg/L	COD mg/L	N mg/L	P mg/L	Free Ammonia (as N) mg/L	SAR	Boron mg/L	TC	FC cfu/100 ml	Total residual chlorine mg/L	Reference
WHO	Restricted irrigation												≤1E5**			WHO (2006)
	Unrestricted irrigation[a]												≤1E3**			
	Drinking quality[b]	6.5–8.5	≤5					50								
USEPA	Unrestricted use[c]	6–9	< 2			<10								0	>1 ppm	USEPA (2004)
	Restricted use[d]	6–9		<30		<30								≤200	1	
CPCB-India (for quality of treated wastewater)	On land for irrigation[e]	5.5–9	-	200		100	-								-	CPCB (2008)
	Into inland surface water[f]	5.5–9		100		30	250								1	
	Into Public sewers[g]	5.5–9		600		350	-								-	
CPCB-India (for discharge of effluent)	Drinking water source[h]	6.5–8.5			≥6	≤2							≤50*			CPCB (2008)
	Outdoor bathing	6.5–8.5			≥5	≤3							≤500*			
	Drinking water source[i]	6.5–9			≥4	≤3							≤5000*			
	Propagation of wild life and fisheries irrigation	6.5–8.5			≥4					≤1.2						
	Industrial[j]	6.5–8.5									26	≤2				

a=Crops eaten raw,

b= drinking water quality 1993,

c= Urban uses, landscape irrigation, crops eaten raw, toilet flushing, recreational impoundments,

d= Restricted access area irrigation, processed food crops, non-food crops, esthetic impoundments, construction uses, industrial cooling and environmental reuse,

e= Indian Standards: 3307 (1974),

f= Indian Standards: 2490 (1974),

g= Indian Standards: 3306 (1974),

h= without conventional treatment but after disinfection,

i= after conventional treatment and disinfection,

j= Irrigation, industrial cooling, controlled waste disposal,

** cfu/100 ml, * MPN/100 ml

5. Drinking water standards as per USEPA, WHO and Norway

Drinking water standards are different in accordance to different institutions as shown in table 9. pH ranges almost same for USEPA, WHO and in Norway. Total dissolved solids (TDS) is considered flexibly by WHO 1000mg/l compared to 500mg/l by USEPA. Base line for turbidity is 5 NTU by USEPA and WHO but should be acceptable to consumers and preferred mostly if less than 1 NTU according to rules in Norway. Ammonia should be less than 1.5mg/l by WHO and 0.5mg/l by Norwegian standards. There is no record of standard for total Nitrogen and phosphorus but nitrate should be less than 10, 10 and 50mg/l as per USEPA, WHO and Norwegian standards respectively. Also nitrite should be less than 1, 0.1 and 0.5 according to USEPA, WHO and Norwegian guidelines respectively. E. coli should be null by all standards and odor should be accepted by consumers in Norway but not defined by other two standards. There are many types of bacteria included in total coliforms. Most of the bacteria are found in environment (soil or vegetation) out of which all of them might not have adverse effect on human or are indicators of sewage contamination. So, total coliforms can act as secondary assessment to drinking water test in order to determine the route of contamination.

Table 9: drinking water standards as per USEPA, WHO and Norwegian standards

drinking water standards				
parameters	unit	USEPA[a]	WHO[b]	norway[c]
pH		6.5-8.5	6.5-8.5	6.5-9.5
TDS	mg/l	500	1000	NA
Turbidity	NTU	5	5	acceptable to consumers less than 1 NTU
Ammonia (as N)	mg/l		1,50	0.5
Nitrate (as N)	mg/l	10	10	50
Nitrite (as N)	mg/l	1	0,1	0.5
total Nitrogen	mg/l	NA	NA	NA
total Phosphorus	mg/l	NA	NA	NA
Total coliforms	Cfu/ 100ml	0	-	-
E. coli	Cfu/ 100ml	0	must not be detected in any 100ml sample	0
odor		NA	NA	acceptable to consumers

a (EPA, 2018), b (WHO, 2011), c (Ministry of Health and Care Services, 2016)

6. Greywater Treatment technologies

Quoted that any system that is recycling greywater has to achieve four main criteria: hygienic safety, aesthetics, environmental tolerance and technical as well as economically feasible. Greywater if compared to mixed wastewater, it is considerably safer in environmental and hygiene point of view at some extent. But if management is not done properly, it might create problems with smell because the organic matters starts degrading quick even in a few hours (Ridderstolpe, 2004). One of the simplest GW treatment was introducing freshly generated GW into an active, live topsoil environment. Though greywater has less pathogens compared to Blackwater or combined wastewater, choosing options for greywater treatment is complex because of huge variation in its composition (Al-Jayyousi, 2003). Design of degree and type of treatment system depends upon the quality of greywater and expected quality of reclaimed water (Surendran and Wheatley, 2007).

6.1 Greywater reuse without treatment

Greywater was used commonly without any treatment before establishment of greywater treatment system and even after some treatment policies were discovered. Before any treatment processes were established, bathroom water was used for gardening for many centuries (Jefferson et al., 2000). Even in recent decades, in countries like Australia (Ryan et al., 2009), Syria (Dalahmeh et al., 2009) and South Africa (Jacobs and Van Staden, 2008), Greywater is used for garden and lawn watering. Meanwhile Israel use greywater for landscape irrigation (Ronen et al., 2010) and Jordan reuse Greywater for fruits irrigation purpose (Halalsheh et al., 2008). Jacobs and Van Staden stated in 2008 that some of nutrients are good while others are bad to for plants. This variations depended upn the types of plants. Regardless, the reuse of untreated greywater has serious drawbacks. Pathogens transmission would be easy during irrigation and toilet flushing. Using untreated GW in irrigation lead to build up of salts, cloggind, surfactants, fats oil and grease. This could damage the plant and soil properties (Christova-Boal et al., 1996, Misra and Sivongxay, 2009). Reusing untreated greywater for toilet flushing might leave stains which consequently discourage the users to think greywater can be reused (Misra and Sivongxay, 2009).

6.2 Chemical treatment:

Treatment of greywater can be done by either coagulation or ion exchange or both (Pidou et al., 2008). A research done in student hall in Cranfield University had concluded that these chemical processes were able to treat greywater up to standards for low strength greywaters (mixed greywater with DOC 12 ± 4 mg/l). However, the chemical treatment processes had not much treatment efficiency on medium or high strength greywater (shower greywater with DOC 56 ± 7 mg/l). Table 10 shows the initial high strength greywater characteristics and treatment done by coagulation (Fe and alum), ion exchange (MIEX®) and both coagulation and magnetic ion exchange. Pidou, Avery et al. also established a concept that the coagulation process although use Fe or Alum, the process is more efficient in acidic conditions. From the table, ion exchange has good removal efficiency on COD and nitrates compared to other processes. BOD was removed better by Alum. Removal of bacteria for all the treatment systems were almost similar although ion exchange had a bit higher number of total coliforms and E coli in the effluent. (Ghaitidak and Yadav, 2015) experimented 8 alternatives to treat greywater. The best one was treatment by Alum at pH 5.5 with optimal dose of 204 mg/l and wrost was lime treatment at pH 8.5. In alum treatment, they were able to achieve turbidity removal above 88%, BOD at range 53-77% and E. coli was removed at 95-99%. This alum treatment had effluent that satisfied most of the reuse standards for land irrigation and industrial cooling in India.

Table 10: performance of chemical greywater treatment (Pidou, Avery et al. 2008)

Optimum	Raw	MIEX® 10 ml l^{-1}, 30 min	Alum 24 mg l^{-1}, pH 4.5	Ferric 44 mg l^{-1}, pH 4.5	MIEX® + Al 5 mg l^{-1}, pH 4.5	MIEX® + Fe 5 mg l^{-1}, pH 4.5
Turbidity (NTU)	46.60	8.14	4.28	5.20	3.01	3.30
COD (mg l^{-1})	791	272	287	288	247	254
BOD (mg l^{-1})	205	33	23	30	27	29
DOC (mg l^{-1})	171.4	78.2	93.4	87.4	78.8	80.7
TN (mg l^{-1})	18	15.3	15.7	17.9	15.3	17.4
NH_4^+ (mg l^{-1})	1.2	1.1	1.2	1.2	1.2	1.2
NO_3^- (mg l^{-1})	6.7	4.7	5.7	6.1	4.4	4.8
PO_4^{3-} (mg l^{-1})	1.66	0.91	0.09	0.06	0.11	0.13
Total coliforms (MPN 100 ml^{-1})	56 500	59	<1	<1	<1	<1
Escherichia coli (MPN 100 ml^{-1})	6490	8	<1	1	<1	<1
Faecal *Enterococci* (MPN 100 ml^{-1})	2790	<1	<1	<1	<1	<1

Li, Wichmann & Otterpohl compiled chemical processes in 2009 undertaken to treat greywater as in table 11. The authors also compared the quality of treated effluent with standards as in table 7. It showed that most of the chemical processes are not done alone rather are adapted along with other secondary treatment options like disinfection, physical or mechanical treatment steps.

Table 11: different chemical greywater treatment processes (Li, Wichmann, & Otterpohl, 2009)

Reference	Process	TSS (mg/l)		Turbidity (NTU)		COD (mg/l)		BOD (mg/l)		TN (mg/l)		TP (mg/l)		Total coliform (cfu/100 ml)		Faecal coliform (cfu/100 ml)	
		In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Lin et al. (2005)	Electro-coagulation + Disinfection	29	9 V	43	4 X	52	22	23	9 V	–	–	–	–	2×10^8	2×10^6 X	–	–
Sostar-Turk et al. (2005)	Coagulation + Sand filter + GAC	35	<5 V	–	–	280	20	195	10 V	–	–	–	–	–	–	–	–
Pidou et al. (2008)	Coagulation with aluminium salt	–	–	46.6	4.28 X	791	287	205	23 V	18	15.7	1.66	0.09	–	<1 V	–	–
Pidou et al. (2008)	Magnetic ion exchange resin	–	–	46.6	8.14 X	791	272	205	33 X	18	15.3	1.66	0.91	–	<59 V	–	–

V: Meet the reuse guideline.
X: Fail to meet the reuse guideline.

6.3 Biological treatment:

Mostly biological treatment is done in order to remove biodegradable pollutants. When biological and physical systems are combined as in MBRs and BAFs, production of high quality of effluent is achieved in a small footprint (Al-Jayyousi, 2003). Various biological treatment technologies have been established for treatment of greywater. They can be categorized into two main systems: Aerobic and Anaerobic treatment systems. Aerobic systems include aerobic bioreactor whereas anaerobic includes biogas reactors such as UASB reactors. A case study from Sneek, Netherlands can be taken as an example where greywater was characterized and treated using biological methods (both aerobic and anaerobic) (Hernández Leal et al., 2010). An aerobic system of Sequential Batch Reactor (SBR) of 3.6 litres and anaerobic system of Up-flow Anaerobic Sludge Blanket (UASB) of 5L were used in this experiment. The treatment efficiencies of SBR and UASB shows that SBR was better than UASB in removal of most of the parameters of table 12. One of the research by (Birks and Hills, 2007) showed that untreated greywater might have high level of potable water indicator micro-organisms (total coliforms, E. coli, faecal coliforms) in a consistent amount. These microorganisms along with BOD might necessitate the application of biological treatment systems if greywater is to be reused. A research done by (Halalsheh et al., 2008) stated that UASB can be made flexible such that in case of low performance, separate filtering reactor can be added as an upgrade.

Table 12 shows the removal and efficiencies of Aerobic, anaerobic and combined systems. The numbers 12, 6 and 7 after SBR and UASB represents the HRT (Hydraulic Retention Time) for each trial. Studying the results, it can be concluded that Aerobic system with HRT 12hours and temperature 32±3 °C can remove COD with efficiency of 90% and surfactants with 92%

efficiency. A combined system under same conditions (HRT 12hours and temperature 32±3 °C) did not have much benefit compared to aerobic system. In conclusion, aerobic system is considered better than anaerobic and combined systems for treatment of greywater based on COD removal, sludge yield and energy consumption.

Table 12: treatment efficiencies of SBR and UASB with different HRT (Hernández Leal, Temmink et al. 2010)

	SBR 12 (aerobic system)	SBR6	UASB12 (anaerobic system)	UASB7	UASB7 + SBR6 (anaerobic-aerobic system)
HRT (h)	11.7 ± 1.1	6.1 ± 0.8	12.3 ± 1.8	7.0 ± 2.0	13.17 ± 2.03
VLR (kg COD/m^{3}d)	1.6 ± 0.5	1.9 ± 0.4	1.7 ± 0.4	2.7 ± 0.8	1.5 ± 0.6
COD removal rate (kg COD/m^{3}d)	1.5 ± 0.4	1.5 ± 0.4	0.8 ± 0.3	1.1 ± 0.6	1.4 ± 0.5
SLR (kg COD/kg VSS d)	0.29 ± 0.07	0.6 ± 0.3	0.12 ± 0.04	0.23 ± 0.08	**
Sludge concentration (g VSS/L)	5.5 ± 1.1	3.3 ± 1.1	12.5 ± 2.4	12.7 ± 4.3	**
SRT (d)	15	379	392	97	**
Yield (kg VSS/kg COD)	0.12	0.06	0.08	0.18	0.18
COD removal (%)	90 ± 7	82 ± 06	51 ± 13	39 ± 15	89 ± 3
COD effluent (mg/L)	82 ± 47	100 ± 33	392 ± 85	528 ± 180	100 ± 33
Anionic surfactants (mg/L)	1.4 ± 1.2	1.3 ± 1.5	33.4 ± 4.1	35.9 ± 5.3	1.3 ± 1.5
Effluent total N (mg/L)	31 ± 20	26 ± 13	34 ± 17	32 ± 10	26 ± 13
Effluent NH4-N (mg/L)	0.35 ± 0.20	0.4 ± 0.1	4.7 ± 2.1	5.4 ± 2.4	0.4 ± 0.1
Effluent NO3-N (mg/L)	1.5 ± 1.4	22.6 ± 13.5	0.2 ± 0.1	0.2 ± 0.1	22.6 ± 13.5
Effluent total P (mg/L)	4.4 ± 2.4	5.8 ± 1.7	5.3 ± 1.5	6.1 ± 1.7	5.8 ± 1.7
Effluent VSS (mg/L)	45 ± 61	30 ± 26	7 ± 9	21 ± 23	30 ± 26
Removal total N (%)	35 ± 37	26 ± 27	15 ± 33	−1 ± 63	2 ± 56
NH4-N removal (%)	51 ± 47	92 ± 4	*	*	7 ± 86
Total P removal (%)	28 ± 50	31 ± 11	11 ± 28	1 ± 36	3 ± 44
Methane flow (NL/d)	**	**	0.76	0.8	0.8
Methane production (NL/m^3)	**	**	123	71.5	71.5

* No ammonium removal
** Not applicable

(Abdel-Kader, 2013) had made a research paper on greywater treatment by biological process using RBC (Rotating Biological Contactors). The layout of the project was as shown in the figure(4) below. The writer concluded that RBC removed BOD in a range of 93-96% and TSS 84-95% for all given concentrations in raw greywater. Sand filter if added before disinfection, it reinforces the efficiency of disinfection. If compared with MBR or SBR, RBC uses less energy for treatment of greywater (Baban et al., 2010). (Baban et al., 2010) also concluded that

RBC is a very effective treatment process and the effluent can be reused for toilet flushing purposes after disinfection. However, there could be present some particles from biofilms which should be removed by a sand filter.

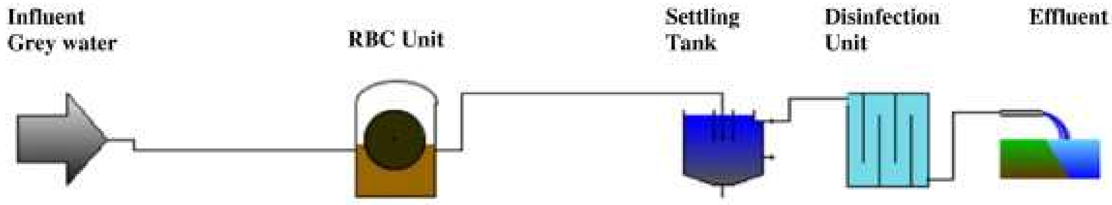


Figure 4: diagram of prototype of greywater treatment by RBC (Abdel-Kader, 2013)

Some other bilogical treatments had been done before to treat greywater. Systems like MBR, UASB, constructed wetland, SBR, Fuidized bed reactor have been used for greywater treatment purposes. However, if combined with other treatments like screening, filtration, sedimentaion and/or disinfection, it can achieve higher quality of effluent. A complete table given by (Li, Wichmann, & Otterpohl, 2009) can be found in APPENDIX figure A-1.

6.4 Physical treatment:

Physical treatment usually consist of coarse sand and soil filtration, membrane filtration followed by disinfection. Usually two stage systems are adopted in the UK. It consists of coarse filtration and disinfection step. Coarse filter is generally made up of a metal strainer and disinfection is done by either chlorine or bromine (Al-Jayyousi, 2003). These systems produce water with high in organic load and turbidity henceforth limiting the disinfection efficiency (Sayers, 1998). Physical steps cannot remove pollutants in desired amount. Normally, reclaimed water from this systems are suitable in using as toilet flushing if working conditions are carefully controlled (retention time 48 hrs and residual chlorine ≥1mg/l in toilet tank) (March et al., 2004). An experiment was done in an ecological settlement in Lubeck, Flintenbreite to treat greywater by a membrane filtration method (Li et al., 2008). A submerged spiral-wound membrane filter received greywater from a double septic tank that removed grease and oil, larger particles and hair. Air bubble was supplied from the bottom to prevent membrane fouling as shown in the figure 5. This system had influent and effluent quality as shown in table 13. Permeate from this method had quality to be used in gardening and soil fertilization and if passed some standards, it was possible to be used as toilet flushing after disinfection.

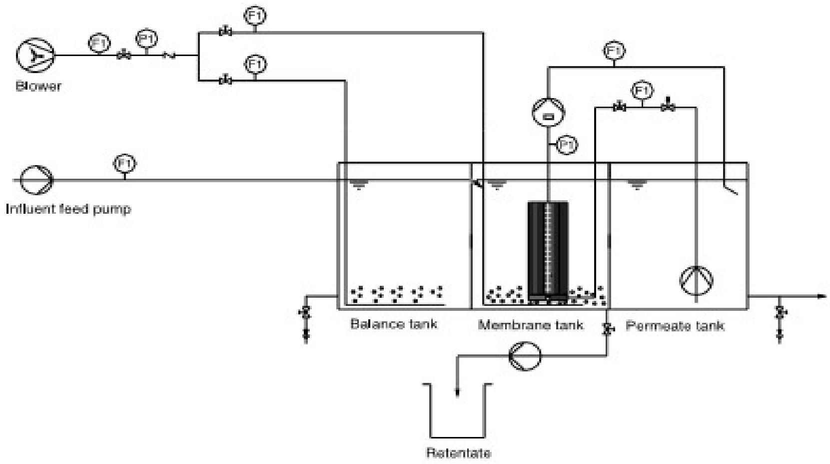


Figure 5: greywater membrane filtration method (Li et al., 2008)

The influent and effluent quality of water in this treatment system is shown in table below.

Table 13: performance of above system (Li et al., 2008)

parameters	Influent	Effluent
Temperature (°C)	20±0.3	21±0.3
pH	7.5±0.5	7.2±0.2
Turbidity (NTU)	140±12	0.5±0.3
Total Nitrogen (mg/l)	16.5±2.3	16.7±1.6
NH4-N(mg/l)	10.1±2.5	11.8±1.8
Total phosphorus(mg/l)	9.7±0.9	6.7±1

Li, Wichmann et al. in year 2009, reviewed technologies that can treat greywater physically as shown in table 14. Most of the systems had a filtration process followed by sedimentation and finally disinfection. The table also shows which of the system fail under which criteria for reusing greywater. For example, cartidge filter passes guideline for reusing greywater (denoted by letter 'V') under TSS but fails in case of turbidity and total coliforms (denoted by letter 'X').

Table 14: various physical treatment processes reviewed by (Li, Wichmann, & Otterpohl, 2009)

F. Li et al. / Science of the Total Environment 407 (2009) 3439–3449

Reference	Process	TSS		Turbidity		COD		BOD		TN		TP		Total coliform		Faecal coliform	
		(mg/l)		(NTU)		(mg/l)		(mg/l)		(mg/l)		(mg/l)		(cfu/100 ml)		(cfu/100 ml)	
		In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Gerba et al. (1995)	Cartridge filter	19	8 V	21	7 X	-	-	-	-	-	-	-	-	2×10^8	2×10^6 X	-	-
Ward (2000)*	Sand filter + Membrane + Disinfection	-	-	18	0 V	65	18	23	8 V	-	-	-	-	-	-	-	-
Brewer et al. (2000)*	Filtration + Disinfection	-	-	21	7 X	157	47	-	-	-	-	-	-	2×10^5	13 V	-	-
CHMC (2002)*	Screening + Sedimentation + Multi-media filter + Ozonation	67	21 V	82	26 X	-	-	130	-	-	-	-	-	-	-	-	-
Hills et al. (2003)*	Coarse filtration + Disinfection		35		40 X		166		40 X						ND V		
March et al. (2004)	Screening + Sedimentation + Disinfection	44	19 V	20	17 X	171	78	-	-	11.4	7.1	-	-	-	-	-	-
Itayama et al. (2004)	Soil filter	105	23 V	-	-	271	40.6	477	81 X	20.7	4.4	3.8	0.6	-	-	-	-
Ramon et al. (2004)	UF membranes (400 kDa)	-	-	18	1.4 V	146	80	-	-	-	-	-	-	-	-	-	-
	UF membranes (200 kDa)	-	-	17	1 V	146	74	-	-	-	-	-	-	-	-	-	-
	UF membranes (30 kDa)	-	-	24	0.8 V	165	51	-	-	-	-	-	-	-	-	-	-
Sostar-Turk et al. (2005)	UF membrane	35	18 V	-	-	280	130	195	86 X	-	-	-	-	-	-	-	-
	NF membrane	28	0 V	30	1 V	226	15	-	-	-	-	-	-	-	-	-	-
	RO membrane	18	0** V	-	-	130	3	86	2 V	-	-	-	-	-	-	-	-
Prathapar et al. (2006)	Filtration + Activated carbon + Sand filter + Disinfection	9	4 V	13	6 X	51	35	-	-	-	-	-	-	>200	0 V	-	-
Birks (1998)	UF membrane	-	-	-	-	451	117	274	53 X	-	-	-	-	-	-	-	-

*: Referenced from Pidou (2006).

**: Referenced in Pidou (2006), the BOD_5 was changed from 8 mg/l to 0 mg/l.

V: Meet the reuse guideline.

X: Fail to meet the reuse guideline.

6.5 Water reclamation at Loughborough

Surendran and Wheatley conducted a Laboratory experiment to reclaim water from greywater at 2007. A 75l capacity package plant was set up in the lab. Physical steps including screening, floatation, settlement, mixing flocculation and filtration along with biological processes were optimally combined. This package had 4 main stages. 1st stage was preliminary step for balancing flows and buffering peak mass loads. Second stage was primary treatment where solid separation and digestion was done in order to reduce sludge. Stage 3 was aerated bio-filter as in secondary treatment to remove most of the organics. Fourth one was deep bed slow flow filtration as in tertiary treatment to generate near potable quality. An option of adsorption was taken in account as fifth step. The laboratory study lasted for 200 days without any maintenance and disinfection producing water with near potable standard and met all the EU/UK bathing water standards. A laboratory set up can be seen below:

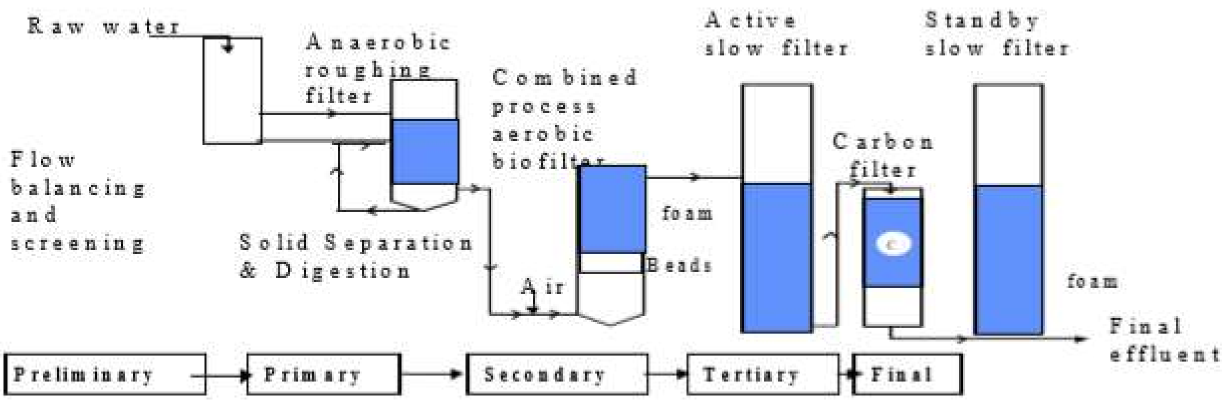


Figure 6: greywater treatment in Loughborough by 3 steps with a fourth as an additional step for polishing the effluent (Surendran and Wheatley, 2007).

This above setup was used for treating greywater and roof rainwater from 33 residents. Greywater contained water from 16 wash basins, 2 baths, 2 showers and some washing machines to reuse water for 4 WCs. Efficiency of the treatment plant can be seen in table 15 below:

Table 15: removal efficiency of above process (Surendran and Wheatley, 2007)

Parameters	Efficiency
Total coliform (cfu/ 100ml)	100%
Turbidity (NTU)	95.9%
Ammonia (mg/l)	92.1%
BOD (mg/l)	95.6%
Total carbon (mg/l)	49.6%
Total suspended solids (mg/l)	93.7%

6.6 Greywater treatment by Electro coagulation

Electrocoagulation is one of the promising electro chemical treatment of greywater. The main principle of electrocoagulation technology is redox reaction. Oxidation process occurs in sacrificial anode and reduction reaction occurs at cathode (Barışçı and Turkay, 2016). When current is applied, cations are produced as a result of dissolving of the metal electrodes. These ions further form a metal hydroxides which destabilizes the suspended solids. These can then be removed by mechanisms like adsorption, charge neutralization and sweep coagulations. The major advantages of treating greywater by electrocoagulation could be cost effectiveness since no chemicals are used, production of less sludge, and compactness. Usually Aluminium (Al) and iron (Fe) electrodes are used. There are few researches that has been done regarding greywater treatment done by electro chemical coagulation. An investigation was carried out in India to treat greywater by electro coagulation process (Vakil et al., 2014). They were able to achieve COD reduction from 380 mg/l to 160 mg/l and turbidity was 15.6 NTU from 104 NTU along with 2 log reduction of total coliforms. Another research done in Cairo, Egypt by (Bani-Melhem and Smith, 2012) showed that if EC process is combined with SMBR (Submerged MBR) process, it is possible to treat greywater. COD 463mg/l, turbidity 133 NTU, TSS 78 mg/l and total coliform $43*10^4$ cfu/100ml were 51 mg/l, 4.1 NTU, no detectable TSS and 49 cfu/100ml respectively after treatment. A study was carried out using bipolar alumunium electrodes along with disinfection process. COD was removed from 55 mg/l to 22 mg/l while there was no presence of any coliform after the treatment (Lin et al., 2005).

An enhanced greywater treatment by combination of Electrocoagulation and ozonation was done in Iran. (Barzegar et al., 2019) concluded that EC/ ozone treatment had high efficiency in TOC and COD removal. Highest removal efficiency of COD and TOC were 85% and 70% that was achieved at pH= 7, current density at 15 mA/cm^2 and ozone dosage at 47.4mg/l and 60 minute of electrolysis time. An experiment adding UV as disinfection after EC/Ozone had 4 logs removal of total bacteria and 96% removal of E. coli but in cost of approximately 2.13 $ increased cost per cubic meter. Table below shows that these combinations had good treatment over COD and BOD_5 but still had high amount of TDS and bacteria. Removal of these seems to require further treatment but in expense of additional costs.

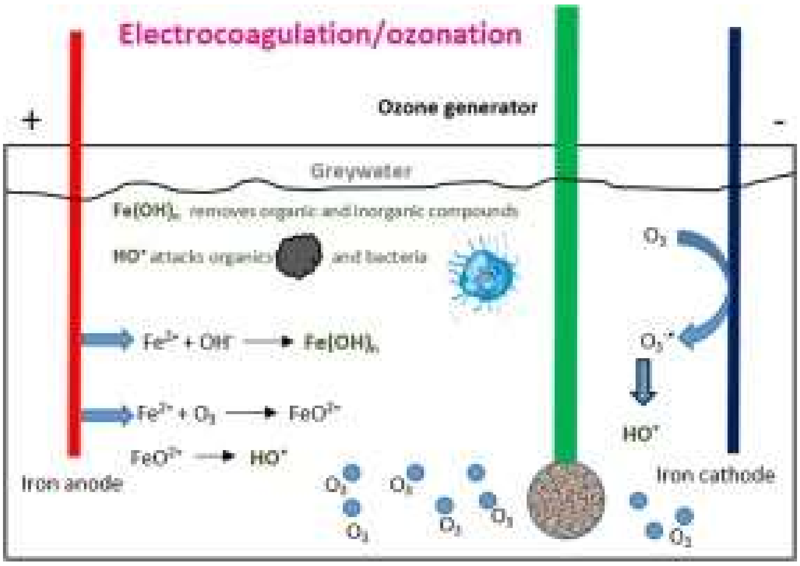


Figure 7: electrochemical coagulation/ozonation for greywater treatment (Barzegar et al., 2019)

Table 16: efficiency of electrochemical coagulation/ozonation for greywater treatment (Barzegar et al., 2019)

Parameters	Raw greywater	EC/ozone	EC/ozone/UV
COD (mg/L)	460 ± 50	53 ± 10	20 ± 5
BOD_5 (mg/L)	180 ± 20	20 ± 10	20 ± 10
TOC (mg/L)	185 ± 5	53.4 ± 3	23.4 ± 3
TDS (mg/L)	3150 ± 20	2650 ± 20	2700 ± 20
Cl^- (mg/L)	780 ± 30	702 ± 20	712 ± 10
SO_4^{2-} (mg/L)	120 ± 10	107 ± 20	104 ± 10
Anionic surfactant (mg/L)	4.3 ± 0.8	0.05>	0.05>
Turbidity (FTU)	242 ± 5	20.2 ± 5	21.3 ± 5
pH	7.2 ± 0.05	7.8 ± 0.1	8.0 ± 0.1
Ammonia (mg/L)	1.1 ± 0.1	0.21 ± 0.0.02	0.1 ± 0.02
NO_3^- (mg/L)	5.6 ± 1.5	5.5 ± 0.8	5.1 ± 1.5
Total coliforms (CFU/100 mL)	2–5 × 10^7	1.9–4.1 × 10^4	1.5–3 × 10^3
Escherichia coli (CFU/100	2–2.8 × 10^3	200–500	50–100

6.7 Onsite treatment:

Onsite treatment of greywater has a main advantage that installation costs is comparatively less than of large centralized systems wished-for for multiple households (Nolde, 2005). A pilot test done by (Friedler et al., 2006) is shown below. This test was conducted in an eight storey building with 6 flats per storey in Technion campus, Israel. Married couple who also might have children were being accommodated there. With the help of proper plumbing, the greywater was gravitationally transported to the plant in the basement. This plant consisted of:

Fine screen: remove solids, hair of size etc. of 1mm

Equalization basin (EB): regulate inflow and outflow along with quality and temperature.

Rotating biological contactor (RBC): attached growth biological treatment system.

Sedimentation basin (SB): to remove sludge

Pre- filtration storage tank (PFST): regulate SB outflow and SF inflow

Sand filter (SF): gravity filter of 10cm diameter and 70cm media depth.

Disinfection: done by chlorination in a batch mode.

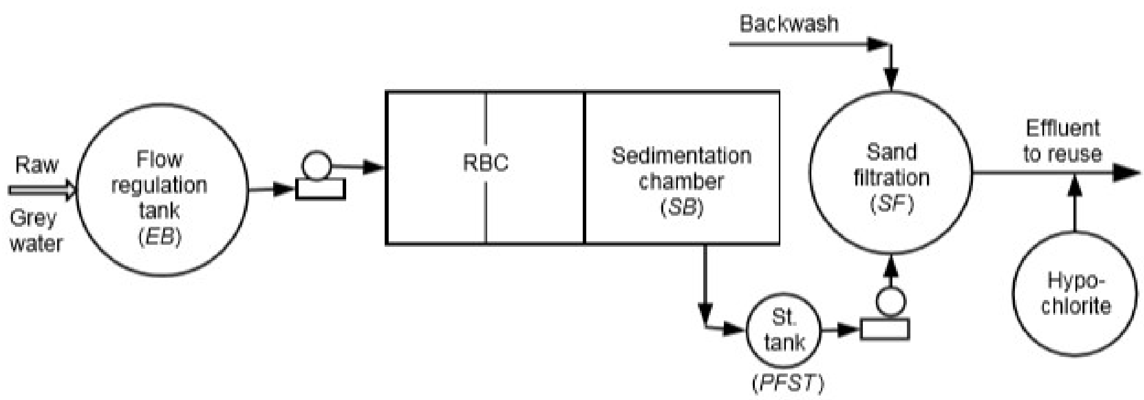


Figure 8: Schematic layout of pilot plant. (Friedler et al., 2006)

Table 17: performance of the above pilot test (Friedler et al., 2006)

parameter	Raw GW	RBC+ SB effluent	filter effluent	disinfection (after 30 min)	total removal
TSS(mg/l)	43	16	7,9	-	82 %
Turbidity(NTU)	33	1,9	0,61	-	98 %
CODt (mg/l)	158	46	40	-	75 %
BODt (mg/l)	59	6,6	2,3	-	96 %
Faecal coliform (CFU/100ml)	5,6*10^5	9,7*10^3	5,1*10^4	0,1	100 %

The pilot plant had these treatment efficiencies. COD removal compared to BOD removal was low which might be because of slowly/ non-biodegradable organics. RBC showed good performance in treating turbidity. SF reduced turbidity further making it drinking water standard quality. This plant also removed 58% of TP and 87% of TKN. 100% of FC was removed.

6.8 Onsite treatment by septic tank, aerobic bio-filter and constructed wetland

Greywater was treated in Kaja student housing at Norwegian University of Life sciences (NMBU) and in Klosterenga using three steps treatment (Jenssen & Vråle, 2003, Sagen, 2014). It was done in three steps as in figure 9 below: first source separated greywater was passed through a septic tank. Then, it was passed through a vertical down flow aerobic bio-filter and finally a horizontal subsurface flow constructed wetland. The bio-filter sprayed STE uniformly over the 60 cm of filter media of grain size 2-10 mm. In Norway, Low Weight Aggregate (LWA) of size 2-4 mm is commonly used If the filter media is lower than 20cm, the bacterial removal was comparatively low. 1m^2 area can treat greywater from 10 person if assumed 100l/ person/day of greywater is produced. After aerobic bio-filter, horizontal sub surface flow constructed wetland is used. Wetlands in Norway have depth of one meter which is more compared to other countries. This is probably to avoid frosting on the top 30 cm. a system of area 2-3 m^2/ person can be used to treat greywater. Performance of the system and efficiency is shown in table 18.

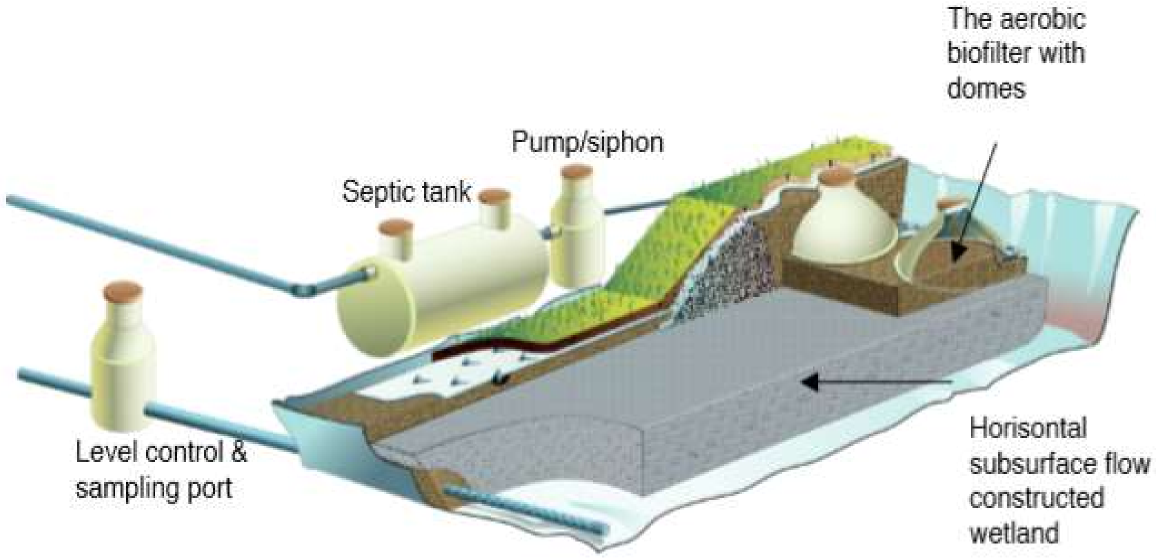


Figure 9: typical 3 steps greywater treatment in Norway (Jenssen & Vråle, 2003)

Table 18: A combination of septic tank, aerobic bio-filter and HFCW in Kaja (Jenssen & Vråle, 2003)

Parameter	Average concentration out of each unit				Percent removal %	Percent removal %	Total removal % Biofilter and Wetland
	Unit	Outlet Septictank	Outlet Prefilter	Outlet Wetland	Biofilter	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			

From the table, we can see that pH was almost same after bio-filter but little raised after wetland. Phosphorus removal was done both in filtration and wetland with 67% and 78% respectively while combined efficiency was 92.8%. BOD_7 removal was better in wetland (81.9%) compared to bio-filter (70%). Only 69.5% of nitrogen was removed by the system where most of it was removed after wetland. Ammonium was removed just 25% by bio-filter and even less (4.2%) by wetland. Amount of nitrate was constant as of septic tank effluent. Thermotolerant coliform reduced from 10^6 to 10^{3}-10^5 by bio-filter and up to 0-1000 TCB per 100 ml. A similar prototype was established in Klosterenga in Oslo (Sagen, 2014). The project gave service to approximately 100 inhabitants from 35 apartments within 6 floors. While the Blackwater is transported to WWTP, the greywater is treated onsite. A septic tank followed by vertical flow aerobic bio-filter and a subsurface HFCW. The effluent is then pumped to a ‘waterfall’ as an aesthetic element in the courtyard before going to Hovin Creek. The area required is 1.5m^2 per person, out of which 1/3 is used up by aerobic bio-filter. First greywater flows through three 30 sq.m. chambers of septic tank. Then it is pumped to an aerobic bio-filter uniformly over a filter material. The area of the bio-filter is 72 m^2. The effluent is then supplied to wetland via two distribution pipes by gravity. One pipe stays high while other one is deep. This is done to keep the system working even in winter. During winter, the higher elevated pipe is shut down while the other one will be supplying greywater.

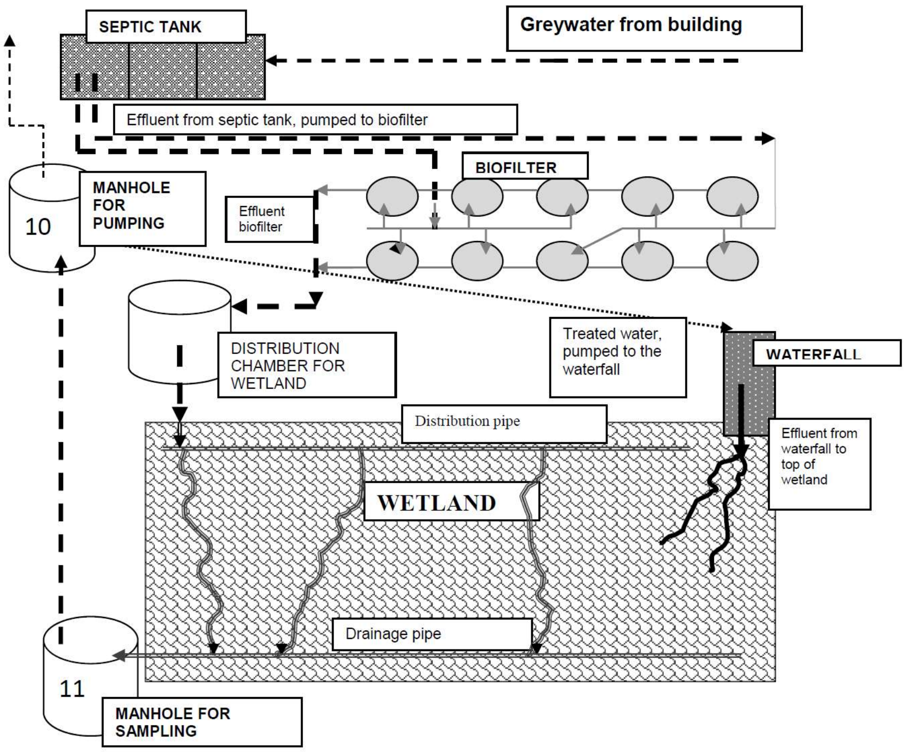


Figure 10: layout of greywater treatment system in Klosterenga (Sagen, 2014)

Table 19: treatment efficiency of greywater treatment system in Klosterenga (Sagen, 2014)

parameters	influent	effluent	efficiency
BOD(mg/l)	225	5	97,78
total phosphorus (mg/l)	0,85	0,27	68,24
total Nitrogen(mg/l)	10,30	2,23	78,35
nitrate(mg/l)	0,14	0,53	-278,57
Ammonia(mg/l)	6,54	2,23	65,90
pH	6,36	7,63	-
Conductivity(µS/cm)	345,60	570,00	-
E. coli	-	18,90	-

To compare with the results from Kaja, Klosterenga had better treatment regarding BOD removal, total nitrogen removal and ammonia removal with 97.78%, 65.9% and 65.9% respectively while Kaja had 94.7%, 69.5% and 28.1% respectively. On the contrary, total phosphorus was removed with better efficiency in Kaja (92.4%) than in Klosterenga (68.24%).

There are some other examples of greywater treatment by wetland system. Nearby of Bergen, 40 houses were built in 1991 who agreed to to separate greywater from blackwater and treat it locally. They did not have an aerobic step as in Klosterenga and Kaja but instead had longer distribution pipes (Jenssen and Vråle, 2003). The effluent was poorer than the systems with aerobic bio-filters and also land utilization was poorer comparatively. The effluent was then finally directed to a nearby lake. The effluent had 15 mg/l of BOD, 2.2 mg/l of Nitrogen and 0.19 of Phosphorus with removal efficiency of 96%, 60% and 79% respectively. In Lubeck, Germany, a settlement with 380 persons, had separately treated greywater and blackwater (Sagen, 2014). The filter media was coarse gravel. The effluent had 14 mg/l of BOD, 2.7 mg/l of Nitrogen and 5.97mg/l of Phosphorus with removal efficiency of 93%, 78% and 29% respectively. If compared cases from Bergen and Lubeck, the effluent of phosphorus was quite high in Lubeck. This might be because of use of phosphorus free detergents in Norway (Cullen and Forsberg, 1988).

6.9 Selection of appropriate technology

Choosing the treatment options depend on various factors like climate, land usage, water usage pattern, degree of pollution and availability of pre-existing drainage systems (Ridderstolpe, 2004). Treatment of Greywater is necessary for reuse to avoid health risk, negative aesthetic and environmental effects. So, the major aspects to be treated in greywater are suspended solids, organic matter and micro-organisms (Li et al., 2009) rather than focusing on nutrients. But we can also not underestimate compounds like PPCPs and taste and odour giving compounds. The physical treatment systems alone cannot reduce organics, nutrients and surfactants to adequate amounts. So, usually physical process alone is not recommended. Chemical process if compared to physical processes have better efficiencies of reduction of turbidity and organic matter to some extent but still not up to standards especially in case of high strength greywater. Chemical processes can be effective in case of low strength greywater but not in medium and high strength greywater. For low strength greywater, chemical process followed by filtration with or without disinfection could meet up desired standards. For medium and high strength greywater, chemical steps are not so reliable unless combined with other processes. Aerobic biological treatment processes are recommended for medium and high strength greywater because most of the biodegradable organic compounds are removed and also regrowth of micro-organisms and odour has less tendency to happen. However, anaerobic processes are not suitable because of its less treatment on organic substances and surfactants. Constructed wetlands are considerably better option as it is environment friendly and cost efficient but requires large space. This is why it is mostly avoided in urban areas. MBR is one of the uprising technology for greywater treatment and reuse in collective urban residential buildings. MBR system is quite economic for buildings more than 40 storeys (Friedler and Hadari, 2006) or collective urban residence serving 500 inhabitants (Li et al., 2009).

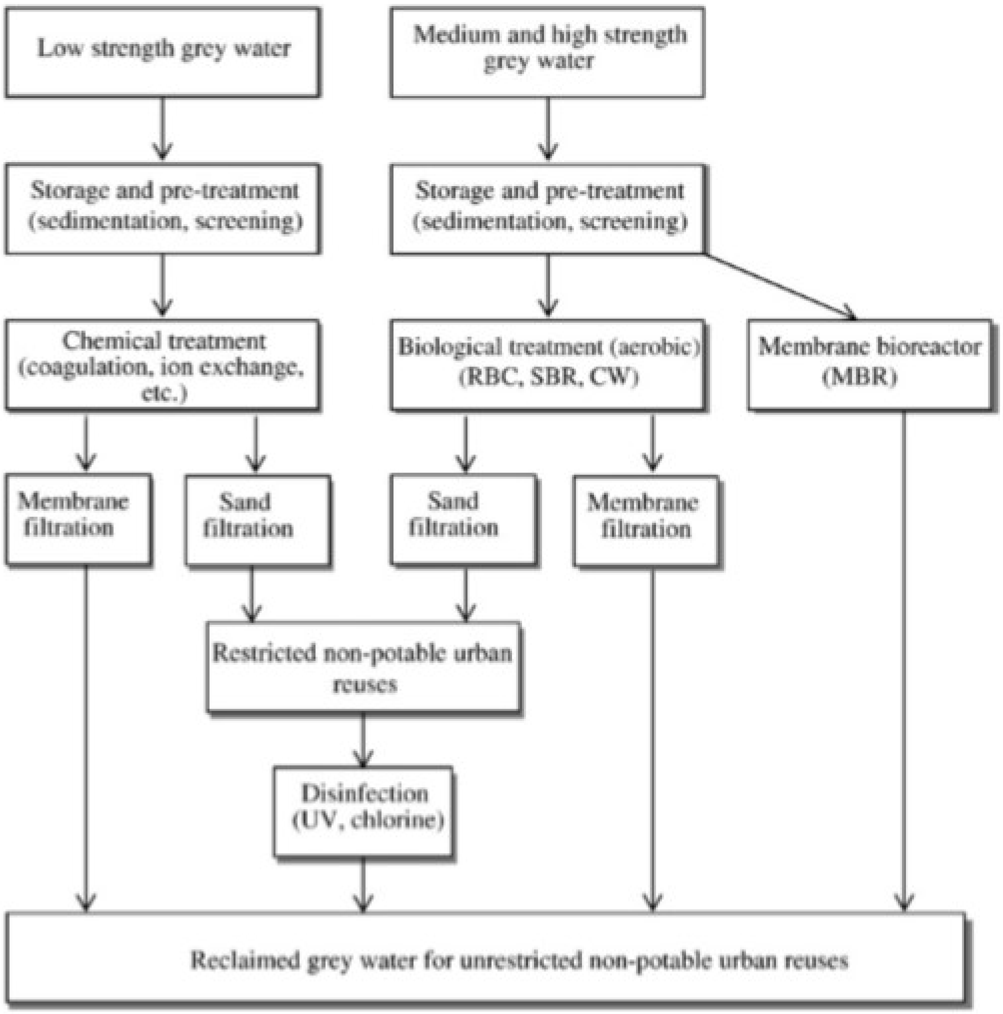


Figure 11: flowchart of appropriate use of technologies to treat greywater (Li et al., 2009)

6.10 Treatment required to reach Drinking water standards

Pollutants like micro- organisms, suspended solids, nutrients are necessary to remove in order to reuse greywater. But along with these, PPCPs and odour cannot be neglected if the water is to be reused as drinking water. The reclaimed water should be aesthetically acceptable and also free from health hazards.

6.10.1 Pharmaceuticals and Personal Care products (PPCPs) removal

Greywater along with other contaminants also has personal care products and pharmaceutical products. Personal care products are in higher amount in greywater compared to pharmaceutical products. Most of the pharmaceutical products are found in human excreta (urine and faeces). Only some products that are used externally (usually on surface, e.g. skin) such as anti-flammatory pharmaceuticals can be found in greywater (Butkovskyi et al., 2016). Although water coming from constructed wetland have high quality, but still there might be presence of some Pharmaceutical and Personal Care Products (PPCPs). It is because horizontal flow constructed wetland cannot treat some major compounds like carbamazepine and diclofenac as shown in table 20. According to a paper by (Matamoros et al., 2009), a pilot test was carried out to remove PPCPs from wastewater coming out of small decentralized plants serving 2 to 280 inhabitants. This paper has also stated that if a system has good efficiency of removing BOD_5 and NH_4^+, then it is likely to have a good treatment of most of the PPCP compounds. Following table shows that bio-filters and sand filters have good efficiencies (ranging from 65-99%) in removal of most of the compounds that is not done by HFCW. So, these could be an option to remove PPCPs in treated greywater in Kaja.

Table 20: different PPCPs and their removal efficiencies (%) by various treatment methods (Matamoros et al., 2009)

treatment methods	salicylic acid	Ibuprofen	OH-ibuprofen	CBZ	Naproxen	diclofenac	ketoprofen	caffeine
biofilters	95	n.r.	n.r.	-	n.r.	-	-	67
sand filters	95	86	75	-	65	82	-	68
HFCW[a]	95	65	71	38	45	21	90	97
VFCW[b]	87	89	85	-	92	-	n.r.	99

a-Horizontal flow constructed wetland, b- vertical flow constructed wetland

Another research done by (Lee et al., 2012) in Albequerque, New Mexico, insights that PPCPs in wastewater were treated with good efficiency by either ozonation followed by bio-filter or reverse osmosis which are done after a MBR system as shown in figure 12 below. 35 out of 41 compounds were already treated my MBR. Reverse osmosis removed the rest 6 compounds by more than 97% efficiency. In the system with ozonation and bio-filter after MBR figure 12 concentration of PPCPs were same in ozonation effluent and bio-filter effluent. This showed bio-filter did not add PPCPs removal but only removed oxidated products from ozonation. To compare between these two systems, both had similar efficiencies if the ozone was dosed 8mg/L. RO is considered to have better action against these compounds but with expense of more energy consumption, more waste production, low water recovery and more maintenance of membrane due to fouling.

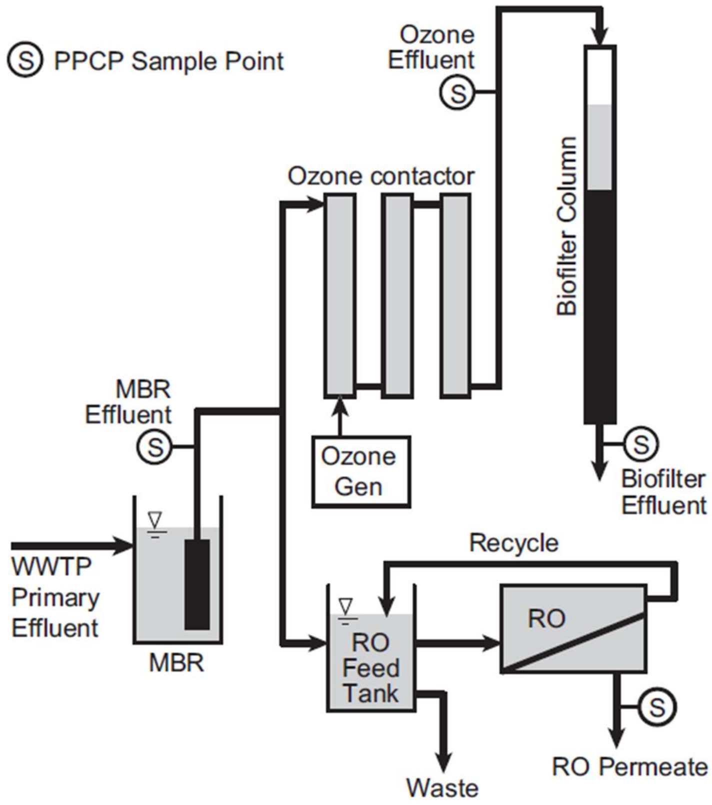


Figure 12: PPCP removal by Ozone Contactor and bio-filter or Reverse Osmosis after MBR (C. O. Lee, Howe, & Thomson, 2012)

As per another paper by (Baumgarten et al., 2007), an experiment was done using Powered Activated Carbon (PAC) in two doses 50 mg/l and 500 mg/l with two different types of PAC Carbotech PAK 800 and Norit SA UF.

Table 21: various treatment options of PPCPs and their removal efficiencies (Baumgarten et al., 2007)

Pharmaceutical compound	MBR treatment in combination with					
	O_3-treatment		PAC-addition		Membrane treatment	
	O_3-concentration/treatment period		PAC * - concentration		Type of membrane/ MWCO	
	40 mg L^{-1}/20 min	40 mg L^{-1}/40 min	50 mg L^{-1}	500 mg L^{-1}	NF/300 Da	RO/100 Da
	Elimination rate (%)					
Fluoroquinolonic acid	98.5	99.6	91.2	>99.7	>99.7	>99.7
Ciprofloxacin	97.9	97.9	79.5	96.5	>97.9	>97.9
Enrofloxacin	98.8	98.8	96.4	97.5	>98.4	>98.4
Moxifloxacin	98.4	98.4	96.8	96.7	>99.6	>99.6

*Norit SA UF

PAC following MBR gave a better result regarding PPCPs removal compared to other treatment options table 21. *Also, PAC is relatively inexpensive and can be applied when required.*

6.10.2 Taste and odor removal

Removing taste and odor is one of the biggest challenge in order to treat wastewater to drinking water. Greywater can turn anaerobic itself producing foul odor. Which might falsely conclude that greywater is health hazardous to reuse (Ridderstolpe, 2004). The 1978 European Drinking Water Directive standardized a threshold for taste and odor (T&O) equal to 3.Recent WHO recommend that the drinking water should not have unpleasant taste and odor in water but does not have any specific guidelines value (Bruchet and Laine, 2005). Though NF and RO proved to be better in removal of some T&O compounds, there was some dispute over taste after these filters. This could be because of too low TDS in water resulting demineralization. So, before using the permeate from NF or RO, it should be mixed with water having higher mineral content to reach a value of 320 to 620 mg/l (Mallevialle and Suffet, 1981). Even low concentrations of organic matters can produce odor in water. Two of the most detectable compounds by the consumers are 2- methyl isoborneol (MIB) and Geosmin as earth-musty odors. So removing these compounds to non-detectable amount (10ng/L) is very much essential in drinking water. These are the compounds that are less likely to be adsorbed during treatment. Hence, these can be taken as the model compounds for taste and odor. Powdered Activated Carbon (PAC) and Granular Activated Carbon(GAC) are most commonly used to remove taste and odor (Lalezary et al., 1986). It is widely known that efficiency of PAC depends on type of carbon used and presence of NOM (Natural Organic Matter). Also simultaneously, the correct dosing of PAC is also important. Overdosing might have positive effect but in long run might be costlier. On the other side, under dosing might not remove compounds to desired level leading to consumers' unacceptance.

A demonstration from an experiment done in Adelaide, Australia is shown in table 22. This shows if we assume 150lpcd, then PAC required for treatment would be approximately 3.5gm and 6.57gm to remove 40 ngm/l of geosmin and MIB respectively to required level at 10ngm/l (Cook et al., 2001).

The adsorption capacity of activated carbon depends upon the particle size of the carbon (Matsui et al., 2015). As the particle diameter decreases from 10µm (PAC) to 0.7 µm (SPAC), there is increment in the adsorption capacity of the activated carbon. PAC is considerably cheaper than GAC but when taste and odor becomes a problem such that activated carbon will be required consistently over a long period, GAC is more economical (Chen et al., 1997).

Table 22: Dosage of PAC required to reduce 40ngm/L of compounds to required level of 10ngm/L with contact time of 50min (Cook et al., 2001).

	PAC(mg/L)	
samples taken from	Geosmin	MIB
Anstey Hill	22	42
happy valley	21	39
hope valley	21	39
Myponga	29	55
Average	**23,25**	**43,75**

Since Activated carbon is known to remove both PPCPs and T&O compounds (2-MIB and geosmin), it could be the best option out of other alternatives.

7. Methodology

7.1 Study area Nesodden

The greywater was retrieved from Nesodden. Nesodden lies around 17km on the south west of Oslo. Greywater was treated in the same way as in Kaja student housing at Norwegian University of Life Sciences (NMBU) and in Klosterenga but in smaller scale. It was done in three steps as in figure 13 below: first source separated greywater was passed through a septic tank. Septic tank removes floating particles as scum on the top and heavy particles that settles down as sludge at the bottom. Then, it was passed through a vertical down flow aerobic bio-filter. The Septic Tank Effluent (STE) was sprayed uniformly over the 60 cm of biofilter of grain size 2-10 mm. This effluent was then finally a horizontal subsurface flow constructed wetland.. The system served a couple and a kinder garden having 6-10 kids. Since the population serving was not so big, the adopted size of the wetland was approximately 6-7 m^2. During the time of sampling, the pump supplying STE to aerobic bio-filter was not working. So the greywater was not spread uniformly on the filter material. This made the system anaerobic in nature.

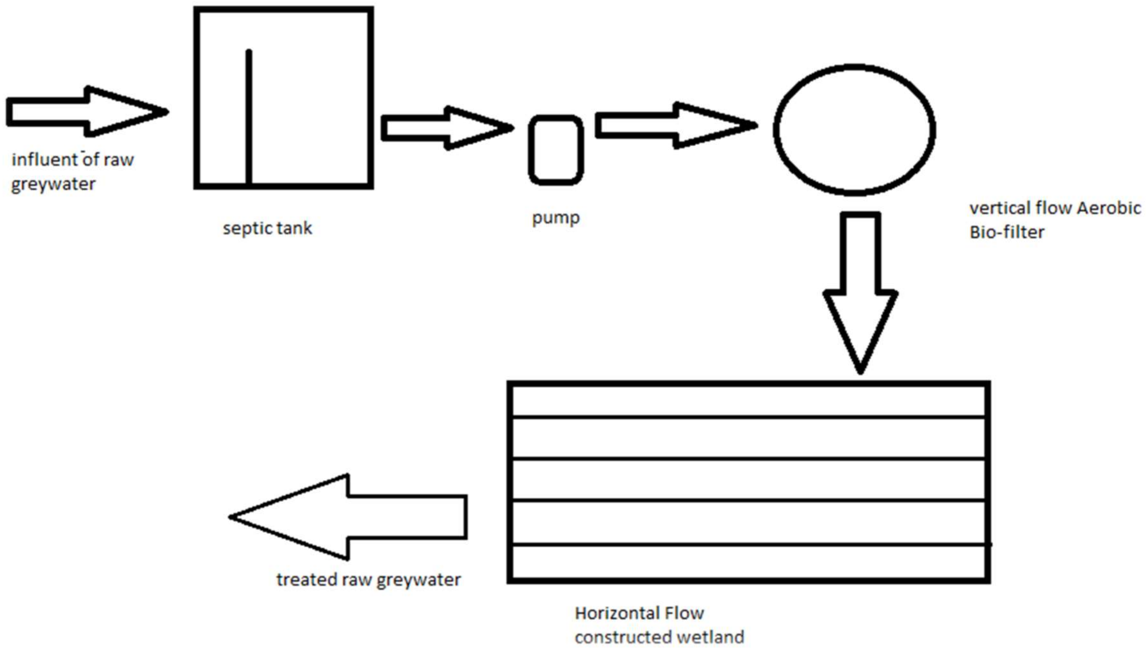


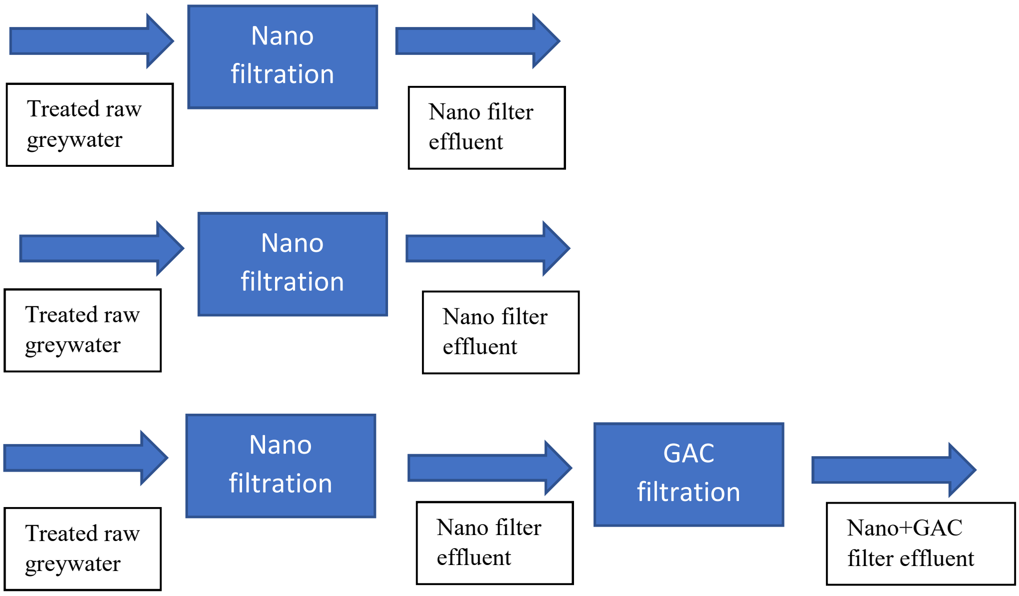
Figure 13: representative diagram of greywater treatment in Nesodden

Sample was brought to laboratory of Ås on 11th of April approximately 12 hours after it was retrieved in Nesodden. At first, the treated raw greywater was poured into a beaker approximately 5L. The sample was mixed again to the same jar containing treated raw greywater to ensure that the sample represents the whole 20L graywater. A Nerox Nano-filter as in figure(14) with pore size 0.3 µm was submerged completely. Permeate was obtained in a 500 ml jar. Sample was stored for further examinations. This permeate was passed through a Granular Activated Carbon (GAC) column of length 30 cm containing 244.7 gm of filter material using a pump. The setup of GAC filtration was done lab like shown in figure 15 below. This material was previously washed with water and dried in oven at 125°C. We had established two columns of GAC so that we could perform trials for Nano-filter permeate and treated raw greywater simultaneously. The samples of all the effluents were stored in a cold freezer as all the tests were not done on the same day.

Figure 14: Nerox nano filter provided by SCANwater

Figure 15: laboratory setup of Granular Activated Carbon filtration

Flow diagram of filtration sequences done in this study:



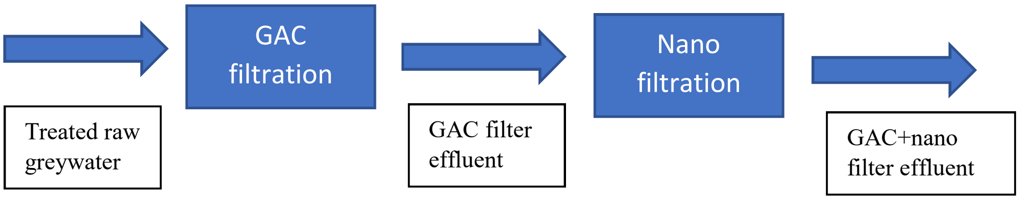


Figure 16: flow-diagram of filtration sequences

7.2 Analytical methods

7.2.1 Bacteria (total coliforms and E. coli)

Bacteria cannot be recognized by color, taste or odor. The only way to know the contamination of bacteria is by testing it (Oram, n.d.). A sample was taken after each step: treated raw greywater, Nano-filtration, Nano- filtration, Nano- filtration and carbon filter, carbon filtration, carbon filtration and Nano- filtration. The method used was Colilert 18/Quanti-trays 2000 (IDEXX, n.d.). Dilution was performed only for treated raw greywater because since it is raw, the probable number of E coli might exceed the maximum limit of the MPN limit. This makes result difficult to calculate the most probable number. But if dilution is done assuming the probable number to come within the chart range, it would give more realistic number of probable total coliforms number. All the samples were transferred to a 100 ml bottle and colilert-18 was added. Colilert provides food for organisms to grow. This solution is left to get settled and was poured to a Colilert 18/Quanti-trays 2000 as in figure 28. It was made sure that the slots had no air bubble in it. The bag was sealed and kept inside oven at 32°C for 18 hours. The tray consists of 49 large slots and 48 small slots. To examine E. coli, trays were checked by UV rays. If any of the slots changed their color into blue, there would be presence of E. coli.

7.2.2 Total Nitrogen and Total phosphorus and Phosphate

To measure the total nitrogen, 1.5 ml of sample from each of 5 sample jars were taken. Since the samples were from treated greywater, they were clear enough for not requiring dilution. In the samples, a small amount of oxidizing agent (sodium peroxydisulphate) was added. This was done to convert all other nitrogen forms even amino acids into nitrates. Then 200µl of 2M NaOH (sodium hydroxide) was added. This solution was then digested in an oven at 120°C temperature. After digestion for almost 30 minutes, samples were taken out and cooled for a while then were analyzed in a Systea analyzer (S.P.A, 2015). In case of drinking water, no standards have a limit for phosphates. So, there was no necessity of measuring phosphates. The analysis of phosphates was done just so to ensure the trend of presence of urine in greywater. This can be further confirmed alongside of ammonium tests.

7.2.3 Ammonium

A simple lab test was done for ammonia. 1.5 ml of each samples were taken in a test tube. Which was then transferred to a systea analyzer (S.P.A, 2015).

7.2.4 Chemical Oxygen Demand (COD)

COD was tested instead of BOD in the lab because BOD test would take a long time (usually 5 days for BOD_5 and 7 days for BOD_7) while COD test can be performed within hours. A set of test tubes as in figure (16) inholding a solution OF 90% sulphuric acid, mercury sulphate, silver sulphate were used for examining the COD. 2 ml of samples were added to the solution. Since the reaction was exothermic, this step was conducted inside a fume cover for precaution. The tube was shaken before and after addition of the sample. It was done to make sure there won't be any residues at the bottom. The tubes were incubated inside a HACH heating device to heat samples to 148°C for 2 hours. It was then cooled down and a HACH COD analyzer was used to examine the COD (HACH, n.d.-b).

Figure 17: set of test tubes containing solution for COD test

7.2.5 Turbidity

None of the effluent samples had visible suspended solids. So the Total suspended solids (TSS) test was not taken but instead turbidity was analyzed. To test turbidity, a HACH 2100N IS TURBIDIMETER was used (HACH, n.d.-a). Samples were taken in a clean test tubes and placed gently inside the device and lid was closed. Since even the handprints would affect the reading, it had to be done very carefully.

7.2.6 pH, conductivity and salinity

pH was measured for each sample by using a portable pH meter WTW pH 3110 in the lab (WTW, n.d.). Conductivity and salinity was measured by WTW 3310 conductimeter with range 0 to 1000 mS/cm and salinity at 0 to 70 (as per IOT) (WTW, n.d.). After tests of each samples, the electrodes were rinsed in deionized water and wiped carefully so that it won't interfere with results of latter samples.

8 Results and discussion

8.1 Comparison of treated raw greywater with other similar systems

Table 23: table showing the effluent quality from Nesodden and comparing them with similar systems in Kaja and Klosterenga

Parameters	Nesodden[a]	Nesodden[b]	Kaja[c]	Klosterenga[c]
E.coli per 100ml	$1.56*10^3$	<1	-	18,9
Total coliform bacteria (MPN/100ml)	$>2.149*10^4$	226	-	-
Thermotolerant coliform bacteria (cfu/100ml)	-	-	<1000	<1000
pH	-	7,96	7,43	7,63
Turbidity(NTU)	-	4,55	-	-
Total Nitrogen (mg/l)	27	7,65	2,6	2,5
Ammonium(mg/l)	9.35	6,218	2,3	2,23
Total Phosphorus(mg/l)	1.73	-	0.05	0.03
Ortho phosphate (mg/l)	0.76	<0.1	-	-
COD (mg/l)	-	22	15,8	19
Salinity	-	0,3	-	-
Conductivity(µS/cm)	-	847	-	570

a- Raw untreated greywater, b- greywater treated by constructed wetland, c- (Jenssen and Vråle, 2003), *- TCB. Thermotolerant coliform bacteria

Table 23 shows the comparison of raw greywater from Nesodden and the effluent of constructed wetland of same place used for this study along with other similar systems like Kaja and Klosterenga. Greywater directly obtained from the source in Nesodden had >$2.149*10^4$ MPN per 100ml of total coliforms and $1.56*10^3$ MPN/100ml of E. coli. Total nitrogen was measured as 27 mg/l and ammonia was 9.35 mg/l., total phosphorus was 1.73 mg/l and ortho phosphate was 0.76 mg/l. The effluent of greywater obtained from Nesodden was not treated as much as in effluent from other two systems. The total amount of Nitrogen and Ammonium were higher in effluent of constructed wetland than the other two systems. The number of COD is also slightly higher in effluent from Nesodden greywater treatment system. This could be because of fault in pump that was supplying the greywater to the aerobic bio-filter. E.coli was not present in sample of Nesodden while there were about 19 E.coli per 100ml in greywater of Klosterenga. Total coliform bacteria were seen as 226 MPN per 100ml in the lab. Meanwhile, greywater from both Kaja and Klosterenga had termotolerant bacteria with range of under 1000 TCB per 100 ml. Kaja and klosterenga had swimming water quality in terms of coliform bacteria as per EU (Jenssen and Vråle, 2003)

8.2 General Overview of the system

Table 24: summary of the post treatment processes; a- Nano filtration, b- granular activated carbon

Parameters	Raw untreated	Raw treated	Nf[a]	C[b]	Nf+C	C+Nf
E.coli	$1.56*10^3$	<1	<1	<1	<1	<1
Total coliform	$>2.149*10^4$	226	<1	>2419	>2419	7.87
COD	-	22	25.6	2.96	4.95	7.33
Turbidity	27	4.55	0.105	1.75	0.14	0.1
Total Nitrogen	27	7.65	6.58	7.114	5.37	5.954
Ammonium	9.35	6.218	6.15	5.992	5.01	5.147
pH	-	7.96	8.02	7.98	7.78	7.87
Total phosphorus	1.73	-	-	-	-	-
Ortho phosphate	0.76	ND	ND	ND	ND	ND
Salinity	-	0.3	0.3	0.3	0.3	0.3
Conductivity	-	847	842	820	810	812

The greywater was treated by Nano filter, carbon filter and both filters kept in different sequences. Table 24 shows the overview of the results obtained from the lab experiments. The detail of each of the parameters were discussed in specific sections as in section 5.

Figure 18 shows the change in quality of effluent from each steps and combinations and compared with treated raw greywater and clean tap water. Raw untreated greywater has quite high turbidity (figure 18). It can be seen that nano filter did not have so much clearer water compared to raw treated greywater. We could also smell some earthy musty smell in nano filtrate but not as much as raw treated greywater. Besides, all other effluents were odor free and comparatively clearer almost as tap water.

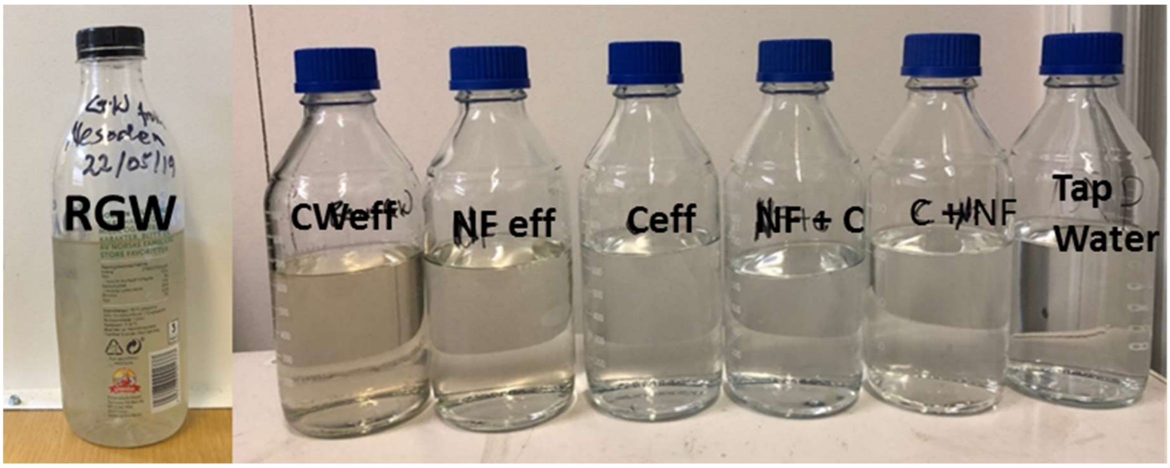


Figure 18: figure showing visual difference of water before and after different treatment steps and comparing them with treated raw greywater and tap water (RGW=raw greywater, CWeff=Constructed wetland effluent, NFeff =nano filter effluent, Ceff=activated carbon

8.3 Indicator Bacteria (total coliforms and E. coli)

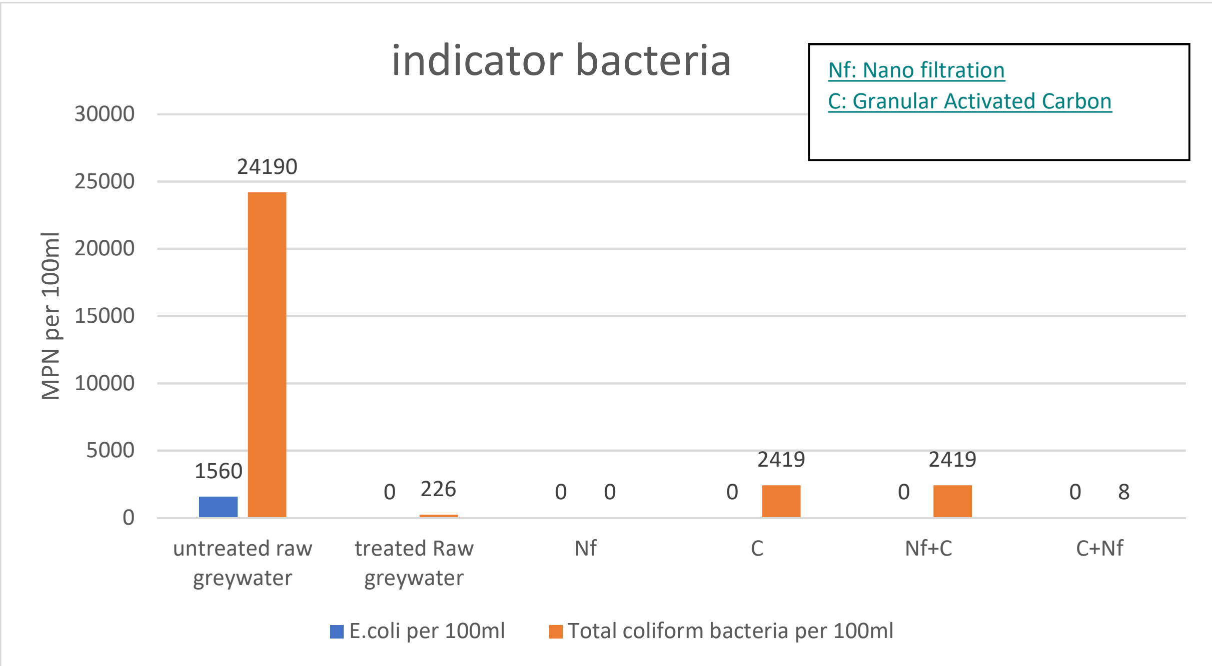


Figure 19: diagram showing most probable number (MPN) of total coliform bacteria and E. coli in different effluents

After keeping Colilert 18/Quanti-trays 2000 at 32°C for 18 hours, there was distinguishable change in colour in some samples as shown in Appendix B. The large and small slots containing a distinguishing yellow colour were counted. The number correspondent to these slots were seen in the MPN chart as shown in Appendix B. This number represented the total coliforms bacteria. For example, sample of GAC effluent showed colour change in 49 large slots and 48 small slots. If we refer to the chart of figure 29, it says the most probable number of coliform bacteria in the sample is somewhere more than 2419.

As shown in figure 19, untreated raw greywater had total coliform >$2.149*10^4$ MPN/100ml. If compared to the reviewed literature, the number of coliforms were fewer. Raw greywater after being treated by constructed wetland had 226 total coliforms per 100 ml. The presence of coliforms in the treated raw greywater from wetland could be because of coliforms previously present in the wetland soil. This number went to less than one for effluent of Nano filtration but was more than 2419 for effluents of Carbon filter and carbon+ nano filtration. But, total coliforms were just 8 per 100ml when carbon filtration was done before nano filtration. There was high number of total coliforms in effluents of Carbon filtration and Nano+carbon filtrations as seen in following figure 19. This could be because of contamination from the trays that were used to keep the activated carbon. This is why we had even higher number than in raw water. The other possibility could be contaminations on the inner surface of the columns which was used for urine filtration before this study. Although the GAC was washed and heated for 125°C, bacteria might have not been removed properly. But when we changed the sequence of nano filter and GAC, we had significant change in result. The contaminants from Carbon were seen to be retained by nano- filtration. However, the effluent of sequence (GAC+nano filter) should have been <1 MPN per 100 ml. There were 8 MPN per 100 ml of total coliforms in this effluent. This suggests that there could be the slightest possibility of contamination during sampling.

There were $1.56*10^3$ MPN/100ml of E.coli in untreated greywater. However there was no indication of E. coli in any of the samples when Colilert trays were kept under UV light. This proves that the constructed wetland had a good treatment efficiency over E. coli. If compared with the standards of drinking water (table 7), even the effluent of constructed wetland can meet up the drinking water standards for E. coli. However, figure above cannot show the efficiency of nano filter and GAC in removal of E. coli. Since, nano filtration had removed total coliforms and combination of GAC+nano filter also had very few number of total coliforms, it can be presumed that nano filter can remove E. coli in similar manner. A research done in 1995 for Nerox Nano filter showed that in influents of 2400 and 12000 coliforms per 100ml, the filter showed 0 coliforms in 2 hours test and 0 coliforms per 100ml in 2 days for both of the influents (NEROX, 1995). Also, size of E. coli is about 1 to 3µm which 10 times larger than pore size of nano filter. Hence, we can conclude that nano filter can retain coliforms including E. coli.

Pore size of a nano filter ranges from 0.0005µm-0.002µm. The nanofiller used for this study was 0.002µm. the bacterial size ranges approximately from 0.5µm to 50µm. E.coli has least dimension of approximately 1µm. So, this way we can confirm that all the total coliforms including E.coli should be retained by nano filter. However, size of virus ranges from 0.008µm-0.09µm. Though most of the viruses can be retained by nano filter, there was no laboratory test of virus removal.

According to the WHO, the preferred choice to be monitored in drinking water is E. coli. This is because although some coliforms other than E. coli may show presence of faecal pollution but mostly occur from non faecal source (WHO, 2006). Even though there could be seen some coliform bacteria, due to absence of E. coli in all the samples, final effluent quality could be possibly of drinkable quality.

8.4 Total phosphorus and Phosphate

Total phosphorus and orthophosphate were tested in the lab using Systea Analyzer. This test was done only to strengthen the recognition of ammonia in the water since ammonia was higher than expected. Therefore, phosphate was tested to see if there was actual contamination of urine in the greywater. If there would be higher amount of phosphate in the sample of raw greywater along with high level of ammonia, there would have been possibility of urine contamination in the source of greywater. The level of total phosphorus and orthophosphate in greywater source were 1.73 mg/l and 0.76mg/l respectively. These numbers are very low compared to other data such as 9.7 mg/l of total phosphorus and 7.5 mg/l of ortho phosphates (Li et al., 2008) and 17.6 mg/l (Edwin et al., 2014) . This confirmed that there was no contamination of urine in the greywater and ammonia was in high amount because of some other factors. Since the raw greywater had low total phosphorus and constructed wetland has a good efficiency in removal of phosphorus (Jenssen and Vråle, 2003 , total phosphorus were not analyzed for other effluents. Orthophosphates in rest of the effluents were below the detection value of the equipment (0.1 mg/l). Since the wetland system was fairly new (constructed about 2 years ago), so the phosphorus adsorption is supposed to be good in constructed wetland as shown by the lab results.

8.5 Total Nitrogen and Ammonia

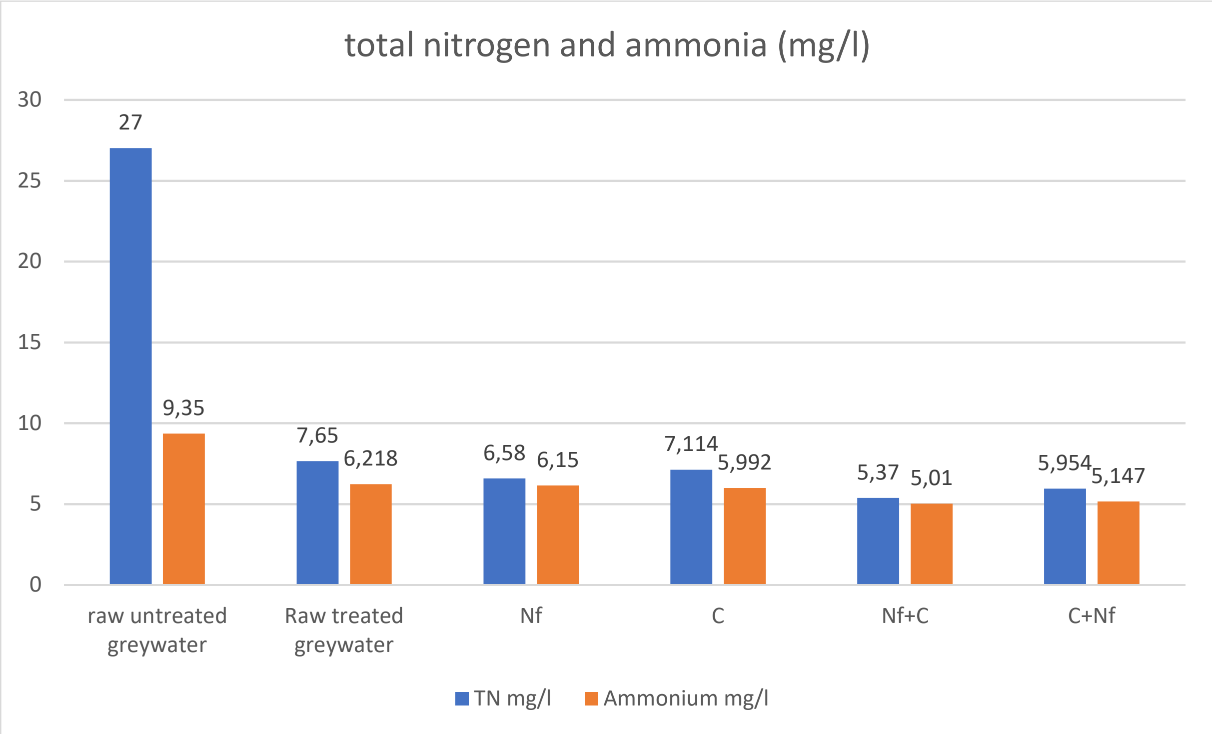


Figure 20: diagram showing concentrations of total nitrogen and ammonia in different effluents

The total nitrogen and ammonia of raw greywater and after each treatment steps can be seen in above figure 20. The untreated raw greywater had total nitrogen of 27 mg/l. Amount of total nitrogen was seen higher compared to some literatures, 0.6-17.6 mg/l (Li et al., 2008, Rose et al., 1991, Edwin et al., 2014). Constructed wetland seems to have a good removal efficiency of nitrogen with a total of 7.65 mg/l, which is however higher than two of the quite similar systems from Klosterenga and Kaja. Vertical flow aerobic bio-filter remove Nitrogen by 38% while constructed wetland removes about 50% (Jenssen and Vråle, 2003). Nitrogen is not much removed as other similar systems in Kaja and Klosterenga. It should have been in range of 2.2 to 2.5 mg/l if the aerobic bio-filter would have been working properly. There was not seen so much of significant nitrogen removal by rest of the tertiary methods. Nano filter reduced total nitrogen to 6.58 mg/l and 7.114 mg/l by carbon filtration alone. It can be seen that neither nano filtration nor carbon filtration had good efficiency in removal of nitrogen with only 14% and 7% respectively. But the nitrogen removal was done with better efficiency by combination of Nano filtration and carbon filtration in different sequence. The effluent of Nano+ carbon filtration had 5.37 mg/l of Nitrogen with treatment efficiency of 30% removal. When the sequence was changed to carbon+ nano filtration, the removal was 22% with 5.954 mg/l in the effluent.

From figure 19, ammonia in the raw greywater was 9.35 mg/l. This value was almost similar to a German research by (Li et al., 2008). Ammonia in the treated raw greywater was recorded as 6.218 mg/l. there was not so significant removal by wetland system and by either of the tertiary fitration methods. There was about 3 mg/l removal of ammonia by aerobic biofilter and constructed wetland even though this is quite higher compared to other similar systems in Kaja and Klosterenga (Jenssen and Vråle, 2003). The septic tank does anaerobic digestion. Because of the anaerobic condition, there could be reduction reaction due to which Nitrates could be converted into ammonia. In an anaerobic condition, substrates that are rich in protein also get hydrolyzed and increase ammonium in liquid phase. That is the reason for amount of ammonia being more in effluent of septic tank than in raw greywater (Assayed et al., 2010). Ammonia is mostly removed in aerobic bio-filter up to 25% while wetland contributes just 4.2% of removal as per (Jenssen and Vråle, 2003). The reason of the high ammonia in the treated raw greywater can be credited to the improper conduct of aerobic bio-filter. Since the pump was not working properly, septic tank effluent could not be sprayed uniformly over the filter media. So, there was low performance of aerobic biofilter and removal of ammonia was hindered. The best treatment was done by combination of Nano filtration and activated carbon filtration. The effluent value of ammonia from Nf+C is 5.01 mg/l of ammonia compared to 6.218 mg/l of raw greywater. Treatment efficiency was about 19.4%. The reverse sequence(C+Nf) had effluent of 5.147 mg/l with 17.22% removal efficiency.

The total nitrates permissible as per WHO is <10 mg/l (WHO, 2011). All the effluents have total nitrogen below 10 mg/l. Even if all the nitrogen has been converted into nitrates, nitrates concentration will stay below the WHO guidelines. Therefore, all the effluents pass the WHO standards regarding total nitrogen and nitrates.

The maximum permissible amount of ammonia according to WHO is 1.5 mg/l and as per Norwegian guidelines is 0.5 mg/l (table 7). When there is higher amount of ammonia in drinking water, problems such as taste and odor and decrease in disinfection efficiency by chlorination can occur. Also, there would be less dissolved oxygen present in the water because most of oxygen will be used up by ammonia for oxidation (WHO, 1996). So the effluents from none of the post treatment units satisfy the drinking water standards in case of ammonia. Even if theoretically we take the effluents from Kaja and Klosterenga and efficiency of ammonia removal from each of above combinations, the results could not meet up the drinking water standards. So ammonia removal is not good enough by any of above combinations. An additional treatment step can be applied in order to remove ammonia. Some of ammonia removal techniques has been discussed in section 5.9

8.6 Turbidity

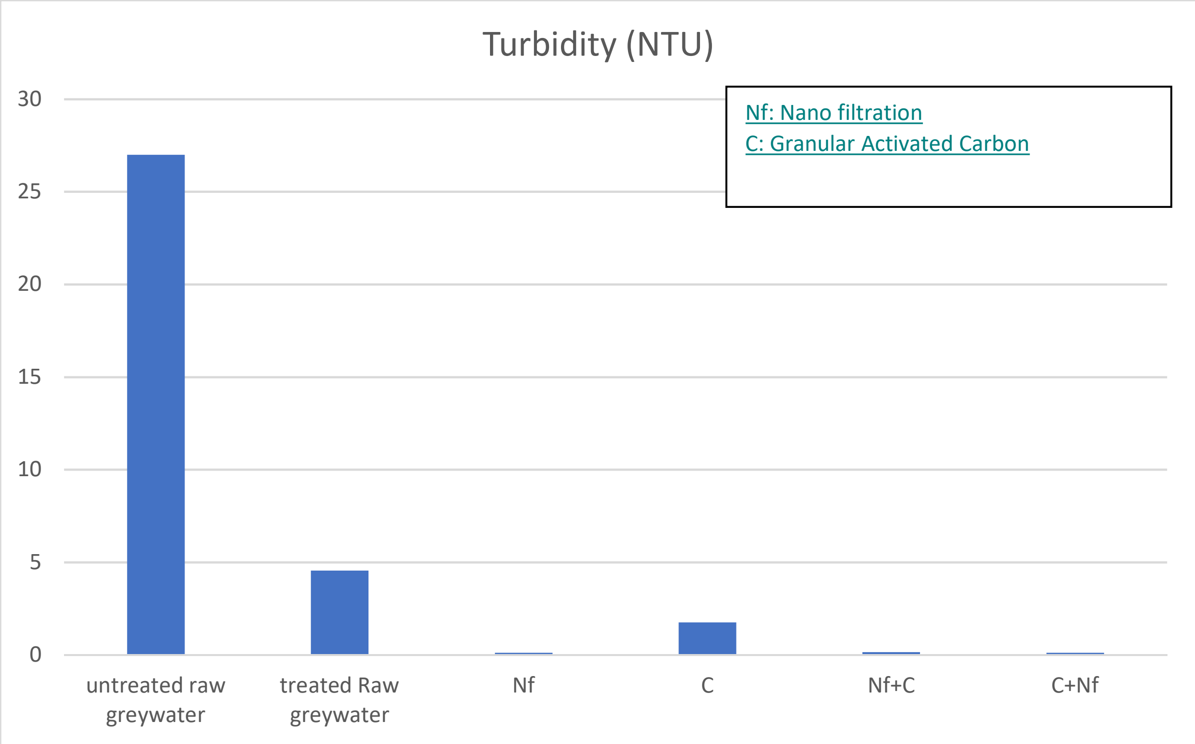


Figure 21: diagram showing turbidity in different effluents

When there is high turbidity in water, it masks the bacteria and makes it difficult in their removal (LeChevallier et al., 1981). High turbidity protects bacteria as well as helps them to encourage their growth (WHO, 1997). This is one of the main reason to reduce turbidity. Turbidity in the raw greywater was 27 NTU (figure 21). This was considerably lower than greywater described in above tables 2, 3 and 4. Turbidity was reduced to 4.55 NTU by constructed wetland system. Turbidity was removed better by Nano filtration than carbon filtration. The effluent of Nano filter had 0.105 NTU turbidity while of carbon filter had 1.75 NTU. Nano+ carbon had slightly higher turbidity than Nano filter alone and carbon+ Nano filtration. This could be because of the micro particles of carbon that is passed along with the treated water from carbon filtration. To reduce this, Granular carbon was washed properly before use but still there might be some particles that might have stayed along. These small particles could be the contributors of the increased turbidity. Except for GAC filtration, other treatment options were able to reach drinking water standards of USEPA, WHO and Norwegian standards (<5, <5, acceptable by consumers but <1 preferable respectively) (EPA, 2018) (WHO, 2011) (Ministry of Health and Care Services, 2016).

So either of combination between GAC and nano filter can be adopted because the difference in turbidity removal is not so much different (0.1 for GAC+ nano and 0.14 NTU for Nano+ GAC) and both come within the WHO drinking water guidelines (WHO, 2011).

8.7 Chemical Oxygen Demand (COD)

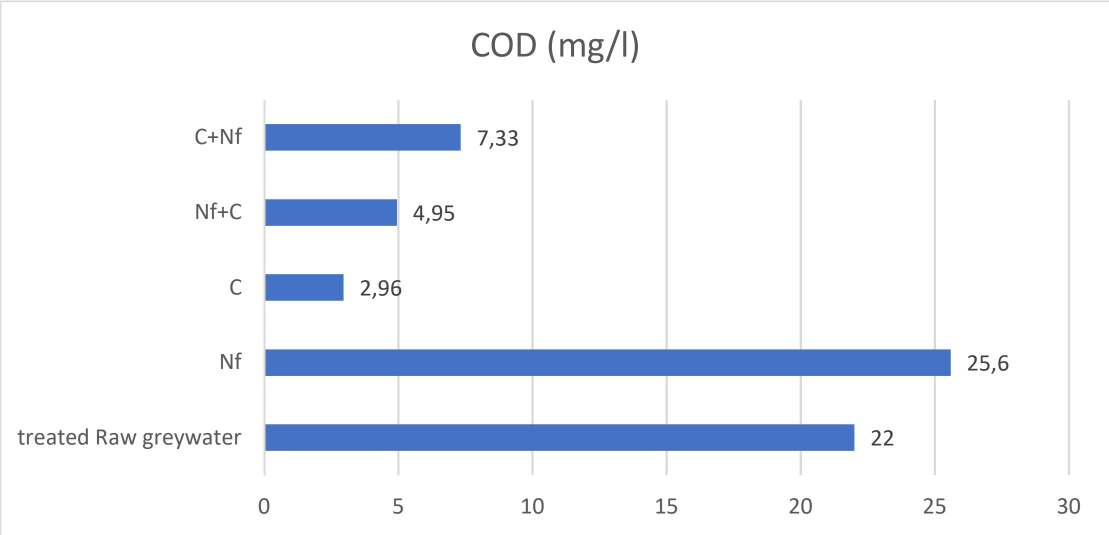


Figure 22: diagram showing concentrations of COD in different effluents

The Chemical Oxygen Demand (COD) is the measurement of chemicals present in water that can consume oxygen to get oxidized (Agrawal, 2009). The low COD in the water reckons that the water has high amount of DO. The high DO in water is good because it makes taste of water better. On the contrary, high DO level might accelerate corrosion on the water supply pipes (LENNTECH, n. d.). When there is increased amount of COD in water, there will be lower amount of Dissolved Oxygen (DO) in the water. So the COD test was performed in order to calculate the amount of organic matter. Greywater from the treatment system had COD measured as 22 mg/l as in figure 22. Since we did not have any samples of raw greywater from Nesodden, we could not quantify the treatment of COD done by Aerobic biofilter and wetland. However concentration of treated raw greywater was quite less than untreated low strength greywater (87 mg/l) and high strength greywater (495 mg/l) as seen in table 3 (Winward et al., 2008). The nano filter used for this study was new and was not washed with distilled water before using it for filtration. So, the surface might have some chemical layer that was washed along which increased the number of COD in nano filtrate but goes down to 2.96 mg/l when treated solely by GAC filter. Nano+ carbon filtration has effluent of 4.95 mg/l and reverse sequence has 7.33 mg/l. Permissible COD in drinking water is 10mg/l (Agrawal, 2009). This concludes that effluents from GAC and both combinations of Nano filter and GAC were clean enough as per WHO for COD.

8.8 pH, Conductivity and Salinity

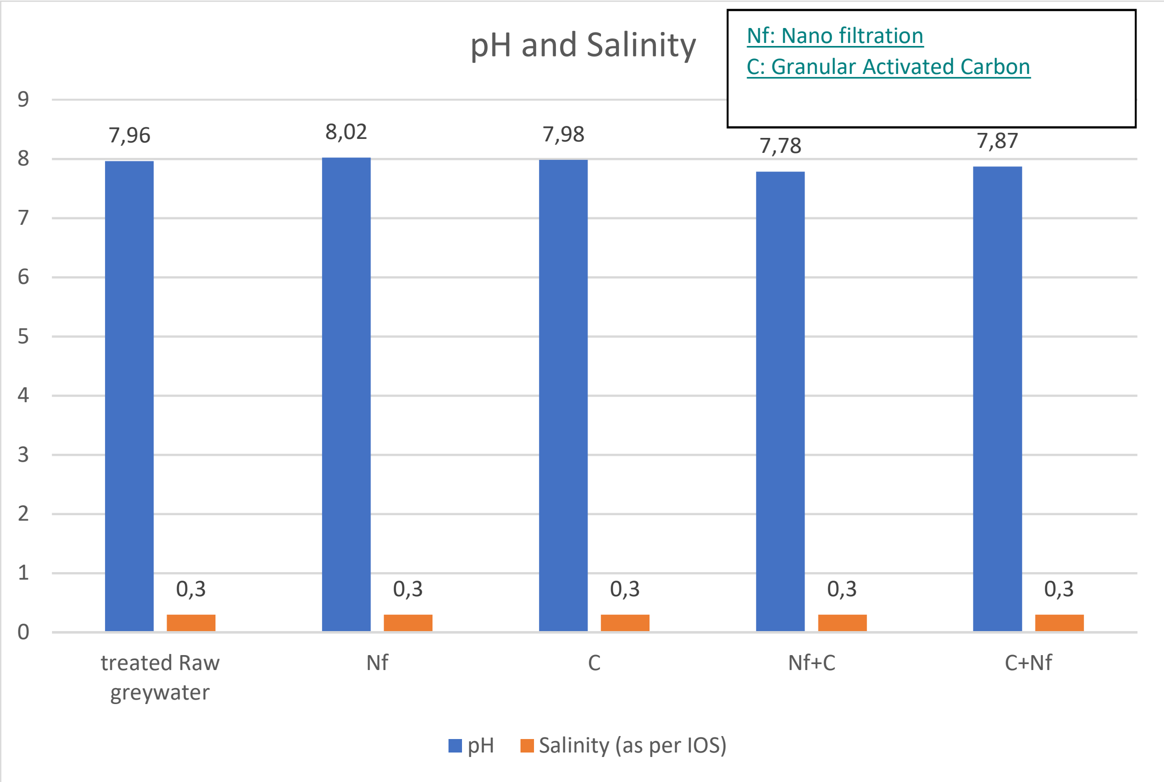


Figure 23: diagram showing pH and salinity in different effluents

Figure 23 shows the chart of pH values of effluents of different post treatment processes. Lower pH (6.5) means the water is acidic and might contain metallic ions that could be toxic in nature while higher pH (>8) means the water is basic and is comparatively hard. Water with higher pH doesn't harm but is aesthetically not suitable (APEC, n. d.). pH in raw greywater was 7.96. There not a huge deviation in the pH value in any of the steps. It could be because of no chemical reactions occurring in any of the steps. Since all the pH value lie near to the neutral value (7), there is no necessity of adjusting pH. The pH was within the range of drinking water standards 6.5-8.5. So, all the effluents pass drinking water quality.

Salinity in water measures the amount of salt present in the water. The salinity was constant for all the samples at 0.3 as shown in figure 23.

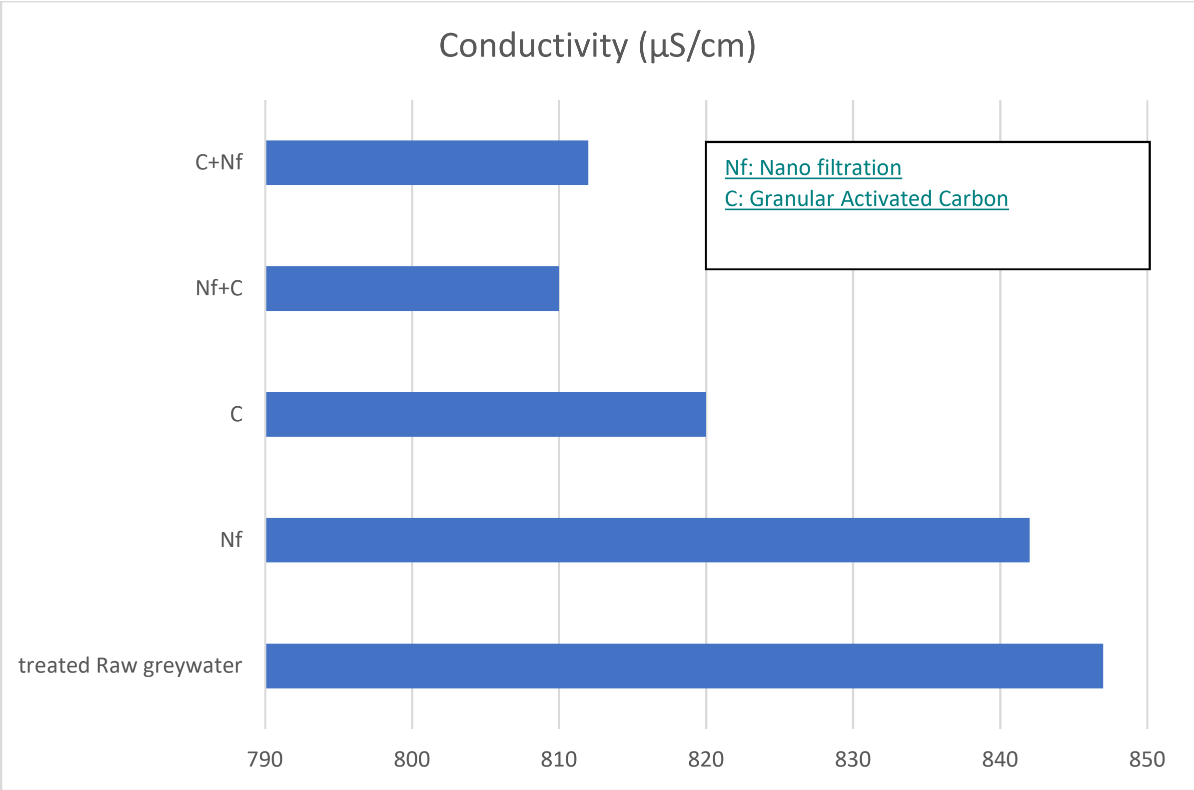


Figure 24: diagram showing conductivity in different effluents

Conductivity is the measure of capability of water to pass current. This value directly depends upon ions present in the water. Higher the ions, higher the conductivity. The conductivity of the samples ranges from 847-810 µS/cm with highest value being of treated raw greywater and lowest value of Nano+ carbon filtration as in figure 24. There is not so much change in conductivity in Nano filtrate. This establishes the fact that both Nano-filter and activated carbon did not retain any ions from the water. The conductivity of salt water is 50000 µS/cm while conductivity of drinking water and ultra-pure water are 50-500 µS/cm and 0.055µS/cm respectively (LENNTECH, n.d.). All the water comes near to the upper range of drinking water category.

8.9 Ammonia removal methods

We can see that the best ammonia removal in the whole post treatment system was by combination of nano filtration and granular activated carbon with effluent of 5.01 mg/l ammonia. Even this number does not satisfy the WHO standards of drinking water. So removal of ammonia seems to be necessary. Some of the ammonia removal techniques are described below:

8.9.2 Ammonia removal by use of natural zeolite

As a solution for removal of ammonia, natural zeolite can be used. Zeolites are aluminosilicate minerals. Zeolites have ammonia removal efficiency up to 97%. This value depends upon various factors like contact time, zeolite loading, initial ammonium concentration and pH. The optimum removal of ammonia could be at 100min of contact time, increases with increasing zeolite loading but reaches equilibrium after certain point. The optimum removal can be attained at pH 4-6 in acidic conditions, but it drops to 40-35% removal in pH 6-8. One of the interesting point is ammonium removal efficiency increases with increased initial ammonia concentration (Widiastuti et al., 2011). (Demir et al., 2002) confirmed that as there is increase in initial concentration of ammonium, there is increase in driving force for absorption of ammonia.

8.9.3 Ammonia removal by sand filtration

Sand filtration could also be an option for removal of ammonia in order to reach drinking water standards. (Langenbach et al., 2010) made a research on how ammonia can be oxidized in a sand filter with the help of nitrifying bacteria. The mean ammonia removal efficiency of this filter was 60%. Ammonia nitrifying bacteria (nitrosomonas) were well established in the filters within 38 days. It was also brought to light that the intermittent time between the hydraulic loadings could be vital in providing necessary air for the growth of nitrifying bacteria. So sand filtration could be adopted on our system.

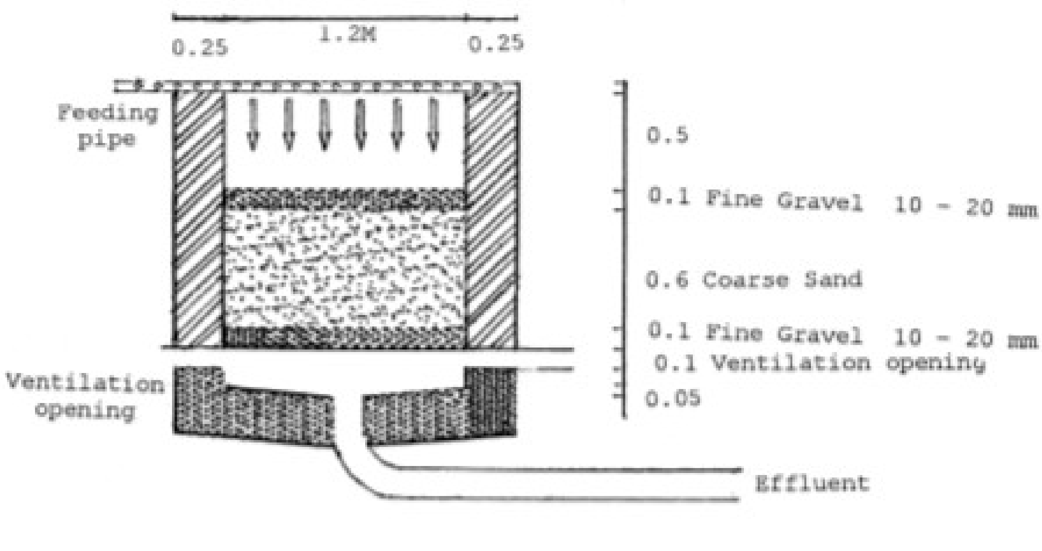


Figure 25: treatment of ammonia by filtration method (Langenbach et al., 2010)

Since the effluent from the greywater does not have huge amount of suspended solids, this sand filter can be projected right after the constructed wetland. This can also increase the efficiency of Nano filter since the hydraulic loading will not have much pollution. Figure 25 shows the typical sand filtration and its constituents.Another research by (Haug and McCarty, 1972) shows a nitrification process by submerged sand filter which was done after methane fermentation. The wastewater was passed in the anti- gravity direction. Since the filter is submerged, it captures all the biological mass which consequently provides control over hydraulic detention time. This makes it possible to apply this system even in cold climates. The ammonia removal was function of temperature and hydraulic detention time. For a certain degree of treatment, the hydraulic detention time would increase when there was decrease in

Table 25: table showing removal of ammonia by submerged sand-filter in various temperatures and detention time (Haug and McCarty, 1972)

Temperature (° C)*	Detention Time (min)†	NH_3-N (mg/l)	
		Influent	Effluent
25	7.5	7.9–8.1	2.1–3.0
		4.2	1.1
	15	7.8–8.1	1.4–2.2
		5.8–6.4	0.6–0.8
		3.9	0.8
	30	7.7	0.4
15	15	9.2–10.6	1.0–1.7
		5.0	0.3
		2.5	0.2
	30	9.8–10.0	0.8–1.0
10	15	9.2–10.4	2.5–3.3
	30	10.0–10.2	1.0–1.7
		5.7	0.4
		3.5	0.1
5	30	9.2–10.2	3.3–3.4
	60	12.0–12.4	2.9–3.3
		6.6	1.2
		3.2	0.5
	120	11.9–12.0	0.9–1.0
1	120	10.6–12.2	0.9–1.0
		13.7–14.0	1.9–2.2

temperature. From the table 25, Ammonia removal at 25°C with 30 min detention time was almost 95%. Almost this efficiency was achieved in 120 minutes at temperature of 1C. Ammonia was more oxidized at the bottom of the tank where it had higher amount of ammonia concentration than at higher levels of the tank. Nitrite concentration was almost same all over the column. Total nitrogen was constant in the filter since there was no sinks or exits for the nitrogen. If such method is to be applied, it should be right after wetland because if the concentration of ammonia is less than 1-2 mg/l, it might require longer detention time. It was also found that this system is stable at 1C but the temperature of treated greywater is much higher than that. So further study will be required to understand the applicability of this system.

8.9.4 Ammonia removal by distillation

Ammonia can be removed by distillation process. Distillation has been come to focus because of its low energy consumption (Xie et al., 2009). Distillation process can be done at point of use. There are various membrane distillation process like direct contact, air gap, sweep gas and vacuum membrane distillation (Xie et al., 2009). Direct contact membrane distillation (DCMD) had ammonia removal efficiency of 52% while Hollow fiber membrane contactors had 88% and modified DCMD had 92% of ammonia removal (Ashoor et al., 2016). According to (El-Bourawi et al., 2007), increasing pH has positive effect in removal of ammonia and vacuum membrane distillation was able to remove 90% of ammonia. About 97% of ammonia removal can be achieved by sweep gas membrane distillation (Xie et al., 2009). Along with ammonia treatment, membrane distillation comes with limitations such as low distillation and membrane pore wetting (Shirazi et al., 2015). Therefore more extensive study has to be carried out in order to implement in required scale.

Apart from these methods, there are some other conventional methods like aeration or chlorination (Chiayvareesajja and Boyd, 1993, Pressley et al., 1972, Zhang et al., 2015). In chlorination, ammonia is treated chemically but the by-product chloramines again with be necessary to be dealt with.

8.10 Selection of combinations

Table 26: two sequences of GAC and nano filtration adapted in the lab

Parameters	Sequence: 1 (Nf+C)	Sequence: 2 (C+Nf)
E.coli	<1	<1
COD	4.95	7.33
Turbidity	0.14	0.1
TN	5.37	5.954
Ammonium	5.01	5.147
pH	7.78	7.87
Total bacteria	>2419	7.87
Phosphate	ND	ND
Salinity	0.3	0.3
Conductivity	810	812

As seen in table 26, removal of E. coli and turbidity are almost similar. COD, total nitrogen and ammonia are removed better by sequence 1. However, reverse sequence is better in removing total bacteria since nano filter can retain bacteria coming from externally contaminated GAC. If GAC can be sterilized and avoid possible external contaminations to reduce the number of total coliforms, sequence 1 seems to outperform sequence 2.

Figure 26 shows nano filter used before GAC (left) and nano filter used after GAC filter (right). When GAC column was used before nano filter, sludge as seen in figure 26 can be avoided. Henceforth, life span of nano filter will be extended. This is important in economic point of view since nano filter membrane usually costs more than activated carbon. This could be one important factor to determine the sequence of nano filter and GAC.

Figure 26: nano filter used before GAC (left) and nano filter used after GAC (right)

Since to remove ammonia to reach drinking water standard a step such as sandfilter is required as discussed in section 5.9, this can be added right after wetland. This will not only remove ammonia but also help in increasing the efficiency nano filtration and carbon filtration. Nevertheless, sand filter if used as final step, it might compensate the pollutants that has not been removed by GAC filter or microparticles of carbon that is coming out of GAC. Following two combinations can be proposed:

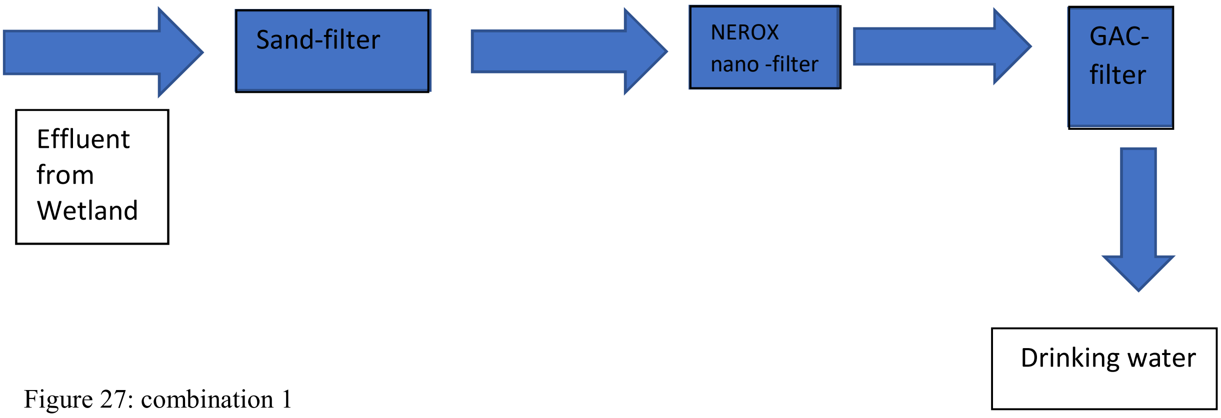


Figure 27: combination 1

Combination 1 has sand filter before nano and GAC filter. This combination has good effect on keeping nano filter clean and prolonging its age. However GAC is at the last step which if not sterilized properly, there could be some contaminations in the final effluent as it occurred during the lab experiments.

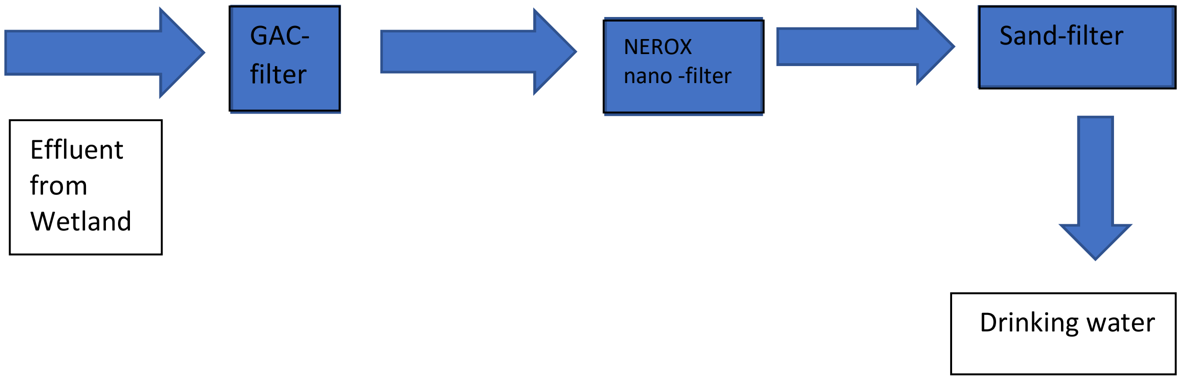


Figure 28: combination 2

Combination 2 has sand filter at the end of the sequence. This combination keeps nano filter clean since GAC filter is used before nano filter. In addition sand filter is kept at the last step to retain all the remaining impurities from GAC+ nano filter along with its main purpose to remove ammonia. The effluent of nano filter might have less total dissolved solids than it should have been (Mallevialle and Suffet, 1981). Due to which, there could be demineralization of water. Sand filter at the end can be beneficial in this case. Necessary minerals can be added to the sand for mineralization of the final effluent.

Though both combination focus on prolonged lifespan of nano filter to make system economically sustainable without compromising the final effluent water quality, a further study will be required to determine the most practical combination out of above two possible combinations.

9. Conclusion and recommendations

Following conclusions can be made on the basis of literature review:

Greywater consists of 60-80% of total water consumption but could be more than 90% if water saving or vacuum toilet is preferred. Greywater has a higher amount of volume than rest of the black water but with less amount of nutrients (compared to wastewater including blackwater). So, it is easier to recycle that collective wastewater. Many Chemical, physical, biological, onsite treatment systems, and natural greywater treatment systems have been discovered. Most of these treatments of greywater are done for reusing in non-potable purposes such as irrigation, toilet flushing or using water for natural landscape recreational aspects. Even in recent decades, for various purposes like landscape irrigation and toilet flushing, greywater is being reused without treatment. Greywater includes about 50% of total organic matter in the waste water. There could be risk of pathogens coming out of kitchen sink, bath and showers or possible faecal contamination by washing diapers or anal cleansing. Although any system that has good removal of BOD and ammonia has good removal of PPCPs, it could be still an issue if the treated water is to be used as drinking water. Along with PPCPs, taste and odor (T&O) are also one of the major components to be removed because taste and odor in water discourages people to drink the water even though it is totally harmless.

Following conclusions can be made on the basis of experiments done :

This study shows that constructed wetland has good treatment efficiency over E. coli. Some total coliforms were found in effluent of constructed wetland. These could be previously present coliforms in the soil of wetland and later could be transported by greywater. Since treated raw greywater had E. coli less than one and satisfy WHO standards, further post treatments were done without focusing in removal of E. coli. COD removal was better removed by GAC while nano filtration had better action on removing turbidity. Though least COD was obtained in GAC filter 2.94 mg/l, all the effluents had COD below drinking water standards. Constructed wetland effluent had almost drinking water quality regarding turbidity and total nitrogen but was not so effective when ammonia is taken into consideration. The reason for higher ammonia in the treated greywater could be because of fault in the pump supplying septic tank effluent uniformly over aerobic biofilter. This made the system anaerobic decreasing the ammonia removal.

Removal of E. coli by nano filtration and/or Granular Activated Carbon could not be quantified because treated raw greywater had E. coli already less than one. Total coliforms were nullified by Nano filtration. Number of coliforms increased when activated carbon was used. This was because of previously present contamination in the tubes that were used for GAC. COD increased in number when using Nano filter because the filter we used was a new one so there was chemical coating on the surface of the filter. This chemical was washed along to the effluent thus increasing the level of COD. Activated carbon on the other hand seems to have good treatment over COD. Activated carbon alone was able to remove COD to reach drinking water standard. Both the nano filter and carbon filter were able to reduce turbidity less than what is required for WHO drinking water quality. To compare, carbon filter did not remove turbidity as nano filter because activated carbon might have released some micro particles to add turbidity. There was no significant removal of total nitrogen by nano filter or the activated carbon filter even though the amount of nitrogen was less than WHO standard value. Similarly, ammonia is also not removed in significant amount by either of the filters. Neither of the filters were able to reduce ammonia to drinking water standards. Total phosphorus and phosphates were examined to see if there was urine contamination in the greywater since there was high amount of ammonia. Since phosphate was less than 0.1 mg/l, it was confirmed that there was no urine contamination. pH was within the range of 7-8.5 within WHO standards of drinking water. Salinity was not changed by either of the two filters. There was no removal or retaining of ions resulting not so deviation in conductivity of water. One of the main difference seen were colour and odour of the water. Nano filtration alone could not remove odour and colour in required amount while activated carbon could produce effluent that was almost clear as tap water and had no odour.

When nano filter was used before carbon, coliform was more than >2419 MPN per 100 ml. This was because of contamination in the tubes containing carbon filter. Reverse combination should have null total coliforms but because of possible contamination during sampling, the number was raised to 8. COD, total nitrogen and ammonia removal was better done by Nano+ GAC than GAC+ nano filter. However GAC+ nano filter was better in removing turbidity and total coliforms. Both of the sequence were able to meet WHO drinking water standards except for ammonia. So sand filtration is recommended for removal of ammonia. it was also established that if nano filter is used directly after wetland system, the life expectancy of nano filter would downgrade because of sludge accumulation on the surface. So in order to increase the life expectancy of nano filter without compromising the quality of final effluent, nano filter should not be used directly after wetland; either after activated carbon filter or as sand filter has been recommended, nano filter can be used after sand filter.

In conclusion, combination of nano filter and granular activated carbon (GAC) can produce drinking water from greywater when used as post treatment after constructed wetland. In addition, sand-filter should be adopted along with nano filter and GAC in order to remove ammonia up to desired level of WHO drinking water standard.

It is recommended that the activated carbon and tubes holding activated carbon should be sterilized properly to avoid errors. COD in nano filter was more than raw treated greywater. So nano filter should be first washed with distilled water to remove chemical coating. Only analysing coliform bacteria is not sufficient. Therefore, virus also should be analysed. PPCPs and taste of final effluent were not analysed in this study which should be examined to insure the water is safe to drink.

10. Further Study

As stated in section 6.10, along with other major pollutants removal of PPCPs and taste and odor should also be necessarily removed. Though GAC is known to remove these compounds, these tests were not tested in the lab. So, further study is required to recognize the degree of removal of these compounds. Ammonia was not removed in desirable amount. To remove ammonia, sand-filter has been suggested as in section 8.9 and section 8.10. Therefore, to understand the compatibility and applicability of sand-filter with Nano filter and GAC, a positioning and temporal study is necessary. This study is done focusing on water scarce areas such as dry and arid areas. These areas might have different greywater compositions compared to greywater used for this study. So an experiment is required for treating greywater from such areas.

References

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Appendix

Appendix A

Table A- 1: various biological treatment processes of greywater (Li, Wichmann, & Otterpohl, 2009

Reference	Process	TSS (mg/l)		Turbidity (NTU)		COD (mg/l)		BOD (mg/l)		TN (mg/l)		TP (mg/l)		Total coliform (cfu/100 ml)		Faecal coliform (cfu/100 ml)	
		In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out
Nolde (1999)	Sedimentation + RBC + UV disinfection	–	–	–	–	100–430	–	50–250 BOD_7	<5 BOD_7 V	5–10	–	0.2–0.6	–	10^4–10^8	<10^3	10–10^8	< 10^2 V
Nolde (1999)	Fuidized-bed reactor + UV disinfection	–	–	–	–	113–633	–	70–300 BOD_7	<5 BOD_7 V	–	–	–	–	10^3–10^5	<10^4	10–10^3	< 10^3 V
Friedler et al. (2005)	Screen + RBC + sand filtration filtration + chlorination	43	7.9 V	33	0.61 V	158	40	59	2.3 V	–	–	4.8	2	–	–	5.6×10^5	0.1 V
Liu et al. (2005)	MBR	–	ND V	–	–	130–322	18	99–221	<5 V	–	–	–	–	–	–	–	ND V
Lesjean and Gnirss (2006)	MBR		<1 V			493	24			21*	10*	7.4	3.5				
Merz et al. (2007)	MBR	–	–	29	0.5 V	109	15	59	4 V	15.2	5.7	1.6	1.3	–	–	1.4×10^5	68 V
Elmitwalli et al. (2007)	UASB	–	–	–	–	681	469.9	–	–	27.1[&]	20.6[&]	9.9	7.5	–	–	–	–
		–	–	–	–	647	381.7	–	–	27.1[&]	20.6[&]	9.7	7.6	–	–	–	–
		–	–	–	–	682	456.9	–	–	27.3[&]	24.0[&]	9.9	8.9	–	–	–	–
Gross et al. (2007)	Constructed wetland	158	3 V	–	–	839	157	466	0.7 V	34.3	10.8	22.8	6.6	–	–	5X 10^7	2 X 10^5 X
Hernandez et al. (2008)	SBR, SRT = 378 d HRT = 5.9 h	–	–	–	–	827	100	–	–	29.9	26.5	8.5	5.8	–	–	–	–

*: TN was calculated as the summation of TKN and NO_3–N.
&: TKN.
V: Meet the reuse guideline.
X: Fail to meet the reuse guideline.

Appendix B

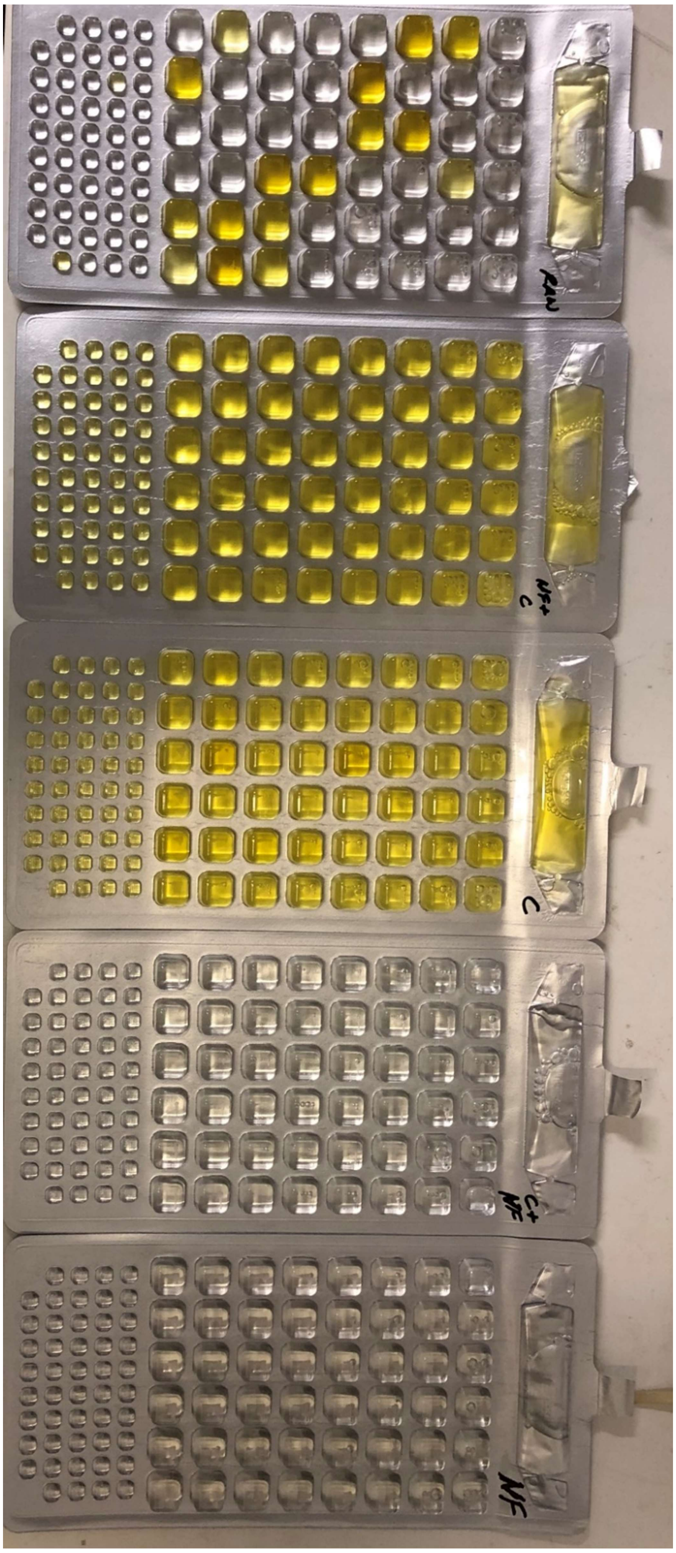

figure B- 1: samples of raw treated greywater, nano+GAC filtrate, GAC filtrate, GAC+nano filtrate and nano filtrate in Colilert 18/Quanti-trays 2000 after keeping them at 32°C for 18 hours

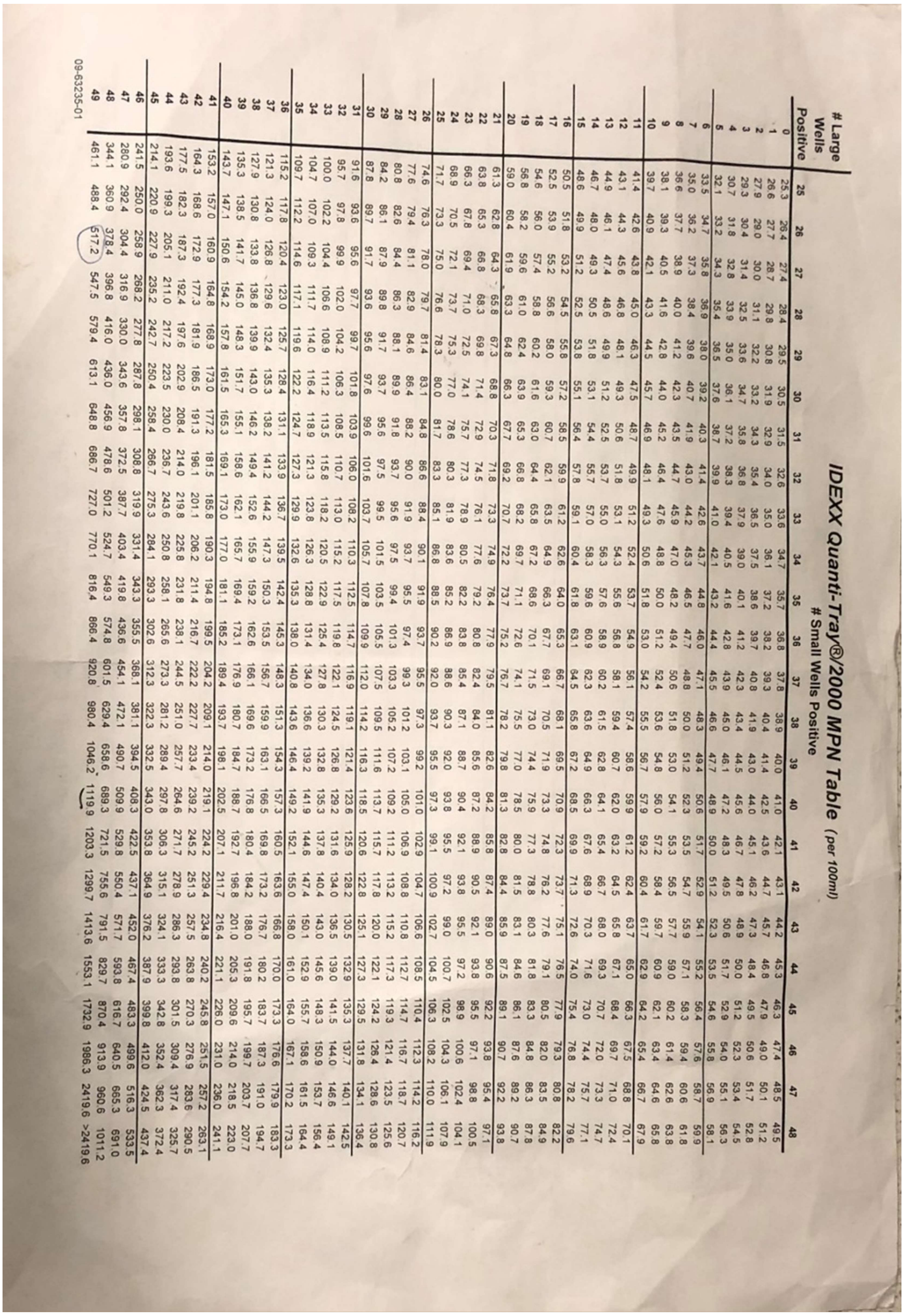

figure B- 2: MPN chart used to determine the most probable number of coliforms

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