ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

CHARACTERIZATION AND ANALYSIS OF WEAK URBAN GREY WATER

M.Sc. THESIS

Esra GİRESUNLU

Department of Environmental Engineering

Environmental Sciences and Engineering Program

Thesis Advisor: Prof. Dr. Ayşe Bilsen BELER BAYKAL
Anabilim Dalı : Herhangi Mühendislik, Bilim
Programı : Herhangi Program

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ZAYIF NİTELİKLİ KENTSEL GRİ SUYUN KARAKTERİZASYONU VE ANALİZİ

YÜKSEK LİSANS TEZİ

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OCAK 2015

Esra Giresunlu, an **M.Sc.** student of ITU **Graduate School of Science Technology and Engineering** student ID **501121712**, successfully defended the **thesis** entitled "**CHARACTERIZATION AND ANALYSIS OF WEAK URBAN GREY WATER**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 15 December 2015
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To my mother and father,

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January 2015 Esra GİRESUNLU

(BS Environmental Engineer)

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ABBREVIATIONS

BOD	**:** Biochemical Oxygen Demand
COD	**:** Chemical Oxygen Demand
EPA	**:** Environmental Protection Agency
MBR	**:** Membrane Bioreactor
sBOD	**:** soluble Biochemical Oxygen Demand
sCOD	**:** soluble Chemical Oxygen Demand
TKN	**:** Total Kjeldahl Nitrogen
TP	**:** Total Phosphorus
TSS	**:** Total Suspended Solids
VSS	**:** Volatile Suspended Solids
WHO	**:** World Health Organisation

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CHARACTERIZATION AND ANALYSIS OF WEAK URBAN GREY WATER

SUMMARY

World population is about 7.5 billion today and according to the estimations of UNDP, about 31% of this population will be added to existing population in less than 40 years. Inadequacy of natural sources and disability of meeting needs of rising population are two main problems that the world is already facing today. Water is one of those basic needs, however 1.1 billion people have no access to safe water at this time. As a result, sustainable use of available sources is gaining importance everyday, as sustainability will lead to ability of using the same sources for longer periods.

Today, domestic wastewater is considered as one of the most popular water source after being treated properly. On the other hand, new domestic wastewater management concenpts are being proposed to be able to use domestic wastewater in the most efficient way. One of those management concenpts, segregation of domestic wastewater streams, can generally be done in two ways as two (grey water/black water) and three (grey water/yellow water/brown water) components, also known as EcoSan (Ecological Sanitation) streams. Grey water is the stream including the water generated from baths, showers, wash basins, washing machines, sinks and dish washers and other streams are generated from toilets. In both segregation applications, grey water stream will stay similar in terms of quantity and quality.

Grey water itself can be segregated into two fractions as light grey water and dark grey water. Light grey water fraction refers to grey water generated from bath/shower and wash basins, while washing machine, sink and dish washer grey water are called dark grey water. Light grey water fraction has lower pollution potential and can be treated easier as compated to dark grey water.

Grey water is considered as a valuable water source as it constitutes about 75% of total conventional domestic wastewater volume with lower pollution potential compared to conventional domestic wastewater volume. Due to its high volume and lower pollution potential, grey water is an attractive water source. Grey water is generally reused for irrigation and toilet flushing at this time, on the other hand it is a source that can be returned to almost any point of the water cycle after treated properly.

In this study, a year-round monitoring was done to characterize raw hotel grey water countinuously and systematically. Additionally, a university student residence hall grey water was sampled and analyzed when possible. Both buildings were collecting grey water from bath/showers and wash basins. Effluents of membrane bioreactors (MBR) employed for grey water reclamation in those buildings were monitored. During analyses, organic matter, suspended solids, nitrogen and phosphorus concentrations were investigated.

In hotel, microbiological analyses were carried out to observe the change in microbiological quality in grey water cycle. Also in toilet reservoir of one of the guest rooms where the grey water is reused, microbiological analyses were done to control possible regrowth of microbiological indicators. In student residence hall, microbiological analyses were carried out with raw grey water and treated grey water. Indicators analyzed were Total Coliforms, Fecal Coliforms, Escherichia Coli and Enterococci.

In addition to those, in the light of the data generated in this work, the importance of physicochemical treatment of grey water was comprehended and preliminary treatment trials with sand filtration and membrane filtration were carried out. Also, as one of the major reuse areas of grey water is irrigation, preliminary plant trials were carried out with pepper seedlings.

The results of this study revealed that even if the sources of grey water were the same in buildings that were monitored, grey water characteristics were not similar. Grey water generated from the hotel had lower pollution potential compared to grey water generated from the university student residence hall. On the other hand, grey water analyzed had lower pollution potential compared to weak conventional domestic wastewater. Year-long monitoring results of hotel grey water did not show a trend based on the seasonal factors. Also, no trend was observed in grey water quality in different days of the week. Apart from physical and chemical parameters investigated, the microbiological indicator concentrations were high in raw grey water and those concentrations were comparable to weak and intermediate strength conventional domestic wastewater sometimes, which makes monitoring of microbiological indicators a priority for grey water management.

Average effluent quality of MBRs treating grey water met the requirements of water reuse standards all around the world. Even though the microbiological indicator concentrations were high in raw grey water, once grey water generated from the hotel and the university student residence hall were treated by MBRs properly, the effluents were free of those indicators.

Results of preliminary physical treatment trials revealed that success of those systems investigated were highly dependent on the raw grey water characteristics. Particulate organic matter removal efficiencies of sand filtration and membrane filtration increased with decreasing sCOD/COD and $sBOD_5/BOD_5$ ratios, as the decrease in these ratios indicate high particulate organic matter content.

Preliminary plant trials on pepper seedlings revealed that grey water was at least as successful as tap water for irrigation.

ZAYIF NİTELİKLİ KENTSEL GRİ SUYUN KARAKTERİZASYONU VE ANALİZİ

ÖZET

Birleşmiş Milletler Kalkınma Programı projeksiyonlarına göre bugün yaklaşık olarak 7,5 milyar olan dünya nüfusuna, 40 sene içinde bu nüfusun yaklaşık %31'i daha eklenecek ve dünya nüfusu 10 milyar kişiye yaklaşacaktır. Nüfustaki bu artış göz önünde bulundurulduğunda, dünyanın karşı karşıya olduğu en temel sorunlardan başlıcaları doğal kaynakların yetersizliği ve artan nüfusun ihtiyaçlarını karşılamaktaki zorluklardır. Su, bu ihtiyaçların en başında gelmesine ragmen günümüzde bile 1,1 milyar insan sağlıklı içme suyu kaynaklarına ulaşamamaktadır. Sonuç olarak varolan kaynakların daha uzun süreler boyunca daha fazla insan tarafından kullanılabilmesi için kaynakların sürdürülebilir bir yaklaşımla kullanımı gün geçtikçe daha çok önem kazanmaktadır.

Günümüzün en popüler su kaynaklarından biri konvansiyonel evsel atıksular olarak görülmektedir. Diğer yandan, evsel atıksuların daha verimli bir şekilde yeniden kullanılmasını öngören atıksu yönetim alternatifleri üretilmektedir. Bunlardan biri evsel atıksularda akım ayırımı uygulamasıdır. Akım ayımı genellikle gri su/siyah su olmak üzere iki ya da EcoSan akımları olarak da bilinen gri su/sarı su/kahverengi su olmak üzere üç akım oluşturulacak şekilde iki farklı yöntemle yapılabilmektedir. Bu akımlardan gri su, evsel atıksuların tuvalet atıksuları dışında kalan duş/banyo, lavabo, çamaşır makinesi, eviye ve bulaşık makinesinden gelen suların tümünün beraber ya da farklı kombinasyonlar ile toplanması ile oluşmaktadır. Her iki akım ayırımı uygulamasında da oluşan gri su miktar ve kalitesi benzer olmaktadır.

Gri su, konvansiyonel evsel atıksu hacminin %75'ini oluşturmaktadır. Bunun yanında evsel atıksuya kıyasla daha az kirlilik yüküne sahip olması sebebi ile gri su değerli bir yenilenebilir su kaynağı olarak görülmektedir. Günümüzde gri su genellikle sulama amaçlı ve sifon suyu olarak kullanılmaktadır. Ancak bu değerli kaynağın ihtiyaçlar doğrultusunda arıtıldıktan sonra su çevriminin hemen hemen her noktasına döndürülmesi mümkün olarak görülmektedir. Bu da gri suyu daha da önemli bir kaynak haline getirmektedir.

Gri su kendi içinde de zayıf gri su ve kuvvetli gri su olmak üzere iki farklı fraksiyona ayrılabilmektedir. Zayıf gri su duş/banyo ve lavabolardan gelen gri suların beraber toplanması ile oluşan gri sui ken, kuvvetli gri su çamaşır makinesi, eviye ve bulaşık makinesinden kaynaklanan gri suları temsil etmektedir. Zayıf nitelikli gri su kuvvetli gri suya göre daha düşük kirlilik potansiyeline sahip olup yine kuvvetli gri suya göre daha kolay arıtılabilmektedir.

Bu çalışmada bir kent otelinden kaynaklanan gri suyun karakteristiklerinin, bir yıl süren devamlı ve sistematik bir izleme ile belirlenmesi hedeflenmiştir. Bunun yanı sıra mümkün oldukça, üniversite öğrencilerine hizmet vermekte olan bir yurt binasından kaynaklanan gri suyun numuneleme ve analizleri de yapılmıştır. İki çalışma alanında da gri su, duş/banyo ve lavabolardan toplanmaktadır. Bu binalarda

gri su arıtımı için membrane biyoreaktörler (MBR) kullanılmakta olup, MBR çıkışındaki arıtılmış gri su kalitesi de ham gri su kalitesine paralel olacak şekilde takip edilmiştir. Takip esnasında organik madde, askıda katı madde, azot ve fosfor konsantrasyonları ölçülmüştür.

Otelde, gri su döngüsündeki mikrobiyolojik kalite değişimini gözlemlemek üzere mikrobiyolojik analizler yapılmıştır. Bunun yanı sıra rezervuarı arıtılmış gri su ile doldurulan odalardan birinin sifonundan alınan numunelerle mikrobiyolojik aktivite oluşup oluşmadığı takip edilmiştir. Yurt binasında da mikrobiyolojik analizler, hem ham gri su kalitesi, hem de arıtılmış gri su kalitesinin ortaya konması için arıtma giriş ve çıkışında takip edilmiştir. Mikrobiyolojik analizler Toplam Koliform, Fekal Koliform, Escherichia Koli ve Enterokok indikatörleri ile yapılmıştır.

Bunların yanı sıra, çalışma esnasında üretilen veriler, gri su arıtımında fizikokimyasal proseslerin de başarılı olabaileceği çıkarımı yapılmıştır. Bu çıkarım doğrultusunda kum filtresi ve membran filtrasyon ön çalışmaları tamamlanmıştır. Gri suyun sulama suyu olarak kullanılmasının yaygın olmasından yola çıkılarak, arıtılmış gri suyun biber fideleri üzerinde sulama suyu olarak kullanıldığı ön bitki deneyleri tamamlanmıştır.

Çalışma sonucunda, toplanan gri su fraksiyonları aynı olsa da, otel ve yurt binalarındaki gri su karakteristiklerinin birbirinden farklı olduğu gözlenmiştir. Otelden toplanan gri su, üniversite öğrencileri tarafından kullanılmakta olan yurttan elde edilen gri suya göre daha az kirlilik yüküne sahiptir. Diğer yandan, takip edilen iki gri su kaynağının durumunun da zayıf nitelikli evsel atıksu kalitesinden daha iyi olduğu saptanmıştır. Otelde sene boyunca izlenen gri su kalitesinin mevsimler içindeki değişimi incelendiğinde, mevsim koşullarına bağlı olduğu gözlenen bir durumun ortaya çıkmadığı tespit edilmiştir. Bunun dışında, ham gri suyun haftanın hangi gününde daha fazla kirlilik yüküne sahip olduğuna dair bir çıkarım yapılamamıştır.

İzlenen fiziksel ve kimyasal parametrelerin yanısıra, ham gri sudaki mikrobiyolojik indicator konsantrasyonları yüksek olarak bulunmuştur. Bu konsantrasyonlar zayıf ve orta kuvvetli konvansiyonel evsel atıksu kalitesi ile benzerlik gösterdiğinden gri su yönetiminde mikrobiyolojik indikatörlerin takip edilmesinin önemli olduğu sonucuna varılmıştır. Ayrıca gri suda mikrobiyolojik indikatörlerin takibinin de en az organik madde kadar önemli olduğu sonucuna varılmış ve gri su geri kazanımında mikrobiyolojik indikatörlerin birincil parametre olarak izlenmesi gerektiği gözlenmiştir.

İzleme yapılan iki binada gri su arıtımı amacı ile kullanılan MBRların çıkış suyu kalitelerinin ortalama değerleri, dünya çapında su geri kazanımı için yayınlanmış olan su kalite standart ve kılavuzlarına uygunluk göstermektedir. Ham gri sudaki yüksek mikrobiyolojik indikatör konsantrasyonlarına rağmen, otel ve yurtta takip edilen MBR çıkışlarındaki arıtılmış gri su örneklerinde mikrobiyolojik indikatörlerden hiçbirine rastlanmamıştır. Buna göre arıtılmış gri suyun, düzgün şekilde arıtıldığı taktirde çok önemli bir su kaynağı olduğu bilgisi doğrulanmış, dünyada yayınlanmış standart ve yönergelere göre gereken hemen her alanda kullanımının uygun olduğu sonucuna varılmıştır.

Gri suyun fiziksel yollarla arıtılması konusunda yapılan ön çalışmalara göre, denenen arıtma sistemlerinin performanslarının ham gri su kalitesine bağlı olarak değiştiği saptanmıştır. Kum filtresi ve membran filtrasyonda elde edilen organik madde giderim verimleri, organik maddenin hangi formda olduğunu gösteren çKOİ/KOİ ve

$çBOİ_5/BOİ_5$ oranlarının düşmesi ile yükselmiştir. Bunun sebebi denenen fiziksel arıtma sistemlerinin partiküler madde tutma konusunda başarılı olması ve çKOİ/KOİ ve $çBOİ_5/BOİ_5$ oranlarındaki düşüşün organik maddenin çoğunlukla partiküler olduğunu göstermesidir.

Biber fideleri üzerinde yapılan ön bitki deneylerinden elde edilen sonuçlara göre, sulama suyu olarak arıtılmış gri su kullanılmasının, en az günümüzde sulama suyu olarak kullanılmakta olan musluk suyu kadar başarılı sonuç verdiği ön bilgisine ulaşılmıştır.

1. INTRODUCTION

One of the main issues that world is facing today is the inadequacy of natural sources and inability of meeting the increasing needs of rising population. According to UNDP estimations (2012), 31% of world population today will be added to recent population by 2050, ending up with 9.5 million people. Two of many problems that come with population increase are water scarcity and deterioration of water quality (Beler Baykal and Giresunlu, 2013).

Problems about supplying water enhanced search for alternative water sources. One of the most important alternative sources of water is considered as domestic wastewater, as it is generated wherever people live. On the other hand, segregation of different domestic wastewater streams enables the use of different streams for different purposes. Segregation of domestic wastewater streams can generally be done in two ways as two (grey water / black water) or three components, also called ECOSAN streams, (grey water / yellow water / brown water). Of those streams, grey water includes the wastewater generated from the cleaning and washing activities such as bath/showers, wash basins, washing machines, sinks and dishwashers, while the other streams come from the toilets bowl.

Due to its high volume of about 75% of conventional domestic wastewater, grey water is a valuable renewable water source that can be returned to almost any point in the water cycle not involved with ingestion, after being processed. Moreover, treatment of grey water is expected to be easier as compared to conventional domestic wastewater, as grey water has lower pollution potential. 41% of all organic matter in conventional domestic wastewater is contained by grey water (Beler Baykal, 2014) which makes organic matter the primary pollutant for grey water reuse, since pollution potential of grey water in terms of nutrients is lower than conventional domestic wastewater. As grey water is collected separately from the toilet wastewater, it is also expected to have low concentrations of microbiological indicators.

Grey water is mostly used for toilet flushing and irrigation at this time. As reusing grey water is gaining popularity, different treatment systems are proposed for reclaiming this water source. Generally biological treatment systems are recommended for grey water treatment as the priority pollutant is organic matter. Membrane bioreactor is one of the most popular grey water treatment systems as it combines the advantages of filtration with biological treatment.

Grey water / domestic wastewater reuse guidelines or standards are being published by certain countries, as reusing grey water and domestic wastewater become more popular day by day. Australia, USA, Germany and Japan are some of the leader countries in grey water / domestic wastewater reusing around the world, however all countries have different definitions for grey water and different requirements for different end-use applications while reusing grey water.

The aim of this work is to carry out a long-term systematic and continuous monitoring of raw grey water, and to monitor the effluent quality of grey water treatment plants of buildings recycling grey water.

The scope of this work is

- To characterize grey water in a continuous and systematical way in terms of organic matter, suspended solids, nitrogen and phosphorus as conventional physicochemical parameters and Total Coliform, Fecal Coliform, E.Coli and Enterococcus as microbiological indicators,
- To monitor two real-scale membrane bioreactors where grey water is being treated, and
- To track the pathogenic indicators among the grey water cycle and to monitor the re-growth of pathogenic indicators in toilet reservoirs, where treated grey water is used for toilet flushing

Results obtained during this work showed that grey water could be treated not only with biological systems, but also through physicochemical treatment systems. Also, as one of the major areas where grey water is reused is irrigation, performing trials on plants with grey water as irrigation water was considered. As a result, in addition, it was decided

- To carry out preliminary treatment trials through sand filtration and membrane filtration, and
- To try treated grey water as irrigation water on pepper seedlings.

In this work, buildings that already have grey water reclamation and reuse systems were monitored in terms of raw grey water quality and efficiency of the treatment plants. All experiments and lab-scale treatment trials were carried out in the laboratory.

This study contributes to literature a continuous and systematic characterization of grey water and its quality after being treated. Also pathogenic indicator concentrations among the reclamation line and in the reservoir were studied in detail.

2. STREAM SEGREGATION

The projection that was made by UNDP (2012) estimates that the world population will be about 9.5 million in 2050, which is 31% more than today's population. Increasing population comes with increasing need for various sources, most importantly water, however 1.1 billion people have no access to safe water and about 2.4 billion people lack any form of sanitation services in world today. A child dies every 15 second due to waterborne diseases (WHO / UNICEF, 2000).

As water stress / scarcity and waterborne diseases are some of the most important issues that world is facing today, supporting sustainability has gained importance besides the search for new water resources. Water usage is inevitable as long as people live, entailing wastewater production (Beler Baykal & Giresunlu, 2013). At this time, domestic wastewater has gained importance as a water resource that is targeted to be reuse, rather than being discarded as a waste to be disposed of. To be able to reuse domestic wastewater in the most efficient way, new domestic wastewater management concepts are being proposed and one of those concepts is segregation of domestic wastewater streams at their source of generation.

Segregation of domestic wastewater streams can generally be done in two ways as two (grey water / black water) or three components, also called ECOSAN streams, (grey water / yellow water / brown water). Grey water refers to domestic wastewater except toilet wastewater and the quality and quantity of grey water are similar for both of those segregation systems. This stream includes the wastewater generated from the cleaning and washing activities such as bath/showers, wash basins, washing machines, sinks and dishwashers. Black water is toilet wastewater including human urine, feces, possibly toilet paper and flush water. Separately collected human urine is called yellow water and brown water refers to feces. Collection of yellow water and brown water is possible with special toilets that work without flush system, or with little amount of flush water that will prevent dilution.

Volume percentages of different domestic wastewater streams are shown in Figure 2.1. According to this figure, feces/brown water constitutes only 0.1% of domestic

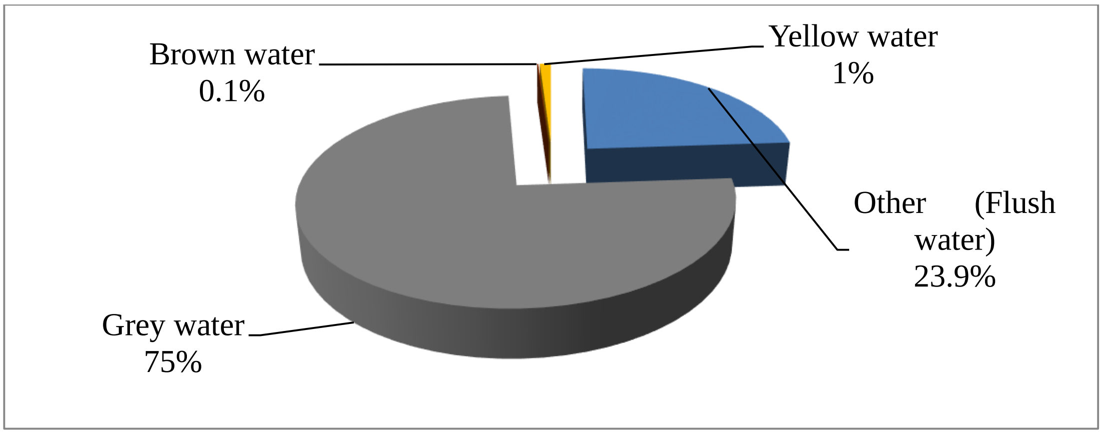


Figure 2.1 : Volumes of domestic wastewater fractions (Beler Baykal, 2014).

wastewater volume, while urine/yellow water constitutes 1% of total volume. On the other hand, 23.9% of water at drinking water quality is used for sweeping human excrement from the toilet down the collection system. Grey water has the highest volume with 75%, which makes it a valuable water resource that could be reused as flush water instead of drinking water.

Figure 2.2 depicts characteristics of ECOSAN streams in terms of their organic matter, nitrogen, phosphorus and potassium content. As may be observed from the figure, most of the nutrients will reside in yellow water which constitutes 1% of the wastewater volume when segregation is done. Likewise, the greatest majority of pathogens will remain in brown water which occupies only 0.1% of the volume. As

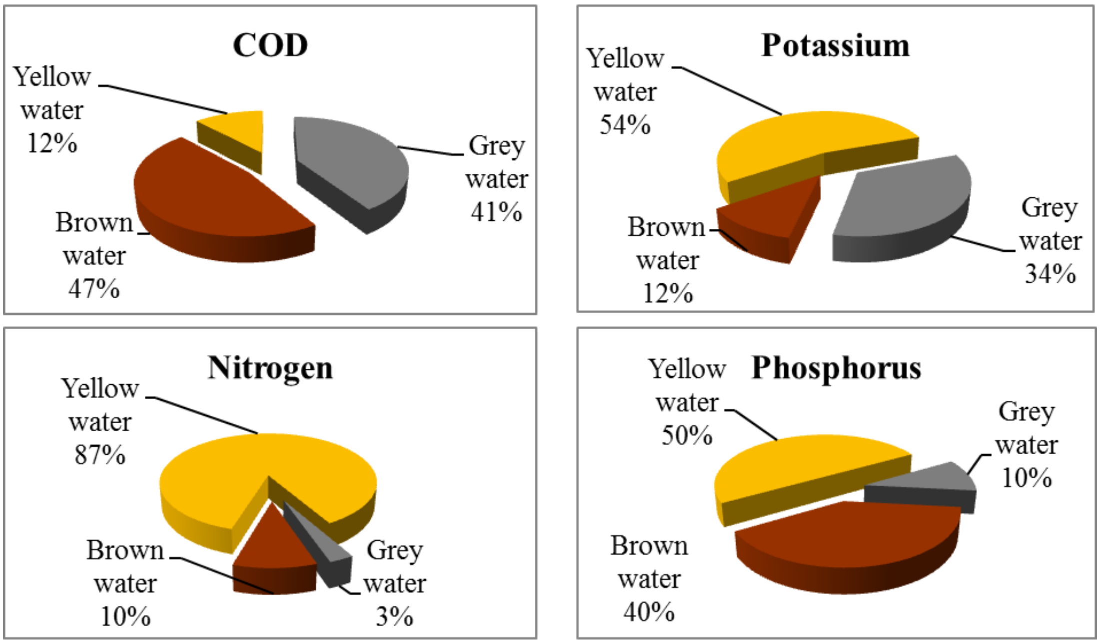


Figure 2.2 : Characteristics of ECOSAN streams (based on Otterpohl et al., 2003).

shown in Figure 2.3, for one person on yearly basis, when mixing occurs as in the case of conventional practice, only 1 % (500 liters) will contaminate the entire domestic wastewater volume which is 80550 liters with nutrients and only 0.1 % (50 liters) will lead to microbial pollution of this entire volume due to pathogens. Hence, when separation is accomplished, 99 % of the volume will be relatively free of problematic nutrients, i.e. nitrogen and phosphorus, and pathogenic microorganisms. Separating grey water from the rest would mean alleviation of the nutrient problem from this specific stream and reduced burden due to pathogens before reuse. This will enable the use of simpler treatment systems as compared to treatment which would be required for the reuse of conventional mixed domestic wastewater. Regular nitrogen removal of any kind including nitrification/ denitrification will be unnecessary and most of the phosphorous problem will also be eliminated (Beler Baykal, 2014).

Table 2.1 shows the distribution of pollutants in domestic wastewater among segregated domestic wastewater streams (Beler Baykal, 2014). According to this table, grey water has the the highest volume with 75% and 41% of all organic matter that exists in conventional domestic wastewater is contained by grey water, which makes organic matter a major pollutant for grey water. However grey water does not pose an environmental risk in terms of nutrients. On the other hand, yellow water

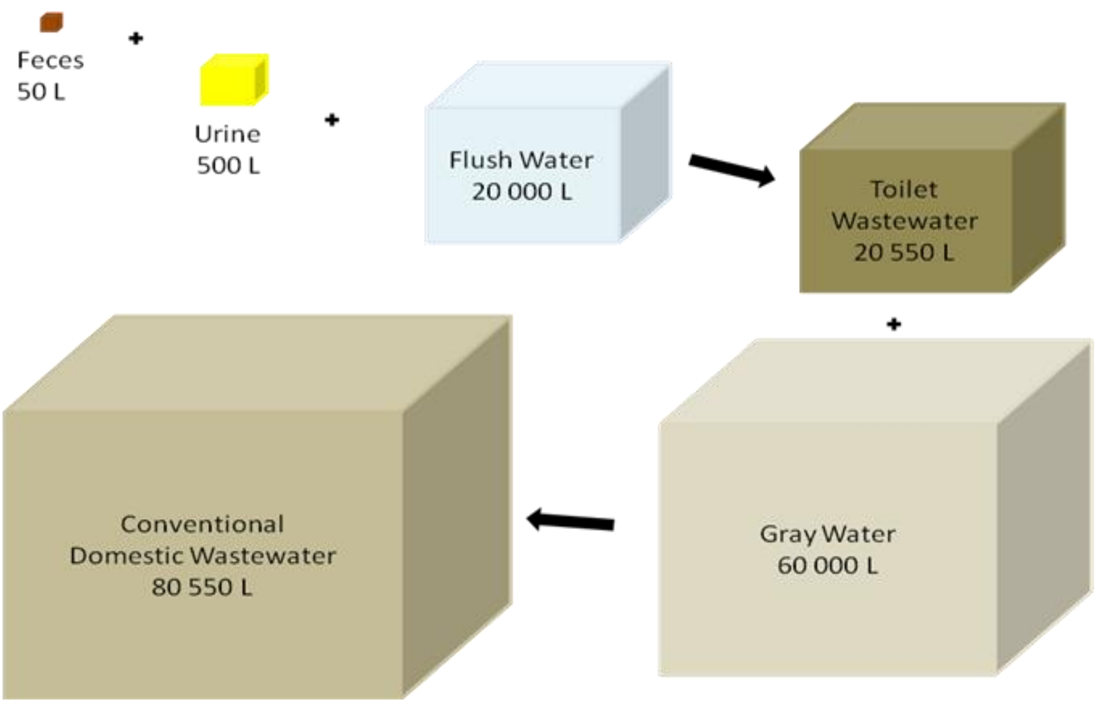


Figure 2.3 : Mixing and contamination in the conventional wastewater collection chain – volumes per capita on annual basis (Beler Baykal, 2014).

Table 2.1 : Pollutants and volumes of segregated domestic wastewater streams (Beler Baykal, 2014).

	Conventional domestic wastewater	Grey water	Yellow water	Brown water	Black water
Organic matter	100%	41%	12%	47%	59%
Nitrogen	100%	3%	87%	10%	97%
Phosphorus	100%	10%	50%	40%	90%
Potassium	100%	34%	54%	12%	66%
Pathogens	100%	Low	Low	High	High
Volume	100%	75%	1%	0.10%	25%

contains high amounts of nutrient, ie. nitrogen, phosphorus and potassium, in only 1% of total domestic wastewater volume. Brown water requires the biggest portion of organic matter with 47% and phosphorus content is also high, but this stream constitutes only 0.1% of domestic wastewater volume. Because black water is the combination of yellow water, brown water and flush water, it contains high amount of organic matter and nutrients, but the volume of black water is high due to flush water addition. Due to the pathogenic indicators that originate from feces, brown water and black water are expected to have high content of pathogenic indicators.

Table 2.2 gives a brief summary of segregated domestic wastewater streams, their constituents, possible treatment alternatives and end use applications. A survey of the table shows that every stream has a potential of being reused for different purposes. Taking conventional domestic wastewater as a problematic waste that needs to be treated, leads to loss of valuable resources, ie. nutrients and water, while reuse of domestic wastewater streams would allow resource recovery as well as help solving environmental pollution (Beler Baykal ve Allar, 2007; Wenlin et al., 2012). As shown in Table 2.2, grey water is considered as a renewable water resource for end use applications that does not require potable water quality, due to its high volume and lower pollution potential compared to other domestic wastewater streams. Moreover, this is a renewable source of water. Yellow water has an important potential of being reused as nutrient source in agriculture as it contains high amounts of plant nutrients (N, P, K) and brown water on the other hand can be used as soil conditioner after composting or energy source through anaerobic digestion. Black water also has biogas production potential based on high organic matter content.

Table 2.2 : Domestic wastewater streams (based on Beler Baykal, 2014).

Domestic wastewater streams	Grey water	Yellow water	Brown water	Black water
Main component	All domestic wastewater excluding toilet wastewater	Urine	Feces	Toilet wastewater
Main constituents	Organic matter	Nitrogen Phosphorus Potassium	Organic matter Phosphorus Pathogens	Organic matter Nitrogen Phosphorus Potassium Pathogens
Possible treatment options	Biological treatment	Direct reuse Storage Dilution Indirect reuse	Anaerobic digestion Composting	Anaerobic digestion
Valuable products	Water	Fertilizer	Biogas Compost	Biogas
End uses	Toilet reservoir Irrigation Vehicle washing Ground water recharge …	Agriculture Landscape Sports areas …	Energy Soil conditioning	Energy

3. GREY WATER

As projected by UNDP, a dramatic increase in the population of the world is expected and Figure 3.1 shows that the world population will be about three times more in 90 years than what it is today. However, available sources will stay unchanged and meeting growing population's demands will be harder day by day. Sustainability is the concept which will lead to the optimal use of those resources for longer periods of time. One of those sources is water, and water scarcity is already a problem in many parts of world. One fifth of world's population lacks enough hygenic water for their demands. Number of people who live in water-scarce basins, where there is not enough financial resources for developing adequate water resources, is 1.6 billion (IWMI, 2007). World map of water scarcity is given in Figure 3.2, where it is pointed out that not only underdeveloped countries are experiencing water scarcity. However, also developing and developed countries are having issues of water stress or scarcity, however reasons are different. Underdeveloped countries are generally threatened because of economic insufficiency, not due to physical reasons, however developed countries are having

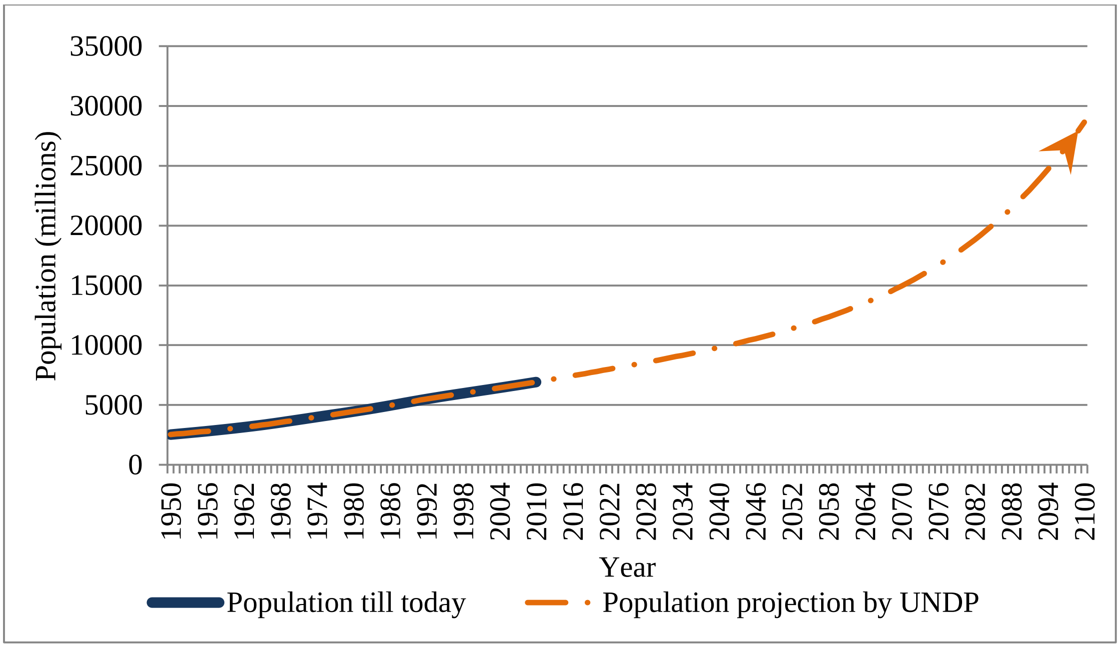


Figure 3.1 : Population till today and projection for future (UNDP, 2012).

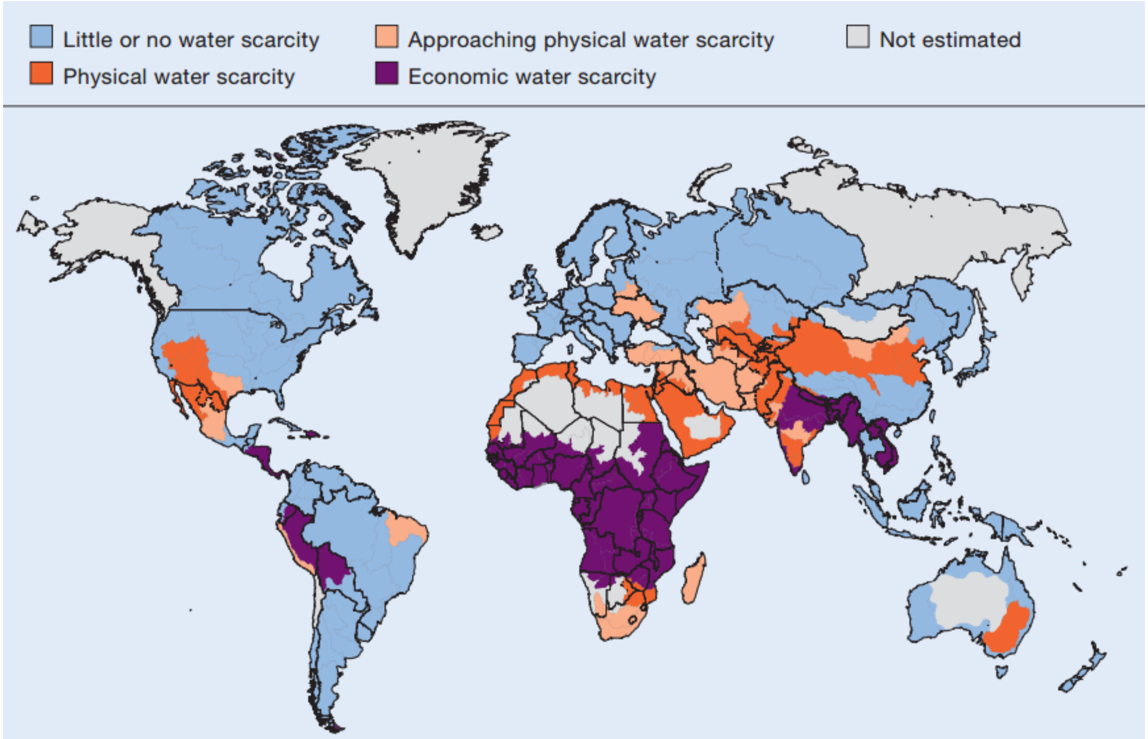


Figure 3.2 : Areas of physical and economic water scarcity (IWMI, 2008).

problems with meeting the water need of their population physically, that is lack of water resources, as they consume lot more water than the citizens of underdeveloped countries (IWMI, 2007).

These challenging factors are forcing people to explore alternative water sources and domestic wastewater is one of those alternatives. Stream segregation enables collection of grey water, which is a more attractive water source that consists 75% of domestic wastewater with lower pollutant concentrations than domestic wastewater. As the challenge includes both a quantitative and a qualitative dimension, while having sufficient quantities of water is an essential issue, provision of satisfactory quality is the other requirement to be fulfilled for accomplishing the task. Within the realm of quality, “fit for purpose” use of water is another important consideration. This can be achieved through efficient matching of the requirements of the intended use with the quality of water to be used for that specific purpose.

Grey water reuse is possible both directly and after treatment (Bob Boulware, 2013). When it is not treated, it can be reused in toilet reservoirs for flushing toilet, however usage of chloride pellets is needed for disinfection (Oructut, 2013). Another direct reuse application of grey water is groundwater recharge (Pacific Institute, 2010), and this application is one of the most affordable and easy choices as soil filtration process provides treatment (Oructut, 2013). On the other hand, if treated properly, grey water is a valuable water source that could be returned to any point of the water cycle, perhaps except for potable uses (Wenlin et al., 2012; Beler Baykal, 2014). Especially in arid environments that lack water resources, usage of this renewable water resource becomes more important (Eriksson et al., 2002; Beler Baykal, 2014). If this domestic wastewater stream is collected and treated to a quality that is required for the application that it will be employed, fit for purpose use of water will be accomplished. Grey water is mostly used for irrigation and toilet flushing at this time, but the current use includes is using it in any area, ie. irrigation of university sport's fields and landscapes, washing vehicles, fire protection systems, concrete manufacturing, groundwater recharge and recreational ponds may be practiced (Okun, 1997; Santala et al., 1998; Pidou et al., 2008). Especially when used for irrigation, nutrients included in soap products and detergents will be taken up by the plants as nutrients which makes irrigation with treated grey water even more attractive (Bob Boulware, 2013). If toilet flushing, vehicle washing and other applications that use potable water, but do not require potable water quality, are done with treated grey water, the demand for potable water will be decreased and the sustainable use of water resources will be accomplished.

Grey water constitutes the biggest portion of segregated domestic wastewater streams with 75% of total volume, and has the lowest pollution potential in terms of nutrients with 3% and 10% of nitrogen and phosphorus respectively, but including 40% of organic matter, which makes organic matter primary pollutant in grey water, as it can be seen from Table 2.1. Abu Ghunmi et al. (2011) states that grey water includes 23% of total suspended solids in domestic wastewater. In terms of pathogens, grey water is stated as almost no hygienic concern, as it is not contaminated with toilet wastewater (Werner, 2003; Langergraber & Muellegger, 2004; Wach, 2007).

Birks & Hills (2007) states grey water itself can also be segregated in two streams as light (weak) grey water, grey water generated from bath/showers and wash basins, and dark (strong) grey water, grey water comes from washing machines, sinks and dish washers, as shown in Figure 3.3. The reason for separating grey water fractions is that the character of grey water changes according to where it is generated from. Light grey water has lower pollution potential and lower concentrations in terms of

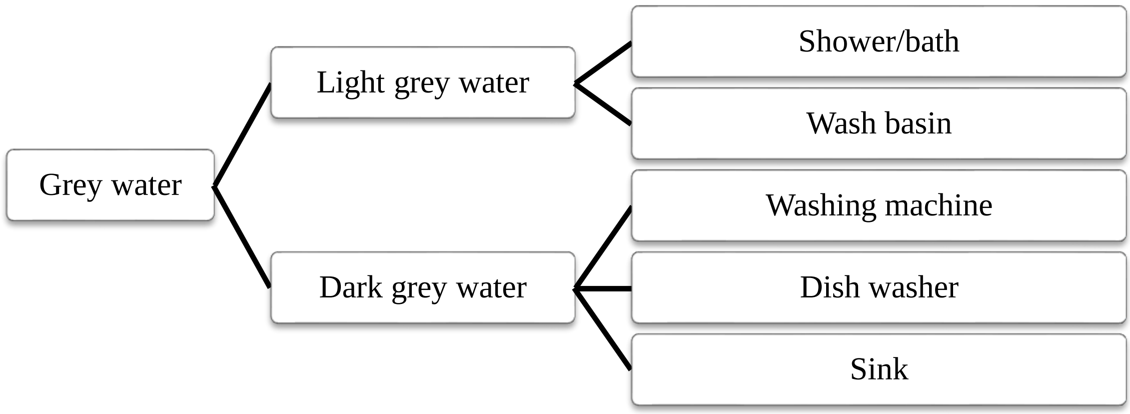


Figure 3.3 : Fractions of grey water (prepared based on Oruçtut, 2013 and Lazarova et al., 2003).

organic matter and nutrients, while dark grey water has higher concentrations including phosphorus due to the detergents that are used in kitchens and washing machines (Oructut, 2013).

Figure 3.4 shows the domestic water usage for different purposes, which illustrates water usage for toilet reservoirs constitutes the biggest portion with 28%. Washing machines use 25% of water, followed by bath/showers and wash basins with 23% and 7% respectively.

Percentages in Figure 3.4 shows that grey water generated from bath/showers and wash basins constitutes 30% of domestic wastewater, namely light grey water, which can be treated easier compared to domestic wastewater and other fractions of grey

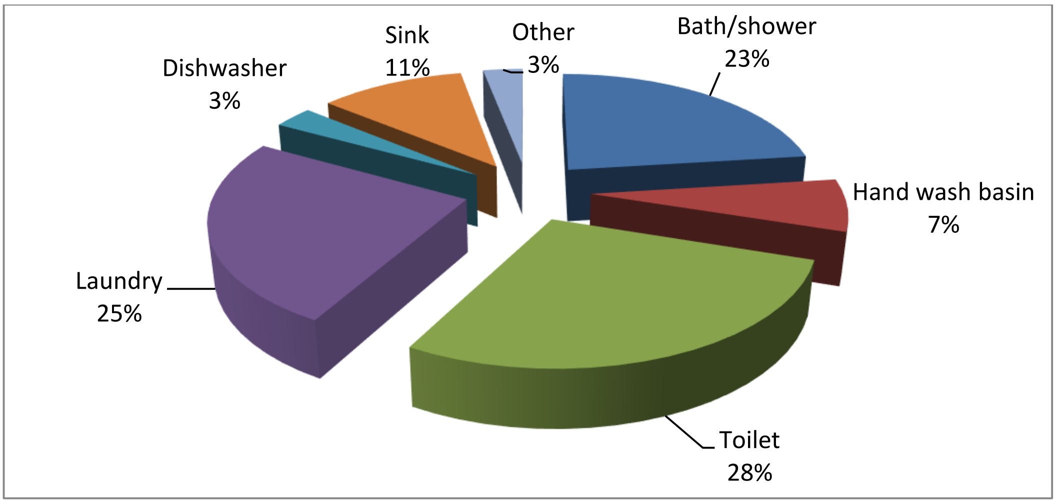


Figure 3.4 : Domestic water use (Beler Baykal and Giresunlu, 2014).

water. Light grey water, which is generated from domestic water use, can be reused for meeting water requirement for flushing toilets, which makes 28% of domestic wastewater use. If the amount of treated grey water is more than the amount needed, it can be used for activities such as house cleaning, irrigation or ornamental plant watering.

3.1 Characteristics of Grey Water

Grey water streams show different quality according to the source of generation, personal habits and water usage. Jefferson et al. (2000) and Al-Joyyousi (2003) state that the quality of grey water is also dependent on geographical location and demographics. Characteristics of grey water may be investigated under three main headings as physical/ chemical parameters, microbiological parameters and micropollutans and hazardous substances.

3.1.1 Physical and chemical parameters

Determination of quality and characterization of grey water that is generated from different household activities is essential for the treatment requirements and reuse applications. Appendix A shows a compilation of the literature work on characteristics of different types of grey water, which are generated from buildings of different functions and Table 3.1 shows the minimum and maximum concentrations of those grey water fractions investigated in the Appendix A. A survey of both the tables indicates the quality of grey water is highly dependent on the origin of generation.

One important issue is that the results of these work are mostly based on a single sample from each source only. Works done with one sample do not provide information about the time-wise characterization and the change in quality. Even if there is a monitoring application, the concentrations are given as the minimum-maximum values, which do not state ratios of important parameters on a one-to-one basis., ie. BOD/COD, dissolved COD/COD, soluble BOD/BOD, TSS/VSS. To be able to serve this purpose, characterization of grey water is important and can be determined by a continuous and systematical monitoring application, and this constitutes one of the major aims of this work as discussed in Part 4.

Table 3.1 : Minimum-maximum concentrations of different parameters in different grey water fractions.

Source	Grey water fraction	Parameters	Unit	Min	Max
House	Shower	BOD	mg/l	70[1]	300[1]
		COD	mg/l	113[1]	633[1]
		sCOD	mg/l	184[2]	221[2]
		PO_4-P	mg/l	5.3[2]	19.2[2]
		NH_3-N	mg/l	1.1[2]	1.2[2]
		TN	mg/l	28.7[3]	
		TSS	mg/l	54[2]	353[3]
		VSS	mg/l	9[2]	153[2]
		Turbidity	NTU	375[3]	
House	Wash basin	BOD	mg/l	42.1[3]	
		COD	mg/l	58[3]	298[2]
		sCOD	mg/l	221[2]	
		PO_4-P	mg/l	13.3[2]	
		NH_3-N	mg/l	0.3[2]	
		TN	mg/l	10.2[3]	
		TSS	mg/l	181[2]	505[3]
		VSS	mg/l	72[2]	347[3]
		Turbidity	NTU	133[3]	
House	Bath/shower and wash basin	BOD	mg/l	50[1]	1354[4]
		COD	mg/l	100[1]	4352[4]
		sCOD	mg/l	29[5]	257[5]
		TP	mg/l	0.11[6]	26[4]
		TN	mg/l	4.3[5]	138[4]
		TSS	mg/l	37[5]	1679[4]
		Turbidity	NTU	33[7]	462[5]
House	Washing machine	BOD	mg/l	48[6]	290[6]
		COD	mg/l	130[8]	1815[2]
		sCOD	mg/l	1164[2]	
		PO_4-P	mg/l	21[2]	
		NH_3-N	mg/l	2[2]	
		TP	mg/l	0.062[6]	42[6]
		TN	mg/l	1[6]	40[6]
		TSS	mg/l	18[8]	315[3]
		VSS	mg/l	97[2]	210[3]
		Turbidity	NTU	20[8]	244[3]

Table 3.1 (continued) : Minimum-maximum concentrations of different parameters in different grey water fractions.

Source	Grey water fraction	Parameters	Unit	Min	Max
House	Kitchen sink	BOD	mg/l	1100[6]	
		COD	mg/l	1079[2]	2244[4]
		sCOD	mg/l	644[2]	
		PO_4-P	mg/l	26[2]	
		NH_3-N	mg/l	0.3[2]	
		TP	mg/l	18.25[4]	
		TN	mg/l	51[4]	
		TSS	mg/l	235[2]	644[4]
		VSS	mg/l	196[2]	
House	Sinks and dishwashers	BOD	mg/l	65[9]	
		COD	mg/l	463[10]	
		PO_4-P	mg/l	0.53[10]	
		NH_3-N	mg/l	11.3[10]	
		TSS	mg/l	35[9]	78[10]
		Turbidity	NTU	43[9]	78[10]
House	Mixed	BOD	mg/l	33.3[11]	1060[12]
		COD	mg/l	120[13]	2570[12]
		sCOD	mg/l	177[14]	
		PO_4-P	mg/l	5.6[16]	7.5[17]
		NH_3-N	mg/l	2.4[16]	10.1[17]
		TP	mg/l	0.4[11]	19.5[4]
		TN	mg/l	8.8[14]*	105[4]
		TSS	mg/l	48[14]	845[4]
		VSS	mg/l	39[14]	
		Turbidity	NTU	13[15]	254[16]
Student residence hall	Bath/shower	BOD	mg/l	97[18]	216[19]
		COD	mg/l	102[18]	575[20]
		PO_4-P	mg/l	1.63[19]	3.5[18]
		TN	mg/l	1.56[19]	16.4[20]
		TSS	mg/l	33[18]	76[19]
		Turbidity	NTU	42[20]	92[19]

Table 3.1 (continued) : Minimum-maximum concentrations of different parameters in different grey water fractions.

Source	Grey water fraction	Parameters	Unit	Min	Max
Student residence hall	Bath/shower and wash basin	BOD	mg/l	20[22]	95[23]
		sBOD	mg/l	31.2[21]	
		COD	mg/l	86[22]	270[23]
		TP	mg/l	0.86[21]	
		TN	mg/l	4.6[21]*	11[21]*
		TSS	mg/l	29[22]	147[23]
		Turbidity	NTU	26.5[21]	57.6[24]
Student residence hall	Sink and dish washer	BOD	mg/l	47[25]	
		TP	mg/l	3.72[25]	
		TN	mg/l	3.73[25]	
Hotel	Bath/shower and wash basin	COD	mg/l	72.7[26]	171[27]
		TN	mg/l	4.1[26]	11.4[27]
		TSS	mg/l	32.2[26]	44[27]
		Turbidity	NTU	20[27]	38.8[26]
Sports center	Shower	BOD	mg/l	59[28]	129[29]
		COD	mg/l	109[28]	197[29]
		sCOD	mg/l	72[30]	166[29]
		NH_3-N	mg/l	<1[29]	8.6[29]
		TP	mg/l	0.3[29]	1.6[28]
		TN	mg/l	15.2[28]	27.17[30]*
		TSS	mg/l	29.6[31]	83[29]
		VSS	mg/l	30[30]	
		Turbidity	NTU	23[31]	29[28]
Institution building	Wash basin	BOD	mg/l	74[32]	
		COD	mg/l	244[32]	248[33]
		sCOD	mg/l	195[32]	
		NH_3-N	mg/l	0.45[33]	
		TSS	mg/l	<10[33]	46[32]
		Turbidity	NTU	12[33]	35[32]

(1) Nolde, 1999, (2) Almeida et al (1999), (3) Prathapar et al (2005), (4) Halalsheh et al (2008), (5) Chaillou (2010), (6) Christova-Boal ett al (1996), (7) Friedler et al (2005), (8) Sostar-Turk et al (2005), (9) Casanova et al (2011), (10) Ban-Melhem et al (2012), (11) Holden & Ward (1999), (12) Dalahmeh et al (2011), (13) Jefferson et al (1999), (14) Atasoy et al (2007), (15) Itayama et al (2006), (16) Paulo et al (2009), (17) Li et al (2008), (18) Lamine et al (2007), (19) Surendran & Wheatley (1998), (20) Pidou et al (2008), (21) Birks & Hills (2007), (22) Winwards et al (2008), (23) Friedler et al (2008), (24) Kadewa et al (2010), (25) Gunther et al (2000), (26) Gual et al (2008), (27) March et al (2005), (28) Merz et al (2007), (29) Santos et al (2011), (30) Gabarro et al (2013), (31) Ramona et al (2004), (32) Friedler & Alfiya (2010), (33) Sarioglu (2011).

House grey water

In Table 3.1, different grey water streams from the same type of buildings are given together. There are shower, wash basin, bath/shower together with wash basin, washing machine, kitchen sink, kitchen sink together with dishwasher and mixed grey water quality for houses. As shown in Figure 3.4, bath/shower and wash basin streams are named as light grey water, which refers to lower pollution potential. The minimum and maximum COD concentrations given for shower grey water are 113 and 633 mg/l while the same values are 58 and 298 mg/l for wash basin and 100 and 4352 mg/l (which is obviously an extraordinary value) if these two streams are collected together. According to this information, wash basin grey water has the lowest pollution potential compared to shower grey water in terms of COD. The maximum BOD_5 concentration among these three streams was reported by Halalsheh et al (2008) as 1354 mg/l BOD_5 for bath/shower and wash basin grey water, which is considered as an outlier concentration. Minimum and maximum BOD_5 concentrations for shower are 70 and 300 mg/l, while there is only one BOD_5 concentration for wash basin in literature as 42 mg/l (Prathapar et al., 2005).

On the other hand, minimum and maximum COD concentrations for washing machine grey water, which is one of those streams forming dark grey water, are 130 and 1315 mg/l, with 48 and 290 mg/l BOD minimum and maximum concentrations. sCOD concentration is investigated by Halalsheh et el (2008) and found 1164 mg/l, while maximum COD concentration is stated by the same reference, which points out sCOD/COD raiot as 13/20, showing 35% of organic matter in washing machine grey water is in particular form. TSS concentration of this stream changes between 18 and 315 mg/l in literature and minimum and maximum concentrations for VSS are 97 and 210 mg/l. Nutrient concentrations ranges are very wide.

Another dark grey water stream kitchen sink shows high concentrations in terms of organic matter. Minimum COD concentration is 1079 mg/l as shown in Table 3.1, while the maximum concentration can go up to 2244 mg/l, and the only work investigated sCOD states 644 mg/l sCOD concetration. Another work states 1100 mg/l BOD concentration. This stream is rich in nutrients, especially phosphorus, as PO_4-P concentration for the stream is stated as 26 mg/l by Almeida et al (1999). No particular study was found in literature about dishwasher grey water quality, however the pollution potential given for dishwasher together with sink is lower than kitchen sink only.

Student residence hall grey water

Student residence halls are other types of buildings that are investigated about grey water characterization. Minimum and maximum values of COD concentrations of bath/shower stream are 102 and 575 mg/l among the studies surveyed, while the minimum and maximum BOD concentrations are 97 and 254 mg/l. On the other hand, during this work, no article with dissolved organic matter content of bath/shower grey water from student residence hall was found. TSS concentration for this stream carry between 33 and 76 mg/l. Orthophosphate content is found as 1.63 mg/l and can go up to 3.5 mg/l, while the minimum concentration for Total Nitrogen is stated as 1.56 mg/l and may increase up to 16.4 mg/l.

There are other articles investigating different streams of grey water from the same type of building, such as the cases that the wash basin stream collected together with bath/shower grey water and the sink & dish washer stream. The minimum and maximum COD concentrations for bath/shower and wash basin stream are 86 and 270 mg/l, which point out a lower pollution potential compared to bath/shower stream. Also the BOD_5 concentration range is 20 and 95 mg/l for the same stream, showing that if the wash basin is collected together with bath/shower stream the pollution potential in terms of biodegredable organic matter decreases. Birks & Hills (2007) states sBOD concentration as 31 mg/l in this stream. On the other hand, TSS concentration of bath/shower and wash basin is higher than the TSS concentration of bath/shower stream.

Sink and dish washer grey water is considered as dark grey water and normally expected to have higher pollution potential when compared to light grey water fractions, however the only reference in student residence hall grey water, BOD concentration is stated as 47 mg/l (Gunther et al., 2000), a low concentration as compared to other streams investigated. Also nutrient concentrations are stated as 3.72 mg/l TP and 3.73 mg/l TN, which are considered as low.

Other grey water

If shower streams of a house and a sports center is compared by looking at Table 3.1, it is clearly seen that the sports center shower grey water has lower pollution potential in terms of organic matter with minimum maximum concentrations as 109 and 197 mg/l in terms of COD, as 72 and 166 mg/l in terms sCOD and as 59 and 129 mg/l in terms of BOD. Also in terms of suspended solids, house shower grey water fraction has higher pollution potential as its concentration can go up to 353 mg/l, but the sports center maximum TSS concentration is stated as 83 mg/l. This situation can be linked to the possibility of people having shower quickly at the sports center and use less soap compared to house usage, so that the organic matter content of grey water from house is measured higher.

Comparison of wash basin characteristics of a house and an institution building is possible through Table 3.1. Comparison reveals that the pollution potential of house wash basin and institution wash basin are similar in terms of organic matter, however the minimum concentrations for house are lower than the ones for institution building in terms of COD and BOD.

Characteristics of light grey fraction, bath/shower and wash basin streams, are available for a house, a student residence hall and a hotel in Table 3.1. In terms of COD, house light grey water shows the highest pollution potential, while light grey water generated from the hotel shows the lowest pollution potential with minimum 73 mg/l and maximum 171 mg/l. BOD concentration is not available for the hotel, but if house characteristics in literature is compared to the student residence hall characteristics, again house grey water shows higher pollution potential in terms of BOD. Pollution potential of light grey water from the highest to the lowest in terms of TSS is also the house, the student residence hall and the hotel, similar to the other parameters investigated.

If the kitchen fraction of grey water including both the sink and the dishwasher of a house and a student residence hall is compared in terms of organic matter, the BOD concentration of house grey water is higher than the BOD concentration of student residence hall grey water as they are stated as 65 and 47 mg/l respectively. Comparison in terms of other parameters is not possible as the parameters investigated for these two streams are not same, similar, or comparable to each other.

Jefferson et al. (2000) and Al-Joyyousi (2003) state that the quality of grey water is dependent on geographical location, demographics and amount of domestic water used. However as shown in Appendix A, the work of Chaillou et al. (2010) reveals that even if the characteristics of the families and the geographical locations are similar, quality of grey water is highly variable, which may be attributed to usage of different detergents and personal care products and also to the water consumption variations.

As most of the nutrients are included by yellow water, grey water is expected to have low concentrations in terms of nitrogen and phosphorus. By looking at Table 3.1, it is possible to state that grey water is generally in line with the expectations and most of the time it is weak in terms of nutrients. In terms of Total Nitrogen, grey water generated from a hotel's bath/showers and wash basins has a concentration of 4.1 mg/l (Gual et al., 2008), however Mandal et al. (2011) states 42.8 and 57.7 mg/l of TN when washing machine stream is collected with light grey water in an institution building, which is quite unexpected. The work by Christova-Boal et al. (1996) states 40 mg/l TN for washing machines. Total Phosphorus concentration is found 0.2 mg/l for light grey water by Chaillou et al. (2010), while it is found as 0.86 mg/l by Birks & Hills (2007). On the other hand, concentration of laundry fraction can go up to 42 mg/l (Christova-Boal et al., 1996), and kitchen fraction has 18.25 mg/l TP (Halalsheh et al., 2008).

Low nutrient concentrations are important as they may be limiting if grey water is to be treated biologically. Al-Jayyousi (2003) reported grey water C:N:P ratio as 1030:2.7.1, however Metcalf&Eddy (2003) reports 100:5:1 ratio for conventional domestic wastewater. It is stated that with the coupling of low biodegradability of organic matter with low nutrient concentrations, the effectiveness of biological treatment of grey water will be effected negatively (Jefferson et al., 1999), unless external sources are provided.

Biodegradability of grey water

Organic matter, the primary pollutant in grey water, is mainly generated from the kitchens due to the food leftovers and the oil and cleaning products that are used in bathrooms, including surface active materials such as detergents. Organic matter in grey water is expected to be in biodegradable form (Ridderstolpe, 2004), however this may change due to the source of grey water. According to Li et al (2009a), sinks and dish washers are the main source of biodegradable organic matter. On the other hand, the same work states that all types of grey water shows good biodegradability. Couto et al. (2013), Li et al. (2009b) and Lamine et al. (2007) states COD/BOD ratios as 1.02 to 2.4, 1.50 and 1.05 respectively, showing that organic matter in grey water has high biodegradability. On the other hand, there are works stating the opposite way, that grey water is non-biodegradable or slowly biodegradable (Jefferson et al, 1999; Al-Jayyousi, 2003; Friedler et al, 2005; Winward et al. 2008). Jefferson et al. (1999) states the COD/BOD ratio may be as high as 4, which indicates low biodegradability, while the experiments which are done by Binte et al. (2013) indicate very high COD/BOD ratios for all types of grey water. In the light of these data, it is possible to state that biodegradability of grey water is dependent on many factors and highly variable.

In this work, important data was generated about the BOD/COD ratio of grey water samples as they showed low biodegradability under BOD_5 test conditions, and the work in literature were reviewed for BOD/COD ratios to compared the results of this work with literature data. Ratios obtained from Appendix A during this work is given in Table 3.2, and a survey of the table shows that the biodegradability of organic matter is highly variable. The lowest ratio is reported by Winward et al. (2008) and Mandal et al. (2011) as 23%, showing that only 23% of organic matter in bath/shower and wash basin grey water from a student residence hall and shower, wash basin and washing machine generated at an institution building is biodegradable under BOD_5 test conditions. On the other hand, highest BOD/COD ratio is 78% reported by Prathapar et al. (2005), which belongs to grey water generated from a washing machine, which is in line with expectations as detergents are indicated to be readily biodegradable, as mentioned before.

The grey water samples tested during this work showed that most of the organic matter present in those grey water samples investigated were in particulate form and to compared the data generated to data in literature, Table 3.3 is prepared. sCOD is investigated in 7 of those works in Appendix A and summarized in Table 3.1, showing that the solubility of organic matter is also highly variable. sCOD is investigated in grey water generated from houses and the lowest sCOD/COD ratio is 26% (Chaillou et al., 2010) which belongs to bath/shower and wash basin grey water stream. The highest value is reported by Almeida et al. (1999) as 88% for bath stream. On the other hand, sBOD is experimented by only Birks & Hills (2007) for light grey water and sBOD forms 67% of BOD, while the BOD/COD ratio is 48% with a COD concentration as low as 96.3 mg/l.

Table 3.2 : BOD_5/COD ratio for different grey water source and fractions.

House	Shower	44%	Prathapar et al. (2005)
	Wash basin	72%	Prathapar et al. (2005)
	Bath/shower and wash basin	37%	Friedler et al. (2005)
	Mixed except sink	31%	Halalsheh et al. (2008)
	Bath/shower and wash basin	47%	Chaillou et al. (2010)
	Bath/shower and wash basin	59%	Chaillou et al. (2010)
	Bath/shower and wash basin	67%	Chaillou et al. (2010)
	Bath/shower and wash basin	59%	Chaillou et al. (2010)
	Bath/shower and wash basin	54%	Chaillou et al. (2010)
	Ablution and wash basin	40%	Halalsheh et al. (2008)
	Washing machine	78%	Prathapar et al. (2005)
	Washing machine	60%	Sostar-Turk et al. (2005)
	Sink	49%	Halalsheh et al. (2008)
	Kitchen, shower and wash basin*	59%	Itayama et al. (2006)
	Mixed*	71%	Palmquist & Hanaeus (2008)
	Mixed*	48%	Palmquist & Hanaeus (2008)
	Mixed	41%	Dalahmeh et al. (2011)
	Mixed	23%	Holden & Ward (1999)
	Mixed	37%	Atasoy et al. (2007)
Student residence hall	Bath/shower	51%	Surendran & Wheatley (1998)
	Bath/shower and wash basin	35%	Friedler et al. (2008)
	Bath/shower and wash basin	23%	Winward et al. (2008)
	Wash basin	58%	Surendran & Wheatley (1998)
	Washing machine	65%	Surendran & Wheatley (1998)
	Sink	57%	Surendran & Wheatley (1998)
University changing room	Shower	65%	Santos et al. (2011)
	Wash basin	34%	Santos et al. (2011)
Institution building	Shower, wash basin and washing machine	40%	Mandal et al.(2011)
	Shower, wash basin and washing machine	23%	Mandal et al.(2011)
School	Bath/shower and wash basin	34%	Godfrey et al. (2010)
Restaurant	Wash basin	31%	Santos et al. (2011)

*BOD_7

As can be seen from Table 3.3, TSS concentrations in light grey water are generally below 100 mg/l, however if the grey water generating from kitchens is included, the concentration may increase up to 845 mg/l. Halalsheh et al. (2008) reported a TSS concentration of 1679 mg/l in a stream excluding kitchen wastewater, which actually is an unexpected value for any type of grey water. Volatile suspended solids are not studied as much as total suspended solids were, however the table reveals that an appreciable amount of suspended solids are volatile / organic.

Table 3.3 : sCOD/COD ratio for different grey water fractions.

House	Bath	88%	Almeida et al. (1999)
	Shower	44%	Almeida et al. (1999)
	Bath/shower and wash basin	43%	Chaillou et al. (2010)
	Bath/shower and wash basin	45%	Chaillou et al. (2010)
	Bath/shower and wash basin	26%	Chaillou et al. (2010)
	Bath/shower and wash basin	26%	Chaillou et al. (2010)
	Bath/shower and wash basin	48%	Chaillou et al. (2010)
	Washing machine	64%	Almeida et al. (1999)
	Sink	60%	Almeida et al. (1999)
	Mixed	72%	Atasoy et al. (2007)

3.1.2 Microbiological Parameters

Presence of fecal contamination is the most important factor that effects microbial quality of grey water and fecal cross-contamination is the general problem that causes deterioration of quality (WHO, 2006). Grey water is expected to have lower pollution potential compared to conventional domestic wastewater in terms of pathogenic / microbiologic indicators, as it is collected separately without being contaminated with toilet wastewater. However, pathogenic / microbiologic indicators are available in grey water due to hand washing after toilet use, washing baby diapers in washing machines and possible food leftovers and uncooked food that come from the kitchens (Eriksson et al., 2002). Contamination is generally measured by the use of coliform groups and enterococci (WHO, 2006).

Table 3.4 shows the Total Coliforms and Fecal Coliforms concentrations in different grey water fractions. Domestic wastewater indicator concentrations are also provided

Table 3.4 : Microorganism concentrations in grey water and domestic wastewater.

	Grey water (Nolde, 1999)			Conventional domestic wastewater (Metcalf & Eddy, 2003)		
	Bath/ shower and wash basin	Bath/ shower	Bath/ shower, wash basin and baby diaper	Weak	Mid	Strong
Total Coliform (cfu/100 ml)	10^4-10^5	10^3-10^5	10^6-10^8	10^6-10^8	10^7-10^9	10^8-10^{10}
Fecal Coliform (cfu/100 ml)	10^1-10^3	10^1-10^3	10^6-10^8	10^3-10^5	10^4-10^6	10^5-10^8

for comparison. Table 3.5 is a review of literature work about microbiological characteristics of grey water. Table 3.4 and Table 3.5 are generally based on Total Coliforms and Fecal Coliforms, as they are being used as conventional indicators for a long time. In Table 3.5, E.Coli and Enterococcus are also shown, as WHO (1997) and USEPA (1999) state these are the best pathogenic indicators for detection of fecal contamination.

According to Table 3.4, Total Coliform concentration of grey water is similar with weak domestic wastewater when baby diapers are washed and the quality in terms of Fecal Coliforms decreases to strong domestic wastewater quality. Quality of grey water fractions bath/shower and bath/shower with wash basin are similar, however if wash basin fraction is collected separately, pollution potential of grey water which is generated from bath/shower is lower. These fractions, namely light grey water, shows better quality in terms of coliforms compared to weak domestic wastewater.

Some of the work about the microbiological indicators in grey water in literature are listed in Table 3.5. According to these data, grey water generally shows mid strength domestic wastewater or better quality in terms of Total Coliforms and Fecal Coliforms. The lowest reported concentration of grey water is 4 logs / 100 ml in terms of Total Coliforms, which is a comparable concentration with weak conventional domestic wastewater, while the highest concentration of Total Coliform is 7 logs, which refers to weak to intermediate strength. In terms of Fecal Coliform, the concentrations reported change in a wide range, between 1 log and 8 logs. The lowest pollution potential in terms of Fecal Coliforms is analyzed in Surendran and Wheatley (1998) with 1 log cfu/100 ml in wash basin fraction of a student residence hall, however Dallas et al. (2004) reported 8 logs cfu/100 ml concentration for mixed grey water, which refers to high strength domestic wastewater. The only indicator analyzed in in the work of Dallas et al. (2004) is Fecal Coliform, which does not enable to compare this datum with other data given in the literature. The changing range of E.Coli concentration is 2 logs mpn/100 ml to 5 logs cfu/100 ml, however enterococci is not studied as frequently as E.Coli is, and there are three concentrations for this indicator microorganism, as 4 logs count/100 ml (Gunther, 2000), 3 logs cfu/100 ml (Birks & Hills, 2007) and 2 logs cfu/100 ml (Winward et al, 2008).

Table 3.5 : Microbial indicator concentrations in grey water.

Source	Grey water fraction	Total Coliform (cfu/100 ml)	Fecal Coliform (cfu/100 ml)	E.Coli (cfu/100 ml)	Enterococcus (cfu/100 ml)	Reference
House	Bath/shower and wash basin	$500 - 2.4*10^7$	$170 - 3.3*10^3$		$79 - 2.4*10^3$	Christova-Boal et al. (1996)*
	Washing machine	$2.3*10^5 - 3.3*10^5$	$110 - 1.09*10^3$		$23 - <2.4*10^3$	
House	Sink, shower, washing machine	$8.03*10^7$	$5.63*10^5$		$2.38*10^2$	Casanova et al. (2001)
House	Mixed		$1.5±4.6*10^8$			Dallas et al. (2004)
House	Bath/shower and wash basin		$5.6*10^5$			Friedler et al. (2005)
House	Kitchen sink	$2*10^7$	$1*10^6$	$7*10^5$		Halalsheh et al. (2008)*
	Mixed except kitchen sink	$3*10^7$	$2*10^6$	$6*10^5$		
	Ablution and wash basin	$5*10^6$	$5*10^4$	$3*10^4$		
	Mixed	$1*10^7$	$3*10^5$	$2*10^5$		
House	Shower, laundry and sink	5,40E+08		5,40E+06		Paulo et al. (2009)
House (with children)	Bath/shower and wash basin			2.07*106	$2.6*10^1$	Chaillou et al. (2010)
House (with children)				3*104	$9.1*10^4$	
House (with children)				2.3*105	$1*10^5$	
House (without child)				3*104	$8.5*10^3$	
House (without child)				2*104	$1*10^6$	

Table 3.5 (continued) : Microbial indicator concentrations in grey water.

Source	Grey water fraction	Total Coliform (cfu/100 ml)	Fecal Coliform (cfu/100 ml)	E.Coli (cfu/100 ml)	Enterococcus (cfu/100 ml)	Reference
House	Sinks and dishwashers	$43*10^4$	$26*10^4$			Bani-Melhem & Smith (2012)
Apartment	Mixed	13634	3565			Atasoy et al. (2007)
Apartment	Bath/shower and wash basin		$3.8*10^4$			Jefferson et al. (2011)
Student residence hall	Bath/shower	$6*10^6$	600			Surendran & Wheatley (1998)
	Wash basin	$5*10^4$	32			
	Washing machine	$7*10^5$	728			
Student residence hall	Wash basin and dish washer				35848	Gunther (2000)**
Student residence hall	Bath/shower and wash basin	$2.2*10^7$		$3.9*10^5$	$2.5*10^3$	Birks & Hills (2007)
Student residence hall	Shower	56500	6490	2790		Pidou et al. (2008)*
Student residence hall	Bath/shower and wash basin	$2.51*10^5$		$6.31*10^2$	$6.31*10^2$	Winward et al. (2008)
Institution building	Shower, wash basin and washing machine (May)	$374*10^2$	$348*10^2$	$372*10^2$		Mandal et al. (2011)
Institution building	Shower, wash basin and washing machine (June)	$380*10^2$	$356*10^2$	$400*10^2$		Mandal et al. (2011)
Institution building	Wash basins	16000		5200		Sarioglu (2011)

Table 3.5 (continued) : Microbial indicator concentrations in grey water.

Source	Grey water fraction	Total Coliform (cfu/100 ml)	Fecal Coliform (cfu/100 ml)	E.Coli (cfu/100 ml)	Enterococcus (cfu/100 ml)	Reference
School	Bath/shower and wash basin		$1.58*10^4$			Godfrey et al. (2010)
Sports complex	Shower		$1.4*10^5 \pm 1.1*10^5$			Merz et al. (2007)
Airport	Wash basin			3,17E+00		Couto et al. (2013)*
	Sink (washing vegetable/fruit)			2,00E+02		
	Sink (washing dishes)			6,71E+02		
	Shower			5,92E+02		

*MPN/100 ml
**Count/100 ml

If Table 3.5 is reviewed for the concentration difference in Total Coliform groups, it is possible to state that the difference may be as high as 3 logs, or as low as none, which means all the coliforms measured may be in fecal form. However a comparison of concentrations of Fecal Coliform group with E.Coli specie, the difference is 1 log at most, which means almost all Fecal Coliforms are E.Coli. A comparison of Enterococci with any other group shown in Table 3.5 is not possible, as Enterococci belongs to Fecal Streptococci/Enterococci group and does not correlate with Total Coliforms, Fecal Coliforms or E.Coli.

A review of Table 3.5 shows that light grey water shows better microbial quality compared to dark grey water, similar to the case of physical and chemical parameters. Mixed grey water is comparable with the grey water which is generated from kitchen sinks in terms of microbial quality.

Some of the works in literature states if biodegradable organic matter exists in treated grey water, there is possibility of microorganism regrowth (Li et al., 2009). In order to prevent regrowth of microorganisms, different disinfection processes, ie chlorination, UV disinfection, have been proposed.

3.1.3 Micropollutants and hazardous substances

As grey water excludes toilet wastewater but includes all other wastewater which is generated from household activities, micropollutants are another concern. Eriksson et al (2002) states that grey water has lower suspended solids, organic matter, nutrients and microorganism compared to domestic wastewater, however heavy metal concentrations are comparable. Detergents, softeners and other cleaning products and personal care products such as shampoo, soap, toothpaste and shaving gel are the main source of micropollutants in grey water and it is stated that in household and personal care products used in Danish households, there are up to nine hundred different substances or group of substances that are written in the list of content which are potentially available in grey water (Eriksson et al., 2003). Palmquist and Hanaeus (2005) states that there are numerous constituents in consumer goods and an average consumer cannot control these as normally it is beyond his/her knowledge.

According to Eriksson et al (2003), average weekly consumption of household chemicals and personal care products is 40 g per person due to the usage of 92 different products and this usage ends up with about 200 different XOCs, several fragrances, some preservatives, pharmaceuticals, flame retardants and drugs in grey water. In another work, 7 out of 16 PAHs, toluene, phthalates, organotin compounds, brominated flame retardants and triclosan are some of the substances detected in grey water (Palmquist & Hanaeus, 2005).

As reuse of grey water gains importance, research for applications to remove the micropollutants from grey water also accelerated due to the presence of priority substances. Removal of micropollutants from grey water was successfully done via Ozone and Activated Carbon (Hernandez-Leal et al., 2011), and via conversion of micropollutants (Butkovskyi et al., 2014).

Control of micropollutants besides conventional parameters is suggested during grey water reuse (Donner et al., 2010; Eriksson et al., 2003; Palmquist ve Hanaeus, 2005) as determination of level of risk associated with non-standard water quality parameters is very difficult due to the knowledge gaps about the presence and fate of micropollutants in grey water (Donner et al., 2010).

3.2 Treatment Options

Grey water reclamation is possible through lots of treatment options, depending on the end-use application, however the treatment systems used for this purpose generally includes a biological process (Pidou et al., 2008; Oruçtut, 2013), due to high organic matter content of grey water. Biodegradability of organic matter in grey water is an important consideration if biological treatment will be applied, as organic matter is the carbon source of microorganisms. As discussed above, there are lots of literature data making different statements about biodegradability of organic matter in grey water. However biodegradable organic matter is not the only source that microorganisms depend on, but also the nutrients. Metcalf & Eddy (2003) states C:N:P ratio as 100:5:1 for growth of microorganisms, while grey water cannot meet this requirement most of the time, looking at Appendix A and Table 3.1. Especially the situations that the kitchen wastewater, namely dark grey water, is excluded in the reuse systems, nutrient deficiency occurs. (Li et al., 2009) Rotating biological contactors (RBC), sequenced batch reactors (SBR) and membrane bioreactors (MBR) are the most widely used biological treatment processes for recycling grey water. Generally a sedimentation tank or filtration is employed before these treatment alternatives (Oructut, 2013). As it can be seen from Table 3.6, these

Table 3.6 : Pollutant removals of different treatment systems.

Source	Grey water fraction	Treatment process	Parameter	Removal	References
Apartment	Mixed	Sand filtration	BOD	63%	Holden & Ward (1999)
			COD	75%	
			Turb.	27%	
Apartment	Mixed	Membrane	BOD	86%	Holden & Ward (1999)
			COD	84%	
			Turb.	99%	
-	Mixed	Filtration	BOD	59%	Jefferson et al. (1999)
			Turb.	96%	
University changing room	Wash basin	Filtration (0.130 mm)	BOD	65%	Santos et al. (2011)
			COD	47%	
			TP	43%	
			TSS	59%	
University changing room	Wash basin	Filtration (0.025 mm)	BOD	61%	Santos et al. (2011)
			COD	72%	
			TP	66%	
			TSS	82%	
University changing room	Shower	Filtration (0.025 mm)	BOD	82%	Santos et al. (2011)
			COD	56%	
			TP	70%	
			TN	90%	
			TSS	35%	
Restaurant	Wash basin	Filtration (0.130 mm)	BOD	59%	Santos et al. (2011)
			COD	50%	
			TP	28%	
			TSS	46%	
Hotel	Bathtub, wash basin	Filtration, sedimentation	COD	54%	March et al. (2004)
			TN	39%	
			TSS	58%	
			Tur.	18%	
	Kitchen, shower, wash basin	Soil filtration	BOD_7	85%	Itayama et al. (2006)
			COD	83%	
			Turb.	32%	
	Laundry	UF membrane	COD	54%	Sostar-Turk et al. (2005)
			TN	38%	
			TSS	49%	
			Turb.	15%	
	Laundry	NF membrane	BOD	56%	Sostar-Turk et al. (2005)
			COD	93%	
			TSS	100%	
	Laundry	RO membrane	BOD	98%	Sostar-Turk et al. (2005)
			COD	98%	
			TSS	100%	
			Turb.	97%	

Table 3.6 (continued) : Pollutant removals of different treatment systems.

Source	Grey water fraction	Treatment process	Parameter	Removal	References
Institution building	Shower, wash basin, laundry (May)	Filtration and aeration	BOD	60%	Mandal et al. (2011)
			COD	51%	
			PO_4-P	0%	
			TN	35%	
			TSS	25%	
			Turb.	60%	
Institution building	Shower, wash basin, laundry (June)	Filtration and aeration	BOD	-	Mandal et al. (2011)
			COD	77%	
			PO_4-P	38%	
			TN	9%	
			TSS	32%	
			Turb.	75%	
Student flats	Wash basin, dish washer	Constructed wetland	BOD_7	98%	Gunther (2000)
			TP	49%	
			TN	99%	
Sports complex	Shower	MBR	BOD	93%	Merz et al. (2007)
			COD	56%	
			TP	19%	
			TN	63%	
			Turb.	98%	
	Shower, wash basin, kitchen	SBR	COD	88%	Hernandez et al. (2007)
			TP	32%	
			TN	11%	
House	Shower/ bath, wash basin	Screen, RBC, sand filter, disinfection	BOD	94%	Friedler et al. (2005)
			COD	75%	
			TP	58%	
			TSS	82%	
			Turb.	98%	

biological treatment options give about 60-98% and 51-88% organic matter removal in terms of BOD and COD respectively. MBR is the most preferred technology among these three options due to its low land requirement and high effluent water quality (Oructut, 2013).

Not as widely used as biological treatment systems, physical and chemical treatment systems are also used for grey water reclamation. According to Table 3.6, filtration and membrane filtration are preferred over other physical and chemical treatment options and 47-98% organic matter removal is possible through these options. The works are done with different grey water fractions and as a result, the efficiencies are also variable. Sostar-Turk (2005) experimented coagulation and sand filter followed by granulated activated carbon and removal efficiencies are reported as 85%, 92% and 94% removal in terms of TSS, COD and BOD respectively. Coagulation with alum resulted with 65% COD and 88% BOD removal (Pidou, 2008).

As discussed in Appendix A and Table 3.1, grey water shows different characteristics in different places and different types of building. Depending on many things, it is not possible to state one quality for grey water, neither selection of a reclamation system is not possible without a systematical characterization work for the grey water that will be reclaimed. However, membrane bioreactors (MBR) are one of the most used and investigated treatment systems at this time.

<u>Membrane filtration and membrane bioreactors (MBR)</u>

Membrane is a selective permeable material that serves as a barrier to some substances (Jefferson et al., 2000). There are different types of membranes according to their size as flat films, hollow fibers, tubular and tubes, and their driving force, separation mechanism and pore size (Kamalesh et al., 1999). In Table 3.7, based on the pore sizes, membranes are called different names as microfiltration (MF),

Table 3.7 : Membrane specifications (Metcalf & Eddy, 2003).

Membrane type	Driving force	Operation range, µm	Permeate description	Constituents removed
MF	Hydrostatic pressure or vacuum in open vessel	0.08-2.0	Water and dissolved solutes	TSS, turbidity, protozoan oocysts and cysts, some bacteria and viruses
UF	Hydrostatic pressure difference	0.005-0.2	Water and small molecules	Macromolecules, colloids, most bacteria, some viruses, proteins
NF	Hydrostatic pressure difference	0.001-0.01	Water and very small molecules, ionic solutes	Small molecules, some hardness, viruses
RO	Hydrostatic pressure difference	0.0001-0.001	Water and very small molecules, ionic solutes	Very small molecules, color, harness, sulfates, nitrate, sodium, other ions

MF: Microfiltration
UF: Ultrafiltration
NF: Nanofiltration
RO: Reverse Osmosis

ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO) and properties of different type of membranes are given.

As the pore size decreases, the amount of pollutants retained in the membranes increases, so the quality of effluent water (Wilf, 2010) as shown in Figure 3.5. For example microfiltration membranes are capable of holding cysts, bacteria, bigger particles of algea, cyanobacteria and colloids, however it should not be employed for removal of sand and human hair as these can be held by a granular filtration media. If suitable pore size is selected, ultrafiltration membranes propose disinfection as they remove bacteria and viruses. They are capable of removing all bacteria, also the viruses can be removed if the pore size of ultrafiltration membrane is selected smaller. On the other hand, dissolved organic matter cannot be removed by an ultrafiltration membrane even if the pore size is selected as the smallest, and a nanofiltration membrane must be employed for removal of dissolved organic matter. Desalination is also possible through membrane filtration, however reverse osmosis systems are required for removal of salts.

As shown in Table 3.7, membranes can be operated by creating pressure on the liquid that is to be treated, or by applying vacuum force on the liquid that is to be treated to suck permeate from the membrane (Metcalf & Eddy, 2003; Le-Clech et al., 2006; Sarioglu, 2011).

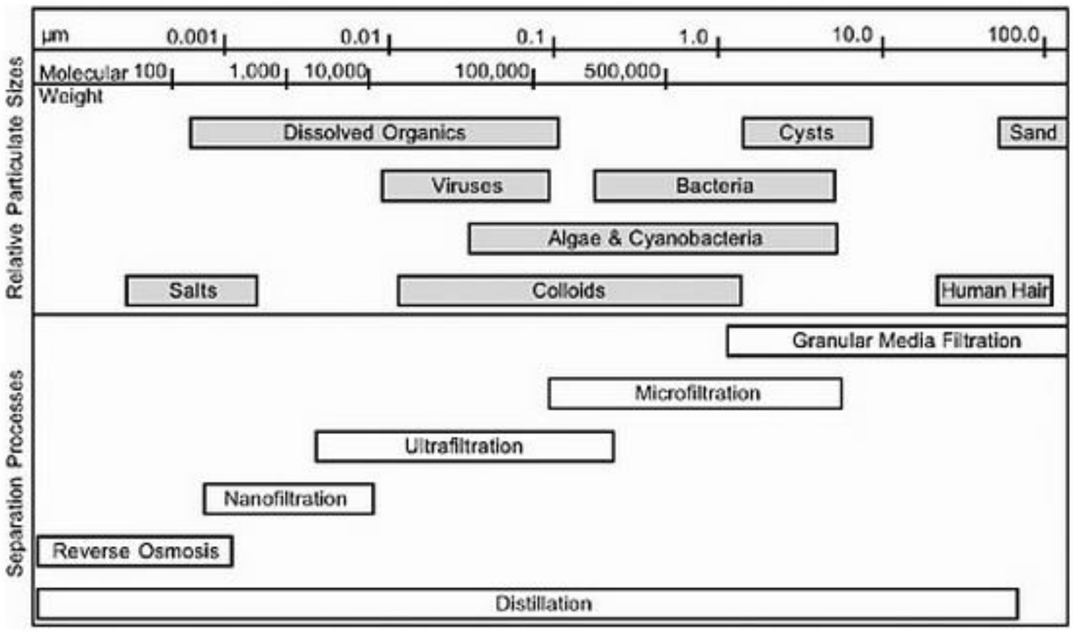


Figure 3.5 : Membrane filtration spectrum (Pankratz & Tonner, 2003).

Membrane bioreactors are the combination of a membrane and a biological reactor and they are similar to activated sludge systems, however the secondary clarification is done by a membrane module (Meuler et al., 2008). The use of this process combines the benefits of biological and physical treatments (Jefferson et al., 1999), as biological treatment is done by microorganisms in the tank while the physical separation is done by the membrane module. Aeration is needed for biological treatment and it is done by air diffusers at the bottom of the tanks.

MBRs can be installed in two ways as submerged and side stream MBRs. Submerged MBR systems require one tank and biological treatment and membrane separation occurs in the same tank as shown in Figure 3.6, however in side stream MBR systems, biologically treated water is sent to membrane module which is in another tank as shown in Figure 3.7.

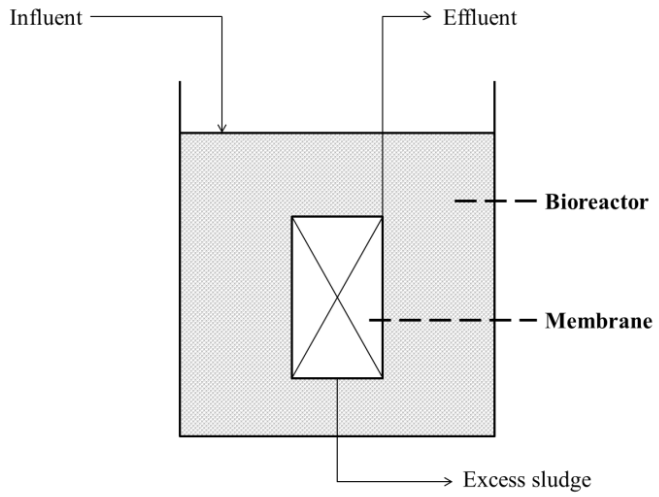


Figure 3.6 : Submerged MBR. (prepared based on Metcalf & Eddy, 2003).

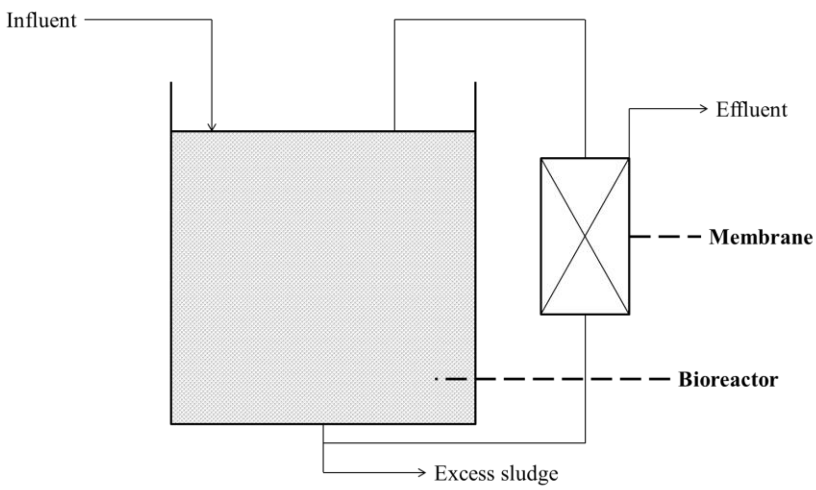


Figure 3.7 : Side stream MBR. (prepared based on Metcalf & Eddy, 2003).

MBRs are advantageous as the effluent water quality is high in terms of turbidity, suspended solids and organic matter. A typical effluent quality of an MBR, which treats domestic wastewater, is given in Table 3.8. These treatment systems may also offer disinfection depending on the pore size of membranes. They are highly preferred as their land requirement is low and can be installed in almost everywhere. However there are disadvantages such as investment cost and energy requirements. Compared to other treatment systems, investment cost of MBR is higher and due to the aeration, energy need is high which causes high operating cost. A skilled person is needed for operation of these systems. Other than that, membrane fouling is a major problem in MBR systems, which is caused by the suspended solid and sludge accumulation on the surface of membranes, causing reduced flux, reduced filtration capacity and deteriorated effluent water quality (Sarioglu, 2011).

At this time, green-building certification is gaining importance in a manner of sustainable use of water, and grey water reuse is one of those water-saving management options, highly preferred in the way of gainin points for those certification programs. Investment, operation and maintenance costs are the other area of interest due to increasing interest in grey water reuse systems.

Investment cost and operation costs of MBRs are worked in Oruçtut (2013) in detail, however the cost of pipelines required for grey water collection and reuse are not included during calculations of investment costs, as this may change depending on many things, i.e. shape of the buildings, distance to the treatment plant. Figure 3.9 illustrates the investment costs and operation costs with pay-back period for a housing site. According to Figure 3.8, in housing sites with more than 200 houses the investment cost is 190 Euro, however if the number of houses decreases the investment cost increases accordingly. Operation cost is reported as 10 Euro/house, if

Table 3.8 : Typical MBR effluent quality treating domestic wastewater (Metcalf & Eddy, 2003).

Parameter	Unit	Concentration
BOD	mg/l	<5
COD	mg/l	<30
NH_3	mg/l	<1
TN	mg/l	<10
Turbidity	NTU	<1

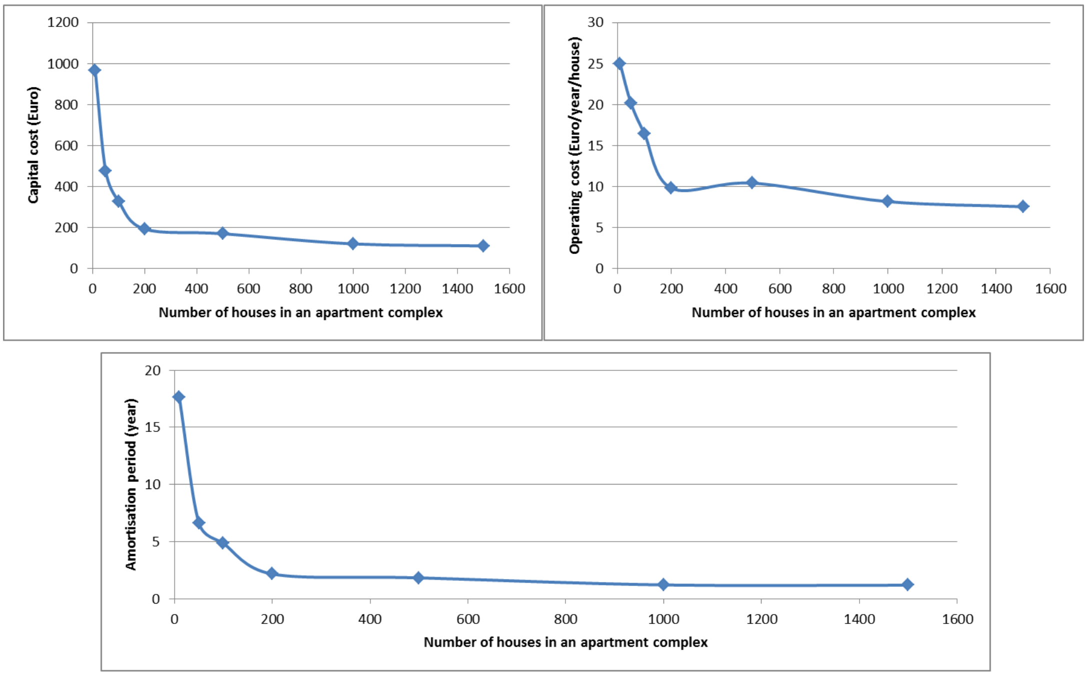


Figure 3.8 : Grey water reuse costs and pay-back period for housing sites (Oructut, 2013).

200 houses are connected to grey water reclamation system and the pay-back period is estimated as 2 or 3 years.

Operating cost and amortization period for grey water reuse systems in hotels are illustrated in Figure 3.9. In cases where 100 or more rooms in a hotel are connected to grey water treatment system, the pay-back period becomes as short as 1.5 year,

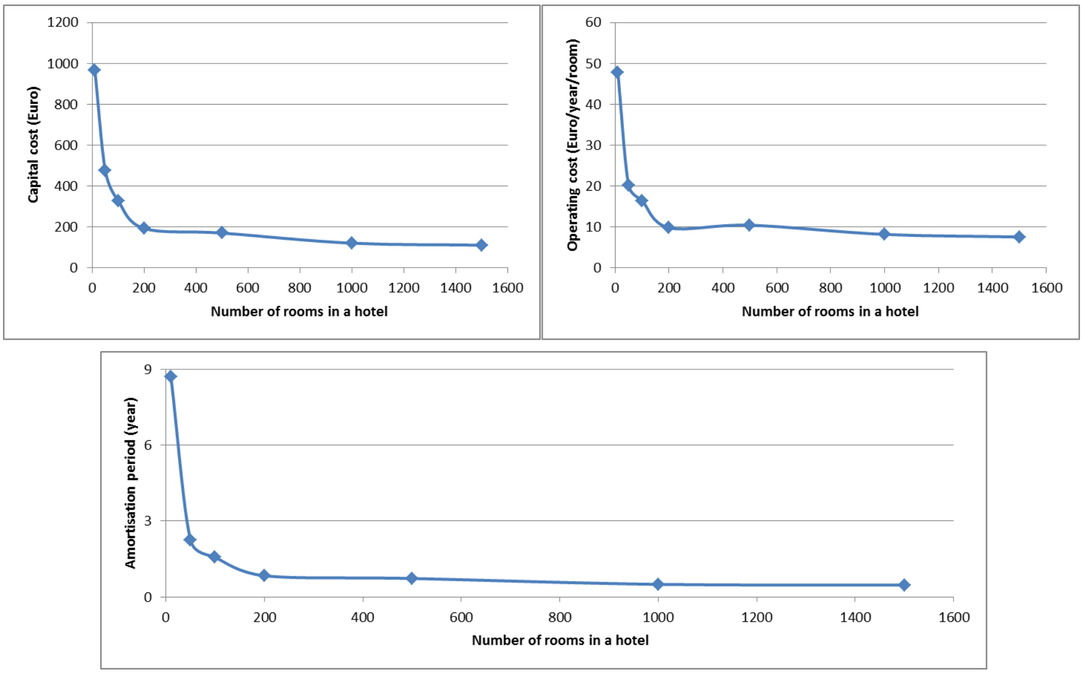


Figure 3.9 : Grey water reuse costs and pay-back period for hotels (Oructut, 2013).

while if the room number is increased to 200, period is shortened to a year only. If 200 rooms are connected to reclamation line, investment cost and operation cost are 200 Euro and 10 Euro per room in a year (Oructut, 2013).

3.3 Standards / Guidelines

Several countries publish standards and guidelines about water reuse due to increasing interest for wastewater and grey water reuse as sources of water (Oron et al., 2004). These standards and guidelines are mostly about the microbiological quality, suspended solid and organic matter content. Turbidity is another parameter that must be controlled for aesthetic reasons.

Preferrance towards wastewater reuse is highly dependent on the status of being water scarce or water stressed. Majority of present standards and guidelines belong to countries that suffer from water stress and at a technological state to reclaim used water. Grey water reuse is even rarer around the world, as stream segregation is a new concept. There is not a differentiation between treated domestic wastewater quality and treated grey water quality prior to reuse, however some countries/states do not define grey water in their regulations and do not include grey water in their domestic wastewater reuse guidelines.

Australia is one of the leader countries in grey water reuse and every state has its own plumbing code, which explains how to calculate the amount of grey water that will be generated in a household and how much of the grey water should be treated and reused for which end-use application (Australian Natural Resource Management Ministerial Council, 2006). Every state of Australia has grey water definition in their plumbing codes and the required quality for different end uses differ according to the state.

United States has a national guideline for water reuse (EPA, 2012) including grey water reuse applications, and similar to other guidelines defining grey water, this guideline suggests the same water quality for grey water and domestic wastewater after treatment. 9 of 50 states do not have any standards about grey water reuse, however all others include grey water in their plumbing codes or other regulations (Yu et al., 2013). The states without grey water definition in their plumbing codes are Indiana, Iowa, Kansas, Louisiana, Mississippi, Oklahoma, Pennsylvania, South

Carolina and Tennessee. On the other hand all the states located in the West of USA, known for suffering due to lack of water, have grey water defined in their plumbing codes. Among all the states, California is specially known for its Title 22 Recycled Water Quality (California Building Standards Commission, 2010) which makes it mandatory to use purple colored pipes that carry recycled water of all types. Asano et al. (1992) states the total reused water quantity for 1987 in California as 330 million m^3, reclaimed by more than 200 wastewater reclamation plants. However grey water definition in USA is not very clear as some states prefer to exclude kitchen wastewater, some prefer to exclude only kitchen sink or only dish washer, and some made grey water definition different in different regulations (Yu et al., 2013).

Prince Edward Island and British Columbia are the only two provinces of Canada with water reuse standards and these standards do not mention grey water systems, however there is a national guideline about wastewater reuse for toilet and urinal flushing (Federal-Provincial-Territorial Committee on Health and Environment, 2010) and this guideline includes grey water definition.

Among European Union countries, Austria, Bulgaria, Czech Republic, Denmark, Estonia, Finland, Hungary, Ireland, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Romania, Slovakia, Slovenia and Sweden are the countries without water reuse regulations (Mediterranean Wastewater Reuse Working Group, 2007). Table 3.9 shows the EU countries with regulations about water recycling. According to Figure 3.10, Spain and Italy are the countries that use large amounts of treated wastewater with 347 and 233 Mm^3/year, however other countries with water reuse standards are far behind them. Shown in Figure 3.10, Turkey is a Eurasian country that uses 2.8 Mm^3 reclaimed water in a year and has a standard about

Table 3.9 : List of EU countries with water reuse standards (prepared based on Jordi Raso, 2013 and Nolde, 2005)

Country	Standard
Cyprus	Decree no: 296/03.06.05
France	Art 24 Decret 94/469, 1994)
Germany	Betriebswassernutzung in Gebauden, 1995
Greece	JMD 145116/11
Italy	Ministerial Decree nr 152 of May 2006
Portugal	ERSAR Technical Guide nr 14: Wastewater reuse
Spain	Royal decree 1620/2007, 7th of December
UK	Water regulations advisory scheme in August 1999

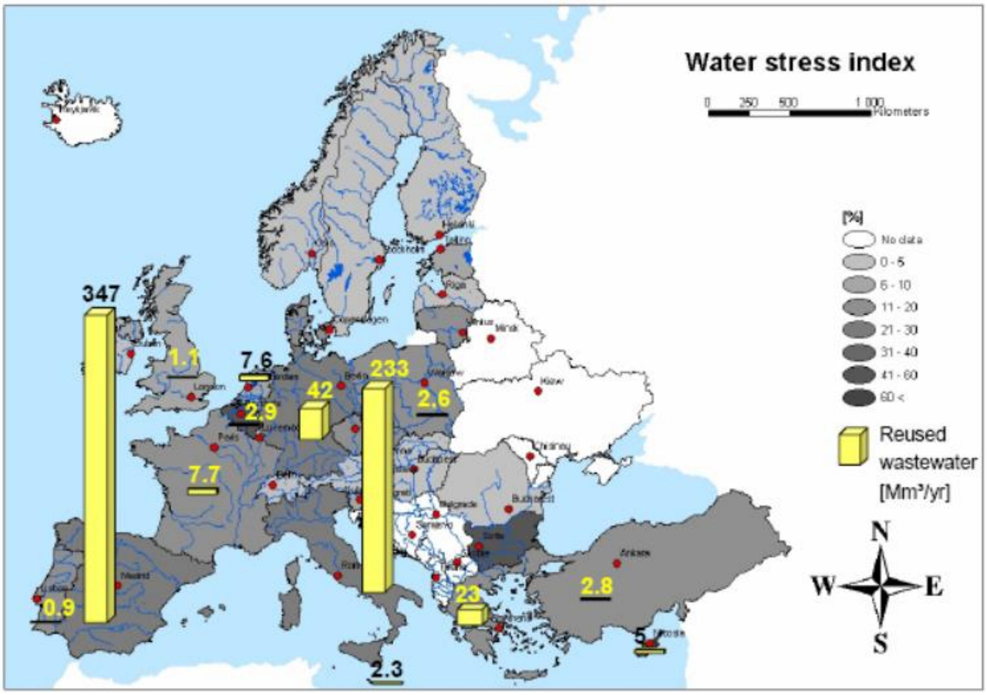


Figure 3.10 : Reused water amounts in European countries (Mediterranean Wastewater Reuse Working Group, 2007)

wastewater reuse, specifically for irrigation, however the standard does not include a definition for grey water. Located in Mediterranean region in an arid environment, Israel is the leader country in the region as it reuses 87% of its treated wastewater (Mediterranean Wastewater Reuse Working Group, 2007).

Among Middle East and North Africa countries, Jordan and Tunisia reuses 85% and 20-30% of their treated wastewater accordingly, however ratio of total reused wastewater do not exceed 2% (Mediterranean Wastewater Reuse Working Group, 2007). Egypt and Syria are two other countries that use treated wastewater for irrigation of non-food crops and landscape.

Tokyo, the capital city of Japan, is another example, as grey water reuse is mandatory for the buildings that has 30,000 m^2 area or larger, or the buildings with a capacity of recycling 100 m^3 or more (Oron et al., 2014). Singapore, China, Korea, Saudi Arabia and Kuwait are the other countries with reuse standards according to literature (Furumai, 2008; Cornel et al., 2011; Oron et al., 2014).

Most of the countries do not have a grey water reuse guidelines/standards and some of those countries have domestic wastewater reuse guidelines/standards. In such condition, domestic wastewater reuse guidelines and standards are used for recycling grey water.

Table 3.10 lists the countries and the states with standards of guidelines for grey water or domestic wastewater reuse. As it can be seen from the table, grey water has lots of end-use possibilities that require different water quality. Treated grey water which is used for irrigation of a playground should not contain any pathogens, however it is questionable if the treated grey water needs to have that high a quality for toilet flushing. In the case of Turkey, a grey water definition is not given in the standards about recycling used water, however as can be seen from Table 3.10 there are different standards for restricted and unrestricted reuse applications. If the reused water is used for irrigation of fruit and vegetables that are eaten raw, no fecal coliforms must be detected and the BOD_5 concentration must be below 20 mg/l. Fecal coliform concentration can go up to 200 per 100 ml and BOD_5 concentration can be 30 mg/l in cases where irrigation is done in restricted areas and possibility of human contact is low. Turbidity must not exceed 2 NTU and minimum chlorine concentration must be 1 mg/l for two types of reuse applications.

Table 3.10 : Grey water or domestic wastewater reuse standards around the world.

	BOD	**TSS**	**pH**	**Tur**	**Cl^-**	**Total Coliform**	**Fecal Coliform**	**E.Coli**	**Reuse Application**
	mg/l			NTU	mg/l	cfu/100 ml			
WHO, 2006[1]	10	10				10			Toilet reservoir
	20	10				200			Fruits and vegetables eaten raw
	240	140				1000			Ornamental pools, fruits and vegetables
Queensland, Australia[2]	10	10	6.5-8.5	1	0.2-1.0			1	Toiler reservoir, laundry, vehicle washing, cleaning
	10	10	6.5-8.5	5				1	Surface irrigation
	20	30						10	Drip irrigation
Victoria, Australia[3]					Not permitted				Toilet reservoir, laundry, surface irrigation
	20	30							Subsurface irrigation
Western Australia, Australia[4]	10	10	6.5-8.5	1	0.2-1.0			1	Toiler reservoir, laundry
	20	30						10	Irrigation
New South Wales, Australia[5]	20	30						10	Toiler reservoir, laundry
	20	30						30	Surface irrigation
Berlin, Germany[6]	5				<1	10			Service water
Arizona, USA[7]						800			Fruits and vegetables eaten raw
California, USA[8]				2	<5	23			Urban use
						240			Fruits and vegetables eaten raw
Florida, USA[9]	20	5					25		Urban use
							800		Fruits and vegetables eaten raw
Georgia, USA[10]	5	5	6-9	2			23		Irrigation, vehicle washing
Hawaii, USA[11]				2			23		Urban use, fruits and vegetables eaten raw

Table 3.10 (continued) : Grey water or domestic wastewater reuse standards around the world.

	BOD	TSS	pH	Tur	Cl-	Total Coliform	Fecal Coliform	E.Coli	Reuse Application
	mg/l			NTU	mg/l	cfu/100 ml			
Massachusetts, USA[12]	10	5	6-9	2	≥1		14		Irrigation
	30	10	6-9	5			100		Urban use, toilet reservoir
Nevada, USA[13]	30						23		Urban use
	30						400		Fruits and vegetables eaten raw
New Jersey, USA[13]		5		2	≥1		14		Irrigation, vehicle washing
Texas, USA[14]	5			3			75		Urban use, fruits and vegetables eaten raw
	20			5			800		Subsurface irrigation
Washington, USA[15]	30	30		2		23			Urban use
	30	30		2		240			Fruits and vegetables eaten raw
Wisconsin, USA[13]	10	5	6-9				0		Irrigation
	30	30					200		Urban use
China[13]	15			10	≥0,2		100		Toilet reservoir
				20	≥0,2		100		Spray irrigation
	15			5	≥0,2		3		Garden watering
Cyprus[16]				20			50		Irrigation
				5			200		Fruits and vegetables eaten raw
UK[17]			5 - 9,5	10	<2	10			Spray irrigation, laundry, vehicle washing
			5 - 9,5	10	<2	1000			Toilet reservoir
			5 - 9,5		<0,5	1000			Garden watering
Spain[13]							200		Irrigation
							1000		Fruits and vegetables eaten raw

Table 3.10 (continued) : Grey water or domestic wastewater reuse standards around the world.

	BOD	TSS	pH	Tur	Cl-	Total Coliform	Fecal Coliform	E.Coli	Reuse Application
	mg/l			NTU	mg/l		cfu/100 ml		
Israel[13]	15	15			≤0,5	3			Fruits and vegetables eaten raw
	35	30			≤0,15	250			Fruits and vegetables eaten cooked
Japan[18]			5,8-8.6		≥0,4				Irrigation
			5,8-8.6			1000			Toilet reservoir
	≤10		5,8-8.6	≤10					Urban use
Korea[13]	10		5,8-8.5	5		10			Toilet reservoir
	10		5,8-8.5	5					Spray irrigation
	10		5,8-8.5	10					Garden watering
Kuwait[13]	10	10			≥1	100			Fruits and vegetables eaten raw
Saudi Arabia[13]	10	10	6-8,4			3			Urban use
Turkey[19]	20		6-9	2	>1		0		Fruits and vegetables eaten raw
	30	30	6-9	2	>1		200		Fruits and vegetables eaten cooked, meadow, restricted

(1) WHO, 2006. (2) Queensland Plumbing and Wastewater Code, 2011. (3) Victoria EPA, 2013. (4) Western Australia Department of Health 2010 (5) New South Wales Department of Energy, Utilities and Sustainability, 2008. (6) Nolde, 1996. (7) OASIS, 2002. (8) State of California, 2000. (9) State of Florida, 1998. (10) State of Georgia, 2009. (11) Hawaii Department of Health, 1991. (12) State of Massachusetts, 2009. (13) Canada Mortgage Housing and Corporation, 2005. (14) Texas Commision on Environmental Quality, 2005. (15) Washington State Building Code Council, 2007. (16) Oron et al., 2014. (17) BS-8525-1, 2010. (18) Ogoshi et al., 2001. (19) Water Quality Control Regulation, 2004)

4. EXPERIMENTAL WORK

The aim of this work is to characterize grey water, an important renewable water source that may be returned to almost any point in the water cycle not involved with ingestion, following a simpler treatment in comparison to the conventional one, and to evaluate how grey water could be used after treatment. To serve this purpose, two different raw grey water samples and treatment plant effluents were monitored. Characterization of grey water was done in a continuous and systematic monitoring program in one of the two systems for a year to serve this purpose, to enable a comparison of grey water quality in all seasons. Following characterization and evaluation of treatment system efficiencies, sand filtration and membrane filtration were tested in lab-scale and the effluent quality was compared with the real- scale treatment systems, which were both MBR systems. As both grey water management systems use treated grey water for toilet flushing, one of the systems was monitored for microbiological quality, to see how the pathogenic indicator concentrations change througout the reuse system, and in reservoir. Also due to the possible end-use application of grey water as irrigational water, the effluent of one of the treatment plants was used for irrigation of pepper plant, enabling a comparison between the effects of tap water and treated grey water on plant growth. As grey water was used for toilet flushing after being treated, pathogenic indicators were monitored in one of the grey water cycle.

4.1 Study Area

During this work two different grey water systems were analyzed in terms of raw grey water and treated grey water quality. The first one was a hotel, the main study area, segregating bath/shower and wash basin grey water, which is also called light grey water, and after treatment, reusing it in flushes and irrigation. The second building was a university student residence hall, where grey water was being collected from the same sources as the hotel and returned to flush water. Both the buildings were built in Istanbul, Turkey.

4.1.1 Hotel

The hotel consists of 499 rooms and a big garden, which is a very large green area compared to other hotels located in the same city. When built, the hotel did not have the pipelines needed for grey water collection and reuse, however segregated collection of grey water and a pipeline for reuse were built with a renovation of the building. At this time the hotel collects grey water from half of the rooms.

Grey water reclamation and reuse line in the hotel is shown in Figure 4.1. Grey water is collected in a tank before being pumped into the treatment system and through pumping it is transferred to an equalization tank in order to balance fluctuating loadings and flows. Equalized grey water is pumped once more and enters membrane bioreactor after being screened by a core screen, which retains the large materials, delays clogging of membranes and protects the membranes from being damaged. The membrane bioreactor used for grey water reclamation is a submerged system and biological treatment and filtration occurs in the same tank. Grey water is disinfected first with chlorination, then with UV after it is treated in MBR. Raw grey water sampled just before the coarse screen placed before MBR tank and treated grey water was sampled at the effluent of MBR as shown in Figure 4.1.

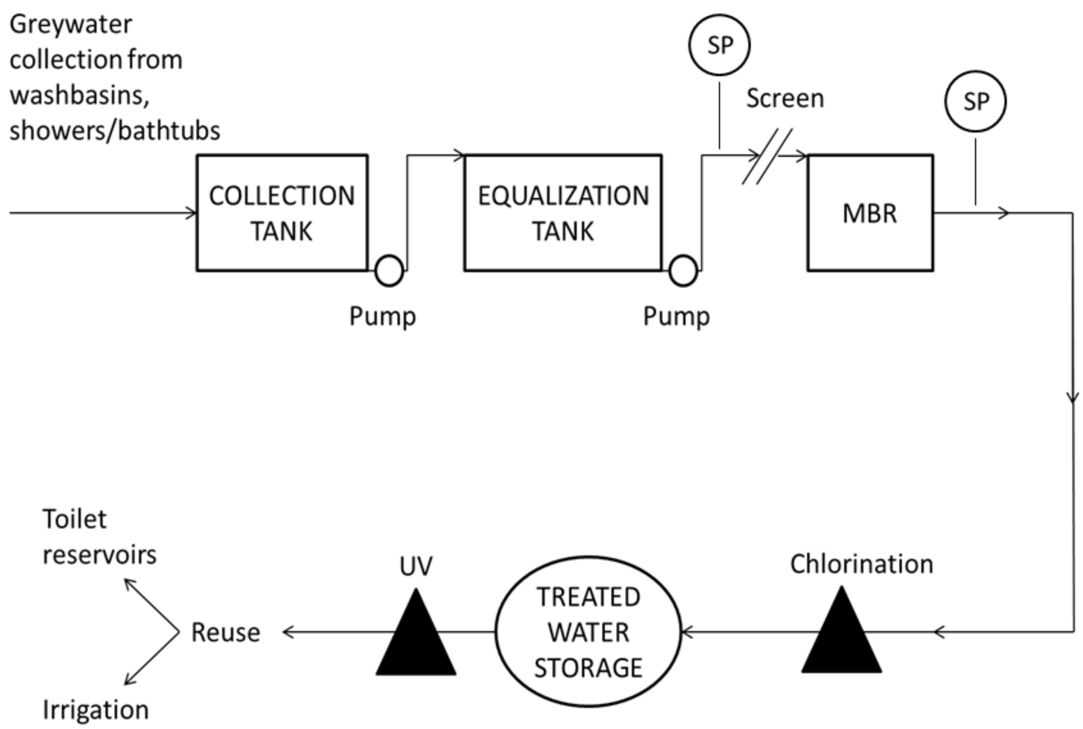


Figure 4.1 : Grey water collection / treatment / reuse in the hotel.

Treated grey water is reused for toilet flushing during winter, however the water need for irrigation of garden increases as summer arrives, so that grey water is used for garden irrigation between May and October. When grey water is not enough for any of these purposes, tap water is used for meeting the entire demand.

4.1.2 University student residence hall

The university student residence hall is located in Kadiköy and is owned by Kadiköy Municipalty in Istanbul and named as Aysel-Abdullah Öğücü Residence Hall. The building serves girls only and has a capacity of 232 students with 77 rooms. When first built, the building didn’t have grey water treatment system and pipelines required for collecting and reusing grey water, however to make a good example for other buildings, it was built by Kadiköy Municipality. Grey water treatment system is built at the basement and receives grey water from bath/showers and wash basins from all rooms.

Grey water management system in student residence hall is shown in Figure 4.2. At this building, treated grey water is used only for toilet flushing. Grey water is collected in a tank that also serves the equalization purpose and then it is pumped through a coarse screen prior to the MBR. Effluent of MBR is collected in a treated water storage tank, where a tap water intake is also available; as sometimes the amount treated grey water is not sufficient to cover the flush water need and the gap is made up for tap water usage. The samples analyzed were taken from the outlet of grey water collection tank to be able to see how the quality changes within the treatment system for raw water samples and the effluent was also monitored to evaluate system performance. The points that samples were taken from are shown in Figure 4.2 with SP.

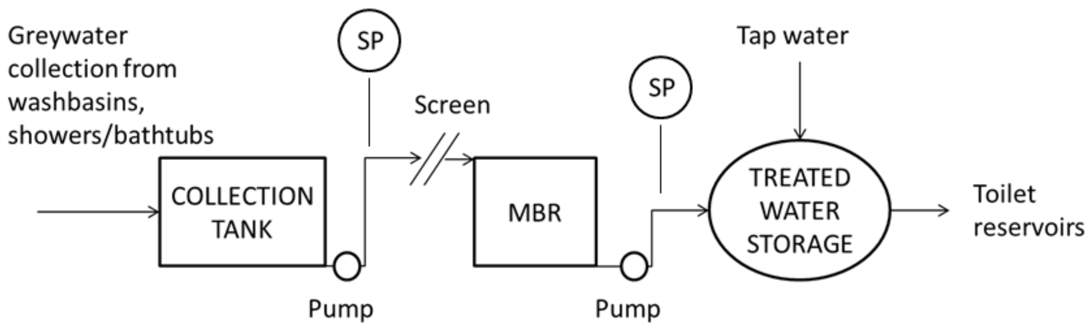


Figure 4.2 : Grey water management system in student residence hall.

4.2 Methods Used for Analyzes

Chemical Oxygen Demand (COD), soluble Chemical Oxygen Demand (sCOD), Biochemical Oxygen Demand (BOD), soluble Biochemical Oxygen Demand (sBOD), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Total Kjeldahl Nitrogen (TKN), Ammonia (NH_3-N), Total Phosphorus (TP) and Orthophosphate (PO_4-P) are the parameters used for the characterization in terms of physicochemical properties and the methods used are given in Table 4.1. During membrane filtration trials, TOC was measured on a Shimadzu VPCN analyzer (Japan) equipped with an auto-sampler by catalytic oxidative combustion at 680 °C.

Microbiological quality is monitored in terms of Total Coliforms and Fecal Coliforms as these indicators are being used for a long time as the common parameters. Additionally, E.Coli and Enterococci indicator microorganisms are used as use of these indicators are suggested by USEPA (1997) and WHO (1999). The analyses were carried on according to ISO 8199 Water Quality - General guidance on numeration of microorganisms by culture with membrane filtration technique.

Table 4.1 : Standard methods used for physicochemical parameters.

Parameter	Standard Method
COD-sCOD	ISO 6060: 1989 Water Quality – Determination of the Chemical Oxygen Demand
BOD_5-$sBOD_5$	Standard Methods for the Examination of Water and Wastewater, 5210 Biochemical Oxygen Demand, 5210 B. 5-Day BOD Test
TSS	Standard Methods for the Examination of Water and Wastewater, 2540 Solids, 2540 D. Total Suspended Solids Dried at 103-105 ^{0}C
VSS	Standard Methods for the Examination of Water and Wastewater, 2540 Solids, 2540 E. Fixed and Volatile Solids Ignited at 550 ^{0}C
TKN	Standard Methods for the Examination of Water and Wastewater, 4500-Norg Niitrogen (Organic), 4500-Norg B. Macro Kjeldahl Method
NH_3-N	Standard Methods for the Examination of Water and Wastewater, 4500-NH_3 Nitrogen (Ammonia), 4500-NH_3 D. Ammonia-Selective Electrode Method
TP	Standard Methods for the Examination of Water and Wastewater, 4500-P Phosphorus, 4500-P D. Stannous Chloride Method
PO_4-P	Standard Methods for the Examination of Water and Wastewater, 4500-P Phosphorus, 4500-P D. Stannous Chloride Method

Ready to use disposable nutrient pads were used during analyses and all samples were taken into sterilized bottles in order to prevent contamination. All samples are worked with three different dilutions and in duplicate. Duration and temperature of incubation and nutrient pads used for indicator organisms are given in Table 4.2.

Table 4.2 : Details of microbiological analyses.

Indicator microorganism	Nutrient pad	Incubation temperature	Incubation duration
Total Coliform	Endo	38 ^{0}C	24 hour
Fecal Coliform	mFC	45 ^{0}C	24 hour
E.Coli	Tergitol TTC	45 ^{0}C	24 hour
Enterococci	Azide	45 ^{0}C	24 hour

4.3 Experimental Plan

Experimental work was carried out in three main groups as;

- Continuous and systematic characterization of grey water in the hotel with a year-round monitoring and additionally sampling of grey water in a student residence hall,
- Monitoring of treatment plants in the hotel and student residence hall in terms of effluent quality, and
- Monitoring of microbiological indicator throughout the grey water cycle and in toilet reservoir in the hotel.

In addition to those groups,

- Preliminary investigations about sand filtration and membrane filtration of grey water, and
- Preliminary trials of irrigation with treated grey water on pepper plants

were carried out.

4.3.1 Sampling of grey water

Grey water characteristics were investigated in two buildings that were used for different functions for the purpose of comparison. During this work, a hotel and a university student residence hall grey water were analyzed.

4.3.1.1 Hotel

Hotel was the main study area, and a systematic monitoring was needed to determine the changes in grey water quality in the hotel, so that a one-year monitoring program was prepared. According to this program, it is decided that three types of sampling should be done which are defined as routine samples, week long samples and day long samples.

- Routine samples: Samples which are taken every week on Thursday, between 9 a.m. and 10 a.m., to observe the changes in grey water quality in different seasons.
- Week-long samples: Samples taken to observe how the grey water quality changes in different days of the week and in different seasons, done during 7 days of a week once in every season.
- Day-long samples: Samples taken for every 2 hours for 24 hours in a day to monitor how the quality changes during a day.

During sampling of grey water for a year, system went under maintenance two times, in October 2013 and in May 2015. Before the maintenance both raw grey water and treated grey water quality deteriorated. The reason for the higher pollution potential at the influent is that there was an overflow pipe from the MBR to the raw grey water collection tank and as the capacity of MBR decreased due to problems being observed, this pipeline serves to transfer the water contacted with activated slugde in MBR reactor to raw grey water collection tank.

4.3.1.2 University student residence hall

Grey water quality in student residence hall is analyzed with two samples in March 2014 and once in a month in April, May, June, November and December 2014. During July, August and September, 2014, almost all rooms were empty as the universities were in vacation and sampling could not be done. Sampling could not be done during October, 2014 as the system was in maintenance.

4.3.2 Monitoring of grey water treatment plants

Both treatment plants, where raw grey water streams sampled, analyzed and characterized, were MBR systems that combine biological treatment with membrane filtration. Sampling of outflow of MBRs were done for determining the treatment efficiencies.

4.3.3 Tracking and monitoring microbiological indicators

On this group of work, pathogenic indicator concentrations in grey water were analyzed in every possible step of the treatment and reuse system. Sampling points used are shown in Figure 4.3. As treated grey water was used for toilet flushing during winter months in the hotel, one of many toilet reservoirs which flushed with treated grey water was monitored for 9 days. The aim of this monitoring was to see any possible increase in concentrations of different pathogenic indicators, if the toilet was not flushed for many days. To follow that, a reservoir was not flushed for 9 days and sampling was done in day 1, 2, 3, 7 and 9.

With this group of experimental work, change in parhogenic indicator in grey water among the grey water cycle was investigated.

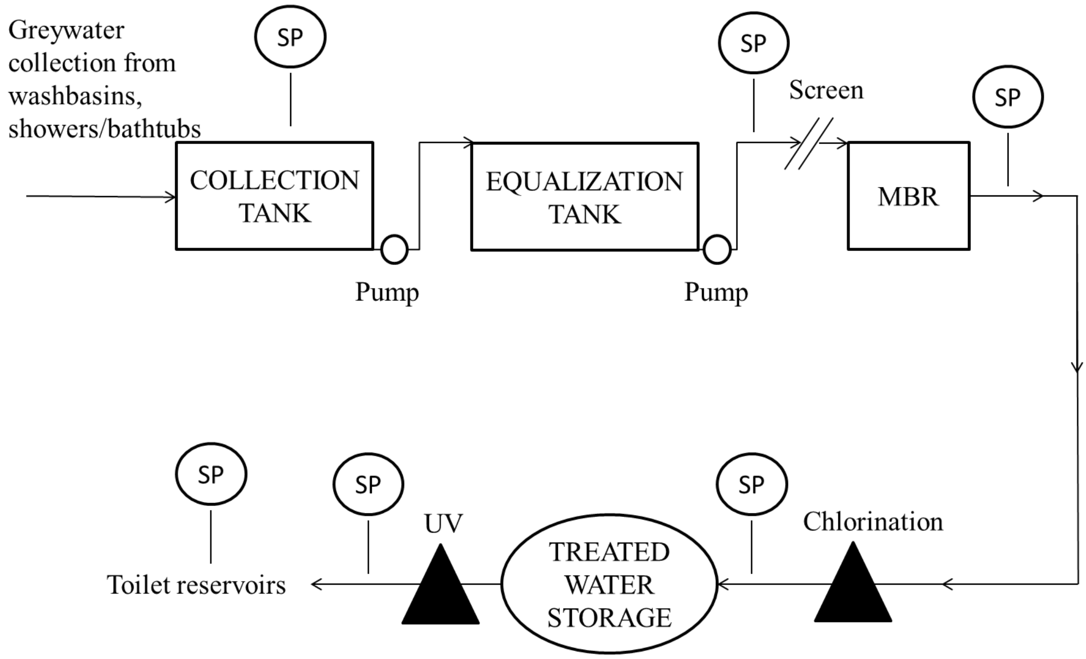


Figure 4.3 : Sampling points for pathogenic indicator monitoring.

4.3.4 Preliminary physical treatment trials

Due to the results obtained from characterization of grey water, trial of physicochemical treatment systems gained importance. According to the biodegradability of organic matter in grey water streams which were analyzed, need for biological treatment became questionable, so that sand filtration and membrane filtration treatment processes were tried in lab-scale.

Sand filtration and membrane filtration were the two processes that were tried.

4.3.4.1 Sand filter

For sand filtration, a Plexiglas column with 4.4 cm diameter and 1 m length was used. Diameter of the sand used was chosen as 0.8-1.0 cm, which is 40 times smaller than the column diameter, to prevent surface tension effect. The column was filled with 84.5 cm of sand which weighted 2.386 kg. The column was operated down-flow with 150 ml/min flow to be able to obtain fast sand filter requirements.

4.3.4.2 Membrane filtration

Membrane filtration unit is shown in Figure 4.4. The pressure was adjusted to 1.5 Bar. The effluent of membrane filtration unit is collected in a beaker and is weighted periodically during membrane filtration. The aim of weighing was to see how the flux changes during filtration and how much water was treated.

Figure 4.4 : Membrane filtration unit, the weighing device and the computer saving weight periodically for flux measurements.

Both laboratory manufactured and commercial ultrafiltration membranes were used during this work. This also enabled the comparison of the membranes manufactured in the laboratory to commercial ones. The pore size of membranes commercially available were 30 kDa. On the other hand the pore sizes of the membranes manufactured in laboratory were not analyzed, however membranes chosen by comparing distilled water flux of the manufactured membranes with commercially available ones.

4.3.5 Preliminary plant trials

The aim of plant trials was to see if there is a positive or negative effect of irrigation with treated grey water. Pepper plant was chosen as it grows fast and the trials were carried out outside in summer 2014. All plants were bought from the same greenhouse claiming all the seeds of the plants were coming from the same type of pepper.

During plant trials, flowerpots of same type with 2.5 liters volume were used. 800 grams of soil was added to all of the pots and one seedling was added to one pot. Four pots were left without addition of fertilizers for controlling purposes. A total of 20 seedlings were planted.

Commercial NPK 20-20-20 and struvite, loaded clinoptilolite and both, which were produced in laboratory by EcoSan Research Group in ITU by recovery of plant nutrients from separately collected human urine were used as fertilizers. These fertilizers were produced through different methods (Dogan, 2015).

Fertilizers were added to the pots in the amount to be equal to each other in terms of nitrogen and phosphorus to make it possible to compare the plants and nutrients with each other. The amount of nutrients added are given in Table 4.3. Every type of

Table 4.3 : Pot numbers according to content, type of irrigation water used and nutrient amounts.

Pot content	Tap water	Grey water	Nutrients
Control	1-2	3-4	None
NPK 20-20-20	5-6	7-8	250 mg NPK 20-20-20
Struvite	9-10	11-12	196.3 mg struvite
Clinoptilolite	13-14	15-16	7 g clinoptilolite
Struvite and clinoptilolite	17-18	19-20	181 mg struvite and 5.5 mg clinoptilolite

planting was done in two pots. A photograph is given in Figure 4.5 that shows the situation of the pepper plants the day after plantation.

Figure 4.5 : First day after plantation of pepper seedlings.

5. RESULTS AND DISCUSSION

The aim of this work is to make a characterization work about grey water and monitoring two different MBR systems that treat grey water. Also microbiological analyses and plant trials were done. Sand filtration and membrane filtration processes were tried for removal of pollutants from grey water.

5.1 Characterization of Grey Water

Characterization of grey water was obtained with a work of a year. The main study area was a hotel, however a student residence hall was monitored when possible.

5.1.1 Hotel

The hotel was the main study area and the characterization work is defined under physical and chemical parameters and microbiological indicators.

5.1.1.1 Physical and chemical parameters

The analyzes of grey water generated from the hotel were planned to make it possible to see if there was any change in grey water quality during changing seasons. Grey water sampling in the hotel was carried out for a year with three types of samples which were called routine samples, week-long samples and day-long samples. Routine samples were taken every Thursday between 9 a.m. and 10 a.m. for a year, to be able to see if the grey water quality changed under different seasonal factors. Week-long sampling was the sampling work done in everyday of a week once in every season for a year and the aim of week-long sampling was to see if the grey water quality changes during weekdays and weekends. Day-long sampling was done with an auto-sampler taking 24 samples a day and this work was carried only once for characterization. Day-long sampling aimed to see if the quality changed during a day.

Routine sampling

Results of routine sampling analyses are depicted in Figure 5.1-5.4 and they are summarized in Table 5.1.

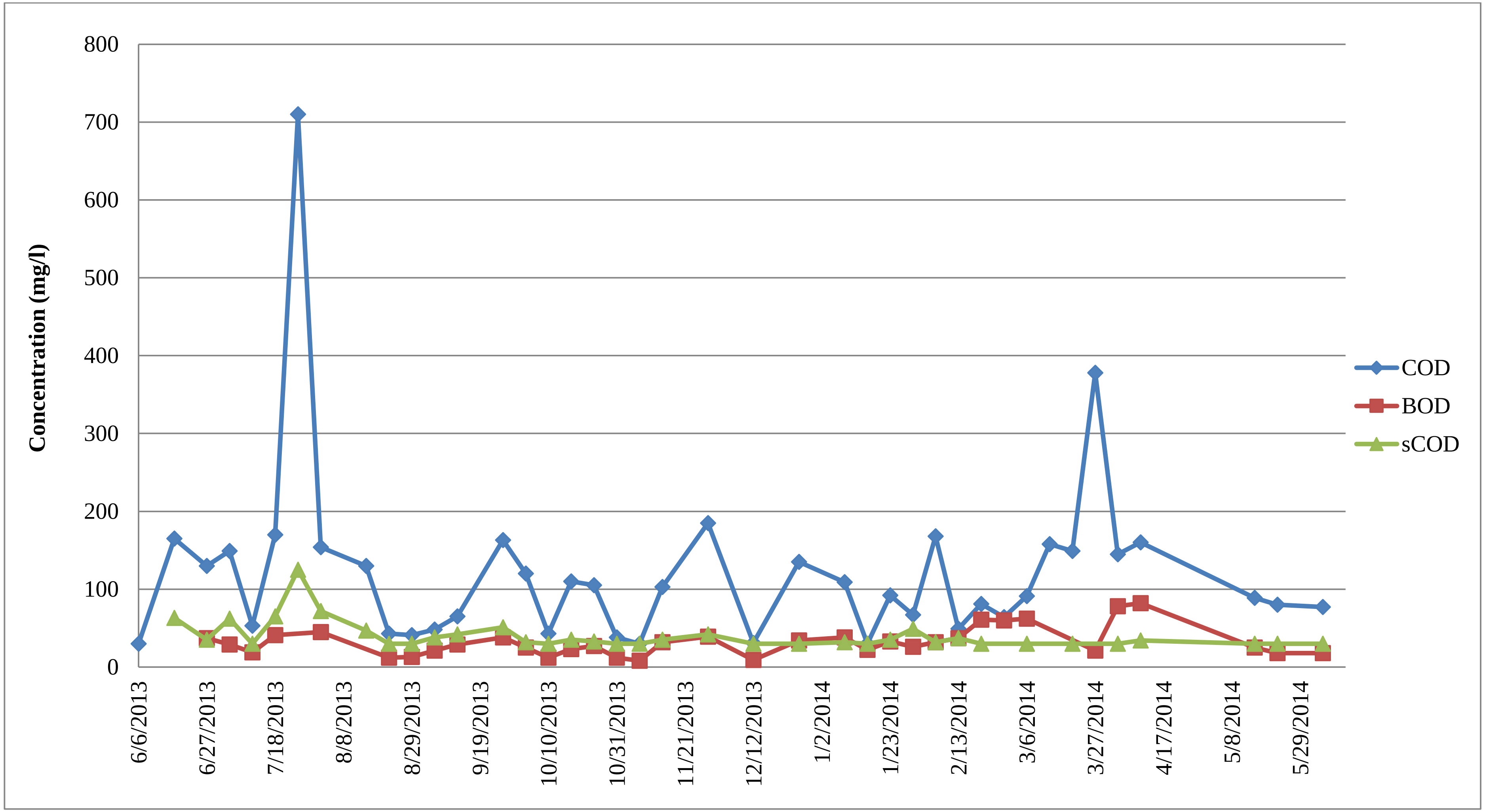


Figure 5.1 : Organic matter concentrations tracked routinely.

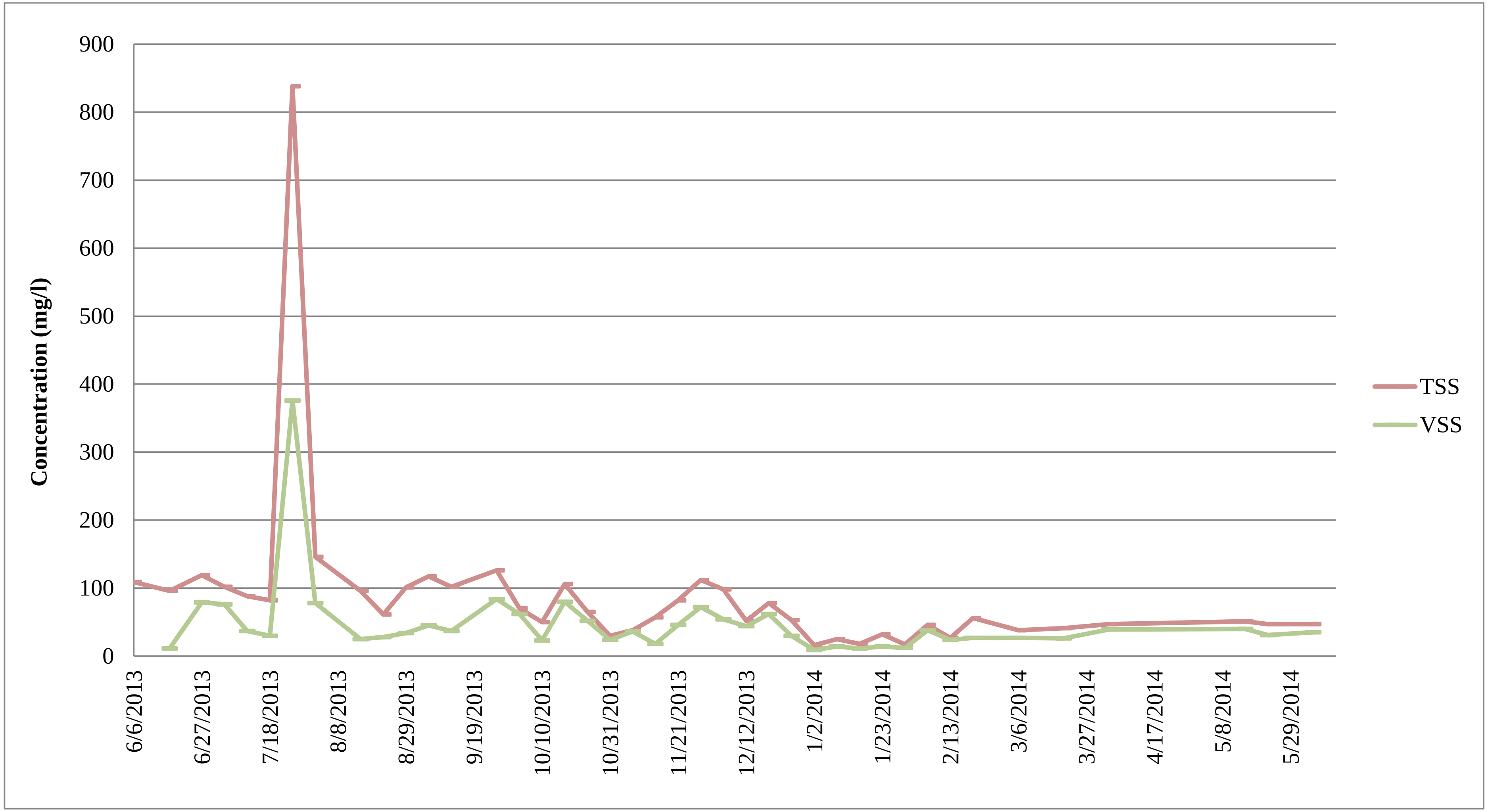


Figure 5.2 : Suspended solids concentrations tracked routine.

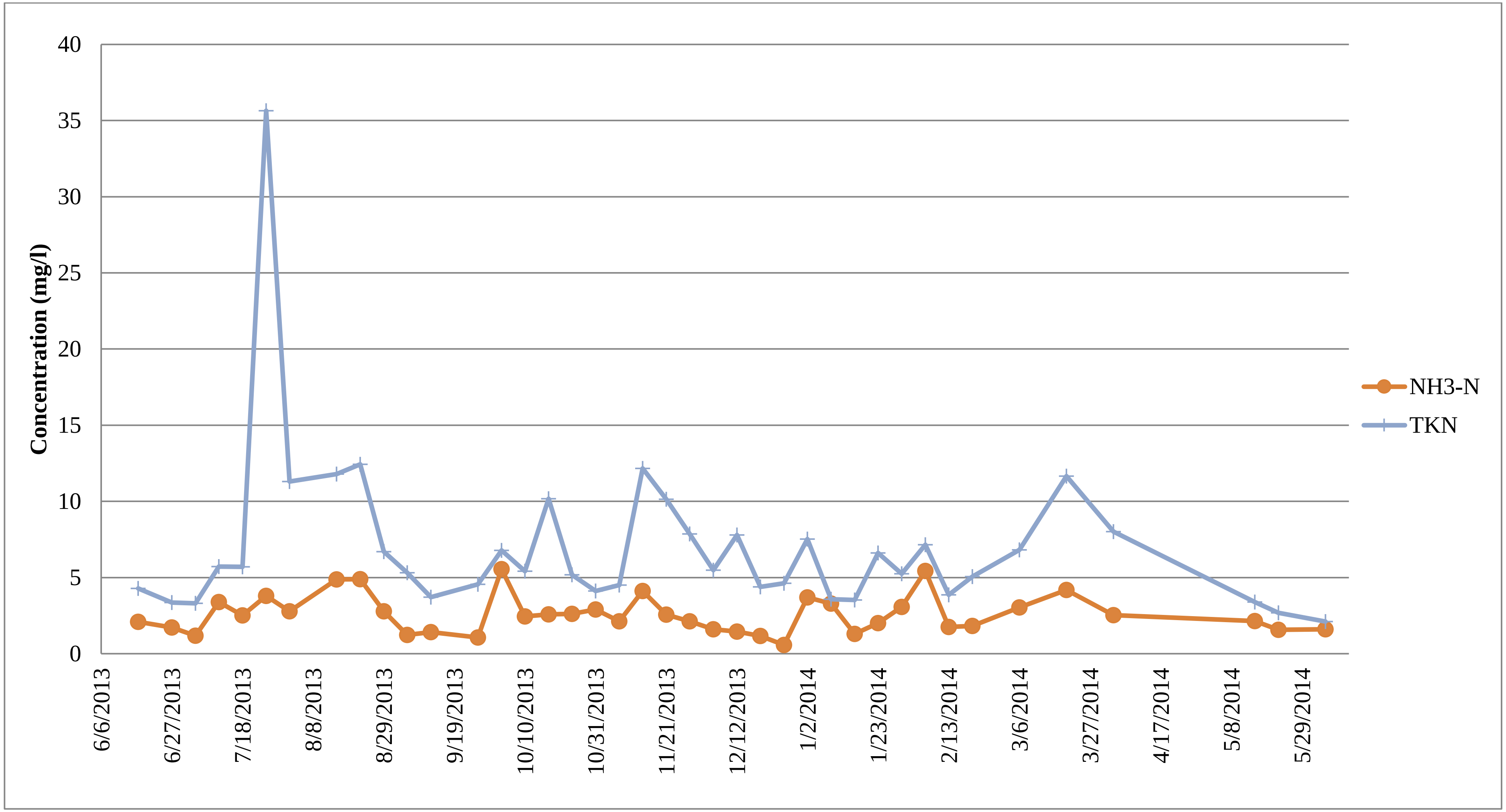


Figure 5.3 : Nitrogen concentrations tracked routinely.

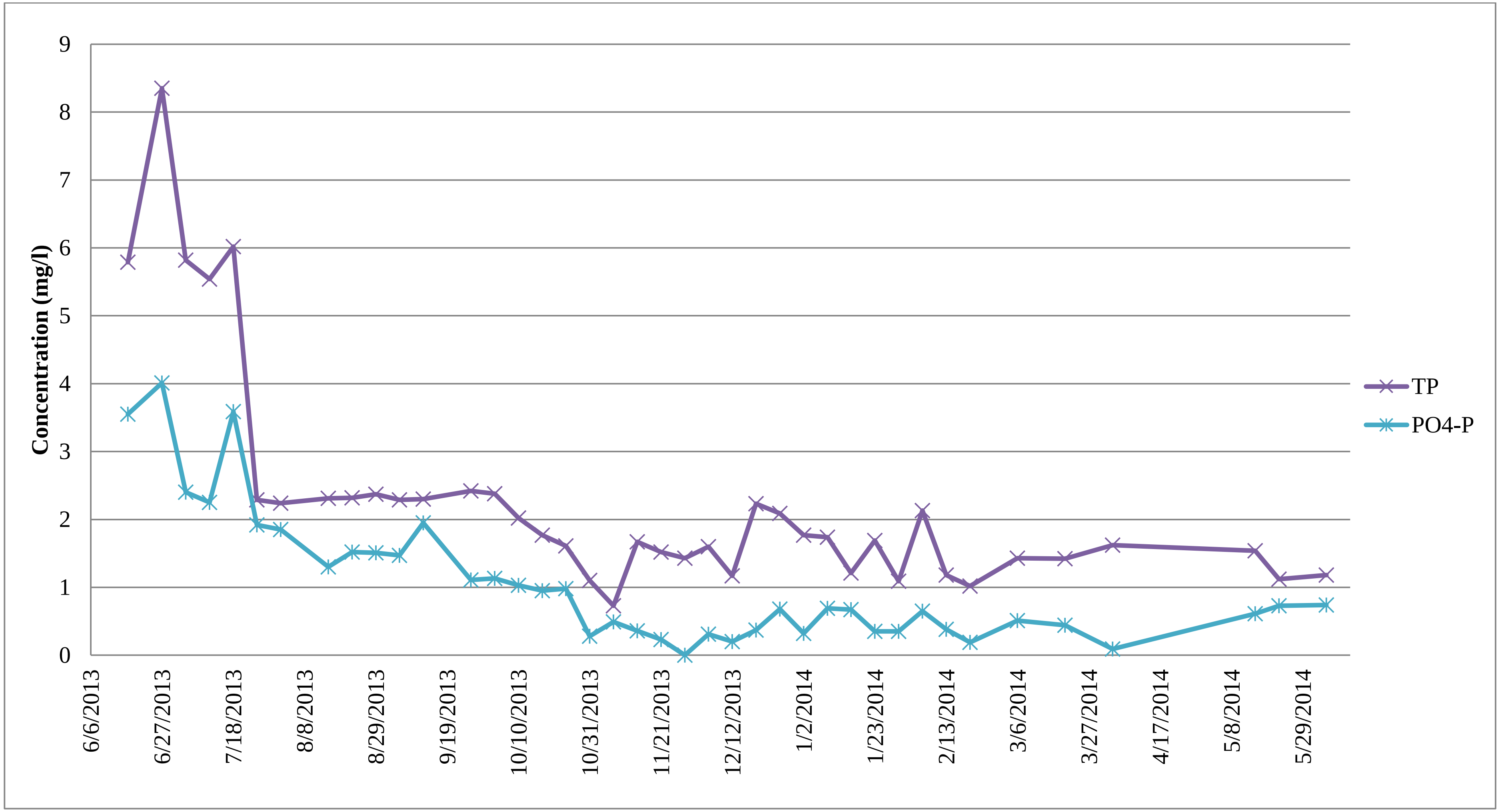


Figure 5.4 : Phosphorus concentrations tracked routinely.

Table 5.1 : Summary of routine grey water monitoring results.

	COD	sCOD	BOD_5	TSS	VSS	TKN	NH_3-N	TP	PO_4-P
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	<30	<30	8	16	9	2.11	0.58	0.73	0
Max	710	125	82	838	376	35.65	5.55	8.35	4.01
Mean	125	40	32	87	47	6.99	2.58	2.29	1.05

Grey water samples taken from equalization tank routinely had exhibited low pollution potential in terms of organic matter as shown in Figure 5.1. For COD and sCOD the minimum detection limit was 30 mg/l as stated in ISO 6060, therefore lower concentrations are shown as 30 mg/l in the figure.

During a year, only 2 out of 41 samples showed concentrations more than 200 mg/l in terms of COD, which were taken in July 25, 2013 and March 27, 2014 with 710 and 378 mg/l respectively, which were considered as off-points. Soluble COD was tested for the same samples and the highest concentration was 125 mg/l, which belongs to the sample taken in July 25, 2013 that showed the highest COD concentration. Except for that sample, all the samples showed concentrations that are lower than 80 mg/l in term of sCOD, while sCOD concentrations of 15 samples out of 40 were lower than 30 mg/l test limit. BOD tests for the same samples gave 82 mg/l at maximum and 8 mg/l at minimum. The mean concentrations in terms of COD, sCOD and BOD were calculated as 125, 40 and 32 mg/l respectively as shown in Table 5.1, which states 64% of organic matter is not biodegradable under BOD_5 test conditions, while 71% of organic matter is in particular form.

A year-round monitoring of grey water was not encountered among the literature work reviewed and literature data is limited about grey water characterization in hotels. Two pieces of work are encountered in the literature about characteristics of bath/shower and wash basin grey water generated in the hotel. According to those papers, COD concentrations for the same grey water fraction are given as 171 and 72 mg/l by March et al. (2005) and Gual et al. (2008) respectively. The COD analyses done in this work are in correspondence with those papers. However, these work do not state a BOD_5 concentration for this fraction and therefore the BOD_5/COD ratio is unknown in these papers, which disenables a complete comparison to this study, in terms of organic matter. Also, sCOD is not investigated in any of those works.

There are other pieces of work about the same grey water fraction generated from building with different functions such as house and student residence hall as shown in Table 3.1 and Appendix A. If this study is compared to the study about house grey water for the same fraction, organic matter concentrations are similar, however the BOD_5/COD ratio is lower than it is stated for house grey water, as shown in Table 3.2.

If the literature work given in Appendix A about bath/shower and wash basin grey water in student residence halls are compared to this study, two of those for residence hall showed lower pollution potential in terms of organic matter (Birks & Hills, 2007; Winward et al., 2008), while another work shows higher pollution potential (Friedler et al., 2008). Work of Kadewa et al. (2010) shows similar organic matter content with this study as COD and BOD_5 concentrations are given as 151 and 44 mg/l respectively, also the BOD_5/COD ratio is comparable as it is calculated as 29% for the same work.

TSS concentrations of grey water samples taken from the equalization tank in routine basis were under 150 mg/l except for 1 sample that showed 838 mg/l TSS concentration at the day the COD concentration was the highest, as shown in Figure 5.2. Maximum VSS concentration 376 mg/l was also seen in the same day, however other 40 samples showed concentrations lower than 100 mg/l. Minimum concentrations were 16 and 9 in terms of TSS and VSS respectively. Mean values for TSS and VSS concentrations were 87 and 47 mg/l, showing that 54% of suspended solids were volatile / organic. The extreme VSS concentration seen in July 25, 2013 is in accordance with the organic matter concentrations for the same day, as the VSS concentration, which indicates organic content, increases with increasing COD.

March et al. (2005) and Gual et al. (2008) report 44 and 32 mg/l TSS concentration for the same fraction of grey water generated from building with same function respectively. Average TSS concentration in this work was calculated higher than those work as 87 mg/l, however none of these concentrations are high. Those pieces of work do not state any VSS concentration, resulting with unknown organic suspended solid ratio in TSS.

Also from Appendix A, it is clearly seen that the TSS concentrations of bath/shower and wash basin fraction are highly variable for houses and student residence halls investigated. Average TSS concentration calculated in this work is sometimes comparable to those work, however it may also be higher or lower than the reported data.

NH_3-N and TKN variations during a year are shown in Figure 5.3. The results reveal that there are 2 samples out of 40 showing higher concentrations than 5 mg/l in terms of NH_3-N, while TKN is concentrations are under 15 mg/l except for 1 sample with concentration of 35.65 mg/l taken in July 25, 2013, the date that COD and VSS concentrations also were extraordinary. The mean concentrations of 40 samples were 2.58 and 6.99 mg/l in terms of NH_3-N and TKN respectively.

Phosphorus concentrations during the first 1.5 month of the monitoring program were measured higher than the rest, as shown in Figure 5.4, which cannot be connected to any possible reason. Questions were asked to the staff responsible for grey water reclamation in the hotel to learn if there was a shift to other brands of shampoo, soap, shaving gel or cleaning products in the hotel that may effect the phosphorus content of grey water, however the answer was no. After the period with high phosphorus concentrations till the end of October, 2013, TP concentrations never exceeded 3 mg/l, while PO_4-P concentrations were always measured under 2 mg/l concentration. Mean concentrations of 40 samples for TP and PO_4-P were calculated as 2.29 and 1.05 respectively as shown in Table 5.1.

Nutrient concentrations were practically low, and the nutrient content of grey water is not practiced as frequently as the organic matter content in the literature. The two articles encountered in the literature states Total Nitrogen concentrations for the same fraction of grey water generated from a hotel as 11.4 and 4.1 mg/l (March et al., 2005; Gual et al., 2008). Average TKN concentration in this work is comparable to those TN concentrations. On the other hand, no phosphorus concentration was encountered for the same fraction coming from the same building.

To enable seasonal comparison, Figure 5.5 and 5.6 are given showing COD, BOD_5, sCOD, TSS and VSS concentrations during different weeks of the seasons. If the figures are analyzed, no obvious trend is observed, however the 5^{th} sample analyzed in summer showed extreme concentrations for all parameters.

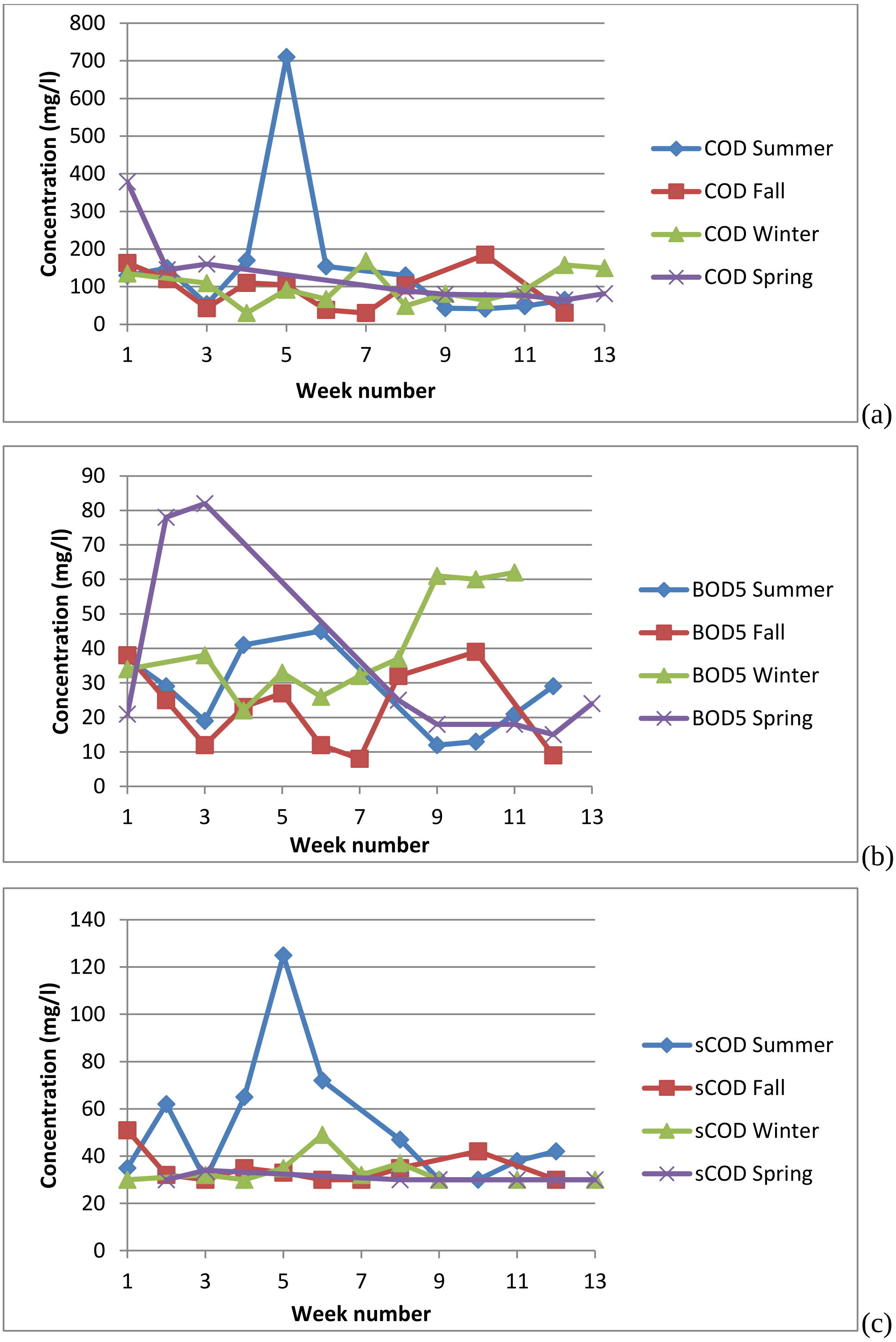
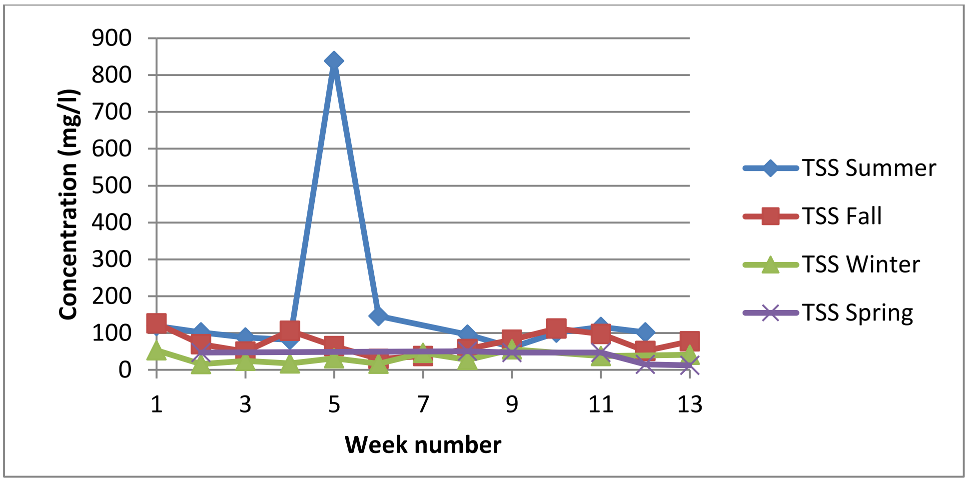
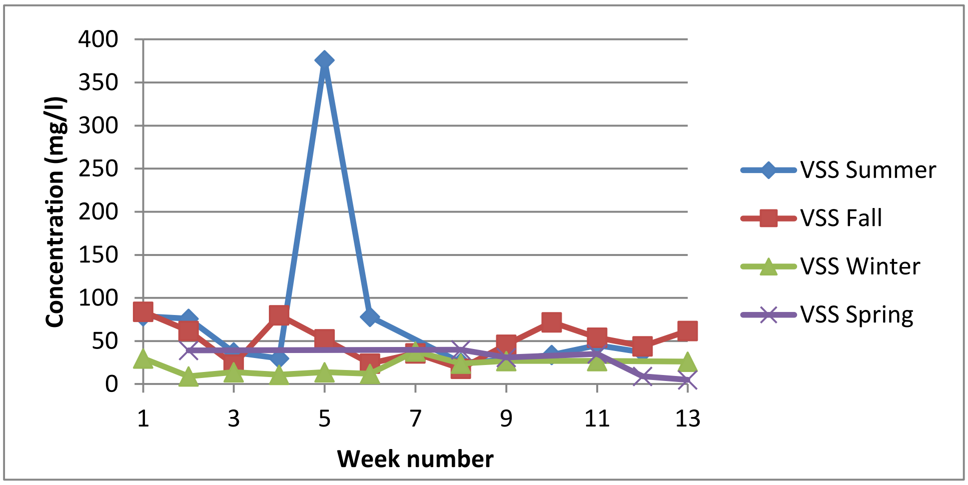


Figure 5.5 : Routine sampling results in different seasons in terms of (a) COD, (b) BOD_5 and (c) sCOD.



(a)



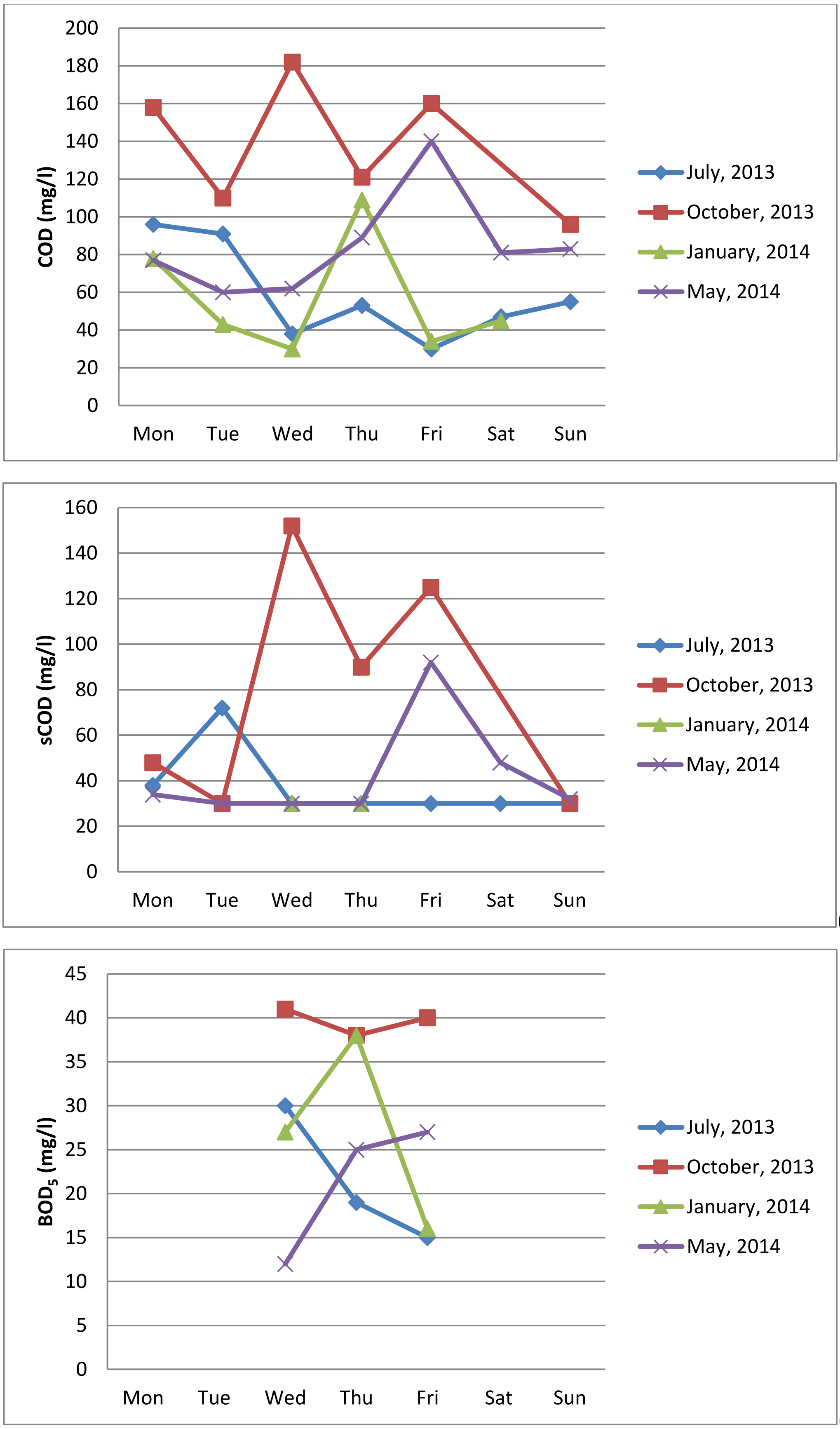
(b)

Figure 5.6 : Routine sampling results in different seasons in terms of (a) TSS and (b) VSS.

Week-long sampling

Quality change of grey water during week days was researched with week-long sampling. The aim was to see if the quality changes among different days of the week, especially if there is a change between the weekdays and the weekends. Also, week-long sampling and analyses were done in four different seasons to see if there is a quality change due to seasonal changes.

Organic matter concentrations for week-long sampling done in four seasons are given in Figure 5.7. According to these graphics, October 2013, representing fall, had the highest pollution potential in terms of organic matter. During the week in October 2013, there is not an extraordinary situation in terms of COD and BOD_5 as compared to results of the analyses of routine samples, however the highest of all sCOD values were recorded in this group of observations at 152 mg/l, on Wednesday in October. During other seasons there is not a remarkable variation and also there is



(a)

(b)

(c)

Figure 5.7 : Organic matter concentrations during week-long sampling in terms of (a) COD, (b) sCOD and (c) BOD_5.

no quality trend among days in different seasons and it is not possible to state a day of the week has higher/lower pollution potential than the other days. The average concentrations in terms of COD, sCOD and BOD_5 were calculated as 69, 45 and 23 mg/l, as shown in Table 5.2. During COD and sCOD measurements, the detection limit was 30 mg/l and the values shown in the graphics as 30 mg/l may refer to lower concentrations.

Such monitoring was not encountered in the literature, however there are pieces of work investigating characteristic of grey water as mentioned in routine analysis part. A comparison of those work by March et al. (2005) and Gual et al. (2008) with this work reveal that the average COD concentrations in this work are lower than those reported. sCOD and BOD_5 concentrations are not studied in those work.

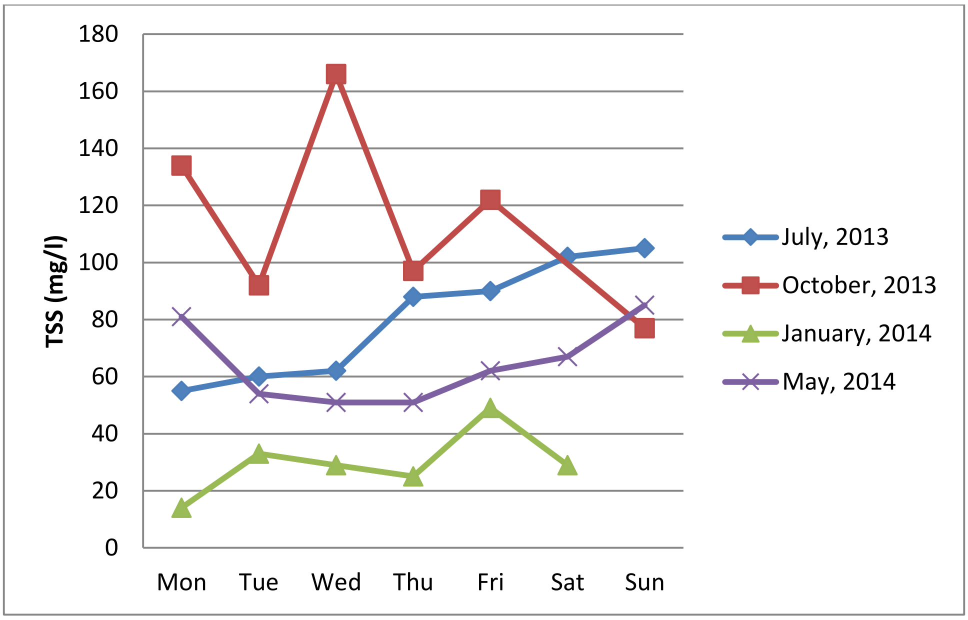
Similar to organic matter, TSS and VSS show higher pollution potential in October, 2013, representing fall, as shown in Figure 5.8. Mean values of TSS and VSS concentrations were calculated as 114 and 68 mg/l for October, 2013 respectively, which are higher than the average values of all seasons shown in Table 5.2. Also in July, TSS concentration exceeded 100 mg/l during weekends. In January, 2014, lowest TSS concentrations were measured and the highest concentration was seen on Friday with 49 mg/l, however it was still lower than all other measurement results. Similar to organic matter, no remarkable result can be stated for the quality changes during weekdays and weekends and for different seasons.

TSS concentrations acquired in this work are lower than those in the literature as March et al (2005) and Gual et al. (2008) reports 44 and 32 mg/l TSS concentrations respectively, which are results comparable to the results accomplished in this work. VSS content of this grey water fraction is not studied in those work.

TSS content of the same grey water fraction, bath/shower and wash basin grey water, generated from houses and student residence halls in the literature are highly variable and to compare those work shown in Appendix A with this study is not possible.

Table 5.2 : Summary of week-long monitoring results.

	COD	sCOD	BOD_5	TSS	VSS	TKN	NH_3-N	TP	PO_4-P
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	30	<30	3	0	0	0.57	0.28	0.21	0.04
Max	182	152	41	166	102	15.27	4.18	5.71	2.48
Mean	69	45	23	56	31	5.17	2.01	2.30	0.87



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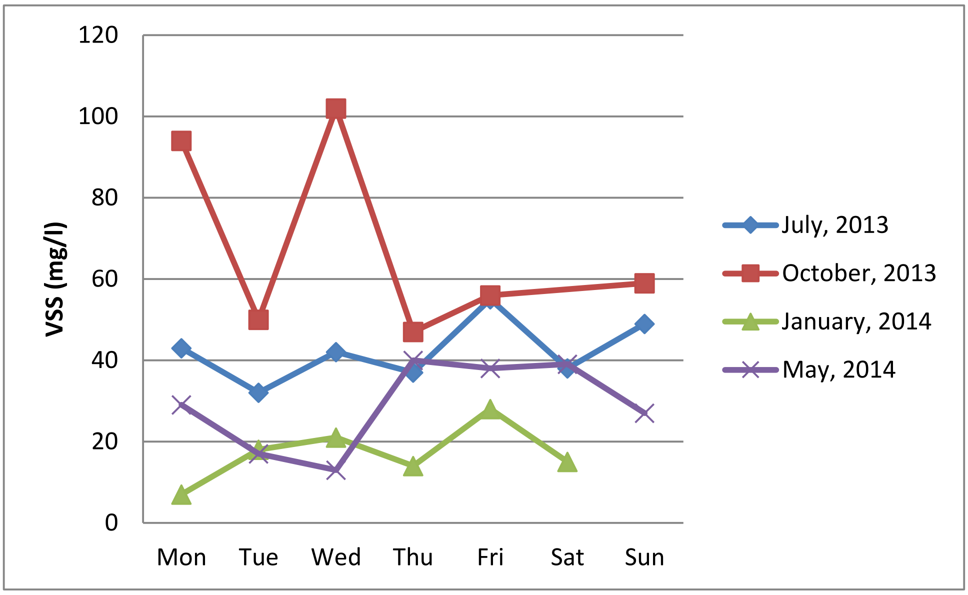
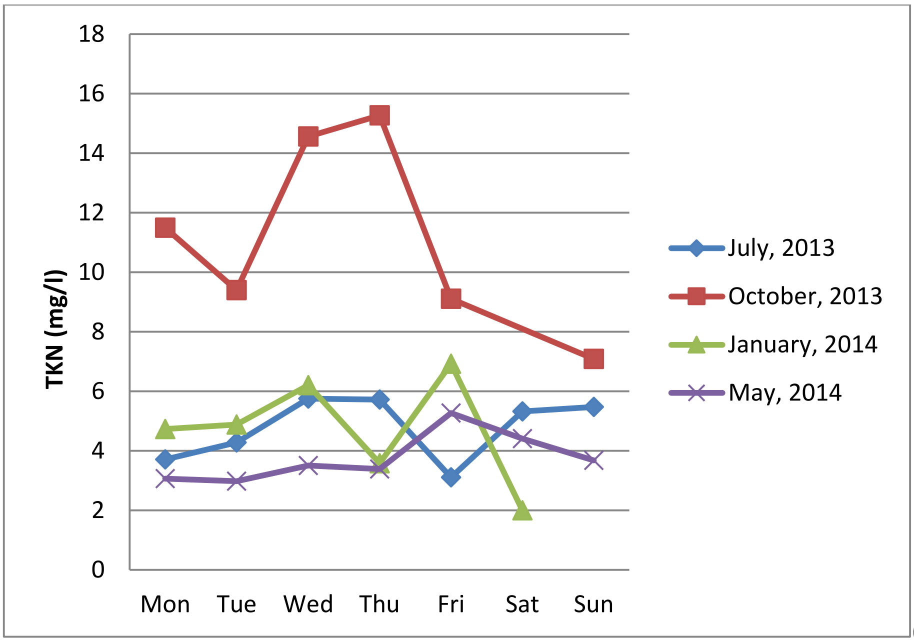


(a)

Figure 5.8 : Suspended solid concentrations during week-long sampling in terms of (a) TSS and (b) VSS.

Results of the analyses done for nitrogen parameters are given in Figure 5.9. October 2013 again showed the highest pollution potential in terms of TKN, however in terms of NH_3-N, quality during sampling week in October, 2013 was similar to those in other seasons. TKN concentrations in October, 2013 were always above 7 mg/l, however during other seasons they were always below 7 mg/l, and mostly below 5 mg/l. The average concentrations were calculated as 2.01 and 5.17 mg/l in terms of NH_3-N and TKN respectively. It is not possible to state a weekly trend between TKN and NH_3-N as they change independently. Also no statement for weekdays and weekends can be made for TKN and NH_3-N.



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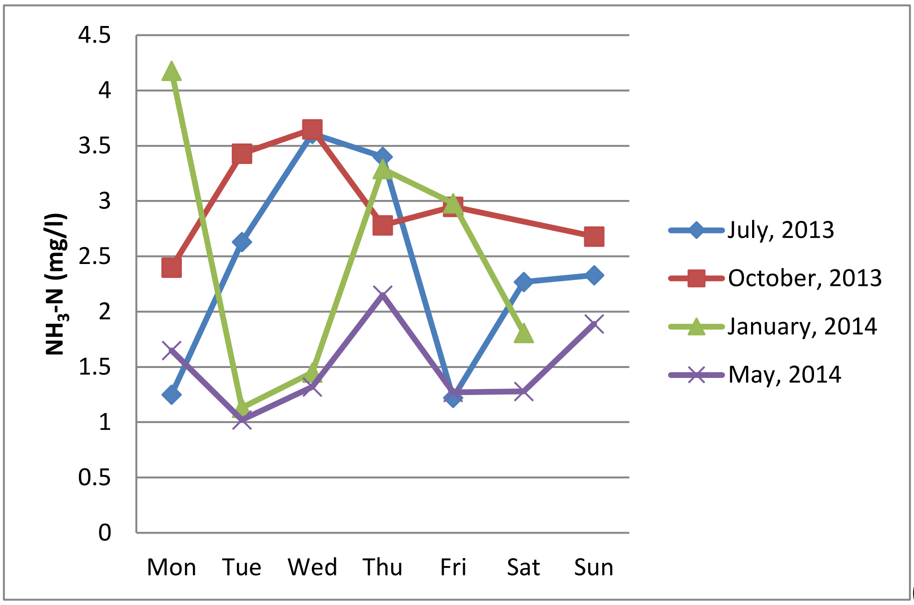
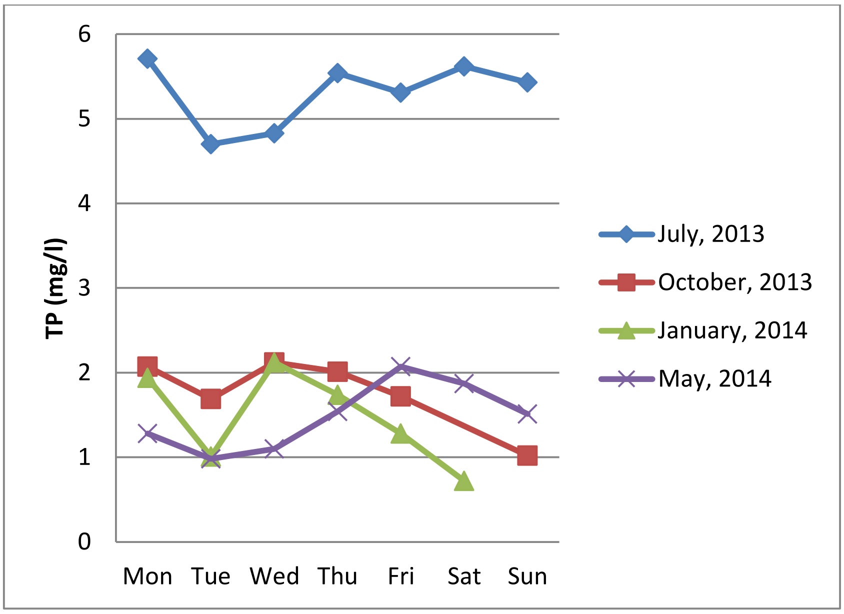


(b)

Figure 5.9 : Nitrogen concentrations during week-long sampling in terms of (a) TKN and (b) NH_3-N.

Bath/shower and wash basin fraction of grey water in hotels are studied in terms of TN, and the TKN results accomplished in this work are comparable to those in the literature.

Different than other parameters, worst quality in terms of phosphorus parameters were seen during July 2013, the samples respresent summer, as shown in Figure 5.10. Samples taken during July, 2013 showed about triple times worse quality than the ones taken during other seasons. Questions were asked to the staff responsible for grey water reclamation and reuse in the hotel to be able to understand if there was a



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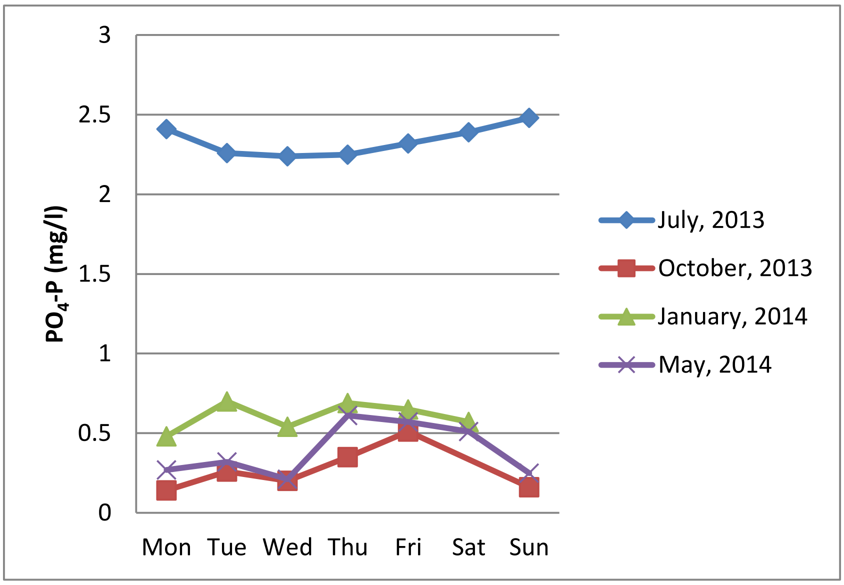

(b)

Figure 5.10 : Phosphorus concentrations during week-long sampling in terms of (a) TP and (b) PO_4-P.

particular reason for this difference, such as usage of a different type of soap/shampoo or shifting between cleaning products, however no reasonable explanation was obtained. During other seasons, there was no extraordinary situation and week-long sampling results showed similar results with those for routine sampling. The average phosphorus concentrations were calculated as 0.87 and 2.30 mg/l in terms of PO_4-P and TP respectively. As for the other parameters, it was also not possible to make a statement of which day shows better or worse quality.

Day-long sampling

Day-long sampling of grey water could be done for one time only, starting at 12:45 in October 23, 2014, by using an auto-sampler that takes samples every hour in different bottles. The aim of day-long sampling was to see if grey water quality changed during a day. It was planned to collect the last sample at 11:45 in October 24, 2014, however due to an unplanned maintenance at grey water treatment plant, last sample could not be collected. 23 samples of 1 liter were collected at the end of sampling and 11 of those were analyzed.

Organic matter concentrations are given in Figure 5.11. According to these results, all concentrations of samples analyzed were below 60 mg/l in terms of COD, near the lower end of long-term routine monitoring COD values. sCOD concentrations were below 30 mg/l lower limit except for one sample which was taken at 8:45 in the morning. BOD_5 analyses were done for only the last two samples as BOD_5 test must be done in 4 hours following sampling and the results were 17 and 25 mg/l. The average concentrations were calculated as 40, <30 and 21 mg/l in terms of COD, sCOD and BOD_5 respectively as shown in Table 5.3, and these results were were lower than the average organic matter content of routine and week-long samples.

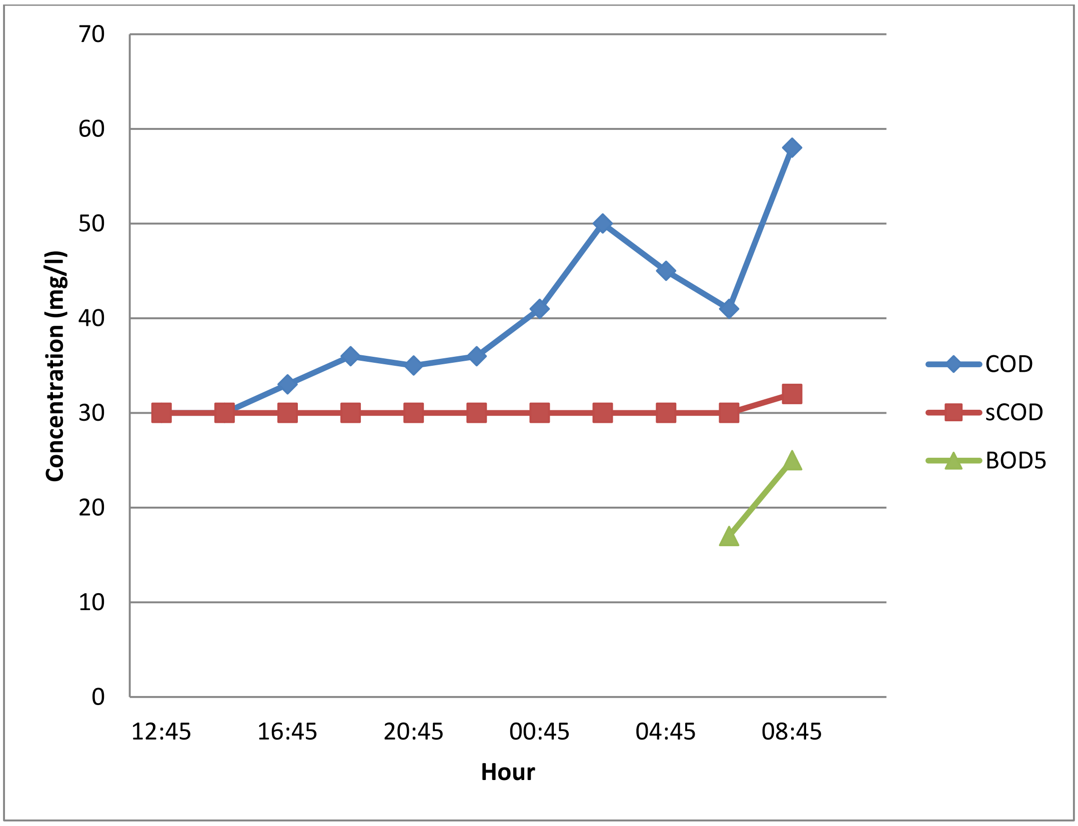

Figure 5.11 : Organic matter concentrations during day-long sampling.

Table 5.3 : Summary of day-long analyzes.

	COD	sCOD	BOD_5	TSS	VSS	TKN	TP
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	<30	<30	17	0	0	3.77	0.26
Max	58	32	25	29	25	50.17	1.26
Mean	40	<30	21	11	8	8.82	0.98

TSS and VSS concentrations were also measured below the mean concentrations for routine samples, as shown in Figure 5.12. Maximum concentrations were seen in the sample taken at 16:45 with 29 and 25 mg/l TSS and VSS respectively. An unexpected concentration of 0 mg/l was seen at the first sample taken at 12:45. From the figure, it is clearly seen that TSS and VSS concentrations increase and decrease together, showing a similar trend.

TKN concentrations were below 6 mg/l except for one sample, as given in Figure 5.13. The sample which showed high TKN concentration was taken at 16:45 and it was also the sample that showed high TSS and VSS concentrations. NH_3-N concentrations were not analyzed as TKN concentrations were already low.

Phosphorus was only analyzed for TP and the concentrations are shown in Figure 5.14. Samples were not analyzed for PO_4-P as TP concentrations were low. TP

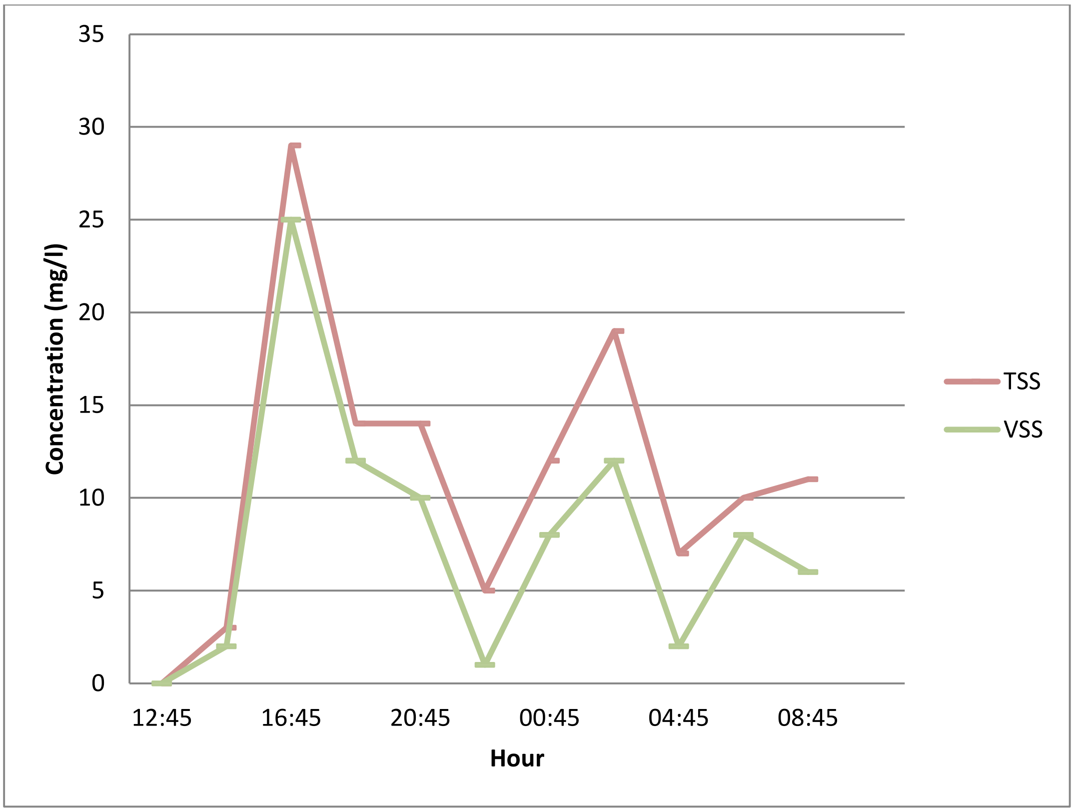

Figure 5.12 : Suspended solids concentrations during day-long sampling.

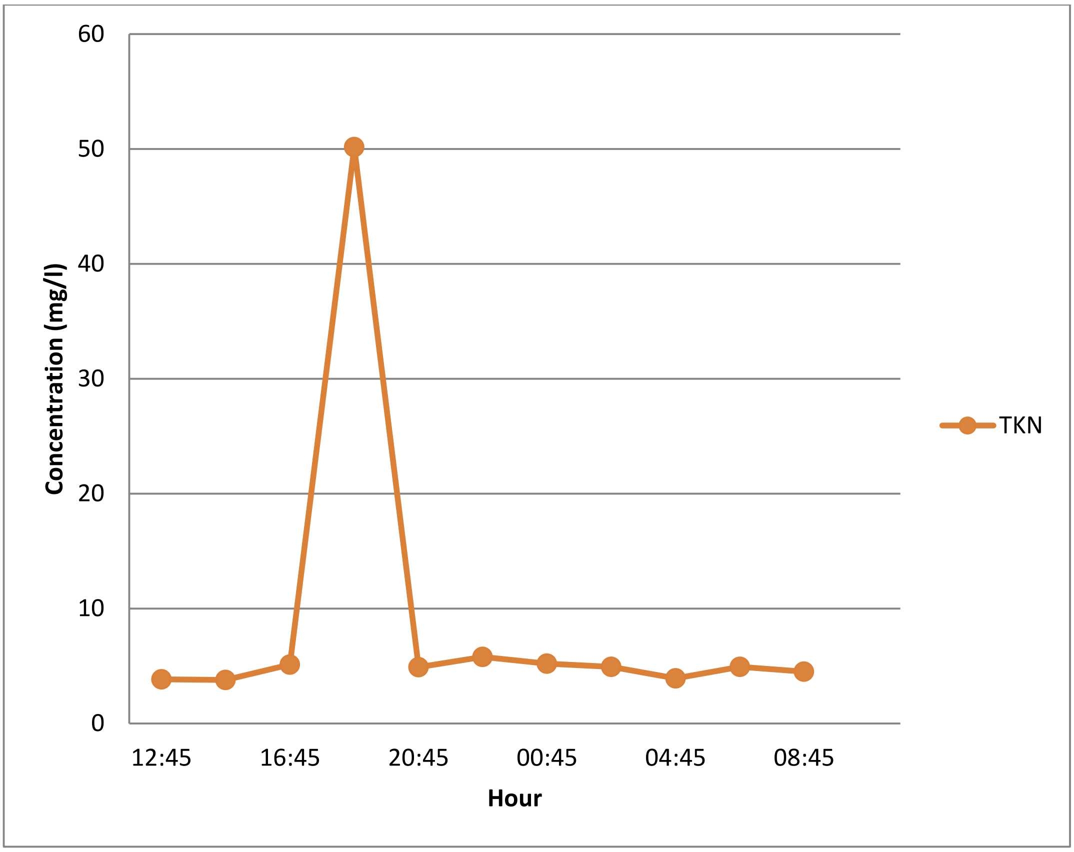

Figure 5.13 : Nitrogen concentrations during day-long sampling.

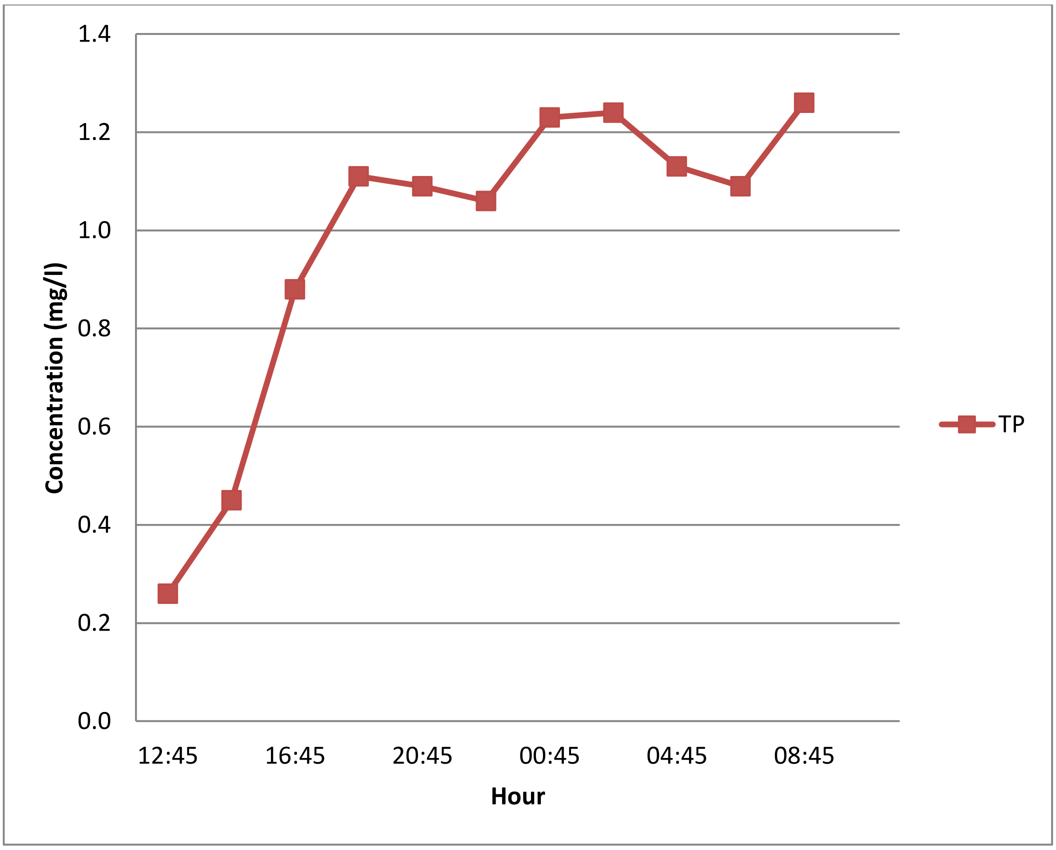

Figure 5.14 : Phosphorus concentrations during day-long sampling.

concentration was minimum at the beginning of sampling at 12:45, and an increase was seen during 24 hours, resulting with the maximum concentration at 8:45. Minimum and maximum concentrations were 0.26 and 1.26 mg/l respectively.

Table 5.3 shows the summary of analyzes done with day-long taken samples. A comparison between Table 5.1 and Table 5.3 reveals that the day the day-long monitoring done had lower pollution potential in terms of parameters investigated. Maximum COD concentration during day-long analyses was 58 mg/l, however the mean routine COD concentration was 125 mg/l. TSS and VSS concentrations for routine samples were 87 and 47 mg/l respectively as given in Table 5.1, higher than the maximum concentrations for day-long samples, 29 and 25 mg/l respectively.

5.1.1.2 Microbiological indicators

Results of the microbiological analyses are given in Table 5.4. According to these results, Total Coliform in grey water samples that were collected from the hotel showed concentrations changing in the range of 5 logs and 8 logs cfu/100 ml. Fecal Coliform concentrations were measured close to Total Coliform concentrations, meaning majority of coliform bacteria has fecal origin. E.Coli concentration in February was the highest with 7 logs, but it decreased 1 log in March and it was decreased to 3 logs/100 ml in May, 2014. Despite high coliform concentrations, enterococcus was not detected in any of the samples.

There is no encountered data in the literature about the microbiological indicators present in hotel grey water, however there are papers investigating these indicators for house and student residence hall grey water samples as shown in Table 3.5. On the other hand, none of those articles in Table 3.5 investigates all indicators analyzed in this study.

The only encountered Total Coliform concentration in bath/shower and wash basin grey water generated from houses is given by Christova-Boal et al. (1996) and

Table 5.4 : Summary of microbiological analyzes of raw grey water.

		February	March	May
Total Coliform	cfu/100 ml	4,20E+07	4,00E+05	2,00E+05
Fecal Coliform	cfu/100 ml	2,65E+07	2,00E+05	2,15E+04
E.Coli	cfu/100 ml	2,50E+07	1,00E+05	2,70E+03
Enterococci	cfu/100 ml	0	0	0

according to that paper, Total Coliform content of changes between 3 logs to 7 logs cfu/100 ml. A summary of work by Birks & Hills (2007) and Winward et al. (2008) reveal that the same grey water fraction generated in student residence halls may contain 5 logs to 7 logs cfu/100 ml Total Coliforms. Data generated in this work was at the higher limit of this data in February, however in March and May Total Coliforms concentrations decreased 2 logs, as shown in Table 5.4.

Fecal Coliform concentrations are investigated by Christova-Boal et al. (1996) and Friedler et al. (2005) in bath/shower and wash basin grey water generated from houses and the range is 3 logs to 5 logs cfu/100 ml. Friedler et al. (2005) investigate only the Fecal Coliforms, so that a relation between Total Coliform and Fecal Coliform groups could not be esteablished. No work was available about the same grey water fraction generated from student residence hall. Fecal Coliform concentrations analyzed in the hotel were higher than those in literature in February and March, but as the concentration decreased 2 logs in May, the concentration in May was comparable to the lower limit given in Table 3.5.

Household grey water which contains bath/shower and wash basin fractions is studied by only Chaillou et al. (2010) in terms of E.Coli, however this work is a compilation of five different household grey water samples. According to the paper, E.Coli concentration in this fraction changes in the range of 4 logs to 6 logs cfu/100 ml. On the other hand, there are two pieces of work encountered about the same grey water fraction generated from student residence halls, and 5 logs and 2 logs cfu/100 ml E.Coli concentrations were reported by Birks & Hills (2007) and Winward et al. (2008) respectively. E.Coli concentration found in this work in February was out of those range as it was 7 logs, however as it decreased 2 logs in March and another 2 logs in May, it became comparable to data in literature.

Enterococci concentration is analyzed in the same papers with those investigating E.Coli indicator. According to those papers, Enterococci concentration in household bath/shower and wash basin grey water may change between 1 log to 6 logs cfu/100 ml, while the range is narrower for student residence halls as it was reported as 2 logs to 3 logs cfu/100 ml. The samples analyzed during this work were free of Enterococci.

5.1.1.3 Summary of all monitoring program for the hotel

Summary of all analyses done with raw grey water samples taken from the hotel is given in Table 5.5, and to compare with domestic wastewater constituents, weak and intermediate strength conventional domestic wastewater quality are given in Table 5.6 (Metcalf & Eddy, 2003). The mean concentrations for COD, BOD_5 and sCOD were calculated as 97, 30 and 41 mg/l respectively. As COD and BOD_5 concentrations of weak domestic wastewater are stated as 250 and 110 mg/l respectively, the grey water fraction comes from the bath/shower and wash basins in the hotel shows lower pollution potential compared to weak domestic wastewater.

In terms of suspended solids, averages of both TSS and VSS concentrations were calculated below the concentrations given for weak conventional domestic wastewater also.

A comparison of nutrient contents of analyzed grey water samples with domestic wastewater characteristics reveals that the grey water in the hotel shows weak conventional domestic wastewater quality.

Microbiological indicator concentrations for the grey water are given in Table 5.4. According to those results, quality in terms of Total Coliforms may be similar to both

Table 5.5 : Summary of analyses done for raw grey water.

	COD	BOD_5	sCOD	TSS	VSS	TKN	NH_3-N	TP	PO_4-P
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	<30	8	19	0	0	2	0.58	0.26	0
Max	710	82	152	838	376	50.17	5.55	8.35	4.01
Mean	97	30	41	72	39	6.90	2.47	2.20	1.01

Table 5.6 : Characteristics of weak and intermediat conventional domestic wastewater (Metcalf & Eddy, 2003).

	Weak	**Intermediate**
COD (mg/l)	250	430
BOD (mg/l)	110	190
TSS (mg/l)	120	210
VSS (mg/l)	95	160
Total N (mg/l)	20	40
Organic N (mg/l)	8	15
Ammonical N (mg/l)	12	25
Total P (mg/l)	4	7
Total coliforms (in 100 ml)	10^6-10^8	10^7-10^9
Fecal coliforms (in 100 ml)	10^3-10^5	10^4-10^6

weak and intermediate conventional domestic wastewater. Fecal Coliform concentrations of grey water samples also are comparable to both weak and intermediate conventional domestic wastewater.

Results of the analyses reveal that the pollution potential of grey water samples analyzed in this work is comparable to those in literature in terms of all parameters investigated, except for Enterococci. On the other hand, it is clearly observed that the grey water quality of building with different functions change in a wide range, and also there are different quality given in literature for buildings with the same function as shown in Appendix A.

Literature data about biodegradability of organic matter present in grey water are limited as there not many work analyzing COD and BOD_5 together. On the other hand, the work analyzing both those parameters are based on average values that makes it hard to investigate the BOD_5/COD ratio to understand if the organic matter in grey water is biodegradable or not.

Also, many of the work investigating organic matter in terms of COD do not investigate sCOD contentrations, so that the amount / percentage of particulate organic matter is unknown. The same problem is available for BOD_5 parameter, as only one data is available in terms of $sBOD_5$.

In this work, the COD and BOD concentrations were low as 97 and 30 mg/l respectively and almost half of the organic matter analyzed in terms of COD was in particulate form. BOD_5/COD concentration was calculated as 31%, which showed low biodegradability of organic matter under BOD_5 test conditions. These data generated lead to the question if biological treatment is necessary for this types of grey water, as the carbon source of microorganisms is limited, and if membrane filtration other than MBR could be employed for the treatment of this type of grey water.

In the light of these data, it was decided to analyze $sBOD_5$ to see how much biodegradable organic matter was held in the membrane by filtration process and how much of it was treated biologically. The analyzes were carried out for 8 samples and the minimum, maximum and mean values of those 8 samples' COD, sCOD, BOD_5, $sBOD_5$, TSS and VSS concentrations are given in Table 5.7. According to the results, average dissolved BOD_5 concentration was only 10 mg/l in raw grey water

Table 5.7 : Results of dissolved organic matter and suspended solids analyzes.

	COD	sCOD	BOD_5	$sBOD_5$	TSS	VSS
			mg/l			
Min	49	<30	21	4	17	12
Max	378	60	78	17	49	39
Mean	143	37	49	10	37	29

while 39 mg/l BOD was in particular form, which could be retained by the membrane via filtration process if there was no biological treatment step in the treatment plant.

Due to these results, the importance of physicochemical treatment processes for this specific grey water was recognized and preliminary trials on sand filtration and membrane filtration processes were added to the scope of this work.

5.1.2 University student residence hall

Grey water sampling in university student residence hall was done twice in March, 2014 and once in April, May, June, November and December. There were almost no residents in the building during July and August as there was no lesson in the university, and in September the treatment plant was under maintenance. Due to these reasons, sampling could not be done during these 3 months.

5.1.2.1 Physical and chemical parameters

Organic matter concentrations in grey water generated from student residence hall are given in Figure 5.15. Dissolved organic matter was not analyzed in the first two samples, however it was decided that sCOD and sBOD concentrations should be checked in following samples. Average COD, sCOD, BOD_5 and $sBOD_5$ concentrations were calculated as 226, 84, 76 and 20 mg/l respectively, as given in Table 5.8. COD concentrations were fluctuating in a wide range, however results of other organic matter were not changing as much as COD concentrations were.

BOD_5/COD ratio was calculated as 34%, showing that sCOD concentration was 37% of COD concentration, stating that 63% of organic matter was in particulate form in this particular grey water. Also $sBOD_5$ was tested and as a result, $sBOD_5$/BOD_5 ratio was found as 26%, which means most of the organic matter which were biodegradable under BOD_5 test conditions were also in particulate form.

If results of this work are compared to literature data for the same type of grey water

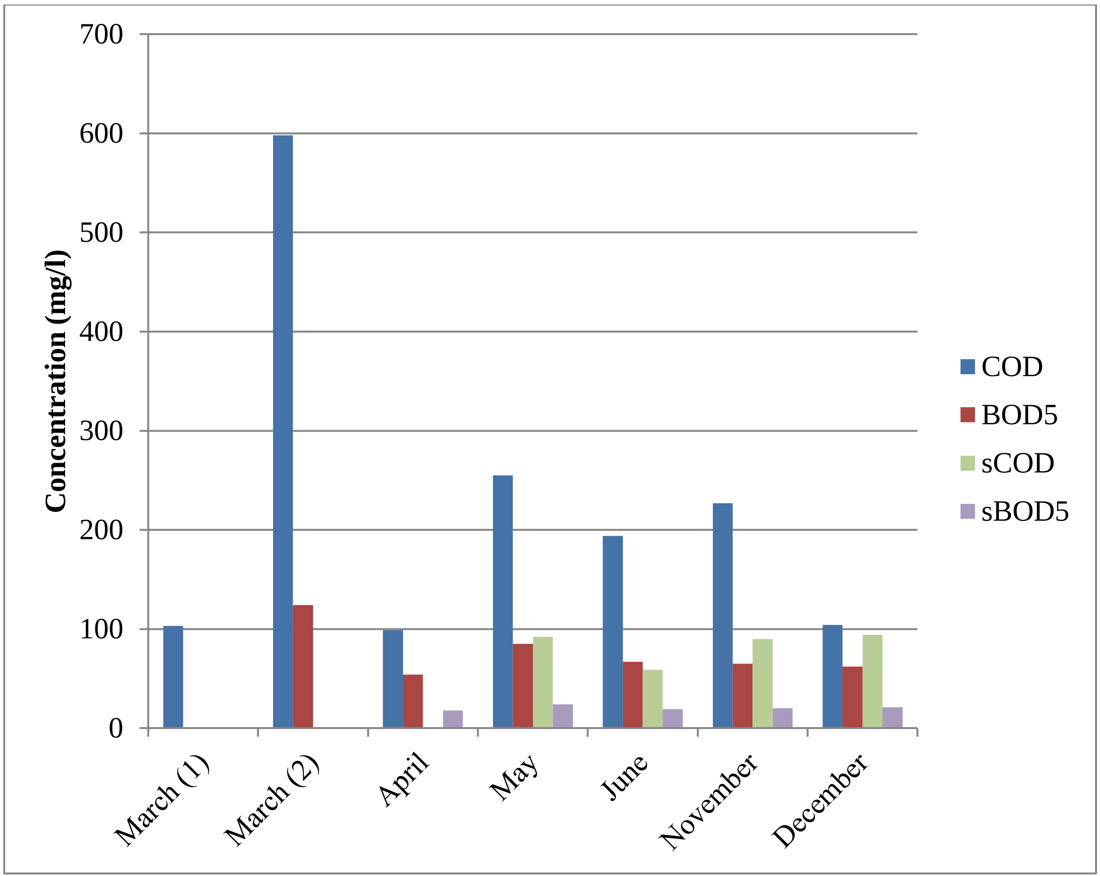

Figure 5.15 : Organic matter concentrations in student residence hall grey water.

Table 5.8 : Summary of analyses done with student residence hall raw grey water.

	COD	sCOD	BOD_5	$sBOD_5$	TSS	VSS	TKN	NH_3-N	TP	PO_4-P
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	99	59	54	18	44	4	4,05	0	1,35	0,27
Max	598	94	124	24	328	216	16,89	0,86	2,17	1,19
Mean	226	84	76	20	145	94	6,61	0,60	1,80	0,76

generating from building with same function given in Appendix A, COD and BOD_5 concentrations are comparable to results of a work by Friedler et al. (2008), however the other three papers state lower pollution potential in terms of organic matter. sBOD is analyzed by Birks & Hills (2007) together with BOD and COD and the results reveal BOD_5/COD and $sBOD_5$/BOD_5 ratios as 48% and 67%, which are higher than the ratios for this study.

Figure 5.16 shows the TSS and VSS concentrations in student residence hall grey water. Figure and results revealed that, TSS and VSS concentrations showed a trend and most of the suspended solids were in volatile / organic form, proved by 65% VSS/TSS ratio. Second sample taken in March, 2014 showed the highest pollution

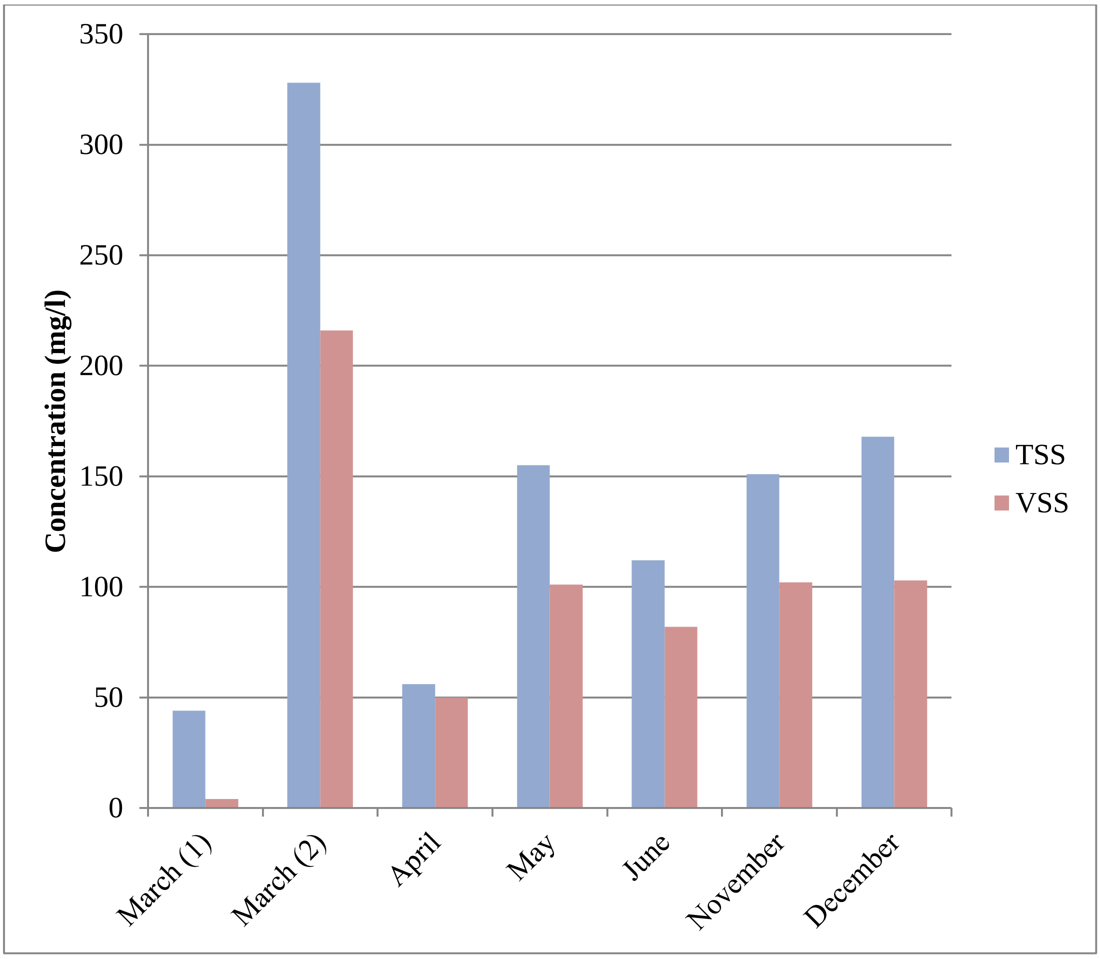

Figure 5.16 : Suspended solid concentrations in student residence hall grey water.

potential in terms of suspended solids with 328 and 216 mg/l TSS and VSS concentrations respectively, however as that specific sample showed the highest pollution potential in terms of organic matter, it was thought that there may have been an unusual situation. Mean value of TSS and VSS concentrations were calculated as 145 and 94 mg/l respectively.

Analyses of bath/shower and wash basin fraction of grey water generating from student residence halls in the literature given in Appendix A show lower pollution potential than the results of this work in terms of TSS except for the work of Friedler et al. (2008) as the TSS concentration of grey water is reported as 147 mg/l, which is a comparable concentration to this study. On the other hand, VSS is not investigated in any of those work.

Nutrient content of student residence hall were investigated in terms of NH_3-N and TKN for nitrogen and PO_4-P and TP for phosphorus, and the results of the analyses are given in Figure 5.17 and 5.18. Average NH3-N and TKN concentrations were

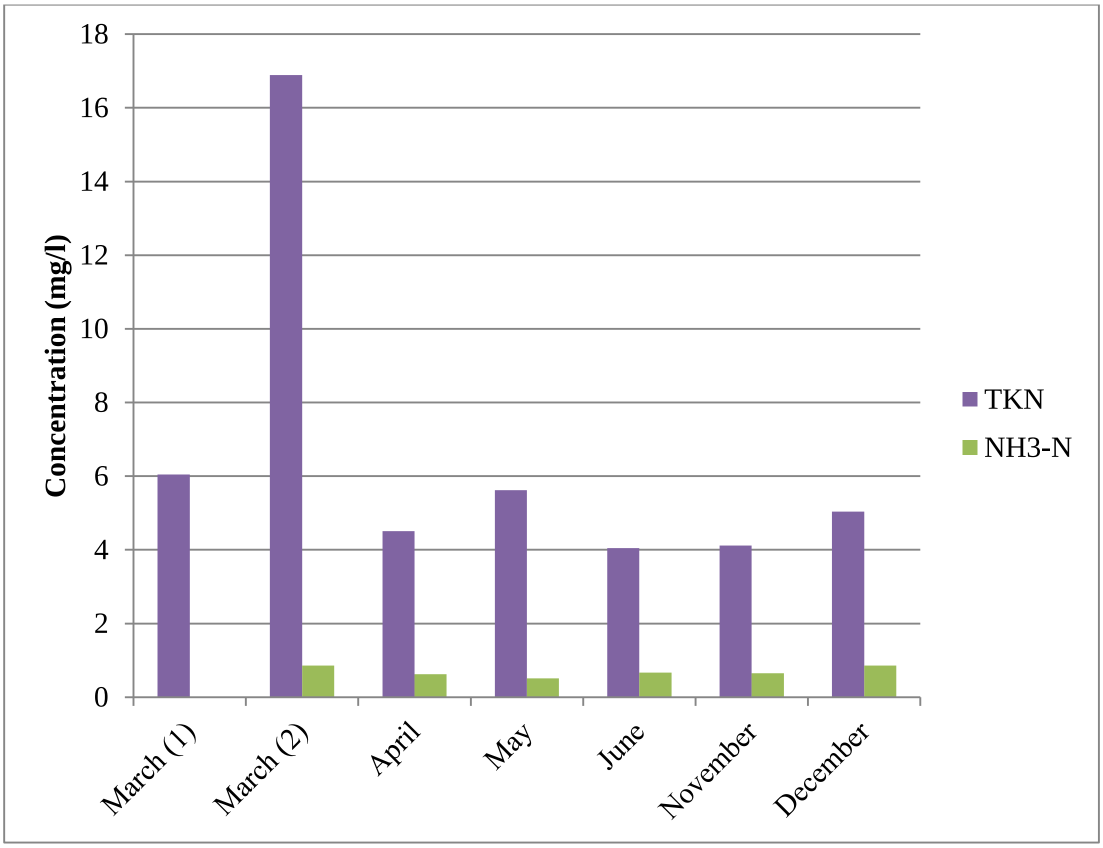

Figure 5.17 : Nitrogen concentrations in student residence hall grey water.

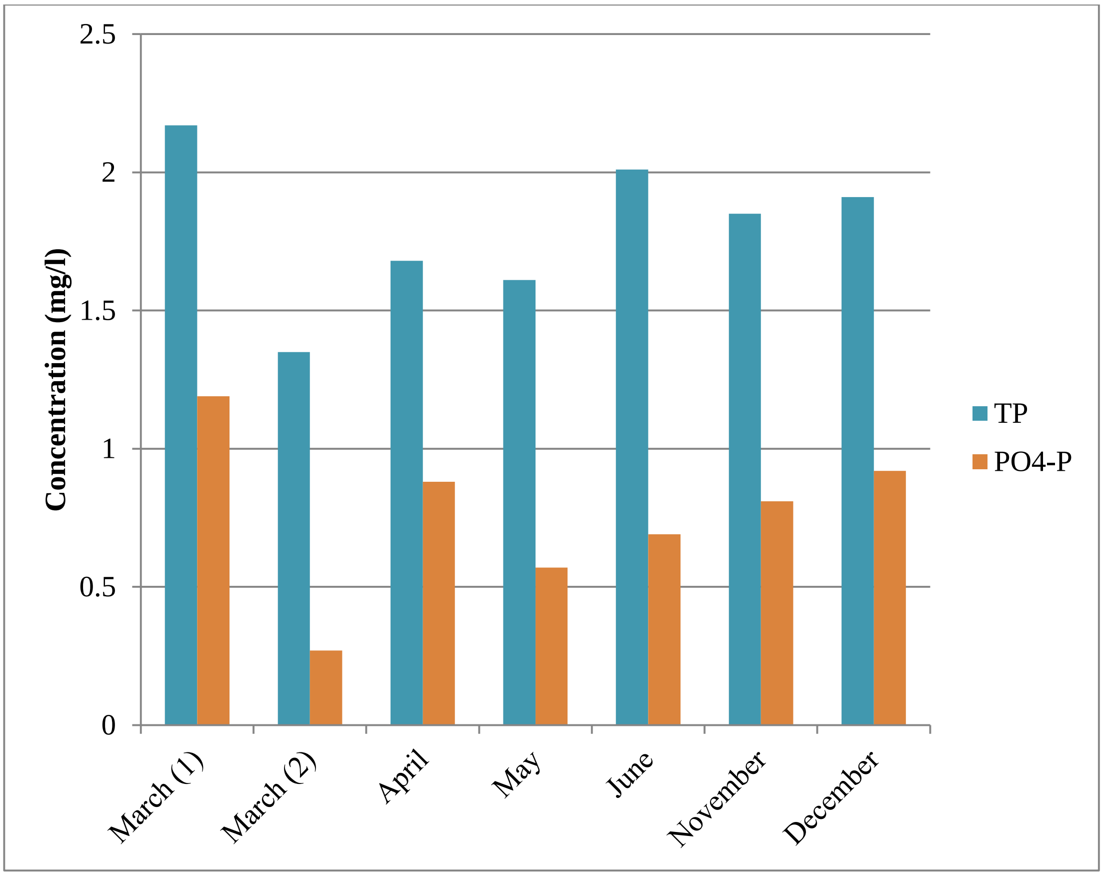

Figure 5.18 : Phosphorus concentrations in student residence hall grey water.

0.60 and 6.61 mg/l respectively. Mean phosphorus concentrations were calculated as 0.76 and 1.80 mg/l in terms of PO_4-P and TP respectively. TKN in this type of grey water is analyzed by two works and the results are reported as 4.6 mg/l and 11 mg/l by Birks & Hills (2007) and Friedler et al. (2008), which leave the average TKN concentration of this work in the middle. On the other hand, TP is investigated by Birks & Hills (2007) only and reported as 0.86 mg/l, which is a lower concentration than the average TP concentration calculated in this study.

5.1.2.2 Microbiological indicators

Microbiological analyzes were carried out twice to see the raw grey water quality in terms of Total Coliform, Fecal Coliform, E.Coli and Enterococcus, and the average of the results are presented in Table 5.9. According to the results, 7 logs cfu/100 ml of Total Coliform was present in grey water and 6 logs cfu/100 ml of that was forms by Fecal Coliform and E.Coli, however no Enterococcus were detected during analyzes. Grey water generated from student residence hall had higher pollution potential in terms of pathogenic indicators, which is linked to the possibility of washing fruits, vegetables and dishes in wash basin in the student residence hall.

Work in literature are limited for this specific fraction of grey water generating from student residence halls, however two papers were encountered. Total Coliforms concentrations are reported as 7 logs and 5 logs by Birks & Hills (2007) and Winward et al. (2008) respectively, which make grey water samples analyzed in this work comparable to the one by Birks & Hills (2007) in terms of Total Coliforms. Fecal Coliforms are not investigated in those work. Average E.Coli concentration of this work is higher than those reported, however 3 logs and 2 logs cfu/100 ml Enterococci concentrations are reported by Birks & Hills (2007) and Winward et al. (2008) respectively, different than this study as no Enterococci was detected.

Table 5.9 : Pathogenic indicators in student residence hall grey water.

Total Coliform (cfu/100 ml)	1,16E+07
Fecal Coliform (cfu/100 ml)	2,11E+06
E.Coli (cfu/100 ml)	4,82E+06
Enterococcus (cfu/100 ml)	-

5.1.2.3 Summary of analyses done in university student residence hall

Summary of the results are given in Table 5.8. According to the results, grey water generated from the university student residence hall showed weak conventional domestic wastewater characteristics given in Table 5.6, in terms of all physical and chemical parameters. Microbiological quality of grey water analyzed showed weak conventional domestic wastewater quality in terms of Total Coliforms, however average of Fecal Coliform concentrations showed that grey water analyzed was at the upper limit of Fecal Coliform concentration of intermediate conventional domestic wastewater.

Bath/shower and wash basin grey water fraction generating from university student residence halls reported show different quality. Grey water samples analyzed during this study showed similar quality to the grey water analyzed in the work of Friedler et al. (2008) in terms of physical and chemical parameters investigated.

Birks & Hills (2007) report similar quality to this work in terms of Total Coliforms, however in terms of E.Coli the concentrations reported are lower. Birks & Hills (2007) and Winward et al. (2008) also investigate Enterococci and report 3 logs and 2 logs cfu/100 ml respectively, which are different data as Enterococci is not detected in this study.

Ratios calculated for different organic matter parameters revealed that most of the organic matter in this grey water is non-biodegradable, and the biodegradable organic matter is in particulate form, which lead to investigation of necessity of biological treatment. Sand filtration and membrane filtration systems were tried in the light of this data as a preliminary study.

5.2 Effluent Quality of Grey Water Treatment Plants

Both the hotel and the student residence hall had MBR technologies to reclaim grey water. Monitoring of these treatment plants were done similar to the raw grey water sampling in both buildings.

5.2.1 MBR in hotel

Grey water collected from the bath/showers and wash basins of the hotel was treated with the MBR unit. Experimental results for MBR effluent in the hotel are given under physical and chemical parameters and microbiological indicators.

5.2.1.1 Physical and chemical parameters

Following results belong to the outlet of that MBR treating grey water as routine samples, week-long samples and day-long samples. The first day-long sampling given does not have the inlet water qualities as there was only one available auto-sampler. The second day-long sampling could not be done at the effluent of the MBR, however it was done at the outlet of UV disinfection.

Routine sampling

Organic matter concentrations for treated grey water are given in Figure 5.19. First four months of routine sampling showed unexpected outflow quality for a typical MBR, whereas the main objective of MBR systems is removal of organic matter. Staff responsible for treatment of grey water was informed about the high organic matter content at the outlet of the MBR and the problem was solved afterwards. An unusual concentration of 340 mg/l, the maximum concentration detected among all analyses done for the MBR effluent, was measured in terms of COD in October 3, 2013. This day was also the day that the maximum sCOD and BOD concentrations were measured as 55 and 42 mg/l respectively. Quality of outlet got better and after October 10, 2013, COD and sCOD concentrations were measured below the lower limit of 30 mg/l, in parallel to the expactations from the effluent of an MBR system given in Table 3.8. High organic matter concentrations in the effluent of the treatment system were linked to the problems experienced in the treatment system, as the treatment plant started working properly after it went under maintenance.

Summary of the routine analyses done with the samples taken from the outlet of the MBR are given in Table 5.10. Minimum concentrations detected were below detection limits in terms of all organic matter parameters tested, while the mean values were 52, 7 and 31 mg/l in terms of COD, BOD_5 and sCOD respectively.

The water reuse standards and guidelines around the world are generally concerned about BOD_5 content of the water to be reused among organic matter parameters, as shown in Table 3.9, where these standards and guidelines are shown. Average BOD_5

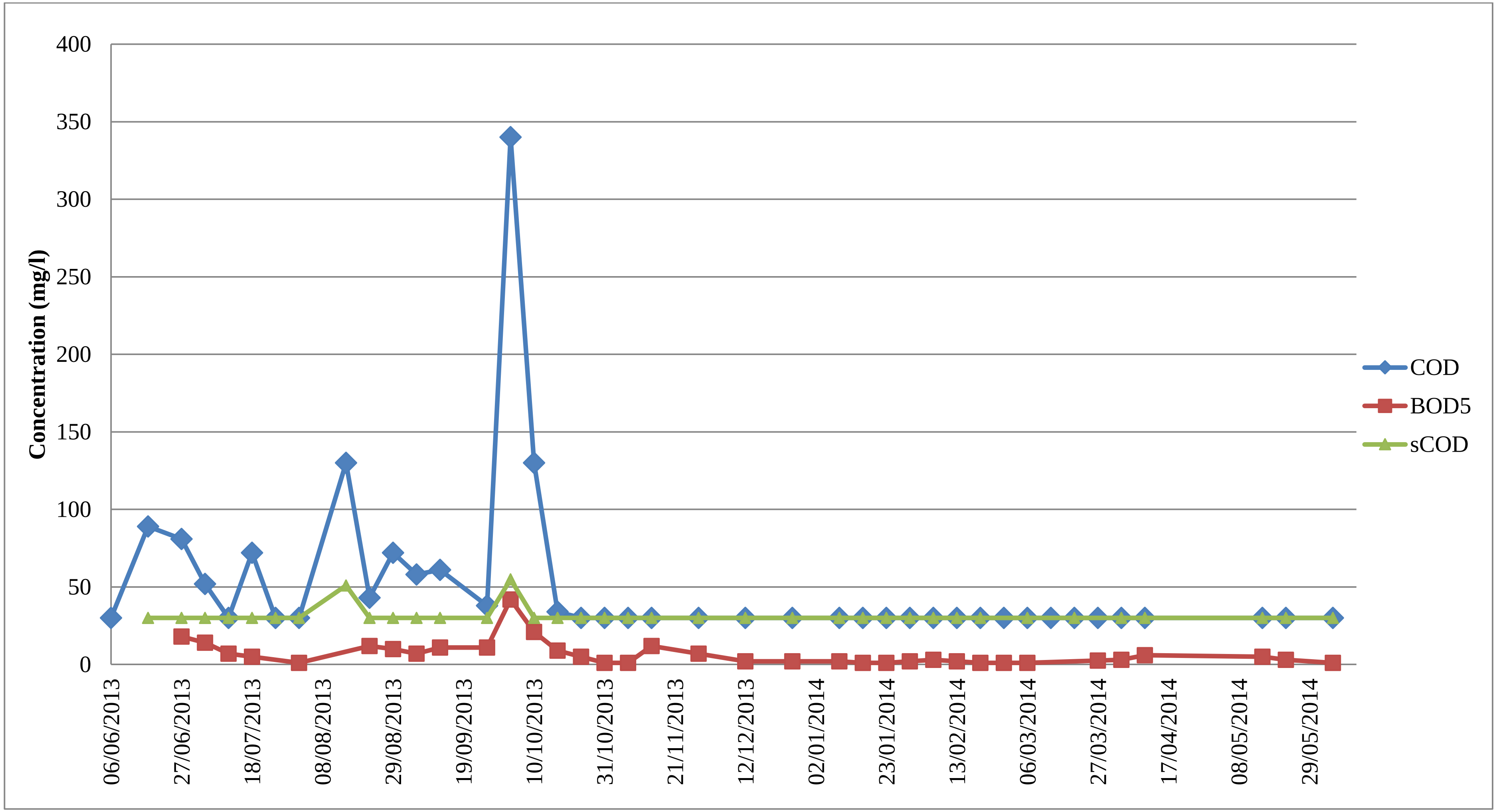

Figure 5.19 : Organic matter concentrations at the effluent of MBR in the hotel.

Table 5.10 : Summary of the routine analyses done at the effluent of MBR in the hotel.

	COD	BOD_5	sCOD	TSS	VSS	NH_3-N	TKN	PO_4-P	TP
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	<30	<1	<30	0	0	0	0,17	0	0
Max	340	42	55	74	36	2,24	4,95	2,27	4,01
Mean	52	7	31	11	4	0,34	1,30	1,08	1,66

concentration of treated grey water was 7 mg/l, enabling every type of reuse applications defined in water reuse standards / guidelines worldwide, such as restricted or unrestricted irrigation and toilet flushing. In case of Turkey, as the average BOD concentration of grey water treated at the MBR system of the hotel was below 20 mg/l, every type of irrigation is permitted.

TSS and VSS concentrations were expected to be about 0 mg/l, as the typical TSS concentration at the effluent of an MBR is 0 mg/l due to the smaller pore sizes of the membranes as compared to the AP40 filters that the TSS and VSS analyses are being carried out with. However, results obtained were different than those expectations due to the problems encountered with the treatment system, similar to parameters measuring organic matter. As shown in Table 5.7, the mean concentrations were 11 and 4 mg/l in terms of TSS and VSS respectively. The maximumum concentrations were measured in November 21, 2013 as 74 and 36 mg/l in terms of TSS and VSS, as shown in Figure 5.20, on the other hand 0 mg/l concentration was measured in 6 samples for both the parameters.

The highest quality that is stipulated by some of the states in USA is 5 mg/l in terms of TSS, as given in Table 3.9 showing the water reuse standards / guidelines around the world. As the average concentration of TSS was 11 mg/l for treated grey water at the hotel, this treated grey water may not be used for every type of reuse application worldwide, however it qualifies the standards and guidelines that stipulates 30 mg/l TSS concentration for restricted irrigation. In Turkey, irrigation of fruits and vegetables eaten cooked, irrigation of meadow and all types of restricted irrigation is possible through reuse of this treated grey water.

Nitrogen and phosphorus concentrations at the outlet of the MBR are shown in Figure 5.21 and Figure 5.22. All the samples showed lower pollution potential than 5 mg/l in terms of TKN and there was 1 sample exceeding 1 mg/l NH_3-N

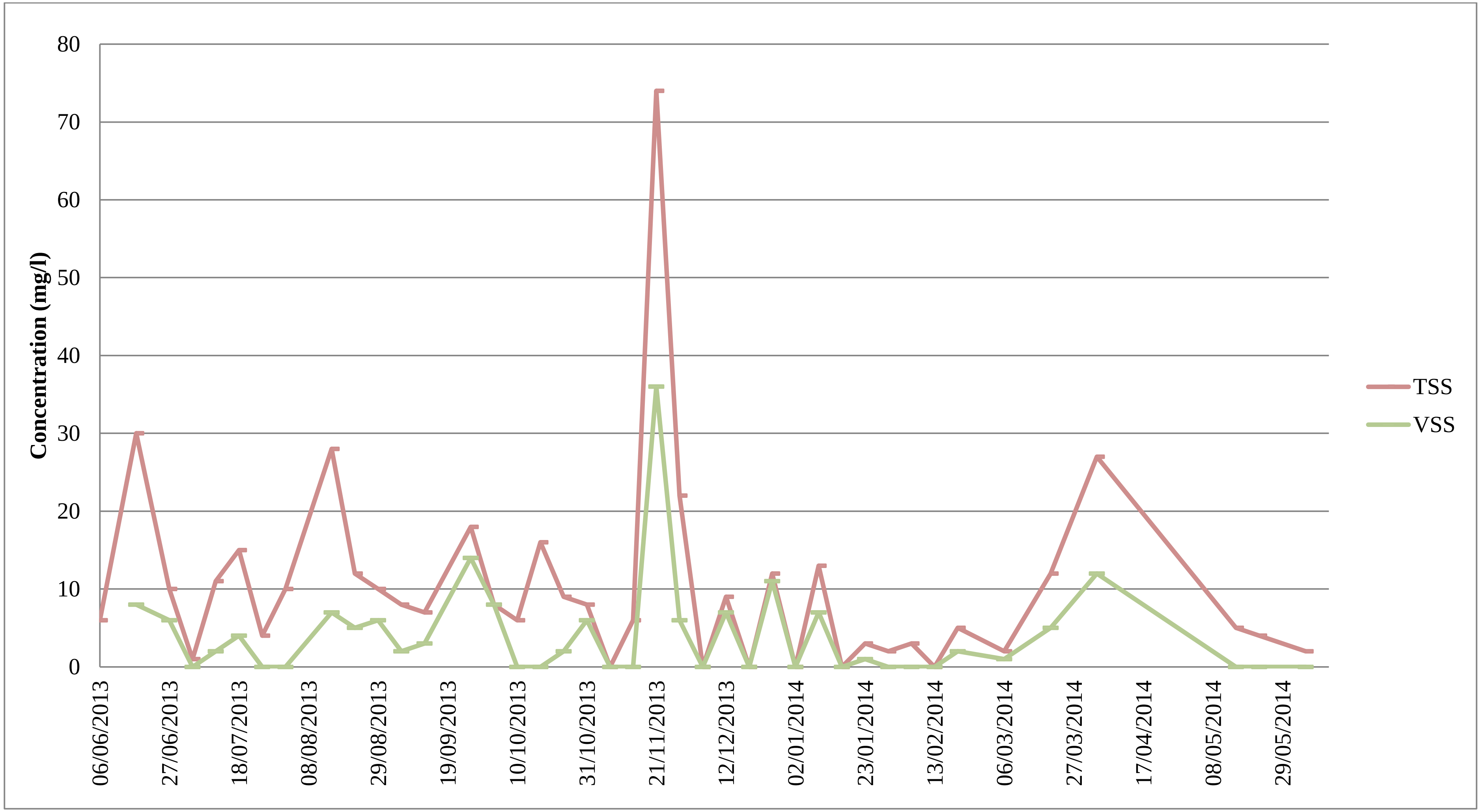

Figure 5.20 : Suspended solids concentrations at the effluent of MBR in the hotel

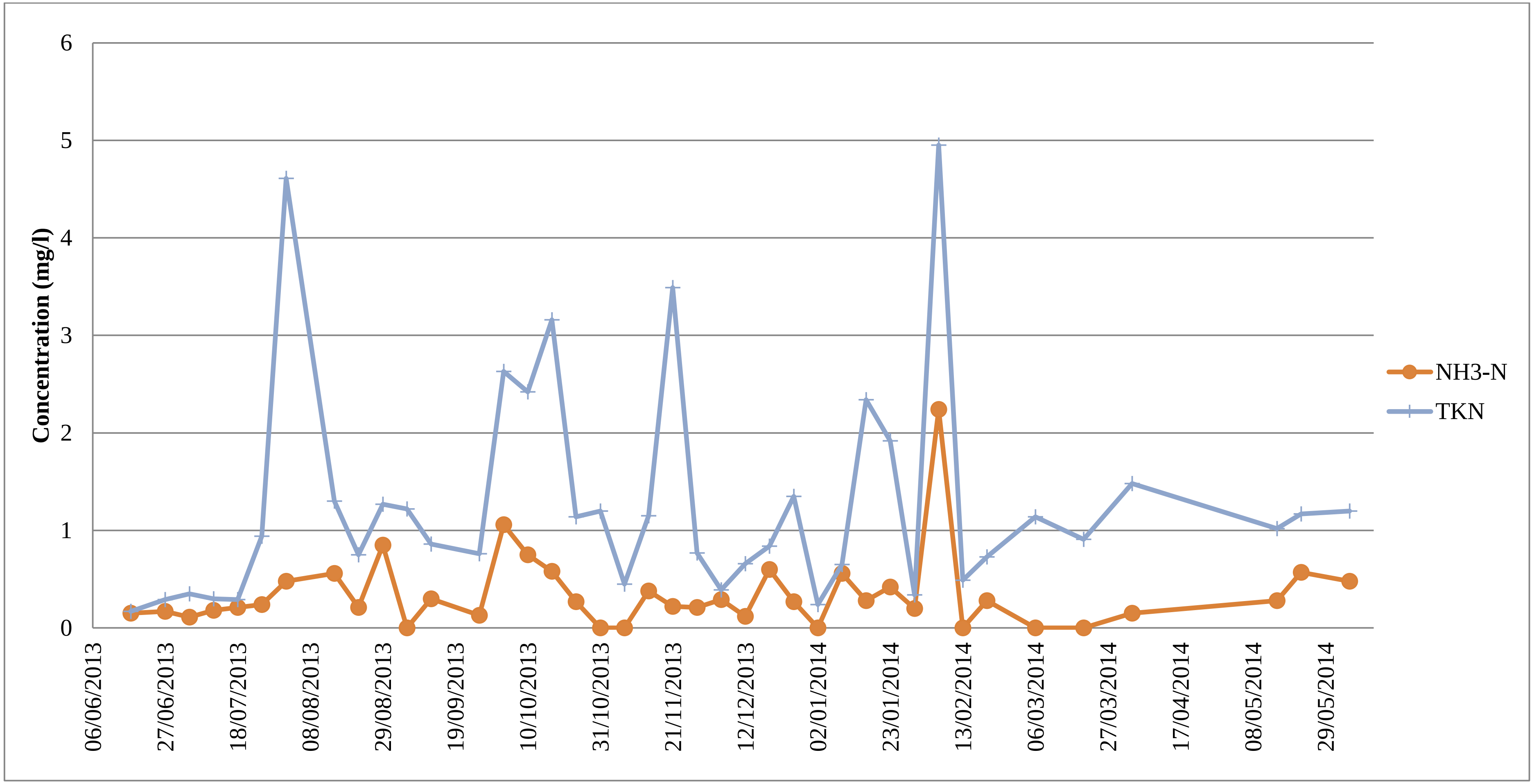

Figure 5.21 : Nitrogen concentrations at the effluent of MBR in the hotel

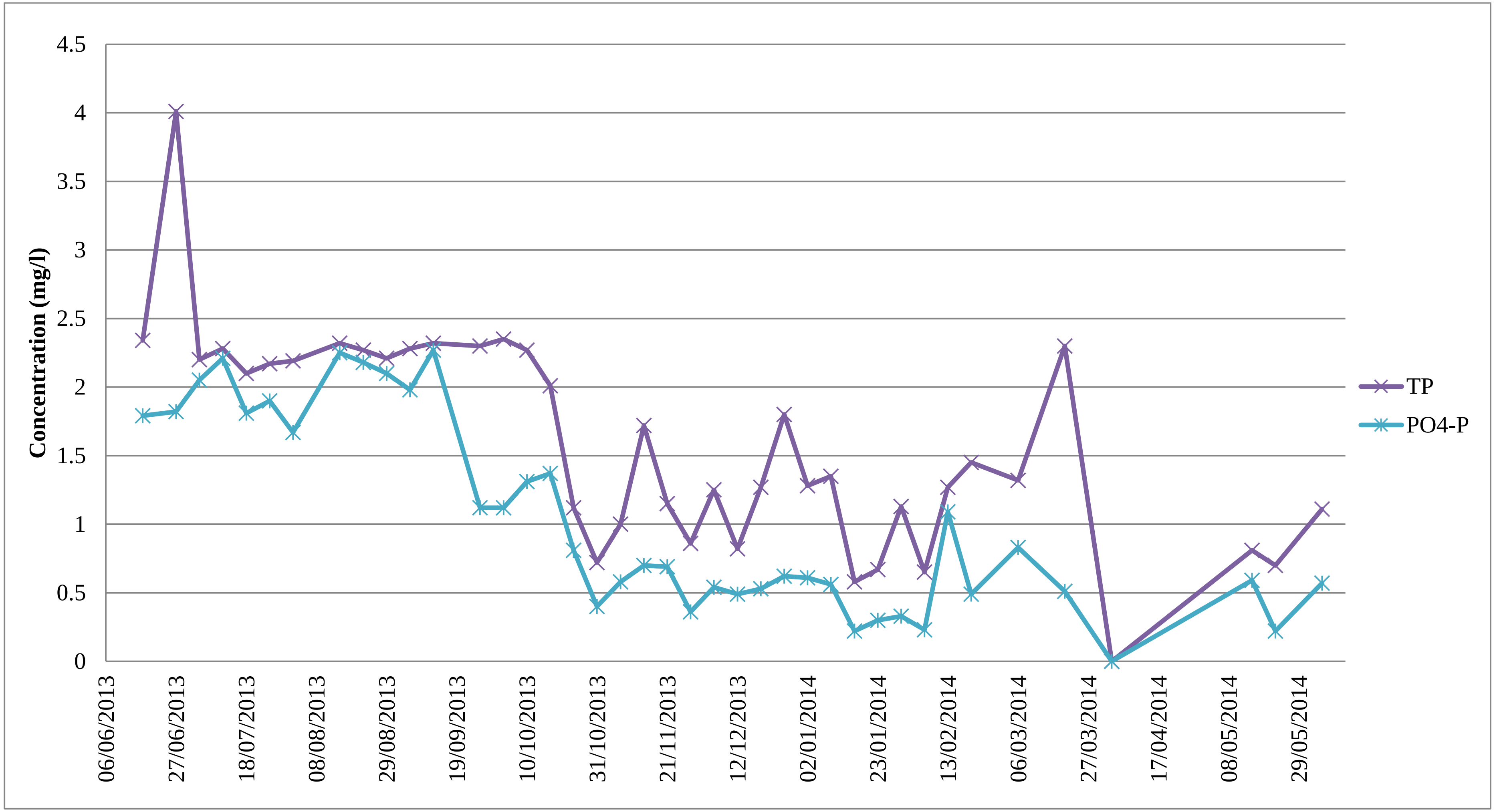

Figure 5.22 : Phosphorus concentrations at the effluent of MBR in the hotel

concentration. The mean concentrations were 0.34 and 1.30 mg/l in terms of NH_3-N and TKN respectively as shown in Table 5.10.

Phosphorus concentrations were measured higher at the beginning of monitoring similar to untreated grey water, and concentrations decreased during monitoring. Highest TP concentration was seen in June 26, 2013 with 4.01 mg/l, however none of other samples showed higher concentrations than 2.5 mg/l in terms of TP. PO_4-P concentrations were always below 2.5 mg/l, and the concentration decreased with decreasing concentrations of raw grey water. The average concentrations in terms of PO_4-P and TP were 1.08 and 1.88 mg/l respectively, while the minimum values were 0 mg/l for both parameters.

The effluent quality of the MBR is given together with the influent quality in Figure 5.21, in terms of organic matter and suspended solids, to enable the comparison of effects of influent quality upon effluent.

Week-long sampling

Week-long sampling of MBR is done in parallel with week-long sampling of equalized raw grey water, to enable a comparison of treatment efficiency according to the inflow water quality. Week-long sampling of MBR effluent is also done for four different seasons, to compare how the weather affects the efficiency of the treatment plant for a whole week.

According to the results presented in Figure 5.23, in July, 2013 and in January, 2014, there were 3 cases that the effluent COD concentrations were above 30 mg/l, however all other samples were below lower limit of 30 mg/l. sCOD concentrations were always below lower limit. BOD_5 concentrations of summer were the highest at the effluent, while the samples taken during winter showed the lowest pollution potential in terms of BOD_5. Table 5.11 summarizes the effluent quality, showing that the maximum COD and BOD_5 concentrations were 45 and 10 mg/l respectively. On the other hand, the average BOD_5 concentration was calculated as 4 mg/l, which enables the use of this treated grey water for every type of reuse applications according to the standards / guidelines published around the world, as the strictest BOD_5 requirement 5 mg/l is being used in Germany and some of the states in USA, as shown in Table 3.9. Turkish regulations state 20 mg/l BOD_5 concentration for every type of irrigation that justifies reuse of this treated grey water.

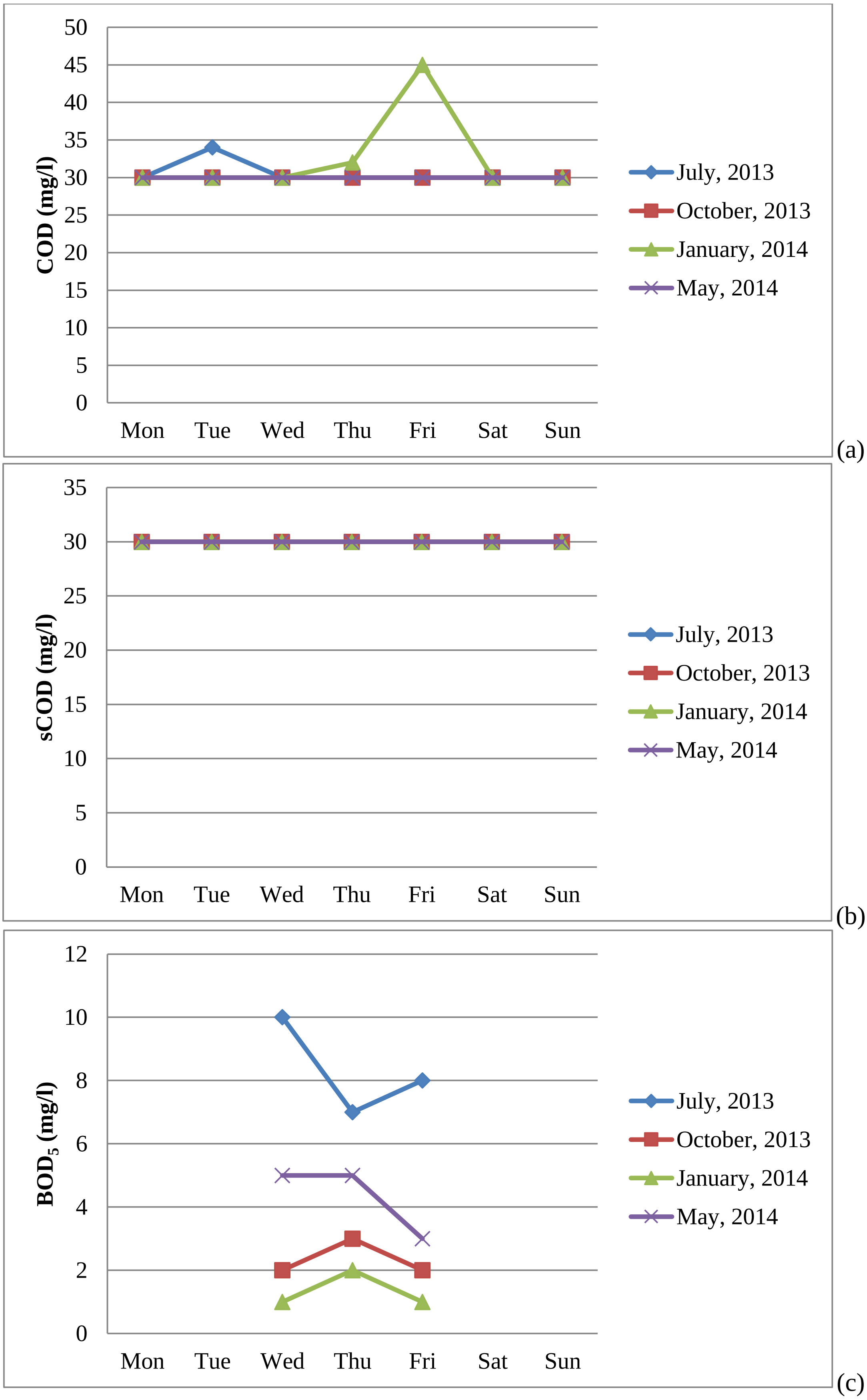

Figure 5.23 : Organic matter concentration change in a week at the effluent of MBR in the hotel in terms of (a) COD, (b) sCOD and (c) BOD_5.

TSS and VSS concentrations after grey water was treated by MBR are given Figure 5.24. The expectations from the MBR system was to see suspended solid free effluent quality, however similar to routine sampling of treated grey water, only 3 out of 28 samples showed 0 mg/l TSS concentration. Maximum concentration of TSS was measured on Wednesday in January as 77 mg/l, however during the following days of the week such concentration was not measured. As this was not an ordinary effluent TSS concentration for MBR systems, a question was asked to the staff responsible for the system if there was an explanation for such quality. The answer was that if the MBR system did not work during night due to low grey water generation, turbidity of the sample taken in the morning was high, because the system stopped for a long period. However during the maintenance in March a surface crack was realized and the capacity of the system was halved to treat grey water with the part that was working properly. The average concentrations in terms of TSS and VSS were measured as 11 and 4 mg/l similar to routine sampling, as shown in Table 5.11. Due to these results, this treated grey water is not permitted to be reused in urban apllications and unrestricted irrigation in some places that regulate treated water requirements, however it is possible to reuse this in Turkey for irrigational purposes.

Highest TKN concentrations in treated grey water were measured during October 2013, representing fall samples, as shown in Figure 5.25. Also, same samples had higher pollution potential in terms of NH_3-N. Except for 4 samples taken during October 2013, TKN concentrations of all samples were below 1.5 mg/l, while NH_3-N concentrations of all samples were under 0.8 mg/l. The average values for NH_3-N and TKN concentrations were calculated as 0.33 and 0.88 mg/l respectively, as shown in Table 5.11.

Phosphorus concentrations at the outlet of MBR system are shown in Figure 5.26. Highest phosphorus concentrations were detected during July, 2013, samples

Table 5.11 : Summary of the week-long analyses done at the effluent of MBR in the hotel.

	COD	sCOD	BOD_5	TSS	VSS	TKN	NH_3-N	TP	PO_4-P
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	30	30	1	0	0	0.27	0	0.21	0.04
Max	45	30	10	77	32	2.24	0.78	2.67	2.35
Mean	31	30	4	11	4	0.88	0.33	1.17	0.77

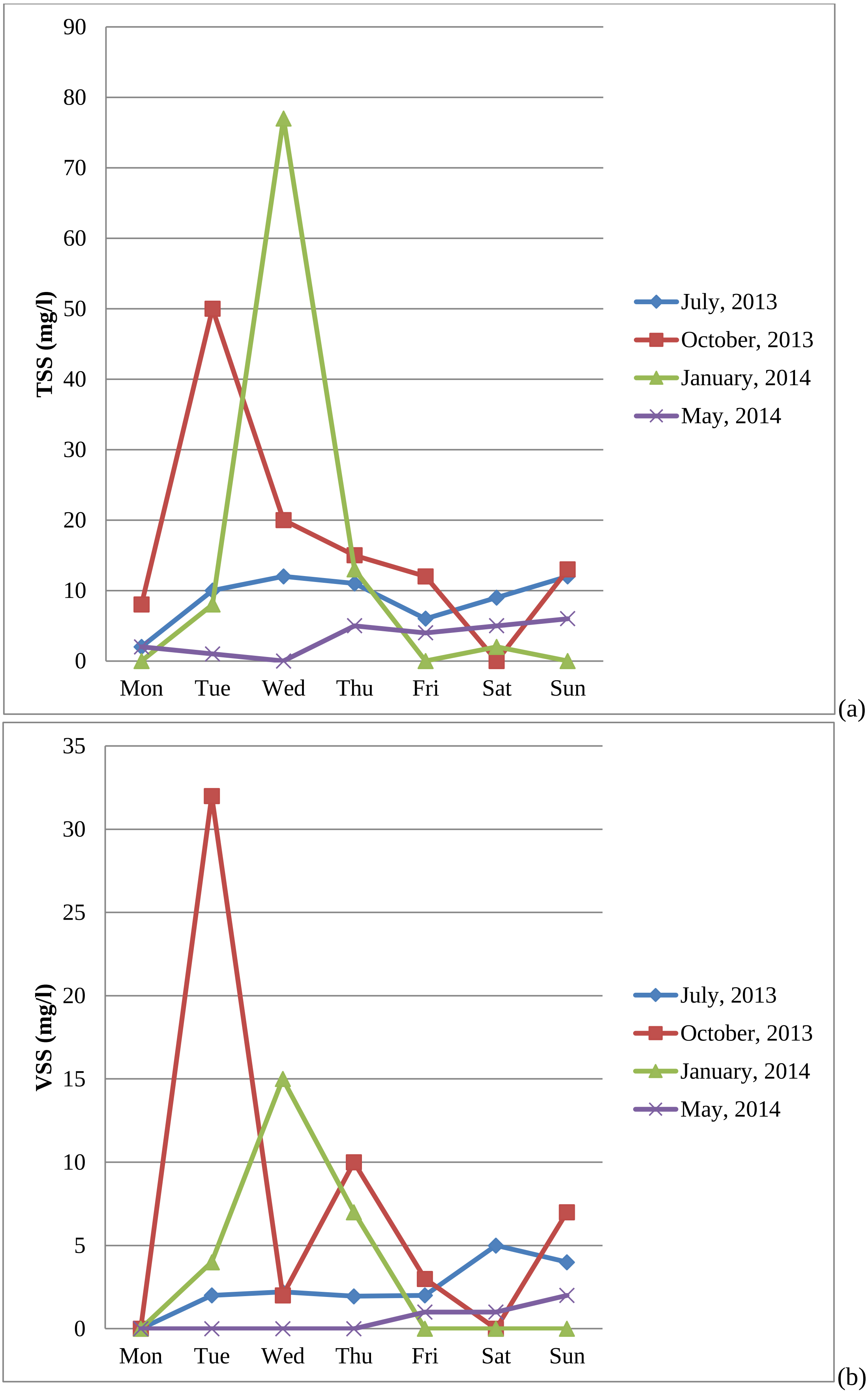

Figure 5.24 : Suspended solids concentration change in a week at the effluent of MBR in the hotel.

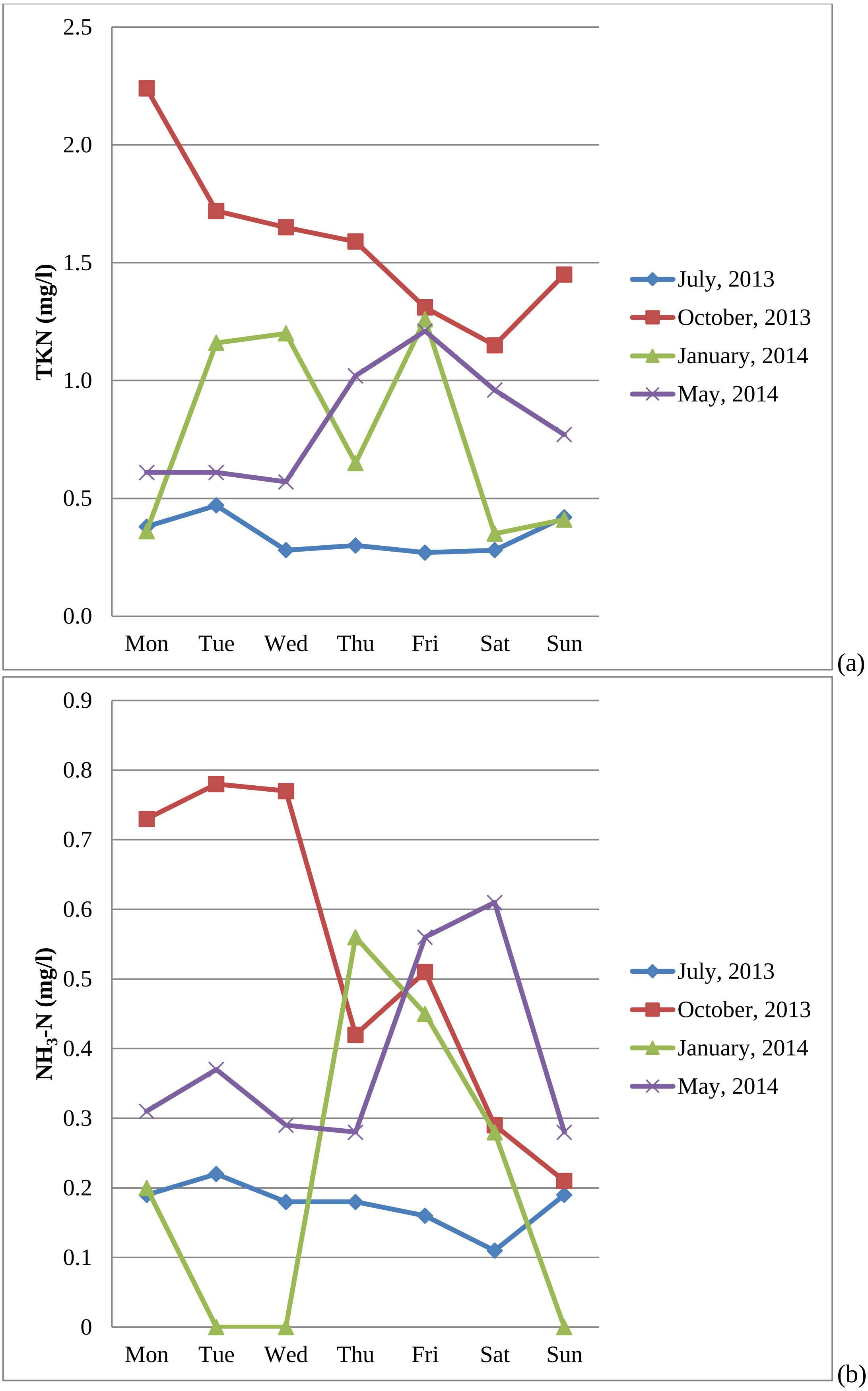

Figure 5.25 : Nitrogen concentration change in a week at the effluent of MBR in the hotel in terms of (a) TKN and (b) NH_3-N.

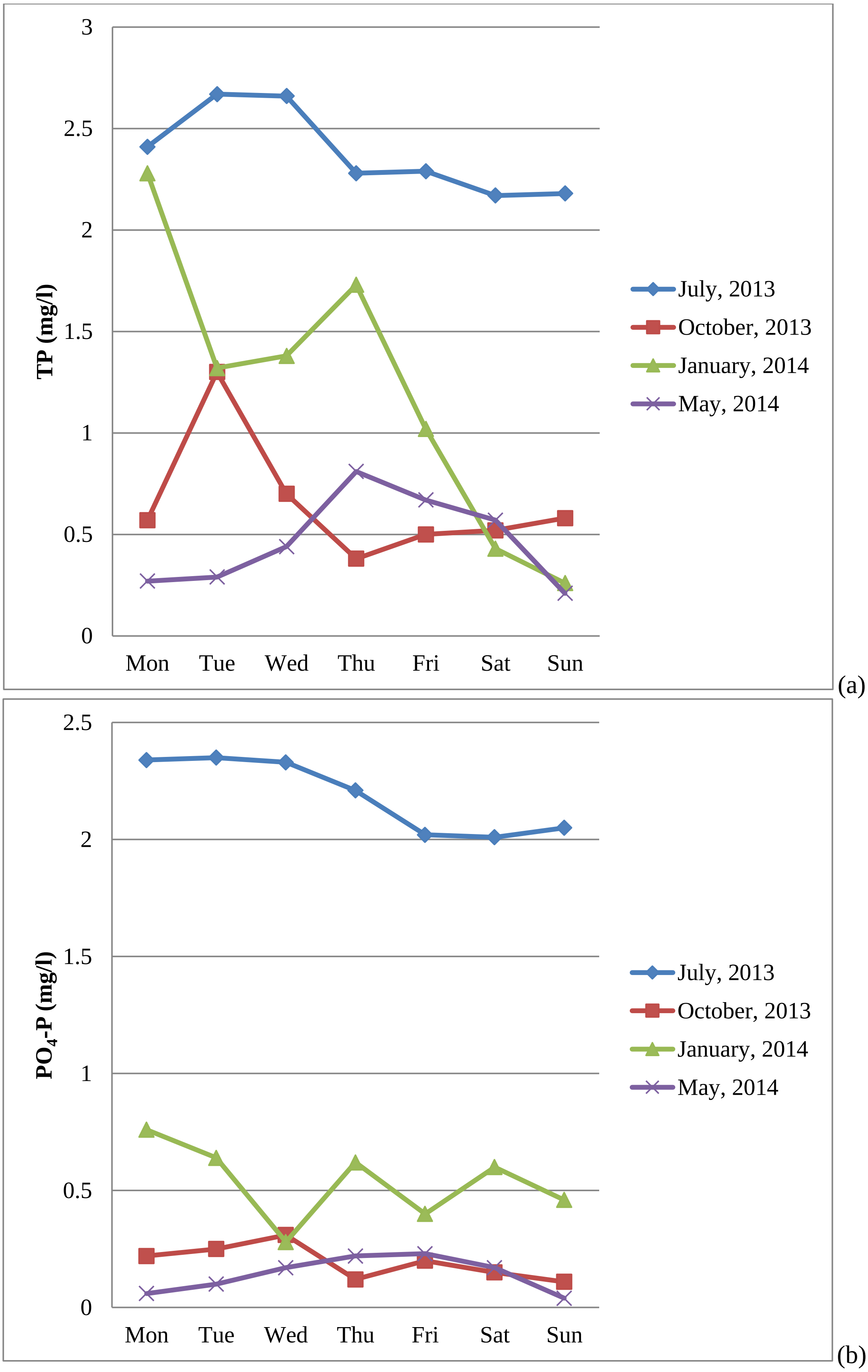

Figure 5.26 : Phosphorus concentration change in a week at the effluent of MBR in the hotel in terms of (a) TP and (b) PO_4-P.

representing summer, in parallel with the routine analyzes, but not paralleling other parameters as the samples taken during summer showed lower pollution potential compared to samples taken in other seasons. The reason for high phosphorus concentrations at the effluent is that the influent phosphorus concentrations were high during summer due to unknown factors, and because the treatment system is not capable of nutrient removal, the influent quality affects the effluent quality. Mean concentrations were 0.77 and 1.17 mg/l in terms of PO_4-P and TP respectively.

Day-long sampling

For monitoring treated grey water quality during a day, 24 hour sampling of MBR outlet was done in October 2013, and the results of analyzes are presented in Figure 5.27-5.30 and summarized in Table 5.12. During sampling, an auto-sampler was used, however because another auto-sampler was not available at the same time, treatment system inlet could not be monitored. Analyses were done with every 2 samples.

According to Figure 5.27, COD and sCOD concentrations after first three analyzed samples were below 30 mg/l lower limit or close to lower limit. The average concentrations in terms of COD and sCOD were calculated as 47 and 36 mg/l as given in Table 5.12. sCOD/COD ratio was calculated as 76% at the effluent of the MBR, showing that the 76% of organic matter was in particulate form at the effluent as expected. BOD_5 test could only be done with last three samples as BOD_5 test must be started after 4 hours following sampling at most. The samples which were analyzed for BOD_5 gave maximum 4 mg/l concentration, revealing that the biodegradable organic matter is treated.

Figure 5.28 illustrates how the TSS and VSS concentration of treated grey water changed during a day. According to the results, after the first three samples analyzed, TSS and VSS concentrations decreased, however they both increased after midnight. Maximum TSS concentration was seen at 14:24 with 21 mg/l. Average concentrations in terms of TSS and VSS were 11 and 2 mg/l respectively, a similar result to those samples taken routinely and week-long. During day-long samplig, there was an obvius trend between TSS and VSS concentrations.

Figure 5.29 and Figure 5.30 shows the quality of treated grey water in terms of nutrients. According to these figures, treated grey water does not pose an environmental threat, as maximum TKN and NH_3-N concentrations were 4.46 and

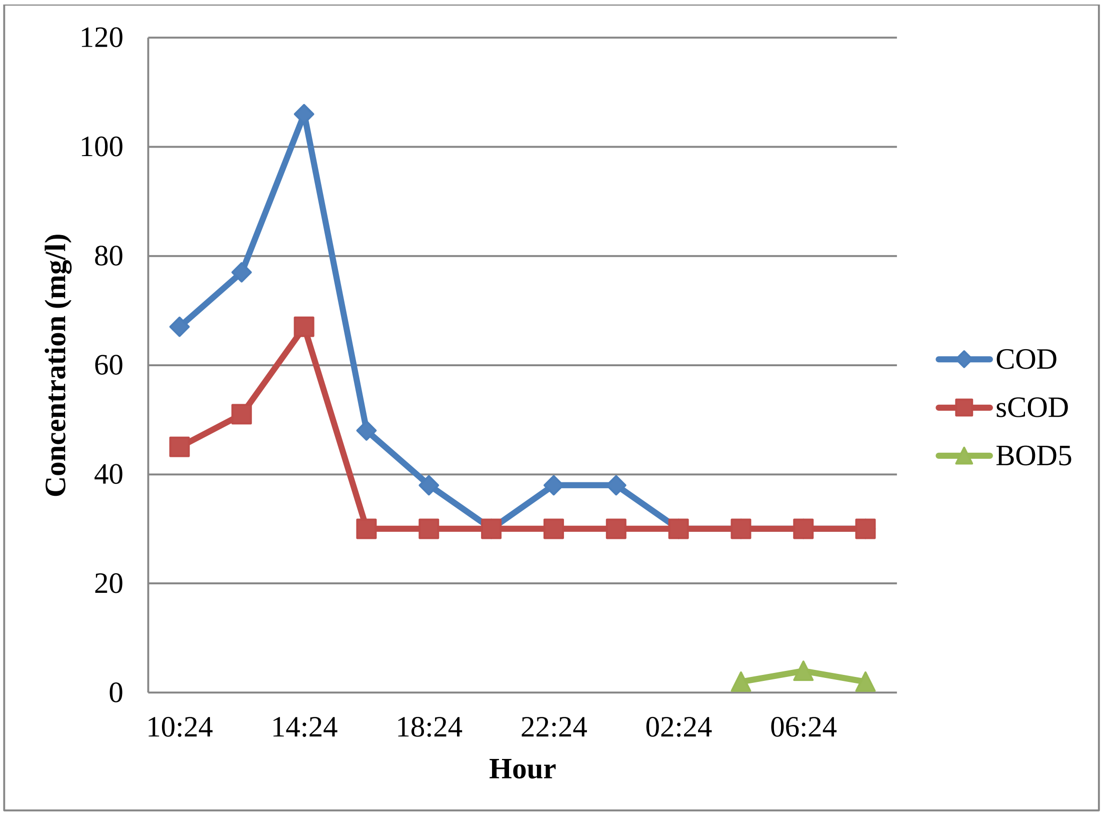

Figure 5.27 : Organic matter concentration change during a day in the effluent of MBR in the hotel.

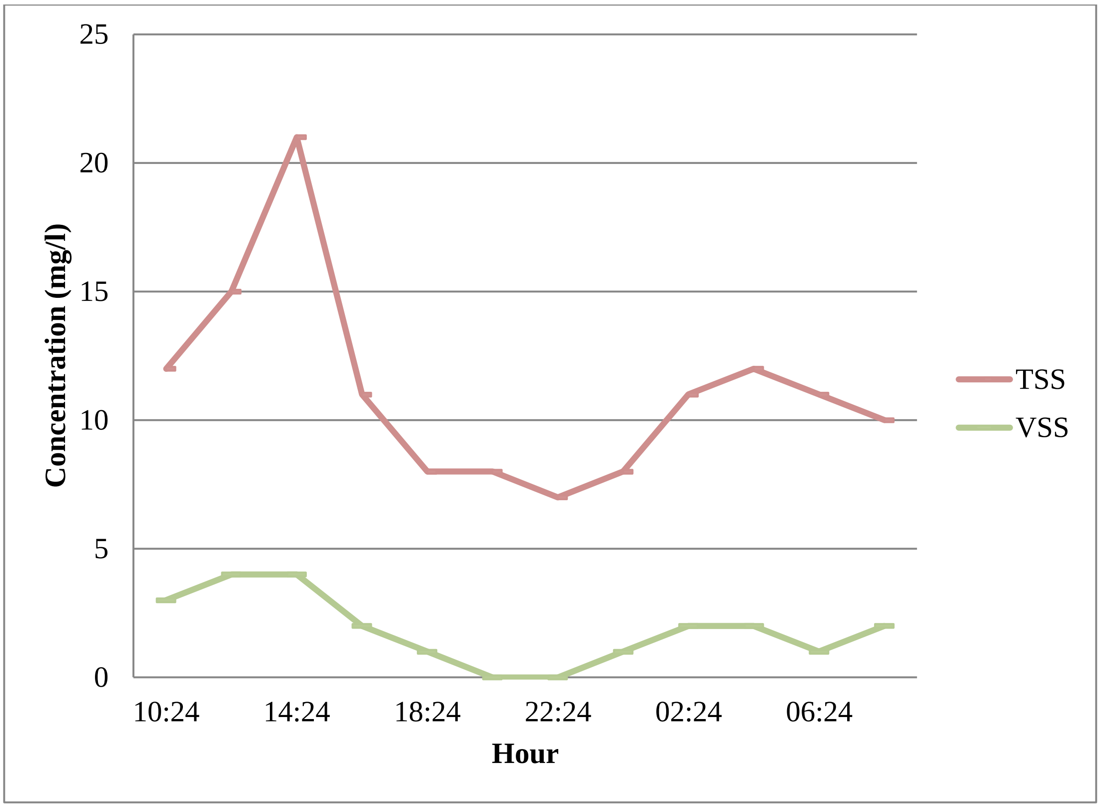

Figure 5.28 : Suspended solids concentration change during a day in the effluent of MBR in the hotel.

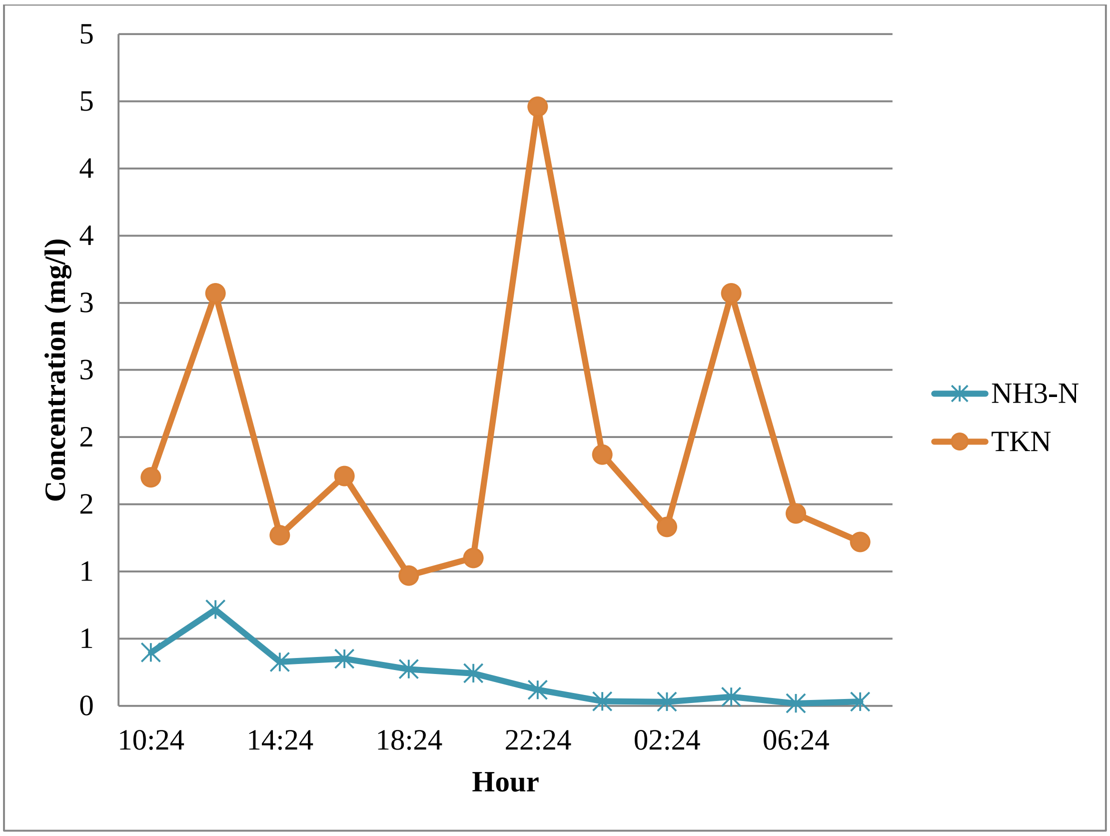

Figure 5.29 : Nitrogen concentration change during a day in the effluent of MBR in the hotel.

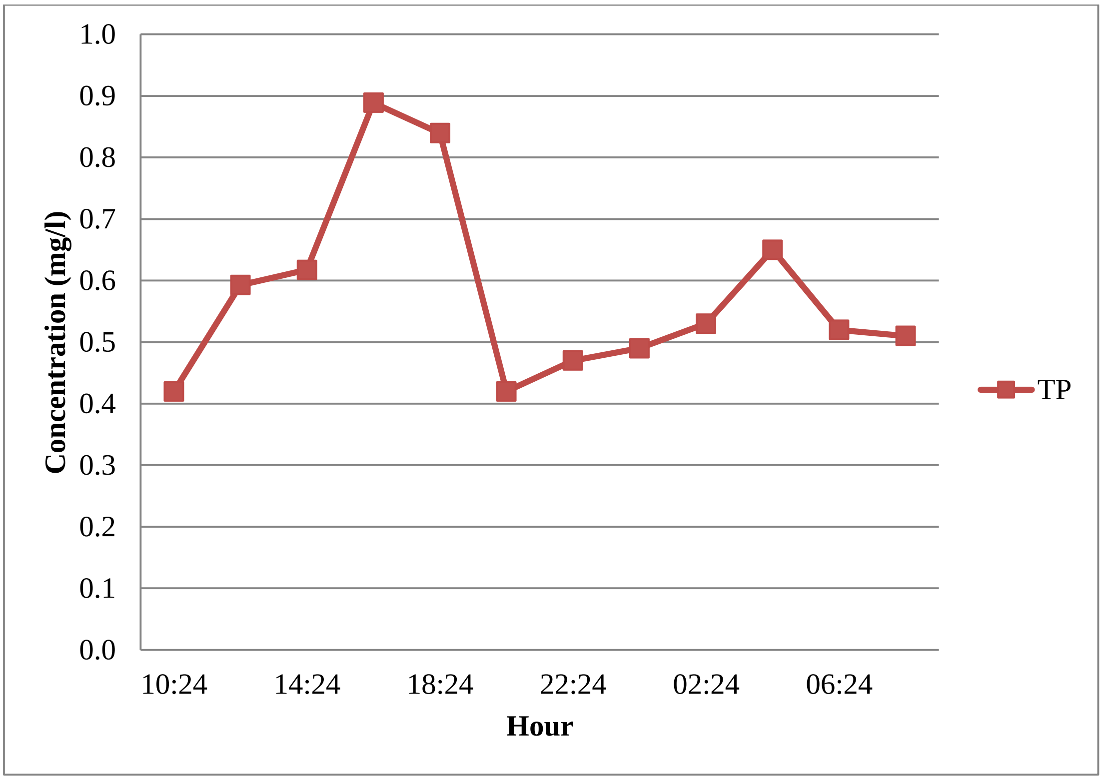

Figure 5.30 : Phosphorus concentration change during a day in the effluent of MBR in the hotel.

Table 5.12 : Summary of the day-long analyses done at the effluent of MBR in the hotel.

	COD	BOD_5	sCOD	TSS	VSS	NH_3-N	TKN	PO_4-P	TP
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	<30	2	<30	7	0	0.02	0.97		0.42
Max	106	4	67	21	4	0.72	4.46		0.89
Mean	47	3	36	11	2	0.22	1.93		0.58

0.72 mg/l respectively, while 0.89 mg/l was the maximum TP concentration and PO_4-P was not analyzed as TP concentrations were low.

In January, two auto-samplers were available and both influent and effluent of grey water treatment plant was monitored, however for effluent, the samples were taken after grey water was chlorinated and UV disinfected. The results are summarized in Table 5.13 and shown in Figure 5.31-5.34.

According to the analyzes done with UV outlet, organic matter concentrations were below lower limit of 30 mg/l in terms of COD and sCOD, and BOD_5 concentrations were 2 and 3 mg/l showing that the biodegradable organic matter was treated in treatment plant. This type of treated grey water can be reused in any area that is defined by the regulations given in Table 3.9.

TSS and VSS concentrations were 0 mg/l except for the first sample taken at 12:45, showing 3 and 2 mg/l respectively. Most of the standards and guidelines are concerned about TSS concentration in water to be reused as shown in Table 3.9. Grey water samples showed 3 mg/l BOD_5 concentration at average, which enables every type of reuse application.

NH_3-N was not analyzed in these samples as TKN concentrations were very low, below 0.8 mg/l, and neither the samples were tested in terms of PO_4-P as TP concentrations changed between 0.8 and 1.2 mg/l, which are considered as low concentrations. The mean concentrations in terms of TKN and TP were calculated as 0.38 and 1.01 mg/l respectively.

Table 5.13 : Summary of the day-long analyses done at the UV effluent in the hotel

	COD	BOD_5	sCOD	TSS	VSS	NH_3-N	TKN	PO_4-P	TP
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	<30	2	<30	0	0		0.06		0.87
Max	<30	3	<30	3	2		0.73		1.11
Mean	<30	3	<30	0	0		0.38		1.01

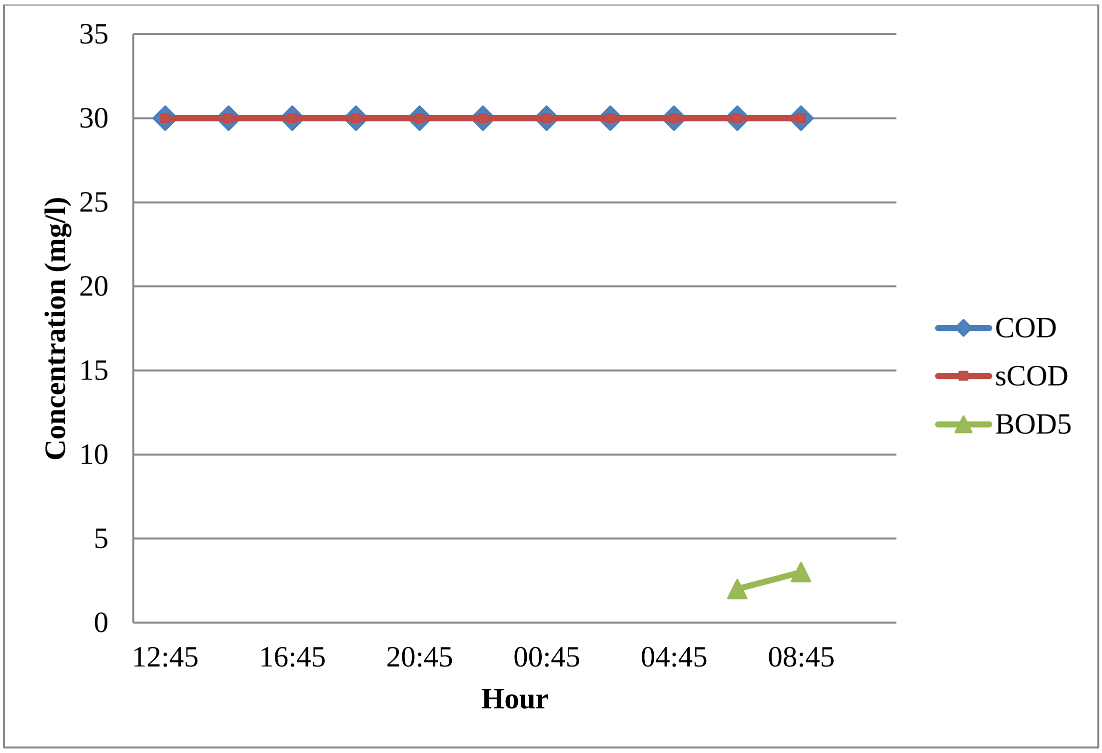

Figure 5.31 : Organic matter concentration change during a day in the effluent of UV disinfection in the hotel.

Figure 5.32 : Suspended solids concentration change during a day in the effluent of UV disinfection in the hotel.

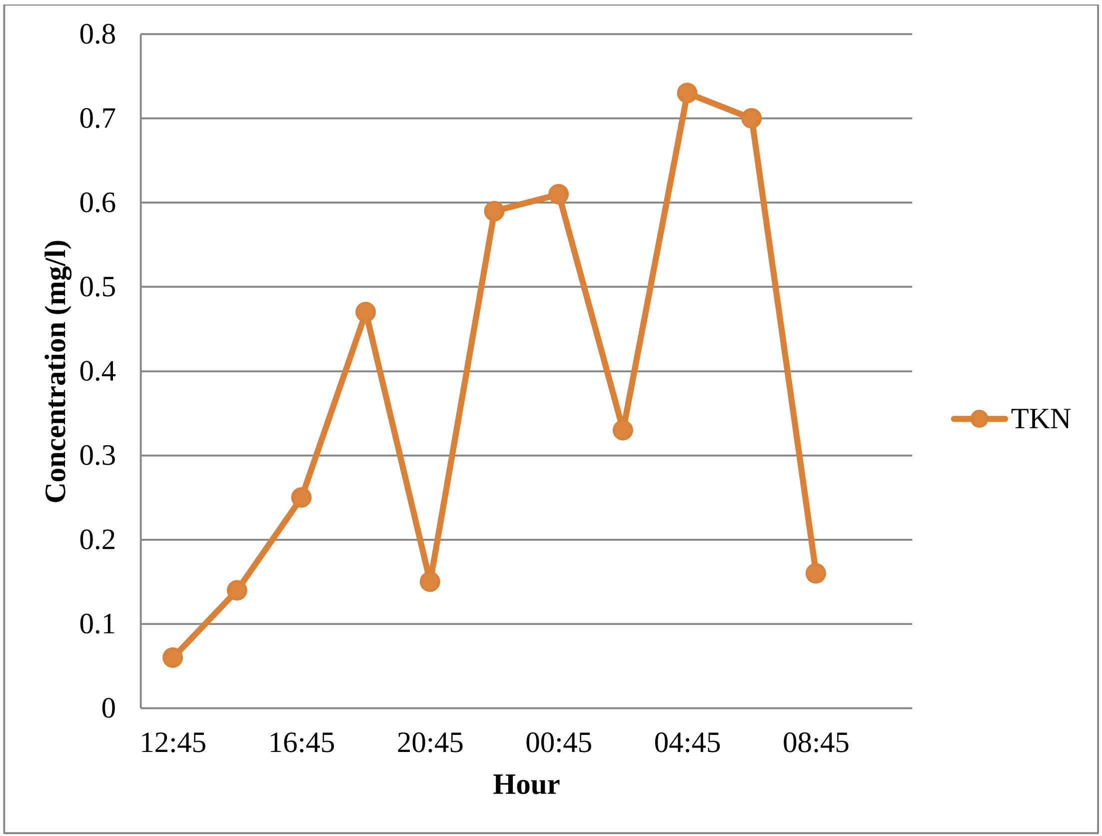

Figure 5.33 : TKN concentration change during a day in the effluent of UV disinfection in the hotel.

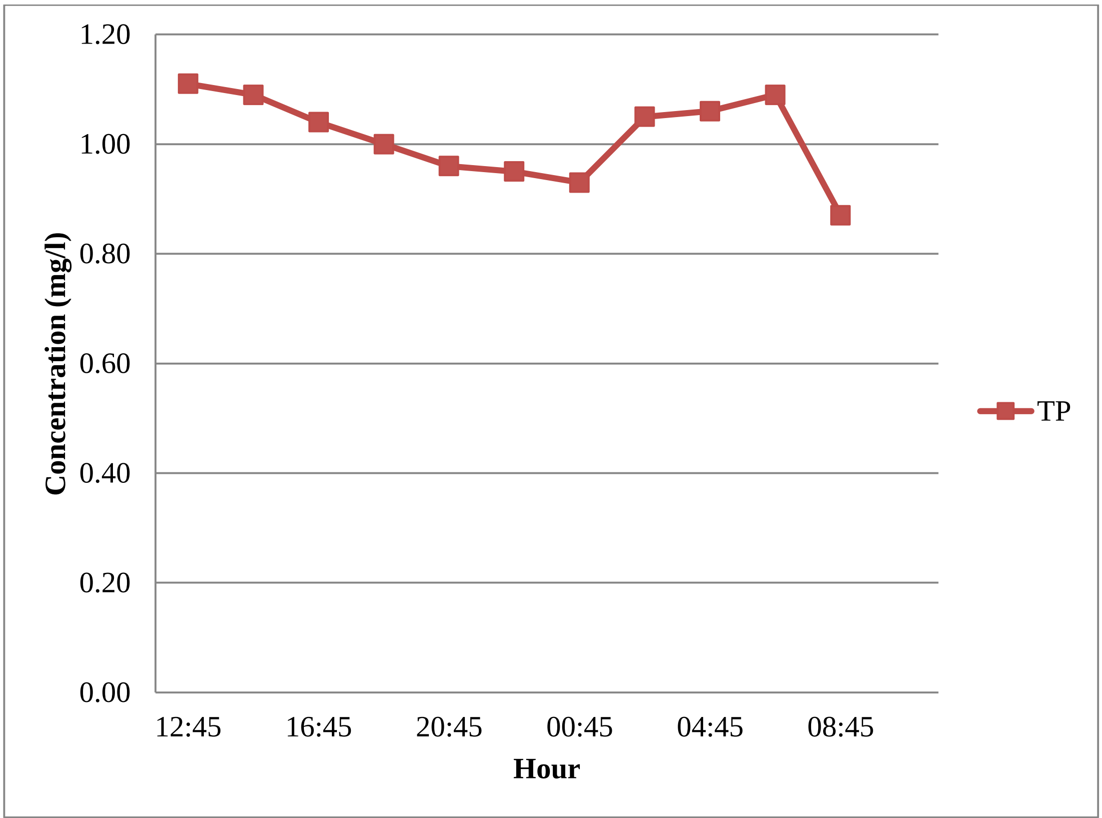

Figure 5.34 : Total phosphorus concentration change during a day in the effluent of UV disinfection in the hotel.

5.2.1.2 Microbiological indicators

MBR effluent was analyzed for Total Coliform, Fecal Coliform, E.Coli and Enterococcus for three months. The results are presented in Table 5.14. During February and March, the effluent was not out of pathogens unexpectedly, as ultrafiltration membranes generally promise holding the bacteria as shown in Figure 3.5. After the maintenance of MBR in May, no pathogenic indicators were measured in the effluent. Effluent was always out of Enterococcus, which may be based on the influent being Enterococcus free.

If the quality of MBR treated grey water in February and March are compared to the standards and guidelines given in Table 3.1, the reuse is not recommended for any type of application according to WHO (2006). On the other hand, the guidelines of Florida, Nevada, Texas in USA and Spain let this quality grey water to be reused for irrigation of fruit and vegetables eaten raw. The quality of treated grey water in May complies with all the standards and guidelines given in Table 3.1.

Table 5.14 : Microbiological indicator concentrations of MBR effluent in the hotel

		February	March	May
Total Coliform	cfu/100 ml	1140	1100	0
Fecal Coliform	cfu/100 ml	246	240	0
E.Coli	cfu/100 ml	183	108	0
Enterococcus	cfu/100 ml	0	0	0

5.2.1.3 Summary of all monitoring program for the MBR effluent in the hotel

Summary of all analyses done with the samples taken from the effluent of MBR system in the hotel are given in Table 5.15. According to the table, mean organic matter concentrations in terms of COD, BOD_5 and sCOD were 43, 6 and 32 mg/l respectively. Normally, COD concentration at the effluent of an MBR treating domestic wastewater should be below 30 mg/l as shown in Table 3.8, however at the beginning of monitoring, there was a problem with the treatment system that resulted with deteriorated effluent quality, and that problem effected the average concentrations. This problem may be linked to the dominating non-biodegradable organic matter concentration as compared to biodegradable organic matter concentration in the influent of organic matter. Average BOD_5 concentration at the effluent was calculated as 6 mg/l for all samples, which also supports that idea.

Table 5.15 : Summary of all analyses done with the samples taken from the effluent of MBR in the hotel

	COD	BOD_5	sCOD	TSS	VSS	NH_3-N	TKN	PO_4-P	TP
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Min	<30	<1	<30	0	0	0	0,17	0	0
Max	340	42	67	77	36	2,24	4,95	2,35	4,01
Mean	43	6	32	11	4	0,32	1,24	0,92	1,30

Average TSS and VSS concentrations were calculated as 11 and 4 mg/l respectively, as shown in Table 5.15. These results were not expected due to filtration process that MBR promises, however these results prove that a problem was during the first half of routine monitoring, effecting average values. After the plant has gone under maintenance, the quality got better in terms of both TSS and VSS, and during second half analyses of only 4 samples showed higher pollution potential than 10 mg/l in terms of TSS. In the light of these data, properly treated grey water can be reused for applications that require 10 mg/l TSS concentration at maximum, however if the treatment plant is not managed as it should be, then the concentrations may increase to a level that is not permitted for reuse.

The nutrient concentrations in terms of nitrogen and phosphorus were low in treated grey water as shown in Table 5.15. This is linked to the influent grey water quality, as the nutrient concentrations were not high in raw grey water samples. The mean concentrations were 1.24 and 1.30 mg/l in term of TKN and TP respectively.

Inland water quality classes are given in Table 5.16. First class in the table refers to the water bodies that can be used for drinking water supply, body contact supports, recreational activities and fish farming, while second class presents the water bodies

Table 5.16 : Quality classification of inland water resources (Surface Water Quality Management Regulation, 2012)

		Water Quality Class			
		I	II	III	IV
COD	mg/l	25	50	300	>300
BOD_5	mg/l	4	8	20	>20
TKN	mg/l	0.5	1.5	5	>5
NH_4-N	mg/l	0.2	1	2	>2
TP	mg/l	0.02	0.16	0.65	>0.65
pH	-	6.5-8.5	6.5-8.5	6-9	-
Fecal Coliform	MPN/100 ml	10	200	2000	>2000
Total Coliform	MPN/100 ml	100	20000	100000	>100000

that can be used for drinking water after treatment, recreational activities, irrigation and fish farming except for trout growing. Third class stands for polluted water bodies and can be used for industrial purposes after treatment and forth class water is highly polluted water and cannot be used unless its quality is remediated. If the quality of treated grey water is compared to these inland water quality classes, it is seen that all requirements were fulfilled for second class water resources in terms of physicochemical parameters and microbiological indicators, except for TP, which means that this treated grey water can be used as drinking water if further treatment is applied.

The influent and effluent quality are given in Figure 5.35 in terms of COD, BOD_5, sCOD, TSS and VSS, to see if the quality fluctuations in the raw grey water effects the outflow quality. It is clearly seen froom Figure 5.35a that there was a problem during the first 3 months, however after that the problem solved and even if the raw grey water quality changed, the effluent was stabilized and always gave similar quality.

Removal efficiencies in the grey water treatment system in the hotel was calculated and the results are given in Table 5.17. According to the table, the least removal was occured in terms of sCOD, 78% of BOD_5 was treated in the reclamation plant among organic matter parameters. On the other hand, TSS and VSS removals should have been close to 100%, however the treatment efficiencies were 87% and 91% respectively. Results for different treatment applications on different grey water fractions in literature are given in Table 3.6 and three of those works in that table are presented in Table 5.18 to enable a comparison with the treatment system in the hotel. No similar work was encountered during this work, however as the grey water treatment system in the hotel is an MBR and treats grey water fraction that is generated at the bath/showers and wash basin, the systems with the similar stream or treatment system are chosen for comparison.

Hotel grey water generated from baths and wash basins are treated through filtration and sedimentation in the work of March et al (2004) and the COD and TSS removals were 54% and 58% respectively, however there is no data about the BOD_5 removal. Filtration and sedimentation are processes that does not include a biological step and therefor the BOD_5 removal efficiency of the system may be lower than the one for MBR systems, however according to COD removal efficiency, the importance of

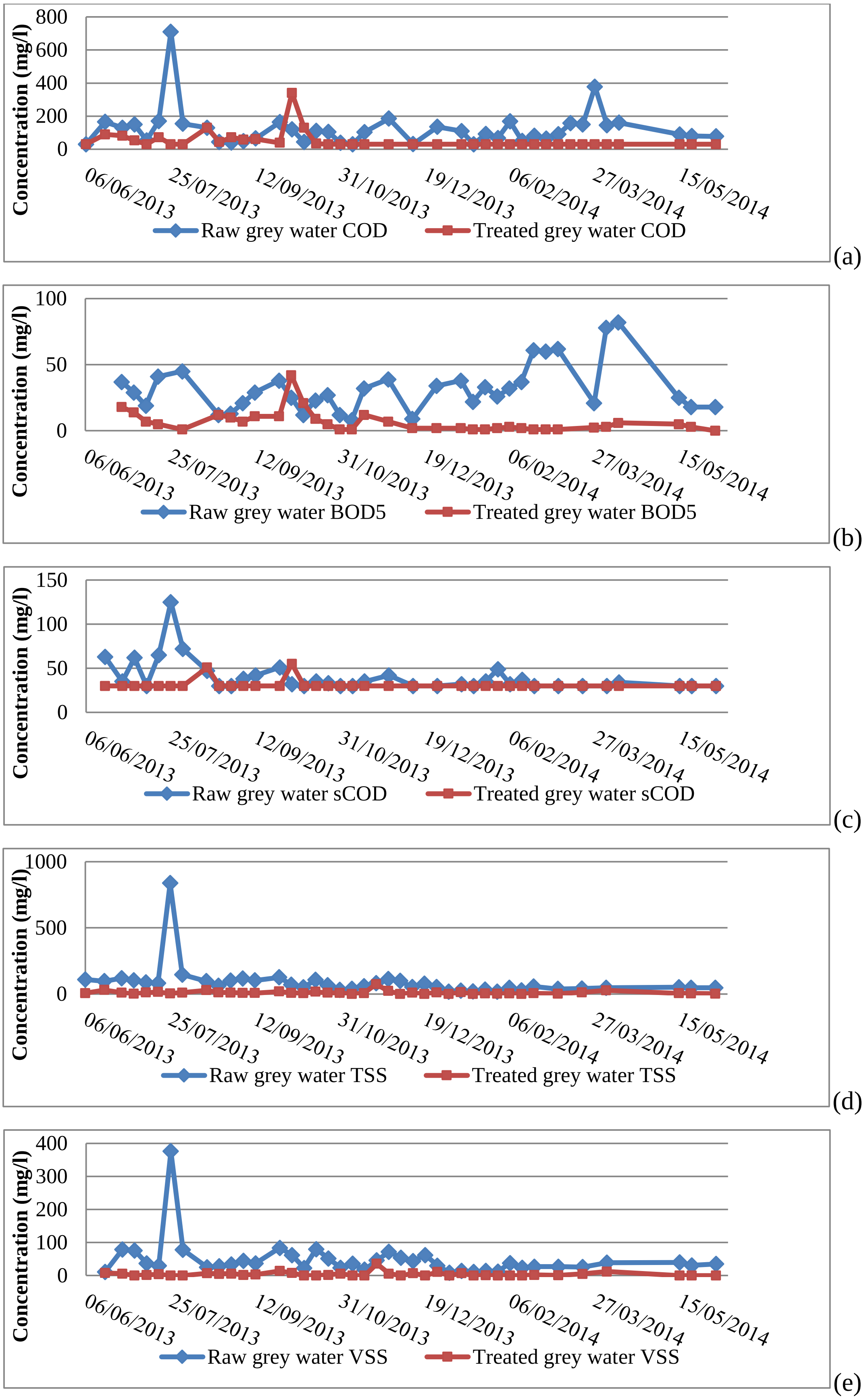

Figure 5.35 : Raw grey water and treated grey water quality in terms of (a) COD, (b) BOD_5, (c) sCOD, (d) TSS and (e) VSS.

Table 5.17 : Removal efficiency in the hotel

COD	BOD_5	sCOD	TSS	VSS
58%	78%	23%	87%	91%

Table 5.18 : Different removal efficiencies of different treatment processes applied to different freactions of grey water

Source	Grey water fraction	Treatment process	Parameter	Removal	References
Hotel	Bath, wash basin	Filtration, sedimentation	COD	54%	March et al. (2004)
			TN	39%	
			TSS	58%	
			Tur.	18%	
House	Shower/ bath, wash basin	Screen, RBC, sand filter, disinfection	BOD	94%	Friedler et al. (2005)
			COD	75%	
			TP	58%	
			TSS	82%	
			Turb.	98%	
Sports complex	Shower	MBR	BOD_5	93%	Merz et al. (2007)
			COD	56%	
			TP	19%	
			TN	63%	
			Turb.	98%	

physicochemical treatment system was comprehended, as there is only 4% difference in terms of COD removal. Also thinking that the grey water generated from hotel bath/showers and wash basins show low organic matter content as shown in Appendix A, the need for biological treatment should be disscussed for this specific grey water fraction.

Another treatment technology used for treatment of grey water is RBC and this biological treatment technology is experimented with a combination of different physical treatment systems for grey water fraction that is generated from shower/bath and wash basins similar to this study, however the source was a house rather than a hotel (Friedler et al., 2005). The raw grey water quality is given in Appendix A for the piece of work mentioned, and the quality is similar to the one in this study with 59 mg/l BOD_5 and 158 mg/l COD, where the TSS concentration is 43 mg/l. BOD_5 and COD removal efficiencies of the treatment system were reported as 94% and 56% by Friedler et al (2005). According to these results, BOD_5 removal of RBC including system is higher than the one in this study, while the COD removal efficiency is lower than this study 2%. Also TSS removal efficiency of these systems are comparable as can be seen from Table 5.12 and 5.13. This shows that even MBR is one of the most frequently applied technology for grey water treatment, other technologies sould be examined carefully.

MBR technology is applied to shower grey water generated from sports complex by Merz et al. (2007) and the treatment efficiencies are given in Table 5.18. According to these results, 93% of BOD_5 is removed through MBR, however the treatment effieciency of the MBR in the hotel was 78%, which was a lower efficiency for an MBR. On the other hand the COD removal efficiencies of the systems are comparable. BOD_5/COD ratio of the grey water analyzed in Merz et al. (2007) is 54%, while the same ratio was calculated as 31% for this study, which may be the factor that is effecting the removal efficiency, as this ratio shows the biodegradable organic matter content of samples under BOD_5 conditions.

5.2.2 MBR in the student residence hall

As for the raw grey water characterization in the student residence hall, seven samples were analyzed for the MBR effluent for physical and chemical parameters and microbiological indicators and the results are presented in Figure 5.36-5.39 and summarized in Table 5.19.

5.2.2.1 Physical and chemical parameters

Organic matter concentrations were analyzed as COD and BOD, however COD concentrations at the effluent were always below the lower limit of 30 mg/l, therefore all COD concentrations are shown as 30 mg/l in Figure 5.36. BOD_5 concentration was less than 5 mg/l except for the first sample which had 6 mg/l, and the average of BOD5 tests was 4 mg/l, meeting the quality requirements for every type of water reuse applications defined in reuse standard / guidelines in Table 3.10.

Results of suspended solid analyzes are given in Figure 5.37. According to the results, TSS concentration was measured below 10 mg/l always and most of the suspended solids were in volatile/organic form. Maximum VSS concentration was measured as 7 mg/l, while there were samples out of any VSS. The average TSS and VSS concentrations were 5 and 3 mg/l respectively, assuring the reuse of this treated wastewater for toilet flushing meets the requirements stated in Table 3.10.

Nitrogen and phosphorus concentrations at the effluent were not at the level to cause any environmental problems as shown in Figure 5.38 and 5.39. Except for the first

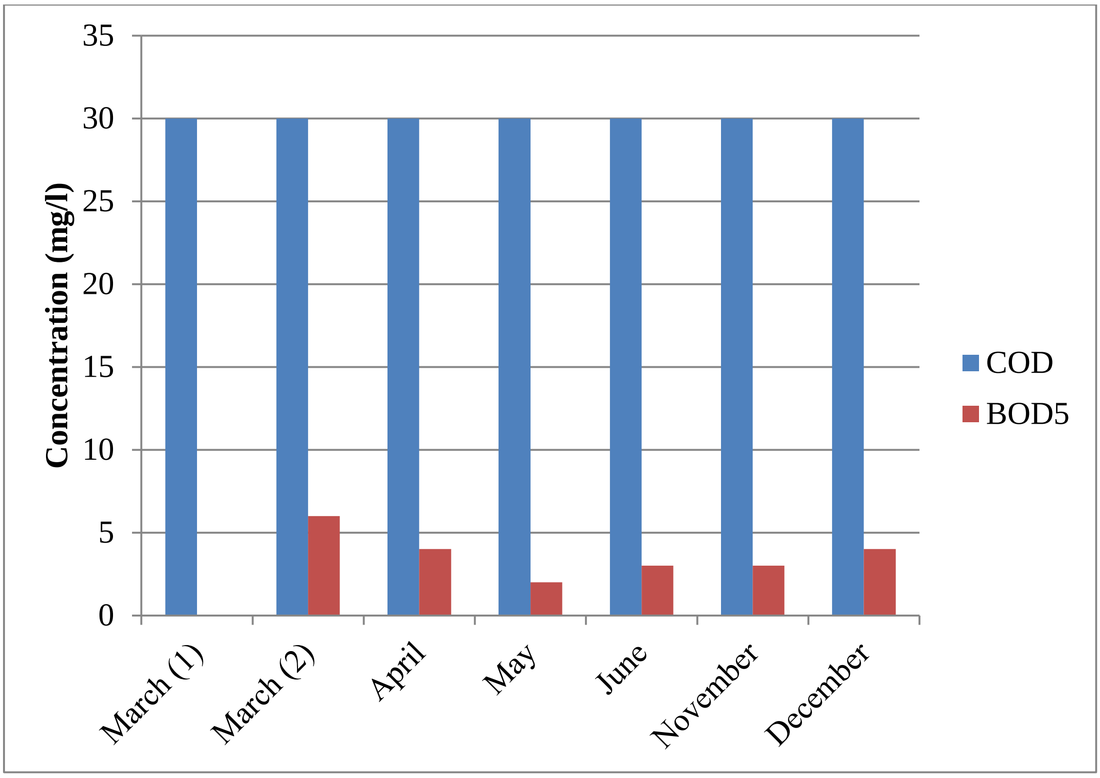

Figure 5.36 : Organic matter in the effluent of MBR at the student hall of residence

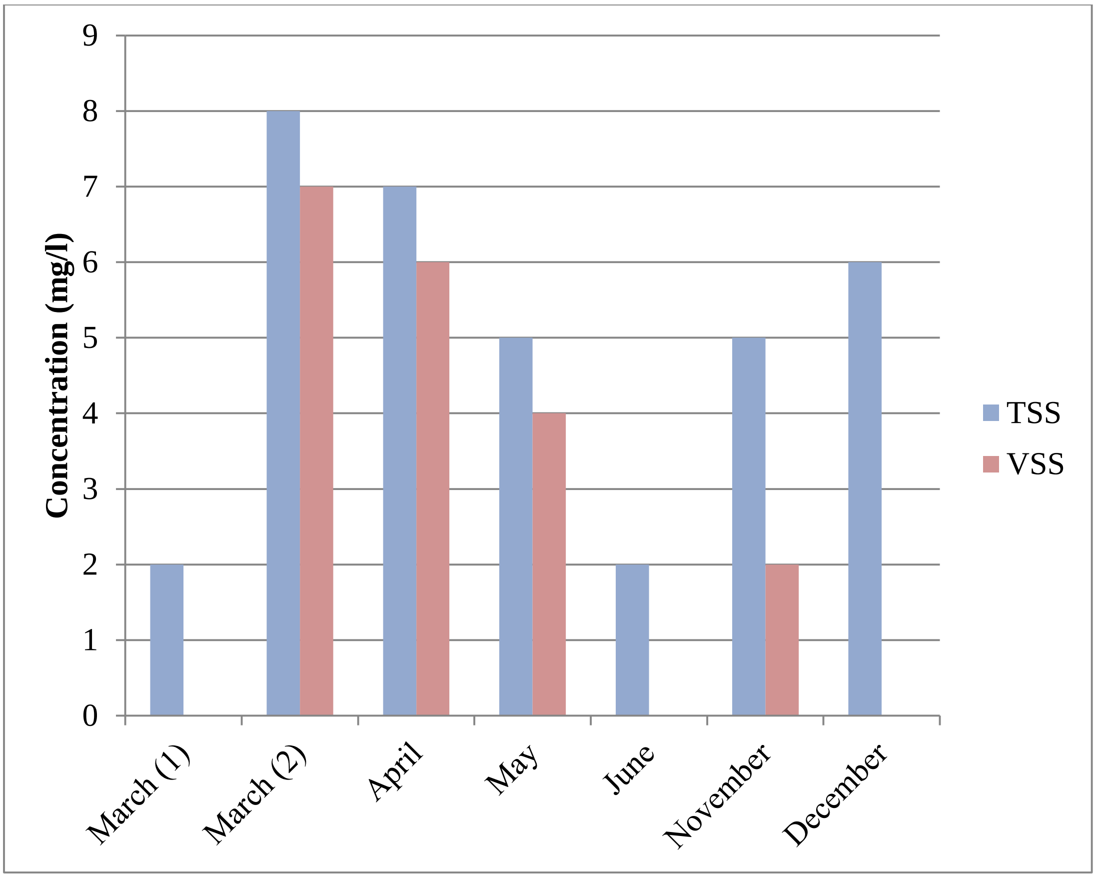

Figure 5.37 : Suspended solids in the effluent of MBR at the student hall of residence

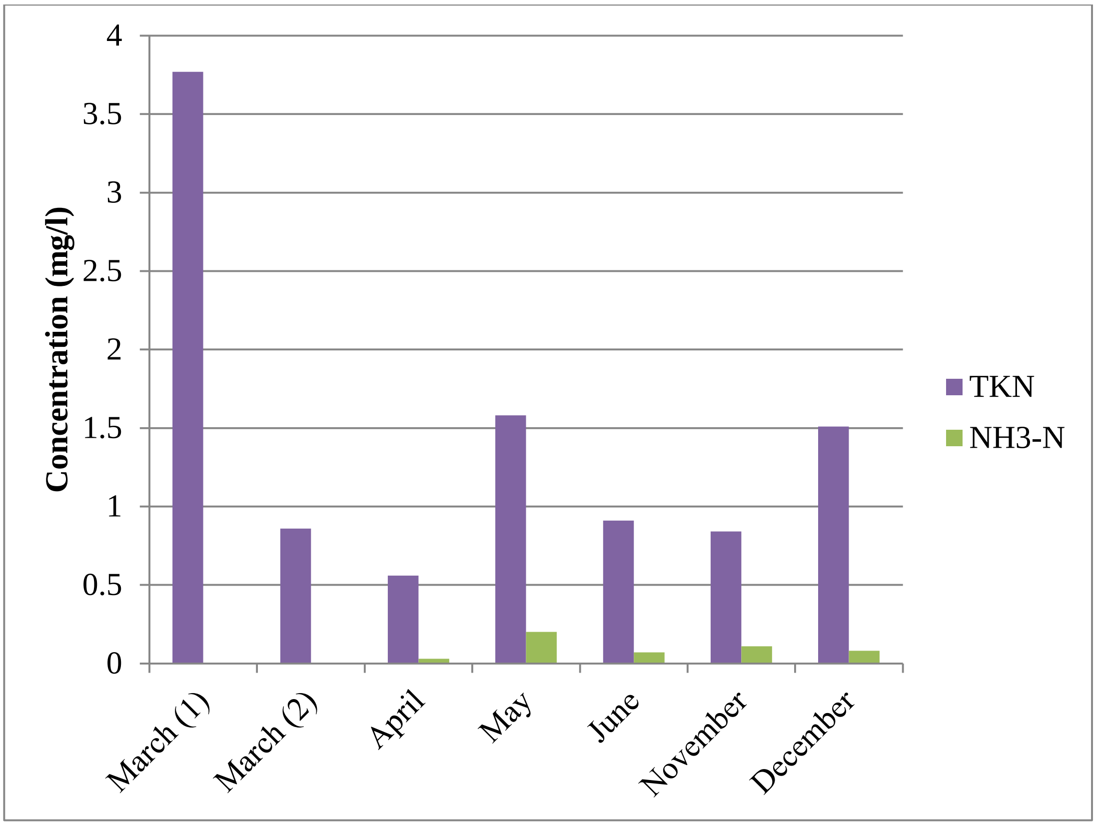

Figure 5.38 : Nitrogen in the effluent of MBR at the student hall of residence

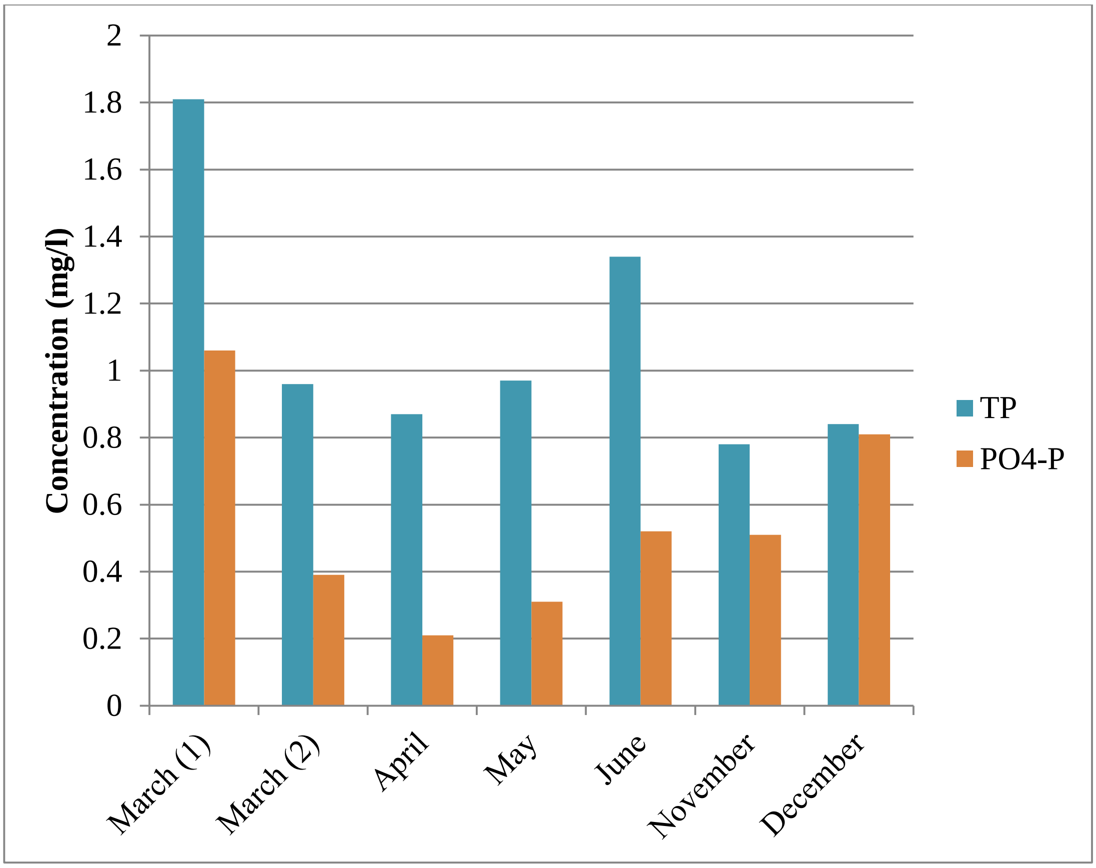

Figure 5.39 : Phosphorus in the effluent of MBR at the student hall of residence

Table 5.19 : Summary of the analyses done at the effluent of MBR in the university student residence hall

	COD	BOD_5	TSS	VSS	NH_3-N	TKN	PO_4-P	TP
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
min	<30	2	2	0	0	0,56	0,21	0,78
max	<30	6	8	7	0,20	3,77	1,06	1,81
mean	<30	4	5	3	0,07	1,43	0,54	1,08

sample with 3.77 mg/l TKN concentration, TKN concentrations were always below 1.6 mg/l, while NH_3-N concentrations for the same samples were always below 0.2 mg/l. TP concentration never exceeded 2 mg/l and the minimum concentration was 0.87 mg/l, while PO_4-P concentration was below 1 mg/l except for the first sample, and the minimum concentration was 0.21 mg/l.

The results given for organic matter comply with all the standards given in Table 3.10, except for the sample that was measured with 6 mg/l BOD_5. MBR in student hall of residence treats the grey water to a quality enabling reuse in every type of defined application.

5.2.2.2 Microbiological indicators

The MBR effluent was tested twice in terms of microbiological indicators using Total Coliform, Fecal Coliform, E.Coli and Enterococcus as indicator microorganism, however the effluent was always out of those indicator and none of those indicators were observed in samples analyzed. These results enable the reuse of treated grey water for every type of application defined in Table 3.10.

5.2.2.3 Summary of analyses for the MBR effluent in the residence hall

According to the effluent quality of the MBR treating grey water in the university student residence hall, reclaimed grey water can be reused for all applications given in Table 3.10, where the water reuse standards and guidelines are outlined. Also, according to the inland water resources classification given in Table 5.16, reclaimed grey water may be classified as first class as the organic matter parameters and microbiological indicator concentrations meet the requirements, which means that if this type of water quality was the quality of a surface water resource, it could have been used as drinking water resource after disinfection. On the other hand, nutrient parameters do not comply with the qualifications for the first class, however nitrogen parameters meet the requirements for second class, which means the water could be used for supplying drinking water after treatment.

Treatment efficiency of the MBR being used in the student residence hall is given in Table 5.20, showing 88% and 95% removal in terms of COD and BOD_5 removal respectively. Also suspended solids removal efficiencies are 97% for both TSS and VSS parameters. These data shows that the MBR in the student residence hall gives better removal efficiency than the MBR in the hotel, which may possibly be linked to the diffent raw grey water quality. As these systems use organic matter as carbon source, higher organic matter content in raw grey water may have been an advantage for the MBR system.

There is not a comparable work in the literature about the treatment systems in student residence halls, however if the treatment efficiency is compared to the MBR treating shower grey water in a sports complex shown in Table 5.14 (Merz et al., 2007), COD removal of the MBR located in the university student residence hall is higher, while the BOD_5 removal efficiencies are comparable.

Table 5.20 : Removal efficiency of MBR in the student residence hall

COD	BOD_5	TSS	VSS
88%	95%	97%	97%

5.3 Tracking and Monitoring Pathogenic Indicators

Tracking of pathogenic indicators were done among the treatment system of hotel and done in terms of Total Coliform, Fecal Coliform, E.Coli and Enterococcus. During this work, the aim was to observe how the concentrations of pathogenic indicators in grey water change from the point of being collected till the end of the treatment system. As treated grey water was used for toilet flushing in the hotel, monitoring of pathogenic indicators in the toilet reservoir was done in order to see any possible re-growth of pathogenic indicators.

Tracking of pathogenic indicators among the treatment system was done three times at total, in February, March and May, 2014 and the sampling points were shown in Figure 4.3. The mean concentrations of Total Coliform, Fecal Coliform, E.Coli and Enterococcus are given in Table 5.21.

Table 5.21 : Mean values of concentrations of pathogenic indicators among the treatment system

	Total Coliform	Fecal Coliform	E.Coli	Enterococcus
		cfu/100 ml		
Collection tank	1,90E+06	3,73E+05	1,01E+05	-
Equalization tank effluent	1,42E+07	8,91E+06	8,37E+06	-
MBR effluent	7,47E+02	1,62E+02	9,70E+01	-
Chlorination effluent	3,92E+02	8,90E+01	1,02E+01	1,33E+00
UV disinfection effluent	3,69E+02	7,00E+01	6,20E+01	1,33E+00
Treated grey water in reservoir	1,91E+03	1,33E+02	1,09E+02	1,33E+00
Tap water in reservoir	-	-	-	-
Room tap water	-	-	-	-

According to the results of the tracking, raw grey water had concentrations of pathogenic indicators that cannot be underestimated in terms of Total Coliform, Fecal Coliform and E.Coli, however it consists no Enterococcus. All coliform bacteria concentrations increase 1 log when introduced to equalization tank and the quality of grey water in terms of Total Coliform and Fecal Coliform were comparable to weak to intermediate strength domestic wastewater as shown in Table 5.6. At the effluent of MBR, the expectation was to see zero indicators as the membranes of the system were ultrafiltration membranes and the pore sizes were smaller than the sizes of the indicators, however the mean value was 2 logs in terms of Total Coliforms and Fecal Coliforms and 1 log in terms of E.Coli. The sample taken in May showed zero concentrations for all four indicators and this may be linked to a possibility of a surface crack in one or more of membranes, as after maintenance the treated grey water quality has improved and met the expectations. Chlorination was not able to kill the indicators in the grey water treated with the MBR. Fecal Coliform concentration decreased 1 log, however Enterococcus appeared at this time. UV disinfection didn’t help solving the problem and treated grey water reached the toilet reservoir with 3 logs cfu /100 ml Total Coliform, 2 logs cfu/100 ml of Fecal Coliform and E.Coli and some Enterococcus. Mean values include the period before the maintenance about the cracks in the membranes, however after the cracked membranes changed in May, no indicators were observed at the MBR effluent.

The water reuse standards and guidelines are mainly concerned about the Total Coliform, Fecal Coliform and E.Coli concentrations. After problems were solved in the treatment system of the hotel, the effluent was free of pathogenic indicator that enables every type of reuse applications if pathogenic indicators were the only consideration. Also, if treated grey water is compared to the inland water quality classes given in Table 5.16, it can be seen that grey water can be used for every type of application including drinking water, as its quality meets the requirements in terms of pathogenic indicators.

Monitoring of grey water quality at the toilet reservoir was done in May, after the maintenance. The results are shown in Figure 5.40. One room in the hotel was specially kept empty to be able to achieve this monitoring, as the toilet was not flushed for 9 days. Sampling from the toilet reservoir was done in day 1, 2, 3, 7 and 9 to be able to see if any re-growth of indicators occurred. These experiments were carried out after the maintenance of membrane bioreactor. No pathogenic indicators were observed at the effluent of MBR and disinfection worked properly as seen in the figure. No occurrence of microbiological indicators was detected during the monitoring work done in the toilet bowl.

Number of work in literature about grey water quality in terms of microbiological indicators are limited, and such monitoring was not done in any of the works reviewed.

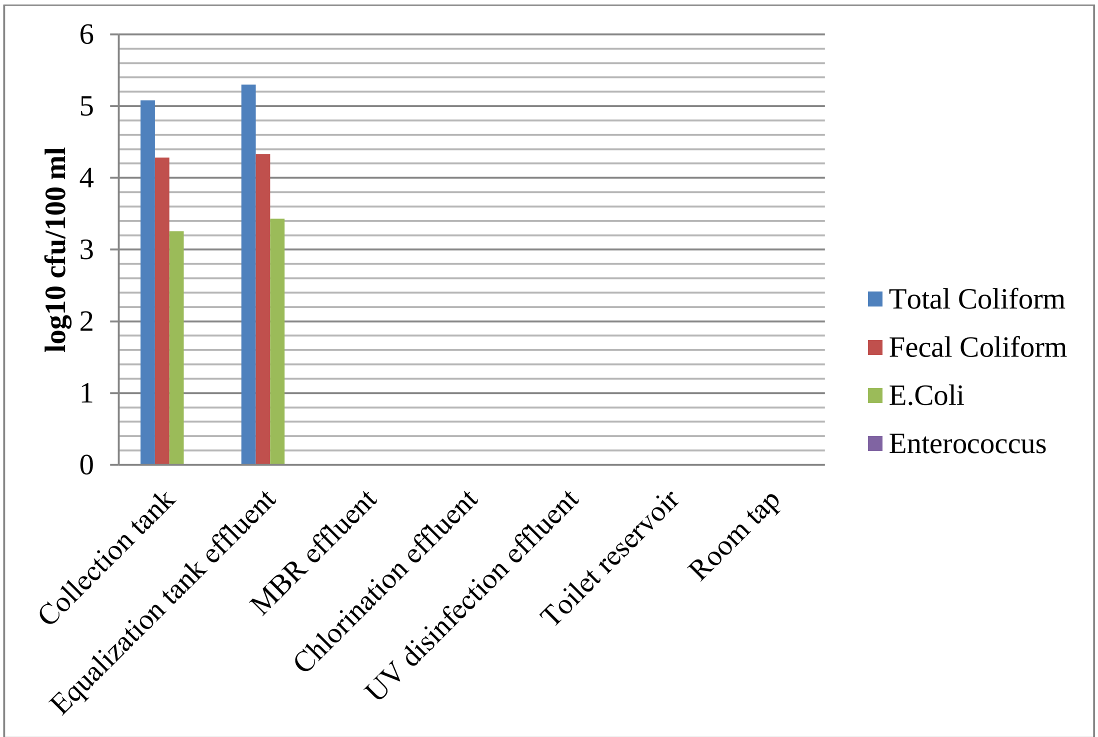

Figure 5.40 : Monitoring of grey water cycle in terms of microbiological indicators

5.4 Preliminary Trials on Physical Treatment of Grey Water

Characteristic of organic matter present in raw grey water revealed the importance of physicochemical treatment systems for grey water management, therefore preliminary investigations on grey water treatment by sand filtration and membrane filtration were carried out.

5.4.1 Sand filtration

Sand filtration was tried for treatment of both hotel grey water and university student residence hall grey water.

Sand filtration was tried on hotel grey water first. The organic matter in raw grey water was mostly in particulate form as the COD, sCOD, BOD_5 and $sBOD_5$ concentrations that the tial was carried out with were 159, 54, 30 and 9 mg/l respectively, showing typical hotel grey water characteristics. The expectation from this work was to see removal of organic matter in particulate form and TSS and VSS removal, however no microbiological indicator removal was expected as sand filters do not promise such removal.

The results of sand filtration trial with hotel grey water are presented in Table 5.22, with influent quality and removal efficiency. According to the results, 75% of COD was held in during sand filtration. BOD_5 concentration was 30 mg/l in the beginning

Table 5.22 : Sand filtration of hotel grey water

Parameter	Unit	Raw grey water quality	Sand filtration effluent quality	Removal efficiency
COD	mg/l	159	39	75%
sCOD	mg/l	54	-	-
BOD_5	mg/l	30	9	70%
$sBOD_5$	mg/l	9	9	0%
TSS	mg/l	214	82	62%
VSS	mg/l	52	1	98%
NH_3-N	mg/l	1.61	1.57	2%
PO_4-P	mg/l	0.58	0.58	0%
TP	mg/l	1.15	1.15	0%
Total Coliform	cfu/100 ml	8.70E+06	2.10E+06	
Fecal Coliform	cfu/100 ml	7.50E+06	6.20E+05	
E.Coli	cfu/100 ml	2.60E+05	3.00E+04	
Enterococci	cfu/100 ml	-	-	

and 9 mg/l of BOD_5 was soluble in grey water. Sand filtration resulted with 9 mg/l BOD_5 and $sBOD_5$, showing that all the particulate biodegradable organic matter was held by the sand filter. TSS and VSS removal efficiency of sand filtration was calculated as 62% and 92% respectively. No considerable nutrient removal occurred as expected and the removal of nutrients were possibly due to the nutrients in particulate form. No considerable microbiological indicator removal was observed.

The results belong to the trial on student residence hall grey water are given in Table 5.23. Raw grey water had 104 mg/l COD, 94 mg/l sCOD, 62 mg/l BOD_5 and 55 mg/l $sBOD_5$, showing that the organic matter was in dissolved form mostly, different than the hotel grey water that the trials were carried out with. Therefore the removal efficiencies were expected to be low as there was limited particulate organic matter in raw grey water.

Removal efficiencies in terms of COD, sCOD, BOD_5 and $sBOD_5$ were 9%, 11%, 2% and 0% respectively, which were very low efficiencies compared to hotel grey water sand filtration efficiencies. 57% of TSS and 50% of VSS was held in filtration. Similar to sand filtration results for hotel grey water, no considerable removal of nutrient and microbiological indicators was observed.

No data was encountered in the literature about only sand filtration of grey water, therefore comparison was not possible.

Table 5.23 : Sand filtration of student residence hall grey water

Parameter	Unit	Raw grey water quality	Sand filtration effluent quality	Removal efficiency
COD	mg/l	104	95	9%
sCOD	mg/l	94	84	11%
BOD_5	mg/l	62	61	2%
$sBOD_5$	mg/l	55	55	0%
TSS	mg/l	168	72	57%
VSS	mg/l	103	52	50%
NH3-N	mg/l	0,86	0,79	9%
PO4-P	mg/l	0,92	0,65	29%
TP	mg/l	1,91	1,89	1%
Total Coliform	cfu/100 ml	5,30E+07	3,27E+07	
Fecal Coliform	cfu/100 ml	9,02E+06	1,08E+06	
E.Coli	cfu/100 ml	2,60E+05	8,10E+04	
Enterococci	cfu/100 ml	-	-	

5.4.2 Membrane filtration

Preliminary membrane filtration trials were carried out to see how the effluent quality would have changed if there biological treatment step was not employed for treatment of light grey water. To accomplish this task, both grey water samples taken from the hotel and from the university student residence hall were tested through membrane filtration. Two types of ultrafiltration membranes were used as the membranes commercially available and the membranes manufactured in Marmara University Environmental Engineering Laboratories. Membrane filtration was experimented directly and after sand filtration to see how the flux changes if the coarse particles were removed from grey water.

Firstly, membrane filtration was tested for hotel grey water directly and after sand filtration, and the results are given in Table 5.24 together with raw grey water quality. Raw grey water showed typical characteristics of hotel grey water, as most of the organic matter was in particulate form as the COD was 159 mg/l, while sCOD was measured as 54 mg/l. Also the BOD_5 concentration was 30 mg/l, while only 9 mg/l of BOD_5 was in dissolved form.

Direct membrane filtration with membranes manufactured in the laboratory ended up with an effluent quality with 48 mg/l COD and 0 mg/l sCOD as expected. Also 90% BOD_5 removal was achieved. As BOD_5 concentration of the influent was as low as 30 mg/l, it was measured as 3 mg/l at the effluent. 100% removal was achieved in terms of TSS and VSS, as expected. Ultrafiltration membrane used was also capable of removing the microbiological indicators tested. On the other hand, when membrane filtration was employed after a sand filtration unit, the effluent quality was higher in terms of COD as the removal efficiency increased 9%, however the results in terms of nutrient removal were not different compared to direct membrane filtration.

Membranes were washed with distelled water periodically, to be able to clean the membrane and continue to filtration with the same membrane to see if the flux at the beginning is changed. The first experiment was carried out with raw hotel grey water and the cleaning period was defined as 60 minutes. However the second trial was carried out with sand filtered hotel grey water and the period was defined as 30 minutes. The flux graphics are given in Figure 5.41. Membrane filtration flux of raw

Table 5.24 : Membrane filtration of hotel grey water with ultrafiltration membranes manufactured in laboratory

Parameter	Unit	Raw grey water quality	Membrane filtration effluent quality	Removal efficiency	Sand filtration effluent quality	Sand filtration + Membrane filtration effluent quality	Removal efficiency
COD	mg/l	159	48	70%	56	34	79%
sCOD	mg/l	54	-	-	54	-	0%
BOD_5	mg/l	30	3	90%	9	3	90%
$sBOD_5$	mg/l	9	-	-	9	-	-
TOC	mg/l	66	20	70%	23	14	79%
TSS	mg/l	214	0	100%	82	0	100%
VSS	mg/l	52	0	100%	1	0	100%
NH_3-N	mg/l	1,61	0,85	47%	1,57	0,8	50%
PO_4-P	mg/l	0,58	0,48	17%	0,58	0,48	17%
TP	mg/l	1,15	1,1	4%	1,15	1,09	5%
Total Coliform	cfu/100 ml	8,70E+06	0		2,10E+06	0	
Fecal Coliform	cfu/100 ml	7,50E+06	0		6,20E+05	0	
E.Coli	cfu/100 ml	2,60E+05	0		3,00E+04	0	
Enterococci	cfu/100 ml	-	-		-	-	

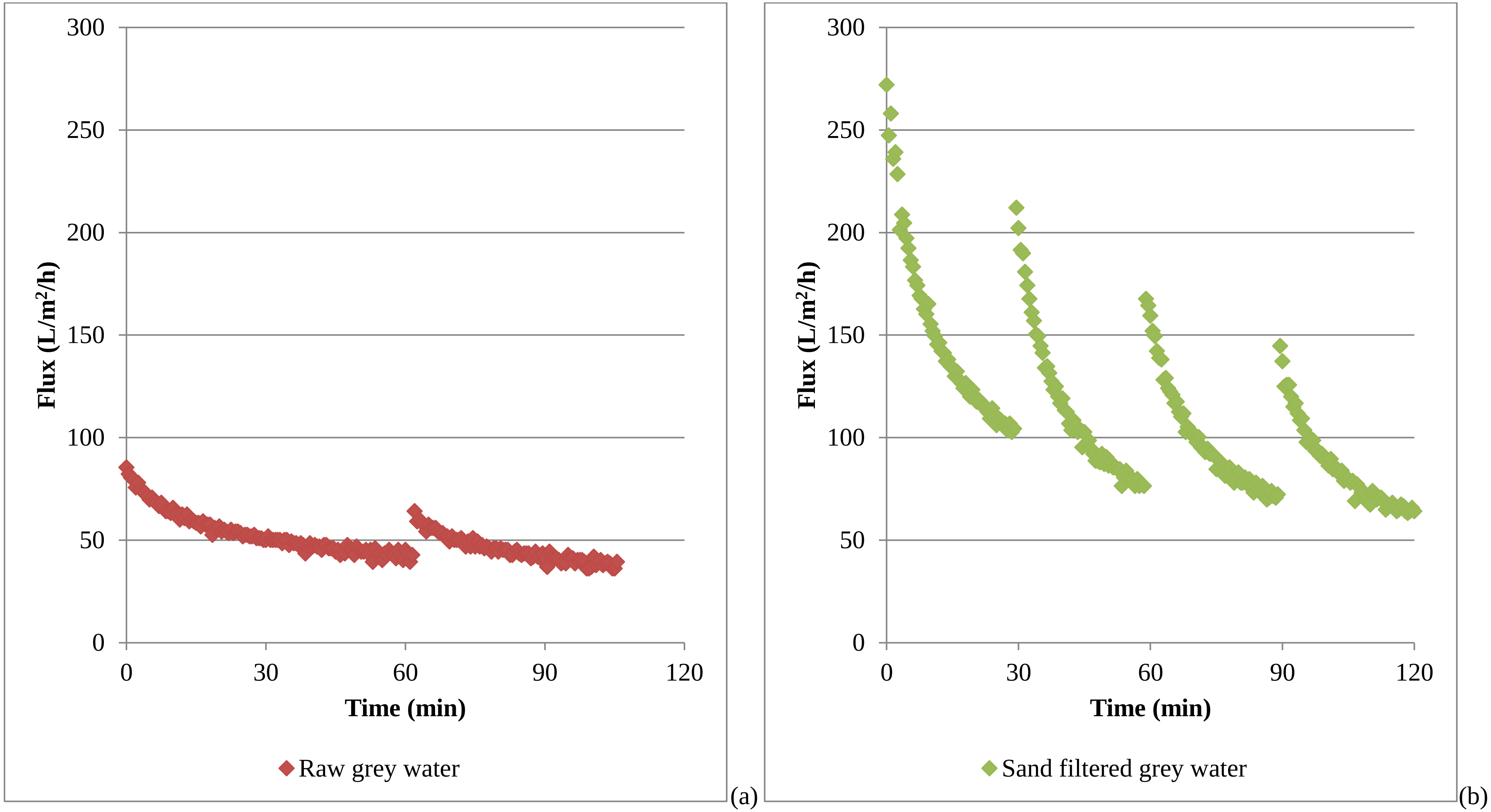

Figure 5.41 : Membrane filtration flux for (a) raw hotel grey water and (b) sand filtered hotel grey water

grey water was started with 85 L/m^2/h and decreased to 41 L/m^2/h in one hour and after cleaning the ultrafiltration membrane, the flux decreased to 62 l/m^2/h and ended up with 39 l/m^2/h at the end of another hour. On the other hand, the flux of membrane filtration of grey water which was sand filtered was calculated as 272 l/m^2/h, which is triple of the flux of filtration process achieved with raw grey water. The flux was decreased to 106 l/m^2/h at the end of half an hour and the membrane was cleaned with distelled water three times successfully. At the end of two hours, the flux was measured as 64 l/m^2/h, which was higher compared to the flux attained during membrane filtration of raw grey water.

At the end of first hour of membrane filtration, 81 ml and 192 ml of raw grey water and sand filtered grey water were collected respectively. Totals of 131 ml and 334 ml of raw grey water and sand filtered grey water were treated through membrane filtration process with success.

These data showed that even if the effluent quality of membrane filtration do not change dramatically depending on if the grey water was treated with sand filtration or not, a sand filtration unit should be employed for this type of grey water to prevent early clogging of membrane due to the coarse particles available in raw grey water. However, this is a result of high particulate matter content of hotel grey water, and a generalization could not be made through one experiment.

The results of membrane filtration trials with university student residence hall grey water are given in Table 5.25 and 5.26 for cases where manufactured membranes and commercial membranes were used respectively. Membrane filtration trials were carried out with raw grey water and sand filtered grey water, similar with hotel grey water.

University student residence hall raw grey water the experiments carried out with does not show typical characteristics as the sCOD/COD ratio is 90%, which is higher than the ratio calcutated from Table 5.8. However, this was good to see the efficiency of membrane filtration when applied to different quality grey water samples. As most of the organic matter was in soluble form in raw grey water, organic matter removal efficiencies were expected to be lower than the efficiencies obtained for hotel grey water.

Table 5.25 : Membrane filtration of student residence hall grey water ultrafiltration membranes manufactured in laboratory

Parameter	Unit	Raw grey water quality	Membrane filtration effluent quality	Removal efficiency	Sand filtration effluent quality	Sand filtration + Membrane filtration effluent quality	Removal efficiency
COD	mg/l	104	70	33%	95	60	42%
sCOD	mg/l	94	70	26%	84	60	36%
BOD_5	mg/l	62	43	31%	61	32	48%
$sBOD_5$	mg/l	55	43	22%	55	32	42%
TOC	mg/l	43	29	33%	39	25	42%
TSS	mg/l	168	0	100%	72	0	100%
VSS	mg/l	103	0	100%	52	0	100%
NH_3-N	mg/l	0,86	0,75	14%	0,79	0,72	16%
PO_4-P	mg/l	0,92	0,64	30%	0,65	0,62	33%
TP	mg/l	1,91	1,82	5%	1,89	1,78	7%
Total Coliform	cfu/100 ml	5,30E+07	0		3,27E+07	0	
Fecal Coliform	cfu/100 ml	9,02E+06	0		1,08E+06	0	
E.Coli	cfu/100 ml	2,60E+05	0		8,10E+04	0	
Enterococci	cfu/100 ml	-	0		-	0	

Table 5.26 : Membrane filtration of student residence hall grey water with ultrafiltration membranes commercially available

Parameter	Unit	Raw grey water quality	Membrane filtration effluent quality	Removal efficiency	Sand filtration effluent quality	Sand filtration + Membrane filtration effluent quality	Removal efficiency
COD	mg/l	104	74	29%	95	68	35%
sCOD	mg/l	94	74	21%	84	68	28%
BOD_5	mg/l	62	45	27%	61	36	42%
$sBOD_5$	mg/l	55	45	18%	55	36	34%
TOC	mg/l	43	31	19%	39	28	35%
TSS	mg/l	168	0	100%	72	0	100%
VSS	mg/l	103	0	100%	52	0	100%
NH_3-N	mg/l	0,86	0,82	5%	0,79	0,73	15%
PO_4-P	mg/l	0,92	0,66	28%	0,65	0,71	23%
TP	mg/l	1,91	1,82	5%	1,89	1,82	5%
Total Coliform	cfu/100 ml	5,30E+07	0		3,27E+07	0	
Fecal Coliform	cfu/100 ml	9,02E+06	0		1,08E+06	0	
E.Coli	cfu/100 ml	2,60E+05	0		8,10E+04	0	
Enterococci	cfu/100 ml	-	0		-	0	

The results revealed that membrane filtration of student residence hall grey water was not as successful as membrane filtration of hotel grey water in terms of both the effluent quality and removal efficiencies. This is linked to the influent characteristics, as most of the organic matter in raw grey water was soluble, therefore the membrane used could not remove organic matter. Removal efficiencies for sand filtered grey water were higher as compared to raw grey water, similar to the case of hotel grey water.

COD and sCOD concentrations were both 70 mg/l in the effluent of membrane filtration carried out with membranes manufactured in the laboratory, showing that all the particulate organic matter was held by the membrane. Furthermore the BOD_5 and $sBOD_5$ concentrations were both 43 mg/l due to the same reason. In the case where sand filtration was applied prior to membrane filtration, the COD and BOD concentrations were 60 and 32 mg/l respectively.

On the other hand, filtration with membrane commercially available showed 74 mg/l COD and sCOD and 68 mg/l BOD_5 and $sBOD_5$ concentrations in the effluent, which were higher concentrations compared to those obtained with membranes manufactured in the laboratory. This may be linked to the reason that the commercially available membranes were 30 kDa exactly, however the pore size of the membranes manufactured in the laboratory were not analyzed and may be smaller.

Both membranes showed 100% TSS removal. Also The effluent was free of microbiological indicators investigated in all cases.

The flux analyses for university student residence hall grey water are given in Figure 5.42. All of the membranes were cleaned with distilled water in 30th minute. Worst flux was observed for the case which raw grey water was filtered through the membrane manufactured in the laboratory, however the flux does not change a lot if commercial membrane was used instead. The flux at the beginning of filtration may be high, however after a minute the graphs look similar. According to the fluxes of sand filtrered student residence hall grey water, sand filtration prior to membrane filtration was not as important as it was in case of hotel grey water, where particulate matter was in abundance. Total volumes of effluent of membrane filtration at the end of an hour of filtration were 60, 82, 81 and 11 ml for raw grey water on membrane

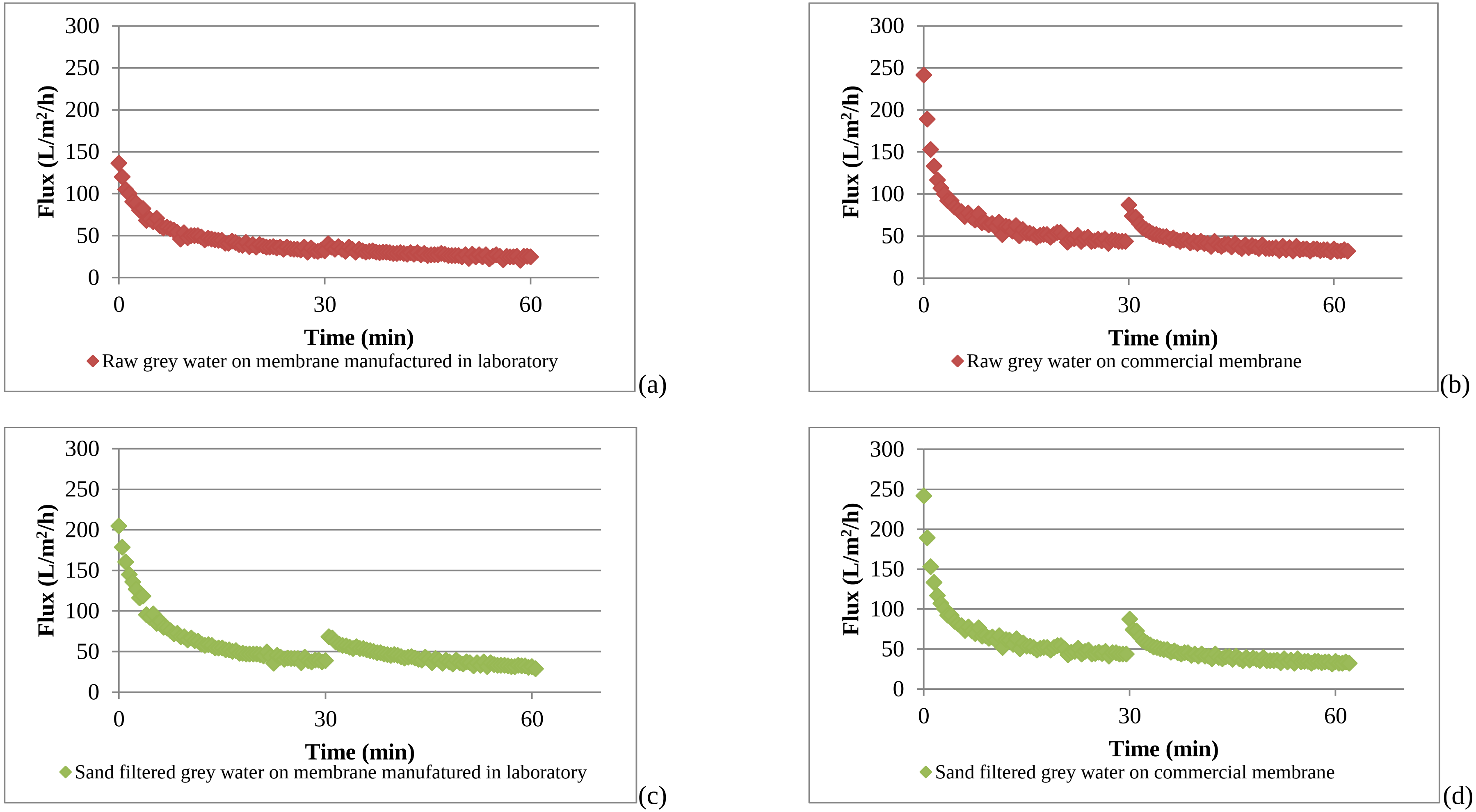

Figure 5.42 : Membrane filtration flux for (a) raw grey water on membrane manufactured in the laboratory, (b) raw grey water on commercial membrane, (c) sand filtered grey water on membrane manufactured in the laboratory and (d) sand filtered grey water on commercial membrane.

manufactured in the laboratory, raw grey water on commercial membrane, sand filtered grey water on membrane manufactured in the laboratory and sand filtered grey water on commercial membrane respectively.

The only grey water membrane filtration trial attained from literature was Sostar-Turk and others' work (2005) as given in Table 3.6 and the grey water fraction used were laundry water, disabling a complete comparison. However, the removal efficiencies in terms of COD and TSS were reported as 54% and 49% when ultrafiltration membrane was used. The removal efficiencies of direct ultrafiltration obtained in this work in terms of COD were 70% for hotel grey water and 29% and 33% for university student residence hall grey water, however TSS removal was always 100%. COD removal efficiency is dependent on the form of organic matter in grey water and the reason for low efficiency may be linked to the possibility of high soluble organic matter content used during trials. On the other hand, low TSS removal efficiency of Sostar-Turk et al (2005) indicates that the ultrafiltration membrane employed for treatment of grey water may have large pore sizes.

5.5 Plant Trials

Plant trials were completed in 30 days. During these 30 days, unexpected weather conditions occurred, however the plants were protected by covering the top of them with a transparent material that allows sun light penetration.

The results of plant trials are given in Figure 5.43 in terms of length of the pepper plants and in Figure 5.44 in terms of flower counts. The results revealed that

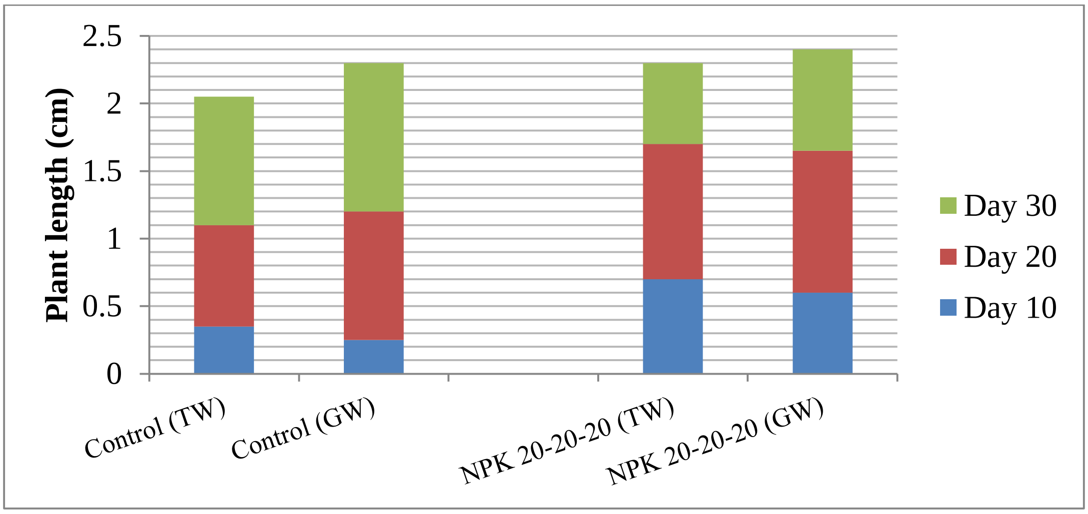

Figure 5.43 : Lengths of plants irrigated with tap water and grey water.

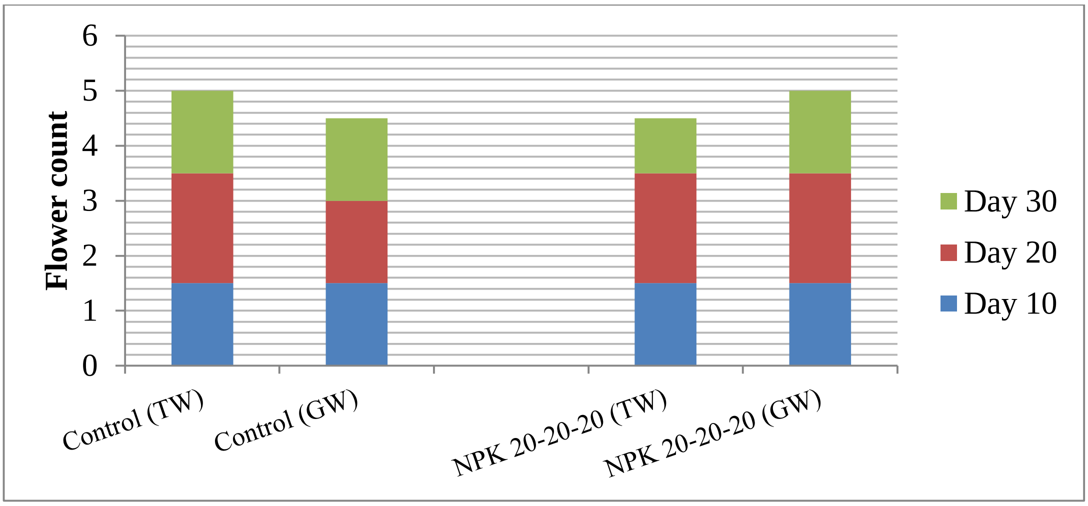

Figure 5.44 : Flower counts of plants irrigated with tap water and grey water.

irrigation with treated grey water gives results as good as irrigation with tap water when control plants and the plants fertilized with NPK 20-20-20 are compared.

Lengths and flower counts of all plants irrigated with treated grey water are given in Figure 5.45 and 5.46 respectively. These results reveal that grey water is as successful as tap water for irrigation, in terms of plant growth. A detailed comparison of the fertilizers experimented is available in Dogan's work (2015).

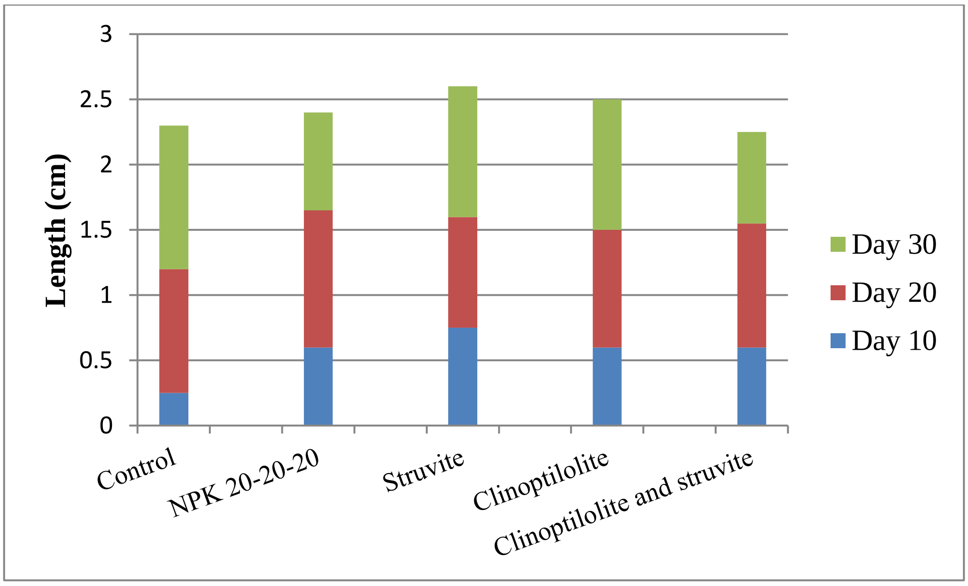

Figure 5.45 : Length of pepper plants irrigated with treated grey water.

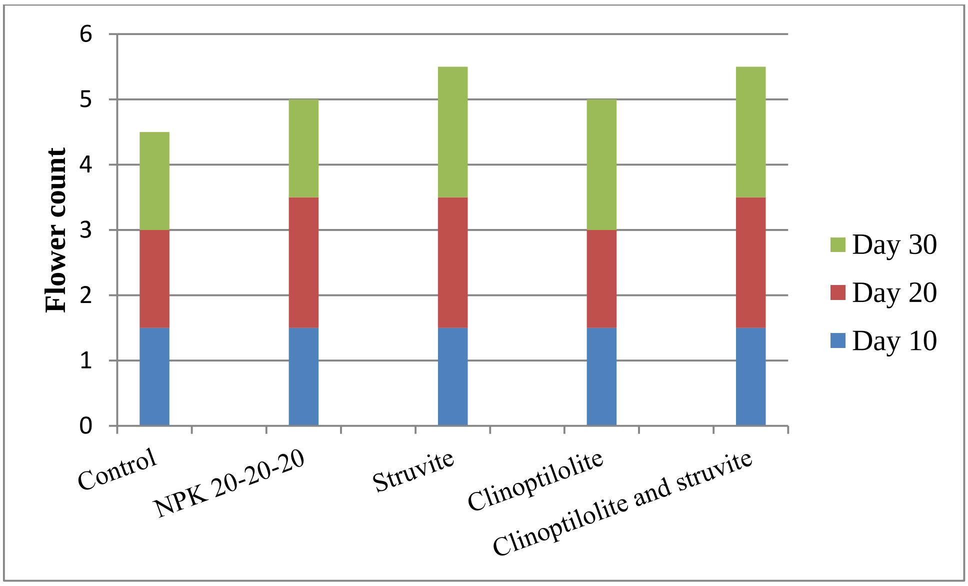

Figure 5.46 : Flower count of pepper plants irrigated with treated grey water.

6. CONCLUSION AND RECOMMENDATIONS

The aim of this work was to characterize grey water in a continuous and systematic way and to evaluate one of the most used grey water technologies, membrane bioreactors, in terms of different physical and chemical parameters and microbiological indicators. Main study area was a hotel, where a year-round monitoring was completed. Additional sampling was done in a university student residence hall that collect grey water from bath/showers and wash basins and treat them by MBR were used to characterize grey water and determine the efficiency of MBR technology for grey water treatment. Monitoring of microbiological indicators, Total Coliform, Fecal Coliform, E.Coli and Enterococcus, was done for determining how these indicators change through the treatment system and if they regrow in toilet reservoirs.

In addition to characterization and monitoring of raw and treated grey water and treatment plants, preliminary investigations about two different physical treatment systems, sand filtration and membrane filtration, were carried out. As treated grey water can be used as irrigational water, preliminary plant trials were also carried out using tap water and treated grey water for irrigation to compare how treated grey water effects the plant growth, while also different types of nutrients were tried on the plants.

- In hotel grey water, average concentrations in terms of COD, sCOD and BOD_5 were 97, 41 and 30 mg/l respectively, and the sCOD/COD and BOD_5/COD ratios were calculated as 42% and 31% respectively. These ratios showed that most of the organic matter in hotel grey water was in particulate form, 69% of all organic matter was not biodegradable under BOD_5 test conditions. Average TSS and VSS concentrations were 72 and 39 mg/l and nutrient concentrations were not considerable.

  Week-long grey water samples taken from the hotel did not show a trend in changing days of a week. Seasonal comparison of routine and week-long samples revealed that making an overall assessment based on seasonal factors would be wrong.

In the light of these data, as the COD concentrations were very low and BOD_5 average BOD_5 concentration was 30 mg/l, it was decided to carry out $sBOD_5$ test to observe how much of the organic matter was in particulate form. The results of $sBOD_5$ tests showed that the average $sBOD_5/BOD_5$ ratio was 20%, showing that 80% of biodegradable organic matter in hotel grey water was in particulate form. As the particulate organic matter is retained by the membrane itself in MBR systems, it was observed that biological treatment was applied to remove 10 mg/l BOD_5 only.

Therefore, the need for biological treatment was questioned, and also the importance of characterization of grey water was comprehended, as chosing the correct treatment system is not possible before knowing the characteristics of grey water to be treated.

With these data, preliminary physical treatment trials of sand filtration and membrane filtration were added to the scope of this work to test the efficiency of these systems.

- University student residence hall grey water showed averages of 226 mg/l COD, 84 mg/l sCOD, 76 mg/l BOD_5 and 20 mg/l $sBOD_5$. These results revealed that the sCOD/COD, BOD_5/COD and $sBOD_5/BOD_5$ ratios were 37%, 34% and 26% respectively. Similar to hotel grey water, it was observed that most of the organic matter in university student residence hall was in particulate form and the biodegradable organic matter concentrations which could not be removed by membrane filtration is 20 mg/l averagely. Average TSS and VSS concentrations were 145 and 94 mg/l, however the nutrient concentrations in terms of NH_3-N, TKN, PO_4-P and TP were not considerable.
- All raw grey water samples tested showed high concentrations in terms of microbiological indicators Total Coliform, Fecal Coliform and E.Coli, consequently microbiological indicators should be considered as major pollutants prior to reuse similar to organic matter, for maintenance of public

health. Grey water samples taken from both buildings were free of Enterococci on the other hand.

- Raw grey water quality of both study areas does not meet the water reuse standards and guidelines around the world for irrigation, toilet flushing or other types of urban reuse, therefore it should not be reused directly for those applications.
- Raw grey water quality at the hotel had lower pollution potential than the one at the university student residence hall in terms of organic matter and microbiological indicators in this work. However, making an overall assessment would be wrong as grey water quality changes in wide ranges proven by the pieces of work in the literature.
- The effluent of MBR treating hotel grey water showed 43 mg/l COD, 32 mg/l sCOD and 6 mg/l BOD_5 concentrations. TSS and VSS concentrations of treated grey water were 11 and 4 mg/l respectively. Nutrient concentrations at the effluent were lower than raw grey water as expected. However, an MBR system should have given better quality in terms of both organic matter and suspended solid parameters.
- MBR treating grey water generated from the university student residence hall gave <30 mg/l COD and 4 mg/l BOD_5 concentrations. TSS and VSS concentrations were 5 and 3 mg/l respectively. Nutrient levels at the effluent were lower than the influent concentrations. Treatment efficiency of MBR at the university student residence hall was better as compared to the MBR at the hotel.
- Even though microbiological indicator concentrations in raw grey water were high, properly treated grey water showed zero concentration in terms indicators tested. No regrowth of any of the microbiological indicators were observed in toilet reservoirs for 9 days.
- The importance of monitoring treatment plants was comprehended, as in the case of hotel, treated water quality was deteriorated time to time, however the problem was solved when the responsible staff was warned about the problem.

In this study, grey water treatment plant at the university student residence hall was more reliable as compared to the treatment plant in the hotel.

- If properly treated, grey water meets the standards and guidelines worldwide, enabling every type of reuse application defined by the regulations or standards.

- Preliminary investigation on sand filtration and membrane filtration treatment systems showed that success of physial treatment of grey water is dependent on the quality of grey water. Biological treatment may not be necessary for treatment of grey water depending on its quality. To be able to decide the treatment needs correctly, characterization of grey water should be done prior establishing the treatment plants.

  Sand filtration was very successful in terms of organic matter and suspended solid removal for hotel grey water as most of the organic matter was in particulate form, however university student residence hall grey water samples that sand filtration carried out with showed high sCOD/COD ratio, so that sand filtration was not as successful as it was for hotel grey water.

  Membrane filtration trials for hotel grey water resulted with high effluent quality as the organic matter in grey water was in particulate form and retained by the ultrafiltration membrane. On the other hand, due to high soluble organic matter content of university student residence hall grey water, trials carried out was not as successful as it was for hotel grey water.

  The trials carried out with hotel grey water showed that a sand filtration step prior to membrane filtration was important to use the ultrafiltration membrane in a more effective way. By employing a sand filter, the flux of membrane filtration was increased, and more grey water was treated in shorter periods.

  Membrane filtration was at least as successful as MBR systems investigated in terms of microbiological indicator removal as expected.

- Preliminary plant trials showed that using treated grey water for irrigation is at least as successful as using tap water in terms of plant growth.

To be able to reuse grey water safely additional work is required and some recommendations are given in the following.

- ✓ Different grey water fractions generated from buildings with different functions should be characterized in a systematic way. Also the organic matter concentrations in those grey water fractions should be analyzed to evaluate the need for biological treatment.
- ✓ Different physicochemical treatment systems should be investigated for grey water treatment in a detailed way. The effluent quality of experimented treatment systems should be compared to biological grey water treatment effluent quality. Also the effluent quality of physicochemical systems should be checked if treated grey water meets the requirements for water reuse standards and guidelines.
- ✓ Micropollutants and hazardous substances in grey water should be monitored and effluent of different treatment processes should be analyzed in terms of micropollutants and hazardous substances.

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APPENDICES

APPENDIX A: Literature review table

APPENDIX A

Table A.1 Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
House	Bath	COD	210	mg/l	Almeida et al. (1999)
		sCOD	184	mg/l	
		PO_4-P	5.3	mg/l	
		NH_3-N	1.1	mg/l	
		TSS	54	mg/l	
		VSS	9	mg/l	
House	Shower	COD	501	mg/l	Almeida et al. (1999)
		sCOD	221	mg/l	
		PO_4-P	19.2	mg/l	
		NH_3-N	1.2	mg/l	
		TSS	200	mg/l	
		VSS	153	mg/l	
House	Shower	BOD	70-300	mg/l	Nolde (1999)
		COD	113-633	mg/l	
House	Shower	BOD	130	mg/l	Prathapar et al. (2005)
		COD	294.3	mg/l	
		TN	28.7	mg/l	
		TSS	353	mg/l	
		VSS	133	mg/l	
		Turbidity	375	NTU	
House	Wash basin	COD	298	mg/l	Almeida et al. (1999)
		sCOD	221	mg/l	
		PO_4-P	13.3	mg/l	
		NH_3-N	0.3	mg/l	
		TSS	181	mg/l	
		VSS	72	mg/l	
House	Wash basin	BOD	42.1	mg/l	Prathapar et al. (2005)
		COD	58.0	mg/l	
		TN	10.2	mg/l	
		TSS	505	mg/l	
		VSS	347	mg/l	
		Turbidity	133	NTU	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
House	Bath/shower and wash basin	BOD	76-200	mg/l	Christova-Boal et al. (1996)
		TP	0.11-1.8	mg/l	
		TN	4.6-20	mg/l	
		TSS	48-20	mg/l	
		Turbidity	60-240	NTU	
House	Bath/shower and wash basin	BOD	59	mg/l	Friedler et al. (2005)
		COD	158	mg/l	
		TP	4.8	mg/l	
		TSS	43	mg/l	
		Turbidity	33	NTU	
House	Mixed except kitchen sink	BOD	1354	mg/l	Halalsheh et al. (2008)
		COD	4352	mg/l	
		TP	25	mg/l	
		TN*	138	mg/l	
		TSS	1679	mg/l	
Family with children (1)	Bath/shower and wash basin	BOD	200	mg/l	Chaillou et al. (2010)
		COD	421	mg/l	
		sCOD	180	mg/l	
		TP	0.2	mg/l	
		TN	15.9	mg/l	
		TSS	115	mg/l	
		Turbidity	125	NTU	
Family with children (2)	Bath/shower and wash basin	BOD	81	mg/l	Chaillou et al. (2010)
		COD	145	mg/l	
		sCOD	65	mg/l	
		TP	0.25	mg/l	
		TN	6.2	mg/l	
		TSS	40.3	mg/l	
		Turbidity	35.3	NTU	
Family with children (3)	Bath/shower and wash basin	BOD	670	mg/l	Chaillou et al. (2010)
		COD	1001	mg/l	
		sCOD	257	mg/l	
		TP	1.12	mg/l	
		TN	11.1	mg/l	
		TSS	360.5	mg/l	
		Turbidity	462	NTU	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
Family without child (1)	Bath/shower and wash basin	BOD	78	mg/l	Chaillou et al. (2010)
		COD	112	mg/l	
		sCOD	29	mg/l	
		TP	0.2	mg/l	
		TN	5.4	mg/l	
		TSS	37	mg/l	
		Turbidity	49.5	NTU	
Family without child (2)	Bath/shower and wash basin	BOD	170	mg/l	Chaillou et al. (2010)
		COD	315	mg/l	
		sCOD	150	mg/l	
		TP	0.35	mg/l	
		TN	4.3	mg/l	
		TSS	78.1	mg/l	
		Turbidity	462	NTU	
House	Bath/shower and wash basin	COD	845±167	mg/l	Antonopoulou (2013)
		TSS	263±103	mg/l	
Apartment	Shower and wash basin	BOD	50-250	mg/l	Nolde (1999)
		COD	100-430	mg/l	
		TP	0.2-0.6	mg/l	
		TN	5-10	mg/l	
House	Ablution and wash basin	BOD	597	mg/l	Halalsheh et al. (2008)
		COD	1489	mg/l	
		TP	26	mg/l	
		TN*	105	mg/l	
		TSS	573	mg/l	
House	Washing machine	BOD	48-290	mg/l	Christova-Boal et al. (1996)
		TP	0.062-42	mg/l	
		TN	1.0-40	mg/l	
		TSS	88-250	mg/l	
		Turbidity	50-210	NTU	
House	Washing machine	COD	1815	mg/l	Almeida et al. (1999)
		sCOD	1164	mg/l	
		PO_4-P	21.0	mg/l	
		NH_3-N	2.0	mg/l	
		TSS	165	mg/l	
		VSS	97	mg/l	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
House	Laundry	BOD	179.7	mg/l	Prathapar et al. (2005)
		COD	231.3	mg/l	
		TN	25.8	mg/l	
		TSS	315	mg/l	
		VSS	210	mg/l	
		Turbidity	444	NTU	
House	Washing machine	COD	280	mg/l	Sostar-Turk et al. (2005)
		TN	11.4	mg/l	
		TSS	35	mg/l	
		Turbidity	20	NTU	
House	Washing machine	BOD	195	mg/l	Sostar-Turk et al. (2005)
		COD	226	mg/l	
		TSS	28	mg/l	
House	Washing machine	BOD	86	mg/l	Sostar-Turk et al. (2005)
		COD	130	mg/l	
		TSS	18	mg/l	
		Turbidity	30	NTU	
House	Kitchen sink	COD	1079	mg/l	Almeida et al. (1999)
		sCOD	644	mg/l	
		PO_4-P	26.0	mg/l	
		NH_3-N	0.3	mg/l	
		TSS	235	mg/l	
		VSS	196	mg/l	
House	Kitchen sink	BOD	1100	mg/l	Halalsheh et al. (2008)
		COD	2244	mg/l	
		TP	18.25	mg/l	
		TN*	51	mg/l	
		TSS	644	mg/l	
House	Sinks and dishwashers	COD	463	mg/l	Bani-Melhem & Smith (2012)
		NH_3-N	11.3	mg/l	
		PO_4	0.53	mg/l	
		TSS	78	mg/l	
		Turbidity	133	NTU	
House	Sinks, showers and washing machines	BOD	65	mg/l	Casanova et al. (2001)
		TSS	35	mg/l	
		Turbidity	43	NTU	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
House	Shower, laundry and sink	BOD	435±256	mg/l	Paulo et al. (2009)
		COD	646±278	mg/l	
		PO_4-P	5.6±3.0	mg/l	
		TN	8.8±4.1	mg/l	
		NH_3-N	2.4±1.1	mg/l	
		TSS	120±83	mg/l	
		Turbidity	254±204	NTU	
House	Kitchen, shower and wash basin	BOD_7	271	mg/l	Itayama et al. (2006)
		COD	477	mg/l	
		Turbidity	13	NTU	
House	Shower, wash basin and kitchen	COD	827	mg/l	Hernandez et al. (2007)
		TP	8.5	mg/l	
		TN	29.9	mg/l	
House	Mixed	BOD	41.2±30	mg/l	Jefferson et al. (1999)
		COD	120±74.4	mg/l	
Houses	Mixed	BOD	167±47	mg/l	Dallas et al. (2004)
		Turbidity	96±39	NTU	
House	Mixed	BOD7	418	mg/l	Palmquist & Hanaeus (2005)
		COD	588	mg/l	
		TP	7.53	mg/l	
		TN	9.68	mg/l	
House	Mixed	BOD7	150	mg/l	Palmquist & Hanaeus (2005)
		COD	335	mg/l	
		TP	4.8	mg/l	
		TN	11.5	mg/l	
		TSS	86	mg/l	
House	Mixed	BOD	1056	mg/l	Halalsheh et al. (2008)
		COD	2568	mg/l	
		TP	19.5	mg/l	
		TN*	105	mg/l	
		TSS	845	mg/l	
House	Mixed	TP	9.7±0.9	mg/l	Li et al. (2008)
		PO_4-P	7.5±0.6	mg/l	
		TN	16.5±2.3	mg/l	
		NH4-N	10.1±2.5	mg/l	
		Turbidity	140±12	NTU	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
House	Mixed	BOD	1060	mg/l	Dalahmeh et al. (2011)
		COD	2570	mg/l	
		TSS	845	mg/l	
House	Mixed	COD	1178±245	mg/l	Antonopoulou (2013)
		TSS	542±179	mg/l	
Apartment	Mixed	BOD	33.3	mg/l	Holden & Ward (1999)
		COD	143	mg/l	
		TP	0.4	mg/l	
		NH_3	10	mg/l	
		Turbidity	44.5	NTU	
Apartment	Mixed	BOD	90	mg/l	Atasoy et al. (2007)
		COD	245	mg/l	
		sCOD	177	mg/l	
		TP	7.3	mg/l	
		TKN	9	mg/l	
		TSS	48	mg/l	
		VSS	39	mg/l	
Student residence hall	Bath/shower	BOD	216	mg/l	Surendran & Wheatley (1998)
		COD	424	mg/l	
		PO_4-P	1.63	mg/l	
		TN	1.56	mg/l	
		TSS	76	mg/l	
		Turbidity	92	NTU	
Student residence hall	Showers	BOD	97±56	mg/l	Lamine et al. (2007)
		COD	102±86	mg/l	
		PO_4	3.5±4.8	mg/l	
		TKN	8.1±3.7	mg/l	
		TSS	33±16	mg/l	
Student residence hall	Shower	BOD	166±37	mg/l	Pidou et al. (2008)
		COD	575±98	mg/l	
		TN	16.4±3.0	mg/l	
		Turbidity	42±9	NTU	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
Student residence hall	Bath/shower and wash basin	BOD	46.4±26.6	mg/l	Birks & Hills (2007)
		sBOD	31.2	mg/l	
		COD	96.3±52.6	mg/l	
		TP	0.86±0.82	mg/l	
		TKN	4.6±2.8	mg/l	
		TSS	36.8±29.4	mg/l	
		Turbidity	26.5±21	NTU	
Student residence hall	Bath/shower and wash basin	BOD	95	mg/l	Friedler et al. (2008)
		COD	270	mg/l	
		TKN	11	mg/l	
		TSS	147	mg/l	
Student residence hall	Bath/shower and wash basin	BOD	20	mg/l	Winward et al. (2008)
		COD	86	mg/l	
		TSS	29	mg/l	
Student residence hall	Bath/shower and wash basin	BOD	43.9±10.6	mg/l	Kadewa et al (2010)
		COD	151±88	mg/l	
		Turbidity	57.6±14.7	NTU	
Student residence hall	Wash basin	BOD	252	mg/l	Surendran & Wheatley (1998)
		COD	433	mg/l	
		PO_4-P	45.5	mg/l	
		TN	0.53	mg/l	
		TSS	40	mg/l	
		Turbidity	102	NTU	
Student residence hall	Washing machine	BOD	472	mg/l	Surendran & Wheatley (1998)
		COD	725	mg/l	
		PO_4-P	101	mg/l	
		TN	10.7	mg/l	
		TSS	68	mg/l	
		Turbidity	108	NTU	
Student residence hall	Kitchen sink	BOD	536	mg/l	Surendran & Wheatley (1998)
		COD	936	mg/l	
		PO_4-P	15.6	mg/l	
		TN	4.6	mg/l	
Student residence hall	Sink and dish washer	BOİ$_7$	47	mg/l	Gunther (2000)
		TP	3.72	mg/l	
		TN	3.73	mg/l	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
Student residence hall	Mixed	BOD	39±17	mg/l	Pidou et al. (2008)
		COD	144±63	mg/l	
		TN	7.6±3.0	mg/l	
		Turbidity	35±16	NTU	
Hotel	Bath/shower and wash basin	COD	171	mg/l	March et al. (2005)
		TN	11.4	mg/l	
		TSS	44	mg/l	
		Turbidity	20	NTU	
Hotel	Bath/shower and wash basin	COD	72.7±50	mg/l	Gual et al. (2008)
		TN	4.1±2	mg/l	
		TSS	32.2±7	mg/l	
		Turbidity	38.8±20	NTU	
Sports center	Shower	BOD	78±26	mg/l	Ramona et al.. (2004)
		COD	170±49	mg/l	
		sCOD	106±42	mg/l	
		TSS	29.8±11.3	mg/l	
		Turbidity	23±8.5	NTU	
Sports complex	Shower	BOD	59±13	mg/l	Merz et al. (2007)
		COD	109±33	mg/l	
		TP	1.6±0.5	mg/l	
		TN*	15.2±4.5	mg/l	
		Turbidity	29±11	NTU	
Sports center	Showers	BOD	65±35	mg/l	Gabarro et al. (2013)
		COD	110±58	mg/l	
		sCOD	72±27	mg/l	
		TP	1.28±1.16	mg/l	
		TKN	27.17±10.04	mg/l	
		TSS	32±24	mg/l	
		VSS	30±23	mg/l	
University changing room	Shower	BOD	129	mg/l	Santos et al. (2011)
		COD	197	mg/l	
		TP	1.3	mg/l	
		NH_3	8.6	mg/l	
		TSS	58	mg/l	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
University changing room	Wash basin	BOD	57	mg/l	Santos et al. (2011)
		COD	166	mg/l	
		TP	0.3	mg/l	
		NH_3	<1	mg/l	
		TSS	83	mg/l	
University building	Wash basins	BOD	74±27	mg/l	Friedler & Alfiya (2010)
		COD	244±121	mg/l	
		sCOD	195±119	mg/l	
		TSS	46±29	mg/l	
		Turbidity	35±19	NTU	
Institution building	Wash basins	COD	248	mg/l	Sarioglu (2011)
		NH4-N	0.45	mg/l	
		TSS	<10	mg/l	
		Turbidity	12	NTU	
Institution building	Shower, wash basin and washing machine (May)	BOD	100	mg/l	Mandal et al. (2011)
		COD	284	mg/l	
		PO_4	1.5	mg/l	
		TN	42.8	mg/l	
		TSS	12	mg/l	
		Turbidity	20.6	NTU	
Institution building	Shower, wash basin and washing machine (June)	BOD	56	mg/l	Mandal et al. (2011)
		COD	244	mg/l	
		PO_4	3.4	mg/l	
		TN	57.7	mg/l	
		TSS	17.6	mg/l	
		Turbidity	38.7	NTU	
School	Bath/shower and wash basin	BOD	170	mg/l	Godfrey et al. (2010)
		COD	493	mg/l	
		TP	0.34	mg/l	
		TKN	12	mg/l	
		NH4-N	13	mg/l	
		Turbidity	161	NTU	

Table A.1 (continued) Different grey water qualities from literature

Source	Grey water fraction	Parameter	Concentration	Unit	Reference
Restaurant	Wash basin	BOD	65	mg/l	Santos et al. (2011)
		COD	209	mg/l	
		TP	0.8	mg/l	
		NH_3	<1	mg/l	
		TSS	55	mg/l	
Airtport	Staff room showers	BOD	82.5±90.7	mg/l	Couto et al. (2013)
		COD	159.0±131.6	mg/l	
		TP	2.4±1.2	mg/l	
		TKN	32.5±12.7	mg/l	
		TSS	99.9±43.9	mg/l	
		Turbidity	26.1±26.9	NTU	
Airtport	Staff room wash basins	BOD	79.7±35.6	mg/l	Couto et al. (2013)
		COD	123.5±48.1	mg/l	
		TP	1.4±0.7	mg/l	
		TKN	6.9±10.1	mg/l	
		TSS	105.2±55.5	mg/l	
		Turbidity	16.4±5.5	NTU	
Airtport	Staff room sinks used for vegetable and fruit washing	BOD	549.4±507.6	mg/l	Couto et al. (2013)
		COD	558.9±528.8	mg/l	
		TP	3.2±3.1	mg/l	
		TKN	12.4±18.3	mg/l	
		TSS	155.6±143.1	mg/l	
		Turbidity	64.1±79.9	NTU	
Airtport	Staff room sinks used for washing dishes	BOD	613.0±243.3	mg/l	Couto et al. (2013)
		COD	912.2±169.3	mg/l	
		TP	8.4±3.5	mg/l	
		TKN	9.3±10.3	mg/l	
		TSS	208.2±67.6	mg/l	
		Turbidity	123.7±158.7	NTU	

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