ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

AN ANALYSIS ON GREY WATER SOURCE SEPARATION AS AN ALTERNATIVE FOR CONVENTIONAL WASTEWATER MANAGEMENT USING THE CASE OF KOCAELI YENIKENT NEIGHBORHOOD

M.Sc. THESIS

Hilal EFE

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

KONVANSİYONEL ATIKSU YÖNETİMİNE ALTERNATİF OLARAK GRİ SU AKIM AYRIMININ KOCAELİ YENİKENT MAHALLESİ ÖRNEĞİ KULLANILARAK ANALİZİ

YÜKSEK LİSANS TEZİ

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ARALIK 2017

Hilal EFE, a M.Sc. student of ITU Graduate School of Science Engineering and Technology student ID 501141747, successfully defended the thesis entitled "AN ANALYSIS ON GREY WATER SOURCE SEPARATION AS AN ALTERNATIVE FOR CONVENTIONAL WASTEWATER MANAGEMENT USING THE CASE OF KOCAELI YENIKENT NEIGHBORHOOD", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

Thesis Advisor :	**Prof. Dr. A. Bilsen BELER BAYKAL** Istanbul Technical University	....
Jury Members :	**Prof. Dr. Fatma Gülen İSKENDER** Istanbul Technical University	....
	Prof. Dr. Nilgün BALKAYA Istanbul University	....

Date of Submission : 16 November 2017

Date of Defense : 15 December 2017

To mom and dad,

FOREWORD

I would like to express my deep appreciation to my academic advisor Prof. Dr. A. Bilsen Beler Baykal for her scientific guidance, her generosity in sharing her knowledge, supportive and encouraging personality. She has always been and will always be a role model.

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November 2017 | Hilal EFE
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ABBREVIATIONS

BOD	: Biochemical Oxygen Demand
CAPEX	: Capital Cost
COD	: Chemical Oxygen Demand
CT	: Cooling Towers
CW	: Constructed Wetland
DW	: Dish Washer
ECOSAN	: Ecological Sanitation
HF	: Hollow Fiber
IR	: Landscape Irrigation
ISU	: Kocaeli Water and Sewerage Administration
LEED	: Leadership in Energy and Environmental Design
MBR	: Membrane bioreactor
MF	: Microfiltration
NF	: Nanofiltration
OIZ or OIS	: Organized Industrial Zone/Site
OP	: Ornamental Pond
OPEX	: Operational Cost
RBC	: Rotating Bioreactor
RO	: Reverse Osmosis
SAR	: Sodium Adsorption Ratio
SH/BT	: Shower/Bathtub
SN	: Kitchen Sink
TF	: Toilet Flushing
TKN	: Total Kjeldahl Nitrogen
TN	: Total Nitrogen
TP	: Total Phosphorus
TSS	: Total Suspended Solids
UF	: Ultrafiltration

UNESCO : United Nations Educational, Scientific and Cultural Organization

USEPA : US Environmental Protection Agency

WB : Wash Basin

WM : Washing Machine SYMBOLS

A_m : Membrane Area

HRT or Θ : Hydraulic Retention Time in Aeration Tank

J_{net} : Net Flux

$J_{net,peak}$: Maximum Allowed Flux

Q_{peak} : Peak Influent Flow Rate

V_{aer} : Aeration Tank Volume

$V_{m,min}$: Minimum Required Membrane Tank Volume

φ_{tank} : Membrane Packing Density in Membrane Tank

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AN ANALYSIS ON GREY WATER SOURCE SEPARATION AS AN ALTERNATIVE FOR CONVENTIONAL WASTEWATER MANAGEMENT USING THE CASE OF KOCAELI YENIKENT NEIGHBORHOOD

SUMMARY

According to World Population Prospect Report published by United Nations, the global population is projected to increase by more than one billion people over the next 13 years, reaching around nine billion in 2030, and to increase further to 10 billion in 2050 and around 11 billion by 2100. In spite of this rapid population increase and urbanization, available water sources remain the same and undoubtedly global water scarcity will pose a risk. As opposed to popular belief, Turkish Republic (T.R) has been sharing global water stress and approaching physical water scarcity according to the reports published by UNESCO and DSI. Although one of the initial steps to prevent the water stress is conservation and efficient use of fresh water resources, in recent years, domestic wastewater is being considered as an alternative water source.

Instead of recovering entire domestic wastewater, stream segregation and ECOlogical SANitation (ECOSAN) approaches enable to collect less polluted streams of domestic wastewater. Within the framework of these concepts, it is possible to collect domestic wastewater streams in two ways. While stream segregation allows the separation of toilet wastewater from other domestic wastewater streams as two streams (grey water, black water), ECOSAN concept involves separation of domestic wastewater into three parts (grey water, yellow water, and brown water) components. Grey water refers to wastewater originated from shower/bathtubs, wash basins, washing machines, sinks, and dish washers. Sub-streams of grey water also defined in two groups as weak (light) grey water including bathing and hand wash wastewater and strong (dark) grey water consisting of basically kitchen wastewater (sink and dish washing) and washing machine wastewater. Grey water is considered as a valuable water source as it constitutes about 70-75% of total conventional domestic wastewater volume with lower pollution content compared to conventional domestic wastewater. Due to its high volume and lower pollution, grey water is considered as an alternative water source.

In this study, stream segregation focusing upon grey water was investigated within the scope of environmental, financial and social sustainability through an appraisal of technical and economical applicability and public acceptance, in an attempt to contribute to grey water management and reuse.

As a sustainable and alternative water source, characterization of grey water and its sub-streams were overviewed and evaluated, and a summary table that indicates typical ranges of each stream was created. Similarly, grey water treatment methods and quality criteria based on various end-uses were examined in detail. Current situation of wastewater management in T.R., as well as in Kocaeli, was reviewed in

terms of conventional wastewater management and wastewater reclamation together with examples of existing practices.

The steps for the implementation of grey water reuse systems were determined by using the example of selected study area as the following;

- Selection of the study area,
- Determination/Prediction of volume and characterization of grey water and its fractions,
- Determination of possible end-use potentials and volume of water demand for these end-use purposes,
- Selection of quality requirements for specific end-use purposes,
- Selection and design of treatment method.

As a result of comparison and matching of grey water generation and demand in terms of quality and quantity in the study area, four different scenarios that indicates grey water reclamation for toilet flushing, cooling, street and car wash were developed and analyzed within the scope of technical and financial applicability and public acceptance. For the financial assessment of scenarios, capital expenditure and operational expenditure of selected treatment methods were calculated. While the capital cost of each system included the costs related to in-building plumbing, distribution pipes of treated grey water, and treatment units; operational costs were arising from electrical and chemical consumptions. The capital expenditure of each scenario was compared with the investment costs of similar capacity conventional systems. Flow charts, water balances and budgets of existing wastewater management system and alternative sustainable systems indicated by scenarios were developed. Operational expenditures of current system and each scenario were calculated and analyzed by using these flow charts and water budgets and compared with each other. Within the scope of financial analysis of scenarios, pay-back periods were also calculated. Similarly, flow charts and water balances were used to estimate the possible water savings in the case of implementation of scenarios. To evaluate the social sustainability of grey water reclamation systems, a preliminary survey was conducted and the levels of acceptance of grey water reuse, background knowledge on grey water, and awareness of water scarcity were questioned.

The results of this work revealed that saving of fresh water sources and operational cost could be achieved due to the separate collection of grey water on its source and reuse. As a result of the case specific assessment of scenarios, water savings could reach to 100%, while the savings could range 15-35% in terms of operational expenditures. From the point of pay-back periods, the results showed that the pay-back periods were comparatively shorter for the grey water reuse in industrial facilities that were located nearby. Within the scope of scenarios, grey water reuse on toilet reservoirs, which is the initial on-site end-use purpose, was reasonable to be implemented in new building projects instead of existing ones.

In addition, the results of this work, the data that gives insight about the environmental, social, and economic viability of grey water reuse was used to produce a guideline (Appendix D) that indicates the method and systematic of implementation of source separation of grey water.

KONVANSİYONEL ATIKSU YÖNETİMİNE ALTERNATİF OLARAK GRİ SU AKIM AYRIMININ KOCAELİ YENİKENT MAHALLESİ ÖRNEĞİ KULLANILARAK ANALİZİ

ÖZET

Birleşmiş Milletler tarafından yayınlanan Dünya Nüfus Tahminleri Raporuna göre, dünya nüfusunun önümüzdeki 13 yıl içerisinde bir milyar kişiden fazla artış göstereceği ve bu artışın 2030 yılına kadar 9 milyara, 2050 yılına kadar 10 milyara ve hatta 2100 yılına kadar 11 milyara yakın olacağı öngörülmektedir. Hızla artan dünya nüfusu ve kentleşmeye karşılık gezegenin tabi yapısından kaynaklı, su kaynakları sabit kalmakta ve gün geçtikçe su sıkıntısı global bir sorun halini almaktadır. Sanılanın aksine su kaynakları yönünden zengin gözükmesine rağmen, UNESCO ve DSI (Devlet Su İşleri) tarafından yayınlanan raporlar, Türkiye' nin de su sıkıntısı sorununu halihazırda yaşadığını ve fiziksel su kıtlığı sınırına yaklaşmakta olduğunu göstemerktedir. Yaşanan bu su sıkıntısını en aza indrmenin yollarından öncelikli olanı, doğal su kaynaklarının korunması ve daha verimli bir şekilde kullanılması olmakla beraber, son yıllarda atıksu alternatif bir su kaynağı olarak görülmeye başlanmıştır.

Konvansiyonel atıksuyun geri kazanımının yanı sıra, evsel atıksuyun daha verimli biçimde yeniden kullanılmasını mümkün kılan sürdürülebilir atıksu yönetim alternatifleri mevcuttur. Bunlardan biri de evsel atıksularda akım ayırımı uygulamaları olmakla birilikte, bu konsept çerçevesinde evsel atıksuyun, gri su ve siyah su olmak üzere iki ya da ECOSAN akımları olarak da bilinen gri su, sarı su ve kahverengi su olmak üzere üç akım halinde, kaynağında ayrı ayrı toplanması mümkündür. Gri su akımı, tuvalet atıksuları dışında kalan duş/banyo, lavabolar, çamaşır makinesi, ve bulaşık makinesinden kaynaklanan evsel atıksuyun beraber, teker teker ya da farklı kombinasyonlarla toplanması sonucu oluşmaktadır. Duş/banyo ve lavabodan toplanan gri su zayıf gri su akımını oluştururken; çamaşır makinesi, bulaşık makinesi ve mutfak lavabolarından kaynaklanan gri sular kuvvetli gri su olarak tanımlanmaktadır. Evsel atıksuya kıyasla daha düşük kirlilik potansiyeline sahip olması ve hacimsel olarak evsel atıksuyun %70-75'ine tekabül etmesi sebebiyle gri su alternatif bir su kaynağı olarak görülmektedir.

Bu çalışmada, gri su akım ayrımı konseptinin çevresel, finansal ve sosyal sürdürülebilirlik kapsamında, teknik ve ekonomik uygulanabilirliği ve toplumsal kabul edilebilirliği açısından, mevcut bir yerleşim alanı örneği üzerinden incelenmesi hedeflenmiştir. Sürdürülebilir bir alternatif su kaynağı olarak gri su akımı ve alt akımlarının karakterizasyonu değerlendirilmiş, tipik konsantrasyonlardan oluşan kılavuz değerler belirlenmiştir. Benzer şekilde gri su arıtma yöntemleri, son kullanım alanları ve bu son kullanım alanlarına yönelik dünya genelinde mevcut olan kalite kriterleri detaylı olarak irdelenmiştir. Türkiye geneli ve Kocaeli ili özelinde mevcut atıksu yönetim sistemi, konvansiyonel atıksu yönetimi ve geri kazanım açısından değerlendirilmiş, mevcut uygulama örnekleri derlenmiştir.

Seçilen çalışma alanı örnek alınarak, gri su geri kazanım sistemlerinin hayata geçirilmesi için izlenecek adımlar;

- Uygulama alanının seçimi,
- Gri su ve alt akımlarına ait hacim ve karakterizasyonun tespit edilmesi/öngörülmesi,
- Potansiyel kullanım alanlarının ve bu alanlara ait su tüketim miktarlarının belirlenmesi,
- Son kullanım alanlarına yönelik kalite kriterlerinin seçilmesi,
- Uygun arıtma metodunun seçimi ve boyutlandırılması olarak belirlenmiştir.

Örnek çalışma alanı için belirlenen gri su akımları ve potansiyel kullanım alanları hacim ve kalite açısından karşılaştırılarak; sifon, soğutma, yeşil alan sulama, yol ve araç yıkama gibi son kullanım alanlarını içeren dört farklı senaryo oluşturulmuştur. Söz konusu senaryolar teknik ve ekonomik uygulanabilirliği ve toplum tarafından kabul edilebilirliği açısından değerlendirilmiştir. Senaryoların finansal değerlendirmesi yapılırken, seçilen arıtma yöntemlerine ilişkin ilk yatırım ve işletme maliyetleri hesaplanmıştır. İlk yatırım maliyetleri bina içi tesisatı, arıtılmış gri su dağıtım hatları ve arıtma üniteleri yatırım maliyetlerinden oluşurken; işletme maliyetleri, elektrik ve kimyasal giderlerini içermektedir. Senaryoların ilk yatırım maliyetleri, mevcut benzer konvansiyonel sistemlerin ilk yatırım maliyetleriyle kıyaslanmıştır. Çalışma alanındaki mevcut atıksu yönetim sistemi ve senaryoların uygulanması halinde uygulanacak alternatif sistemlere ilişkin akım şemaları ve su dengeleri oluşturularak, su bütçeleri çıkarılmıştır. Mevcut atıksu yönetim sisteminin işletme maliyeti açısından analizi ve senaryoların hayat geçirilmesi halinde oluşacak gri su geri kazanım sistemlerine ilişkin işletme maliyetlerinin karşılaştırmalı analizi bu akım şemaları ve su bütçeleri kullanılarak yapılmıştır. Her bir senaryo için yapılmış olan finansal değerlendirme kapsamında, senaryolara ilişkin geri ödeme/amortisman süreleri hesaplanmıştır. Benzer şekilde oluşturulan akım şemaları ve su dengeleri üzerinden temiz su rezervlerinden ne oranda tasarruf edilebileceği irdelenmiştir. Gri su geri kazanım uygulamalarını sosyal sürdürülebilirlik açısından değerlendirmek adına anket çalışması yapılarak, toplumun su sıkıntıları ve gri su hakkında mevcut bilinç düzeyi ölçülmüş, kullanıcılar tarafından gri su geri kazanım sistemlerinin ne derece kabul göreceği irdelenmiştir.

Çalışma neticesinde, gri suyun kaynağında toplanıp arıtılarak yeniden kullanılması sonucu, yalnızca içmesuyu kalitesine getirilmiş su rezervlerinden değil, atıksu yönetim sistemleri işletme maliyetlerinden de tasarruf sağlanacağı bilgisine ulaşılmıştır. Senaryolar kapsamında su tüketimi açısından yapılabilecek tasarruf %100'ü aşabilirken, işletme maliyetleri açısından özellikle seçilen arıtma yöntemine bağlı olarak %15-35 arası tasarruf yapılabileceği görülmüştür. Amortisman sürelerinin ise, geri kazanılacak gri su miktarı arttıkça kısaldığı ve gri suyun kaynağına yakın mesafelerde kurulmuş sanayi kuruluşlarında değerlendirilmesinin finansal açıdan en avantajlı senaryo olduğu sonucuna varılmıştır. Senaryolar kapsamında, gri suyun ilk akla gelen yerinde kullanım metodu olan tuvalet rezervuarlarında yeniden kullanımının, yeni yapılacak binalar için daha uygun olduğu ve yapılacak yatırımın geri ödeme peryodlarının 1 yıl kadar olduğu görülmüştür.

Bunların yanı sıra, yapılan çalışma neticesinde gri su geri kazanım sistemlerinin hayata geçirilmesinde izlenecek metod ve sistematiği içeren bir kılavuz (Ek D) oluşturularak, bireysel ve endüstriyel kullanıcılar ile yerel idarelerin kullanımına sunulmuştur.

1. INTRODUCTION

In today's world, human kind lives as a part of a linear as opposed to cyclic, unilateral system of resources and their processing, distribution, consumption, and disposal of waste generated, without considering recycling. Yet, the physical nature of our planet has many limits that seem closer by the minute due to population growth and rapid urbanization. The truth is linear and unilateral systems are not sustainable. Devising self-sufficient non-linear/cyclic systems within natural boundaries is one of the most essential steps to take for environmental sustainability.

With the population growth and rapid urbanization Turkish Republic (T.R.) has been sharing global water stress as water resources remain the same [1]. In that regard, UNESCO defines T.R. as one of the countries approaching physical water scarcity [2]. Environmental sustainability would necessitate the reuse of treated wastewater as a non-linear component, alongside common practices such as treatment and discharge to a receiving environment. In recent years, ECOlogical SANitation (ECOSAN) appeared as a supporting approach on wastewater reuse. The concept involves the separation of wastewater at its source into three streams; grey water, yellow water and brown water or in terms of stream segregation, it could be separated in two; grey water and black water, where grey water refers to all domestic wastewater sources excluding toilet wastewater (black water). Compared to reclaimed domestic wastewater, after source separation, grey water would require less sophisticated treatment methods as it includes considerably less nutrients, organic matter, pathogens, and suspended solids. According to the "fit for the purpose" concept, it is not necessary to use potable quality water for the applications such as industry, irrigation, and etc. and is possible to reuse greywater instead.

In this study, stream segregation focusing upon grey water is going to be investigated within the scope of environmental, financial and social sustainability through an appraisal of technical and economical applicability and public acceptance, in an attempt to contribute to grey water management and reuse which is still not widely recognized and used worldwide as well as in T.R.

As a result of drought faced in 2014 in T.R., Kocaeli Municipality searched for other potential water sources. As an alternative solution towards this water stress, 11% of total domestic wastewater is currently reclaimed by an additional treatment process applied to the effluent of conventional wastewater treatment plants [3] [4]. However the analysis of domestic water consumption in Kocaeli indicates that if conventional domestic wastewater across the city is separated into two streams as grey water and black water, possible water to be reclaimed as grey water is approximately 55 million m^3/year, which is almost equal to the usable volume of Yuvacik Dam (51 million m^3), the main water reserve of Kocaeli [3, 5]. This possible volume of grey water is able to supply the water demand for industrial processes, landscaping and toilet flushing. It can also replace already existing reclaimed wastewater and well water consumption. The effects of source separation focusing upon grey water are investigated on the case of Kocaeli Municipality Gebze, Yenikent Neighborhood. Since it is located 70-80 km away from the main water supply of Kocaeli (Yuvacik Dam), Yenikent is considered as the source of grey water, while Guzeller and Gebze Organized Industrial Zones, Gaziler Natural Park are selected as main areas of reuse.

The scope of this study constitutes:

- An overview of grey water in terms of the characterization of mixed, weak, and bathroom grey water and a summary table that indicates typical ranges of each stream,
- An overview of grey water quality criteria based on end-uses,
- An overview of current situation in terms of wastewater management in T.R., as well as in Kocaeli,
- Scenarios developed for reclamation of grey water in order to reuse for toilet reservoirs, car washing, urban cleaning, cooling, and landscape irrigation and development of water balances for each scenario,
- Investigation of the scenarios in terms of quality requirements and selection of the suitable treatment systems,
- Assessment of the scenarios in terms of water saving,
- Financial analysis of scenarios including a comparison between source separation of grey water and conventional wastewater management system,
- A preliminary survey on public acceptance/attitude for grey water reuse.

Another goal of this work is to produce data that give insight about the environmental, social, and economic viability of grey water reuse, which could be used as a resource/guide by local governments as well as individuals. As a result of this work, a guideline (Appendix D) which presents the method and systematic is prepared, that could be applied for source separation of grey water.

2. STREAM SEGREGATION AND GREY WATER

According to World Population Prospect Report published by United Nations, the global population is projected to increase by more than one billion people over the next 13 years, reaching around nine billion in 2030, and to increase further to 10 billion in 2050 and around 11 billion by 2100 as given in Figure 2.1 [6]. In spite of this population increase, available water sources remain the same and undoubtedly global water scarcity will pose a risk.

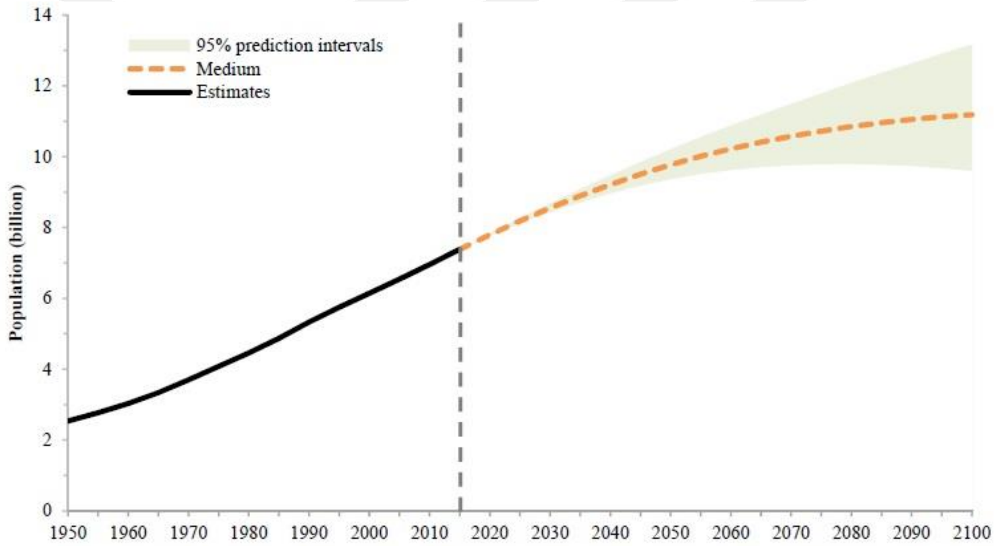

Figure 2.1: Population projection. [6]

The water availability report prepared by Water Resources Group agrees that by 2030, global water requirements would grow from 4,500 billion m^3 today to 6,900 billion m^3 [7]. As Figure 2.2 also shows, water stress does not only imply physical water scarcity. UNESCO defines water stress as a function of the availability of water resources and a function of access to water reserves [2]. All of these water related challenges lead water science and technology focus on developing new concepts to recover water resources including non-conventional practices. Domestic wastewater is one of those alternative water sources in order to conserve fresh water reserves.

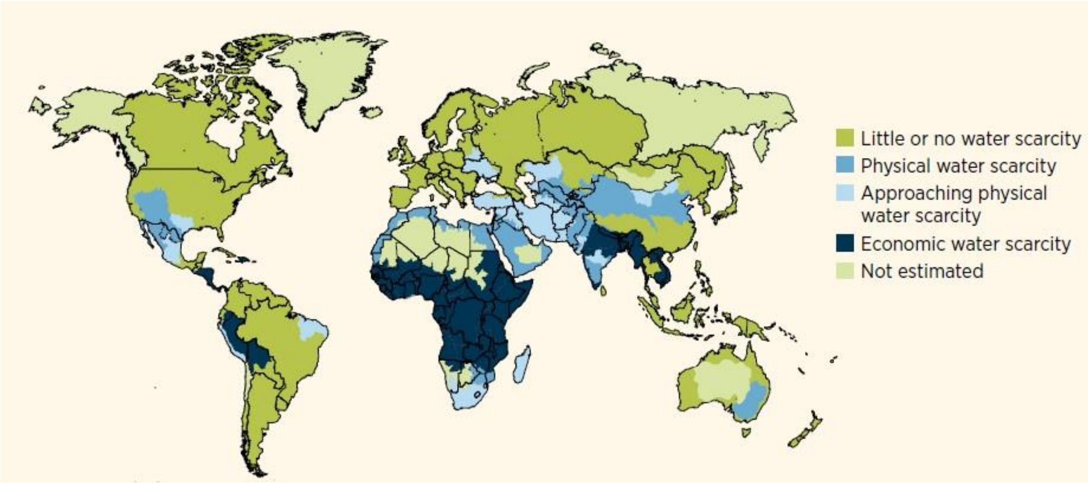

Figure 2.2: Global physical and economic water scarcity.

(Stress: 1,700-1,000 m^3/capita.year; Scarcity: 1,000-500 m^3/capita.year; Absolute Scarcity: <500 m^3/capita.year)[2]

Instead of recovering entire domestic wastewater, stream segregation and ECOlogical SANitation (ECOSAN) approaches enable to collect less polluted streams of domestic wastewater. Within the framework of these concepts, it is possible to collect domestic wastewater streams in two ways. While stream segregation allows the separation of toilet wastewater from other domestic wastewater streams, ECOSAN concept involves separation of domestic wastewater into three parts; where toilet wastewater is also segregated in two streams by the use of urine diverting toilets.

In terms of stream segregation, wastewater generated in toilets which is a mixture of faeces, urine, and flush water is termed as black water and all other wastewater generating streams except toilet wastewater is defined as grey water. This stream originates from different washing activities in the households like bathtub/showers, wash basins, washing machines, kitchen sinks, and dish washers. In addition, there are also sub-streams of grey water grouped in two as weak (light) grey water including bathing and hand wash wastewater (such as shower/bathtub, wash basin) and strong (dark) grey water consisting of basically kitchen wastewater (sink and dish washing) and washing machine wastewater. As given in Figure 2.3, Gross and others [8] stated that the use of water in general and the generation of grey water in particular vary between locations depending on factors such as water availability, consumption habits, and economic status.

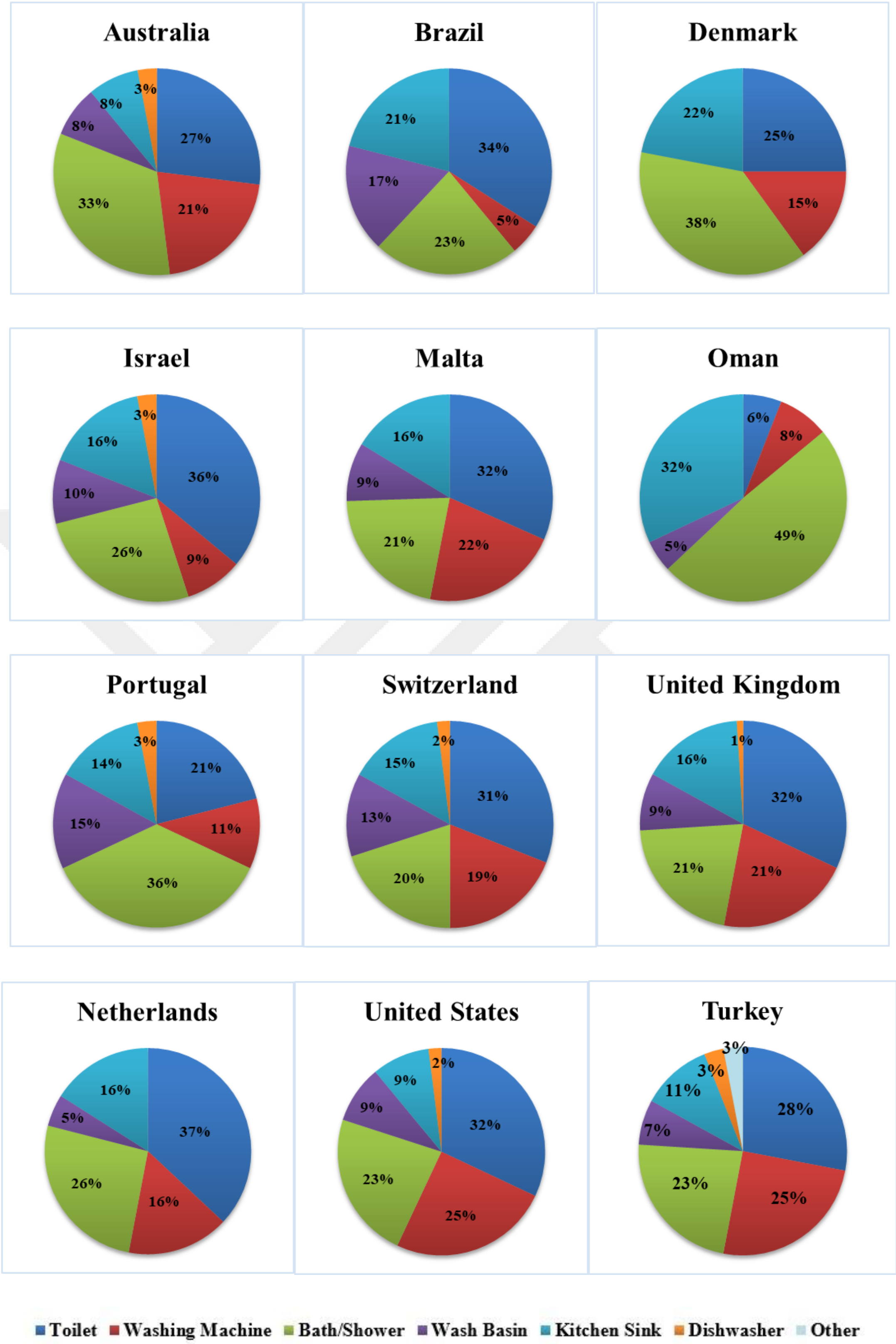

Figure 2.3: Volume % of domestic water consumption by origins in different regions. (Based on [8] and [9])

Figure 2.3 illustrates that grey water in general constitutes about 3/4 of domestic wastewater. Particularly in Turkish Republic (T.R.), weak grey water constitutes 30% of domestic wastewater by volume, while this percentage rises up to 55% if it is collected together with washing machine grey water.

Not only the quantity, but also quality of grey water shows that grey water has a potential of being reused as an alternative water source. The distribution of pollutants in segregated domestic wastewater streams is presented in Figure 2.4, which shows that 41% of organic matter content in domestic wastewater is contained in grey water. Although the organic matter is the primary pollutant for grey water, nutrients are not the main concern about the quality of grey water. In other words, 97% of nitrogen and 90% of phosphorus content of conventional wastewater is separated from grey water at its source and remains in black water stream, which makes grey water an easier-to-deal-with water source in comparison with domestic wastewater.

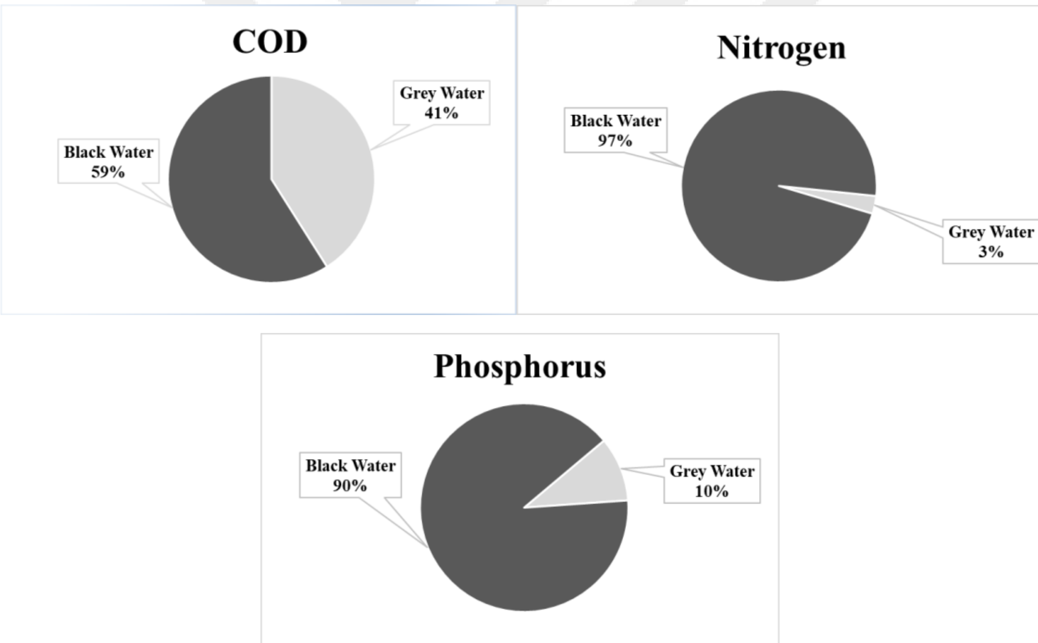

Figure 2.4: Characteristics of black and grey water streams. (based on [10])

In terms of pathogens, grey water might have considerable amount of microbiological indicators. Giresunlu and Beler Baykal [11] reported that microbial quality of grey water is in the range of low-to-medium scale domestic wastewater, which points out that microbiological content of grey water could be as significant as organic matter.

2.1 Characterization of Grey Water

As grey water is less polluted than domestic wastewater in the absence of black water (faeces and urine), reuse potential of grey water is higher compared to domestic wastewater. In order to select the suitable treatment method prior to reuse, it is significant to determine the quality of grey water that is generated from different household activities. However the characterization of mixed grey water differs widely depending on several features such as water availability, consumption habits of the occupants, and location; different fractions of grey water also show different characteristics according to the sub-streams/washing functions contained in grey water. Oructut [12] stated that quality of raw grey water might also change during storage as a result of chemical and biological degradation.

In Table 2.1, literature review on characteristics of mixed grey water (includes all streams; shower/bathtub, wash basin, washing machine, sink, and dishwasher) originating from households is presented. Out of 32 references in literature, the minimum and maximum COD concentrations observed for mixed grey water collected from households are 171 and 2568 mg/L. Although the highest COD concentrations, such as 2568 mg/L [13] and 1710 mg/L [14], are usually reported in the studies carried out in Jordan, there is also an extreme COD concentration observed in Netherlands and Greece which are 1583 mg/L [15] and 1178 mg/L [16]. Considering these references that indicate peak COD concentrations, the organic matter concentration of grey water lies way outside of the others reported in the literature. It is stated by these references that the water consumption in the locations, where these extremely high concentrations are observed, is lower than average; however these high COD values cannot be fully explained. Halalsheh and others [13] mentioned that these values are even higher than concentrations reported for combined sewage in the location where it is tested.

Similarly, the highest pollution concentrations in terms of BOD are also reported in Jordan by Ammari [14] and Halalsheh [13], while the minimum concentrations are detected as 60 mg/L and 65 mg/L in Malaysia and USA respectively [17] [18]. TSS and nutrient concentrations reported in these references are also very high compared to the other literature data, possibly as a result of consumer habits.

Among all of the other references, another extraordinary concentration reported as 630 mg/L for TSS and 206 mg/L for total nitrogen [19] [20]. However there are no reasons stated to explain these values that show incongruity with other literature data.

In Table 2.2 and Table 2.3, characterization of weak grey water that constitutes shower/bathtub, wash basin and characterization of bathroom greywater which is basically weak grey water collected together with washing machine from households are given. While COD concentrations for weak grey water ranges between 112 – 1001 mg/L, the same values are 35 – 900 mg/L if weak grey water is collected together with washing machine. However for bathroom grey water to have a lower COD concentration range is unexpected and could be a result of different experimental conditions in each reference. However, 1001 mg/L COD reported by Chaillou and others [21] is way over of the others given in other references for weak grey water. It is explained that higher COD concentrations were originated from households where solid soaps were used. In light of this data, mixed grey water shows higher pollution potential in comparison with weak grey water in terms of COD. However, COD concentration tends to increase when washing machines contributes to COD content.

In terms of BOD, grey water generated in bathrooms shows a less polluted profile in comparison with weak grey water, while mixed grey water still has the highest BOD concentration. An extreme BOD concentration in weak grey water, 670 mg/L is also reported by Chaillou and others [21] resulted from the same reasons given for high COD concentrations. Among all BOD concentrations in bathroom grey water, 536 mg/L reported by Gharir and others [22] is not in line with the other data given in literature. The methods applied for the treatment of grey water is usually consisting of biological processes as a result of its high organic matter content. One way to assess the biodegradability of organic matter in grey water is to compute the ratio between BOD and COD. The higher BOD/COD ratio means the larger the portion of biodegradable organic matter in grey water. While BOD/COD ratios in literature ranges between 0.34 [23] to 0.77 [24] for mixed grey water, it is reported as 0.32 [25] to 0.69 [21] for weak grey water. The biodegradability of grey water collected from bathroom is lower, since it is reported as 0.10 [8], 0.33 [26], and 0.58 [22] in literature. It should also be noted that C:N:P ratio in grey water is also significant as it effects the

Table 2.1: Characterization of mixed grey water from households.

		Netherlands			Germany		UK	Sweden			Norway		Greece		Turkey					
		Hernandez et al. (2007)		*Hernandez et al. (2010)*	*Li et al. (2008)*	*Nolde (1996)*	*Jefferson et al. (1999)*	*Dalahmeh et al. (2011)*	*Palmquist & Hanaeus (2005)*		*Karabelnik et al. (2012)*		*Antonopoulou (2013)*		*Barisci et al. 2014 and Barisci 2017*	*Barisci & Turkal (2016)*	*Kader (2011) and Baban et al. (2010)*	*Kepoglu (2013)*	*Hocaoglu et al. (2010)*	*Atasoy et al (2007)*
T	*C*				20										22		22	14		22
pH					7.5	6.9 - 8		7.8	7.5		6.8 ± 0.2	7.0 ± 0.2	9.03	7.27	7.2	7.62	7.1	7.64	7.2	7.1
Alkalinity	*mg/L*																		192	
Turbidity	*NTU*				140 ± 12		69								50	53.4 ± 1.12	103			
Color	*Pt-Co*																			12.2
EC	*µS/cm*				1115 ± 110			1960 ± 140					1985 ± 294	842 ± 99		802.2±0.07		451		401
TDS	*mg/L*												1269 ± 188	539 ± 63						301
TSS	*mg/L*								630	86	160 ± 63	130 ± 14	542 ± 179	263 ± 103		33.5 ± 0.98	79		63	48
VSS	*mg/L*																		47	39
BOD	*mg/L*					250 - 550				150					120					
BOD5	*mg/L*	215 ± 102					121	425 ± 56									119		111	90
BOD7	*mg/L*								418		500 ± 175	385 ± 72								
COD	*mg/L*	425 ± 107	1583 ± 382	833 ± 188		401 - 700	171	890 ± 130	588	335	750 ± 197	640 ± 135	1178 ± 245	845 ± 167	270	229 ± 3.21	347	346	295	245
sCOD	*mg/L*	175 ± 48	576 ± 146	224 ± 59													214		191	177
COD sus.	*mg/L*			411 ± 151																
COD col.	*mg/L*			204 ± 58																
TOC	*mg/L*	114 ± 28	254.5		161 ± 20			304							42.2			76.28		
T.N	*mg/L*	17.2 ± 4.7	47.8 ± 27	41.2 ± 27.2	16.5 ± 2.3	10 - 17		75 ± 10	9.68	11.5	16.5 ± 5.7	13 ± 2.6				11.1 ± 0.26				
TKN	*mg/L*														9.1		8		7.4	9
NH4	*mg/L*	7.2 ± 3.7	16.4 ± 6.8	1.0 ± 0.7	10.1 ± 2.5						5.8 ± 4.1	1.9 ± 1.4					2.2		1.6	1.3
NH3	*mg/L*						1													
NO2	*mg/L*				0.01											0.067±0.08				
NO3	*mg/L*			0.12 ± 0.08	0.01						0.02±0.003	0.02±0.005			0	0.375±0.12	0			
T.P	*mg/L*	5.7 ± 2.6	9.8 ± 8.5	6.6 ± 2.7	9.7 ± 0.9	3 - 8	0.36	4.2 ± 0.2	7.53	4.8	7.5 ± 6.3	6.8 ± 2.7			3.55	1.07 ± 0.05	9.8		7.3	7.3
PO4	*mg/L*	2.3 ± 1.3	2.3 ± 0.3		7.5 ± 0.6			2.1 ± 0.4			5.5 ± 5.1	3.9 ± 1.2				0.311±0.01				
SO4	*mg/L*															155.8 ± 6.5				
Oil & Grease	*mg/L*																			2
Cl	*mg/L*															726 ± 10.2				
K	*mg/L*	11.2 ± 2.3	23.3 ± 8.5																	
Ca	*mg/L*	60.8 ± 8	65.5 ± 29.4																	
Mg	*mg/L*	6.15 ± 0.7	30.5																	
Na	*mg/L*	86.35 ± 18.9	159.7 ± 45																	
Fe	*mg/L*	0.11 ± 0.06	1.28 ± 0.36																	
Cu	*mg/L*	0.08 ± 0.04	0.12																	
Boron	*mg/L*	0.42 ± 0.15	0.87 ± 0.49																	
Si	*mg/L*	11.97 ± 1.52																		
Al	*mg/L*	0.49 ± 0.31	7.3 ± 6																	
Zn	*mg/L*	0	0.13																	
Faecal Coli	*cfu/100 mL*							1.73E+05 - 3.3E+05												3.57E+03
T. Coliform	*cfu/100 mL*															1.00E+05				1.36E+04
E.Coli	*cfu/100 mL*																			

Table 2.1 (continued): Characterization of mixed grey water from households.

		Jordon								Israel			Egypt	Kenya	South Africa	Malaysia	Japan	USA	Brazil	Costa Rica
		Ghrair et al (2016)	*Assayed et al. (2015)*				*Ammari et al. (2014)*	*Halalsheh et al (2008)*	*Al-Jayyousi (2003)*	*Maimon et al (2014)*	*Penn et al (2012)*	*Gross et al (2007)*	*Abdel-Shafy et al. (2014)*	*Kraft (2009)*	*Rodda et al. (2011)*	*Wurochekke et al. (2014)*	*Itayama et al (2006)*	*Casanova et al (2001)*	*Paulo et al (2009)*	*Dallas et al (2004)*
T	*C*												27.55	18.3						
pH		7.5	7.18	7	6.7	7.29	5.44	6.35		7.5		6.3 - 7	6.71	8.4	8.1 - 9.8					
Alkalinity	mg/L														330 ± 58					
Turbidity	*NTU*								69							35.1 - 67.9	13	43	254 ± 204	996 ± 39
Color	Pt-Co																			
EC	µS/cm		937 ± 173	1132 ± 30	1610 ± 125	1470	805 - 3840	1830		1200		1200 ± 100	688	1247	267 ± 30			4300		
TDS	*mg/L*	980					1113 - 2930						509.87	981						
TSS	*mg/L*	436	78 ± 29	114 ± 67	206 ± 86	101 ± 11	213 - 803	845		75.9	286	158 ± 30	105			54 - 153	105	35	120 ± 83	
VSS	mg/L																			
BOD	*mg/L*									123.9	458	466 ± 66		455		60 - 309	271	65	435 ± 256	167 ± 47
BOD5	*mg/L*	536	217 ± 61	785 ± 25	520 ± 63	259 ± 25	600 - 1710	1056	121				298.6							
BOD7	*mg/L*																			
COD	*mg/L*	900	385 ± 126		676 ± 121	385 ± 42	816 - 2560	2568	371		804	839 ± 47	392		280 - 310	469 - 705	477		646 ± 278	
sCOD	*mg/L*																			
COD sus.	mg/L																			
COD col.	mg/L																			
TOC	*mg/L*																			
T.N	*mg/L*											34.3 ± 2.6			206 ± 5.8		20.7		8.8 ± 4.1	
TKN	*mg/L*							128			218		28		206 ± 2.7					
NH4	*mg/L*										1.4			7.32						
NH3	*mg/L*	24						75	1				8.4			1.24 - 3.83			2.4 ± 1.1	
NO2	*mg/L*											0.3 ± 0.2							0.05 ± 0.05	
NO3	*mg/L*						54.30 - 155.03					3 ± 1.3	0.4		88 ± 1.1				0.05 ± 0.04	
T.P	*mg/L*							19.5	0.36		39	22.8 ± 1.8		8.28			3.8			
PO4	*mg/L*						5.20 - 9.14						10.54		69 ± 0.6					
SO4	*mg/L*	222					185 - 213	89							576 ± 27			60		
Oil & Grease	mg/L												118.5							
Cl	*mg/L*	243					126 - 216											21		
K	*mg/L*														31 ± 2.7					
Ca	*mg/L*						52 - 80						290.36		8.3 ± 1.7					
Mg	*mg/L*						14.3 - 64.4						105.64		7.5 ± 1.7					
Na	*mg/L*												320.98		188 ± 27					
Fe	*mg/L*																			
Cu	*mg/L*														0.1 ± 0.1					
Boron	*mg/L*											1.6 ± 0.1			3.4 ± 3.2					
Si	*mg/L*																			
Al	*mg/L*																			
Zn	*mg/L*														0.24 ± 0.4					
Faecal Coli	*cfu/100 mL*							3.00E+05				5.00E+07 ± 2.00E+07		1.00E+07						1.5E+08 - 4.6 E+08
T. Coliform	*cfu/100 mL*						6.20E+04 - 3.89E+06	1.00E+07											5.40E+08 ± 6.30E+08	
E.Coli	cfu/100 mL	1.70E+05	2.30E+02	2.40E+07	1.60E+04	1.30E+03	3.10E+04 - 4.10E+05			1.40E+05									5.40E+06 ± 4.50E+05	

efficiency of biological processes. Optimum C:N:P ratio for biological treatment reported as 100:20:5 in literature [8].

As given in Table 2.2 and 2.3, TSS concentrations in weak and bathroom grey water shows a pretty similar range, however if the grey water generated from kitchens is included, it tends to have a higher concentration as kitchen sink stream constitutes about 58% of total suspended solids [8]. However the TSS concentration reported by Finley and others [27] is higher in comparison with the other data given in literature for bathroom grey water and was indicated by the authors to be low-to-medium-grade wastewater.

In terms of nutrients, all mixed, weak and bathroom grey water have a pretty low concentration in comparison with domestic wastewater as most of the nutrients are separated and discharged into sewer system in yellow water. As expected, nitrogen content of weak grey water ranges between 4 and 20 mg/L, while it is 5.3 – 68 mg/L in grey water collected from bathroom. In terms of T.P, Table 2.3 shows that concentrations tend to increase when washing machine grey water is collected with weak grey water, which is as expected due to the phosphorus content of detergents.

Microbial characteristics of grey water are also significant even if it generally shows mid strength domestic wastewater or better quality [11]. Gross et al. [8] stated that the microbial quality of greywater depends on many factors such as water source, temperature, and personal hygiene habits and main sources in raw grey water could be listed as hand wash, dirty laundry, external body parts, and food preparation (which is not the case for this study since kitchen grey water is excluded).

Given in Table 2.1, 2.2, and Table 2.3, as microbial quality reported on literature vary widely ranging between 2 log to 9 log for mixed, weak, and bathroom grey water in terms of *Escherichia coli.*, faecal coliforms, and total coliform; microbiological parameters become one of the main concerns need to be eliminated prior to reuse especially for purposes with possible human contact such as, toilet flush and irrigation [11]. Generally fecal contamination of mixed grey water is higher than weak grey water and weak grey water collected with washing machines. However, in some cases such as the ones reported by Asan [28] and Nolde [29], the microbial content could be

Table 2.2: Characterization of weak grey water from households.

		Australia	Israel					Spain	Denmark	France					Germany		
		[30]	*[31]*	*[32]*	*[25]*	*[33]*	*[34]*	*[35]*	*[36]*	*[21]*					*[37]*	*[29]*	*[29]*
pH		6.4 - 8.1						7.6							7.5 - 8.2		
BOD	*mg/L*	76 - 200	59	95	122	95	257		93	170	78	670	81	200	85 -200	70 - 300	50 - 100
COD	*mg/L*		158	148	370	148	400	171	142	315	112	1001	145	421	150 - 400	113 - 633	100 - 200
sCOD	*mg/L*			86						150	29	257	65	180			
TOC	*mg/L*			29				58	72								
TSS	*mg/L*		43		216		157	44		78.1	37	360.5	40.3	115	30 - 70		
Turbidity	*NTU*	60 - 240	33	33		33		20									
T.N	*mg/L*	4.6 - 20						11.4		4.3	5.4	11.1	6.2	15.9	4 - 16		5 - 10
TKN	*mg/L*						118										
NH_4	*mg/L*						0.8		2.04								
T.P	*mg/L*	0.11 - 1.8	4.8							0.35	0.2	1.12	0.25	0.2	0.5 - 4		0.2 - 0.6
T. Coliform	*mpn/100 mL*	500 - 2.4E+07														1.00E+03- 1.00E+05	1.00E+04- 1.00E+05
Feacal Coli	*mpn/100 mL*	170 - 3.3E+03														1.00E+03	1.00E+03

as high as mixed grey water when baby diapers are contained in washing machine grey water.

It is also stated that there is a possibility of microbial regrowth if biodegradable organic matter exists in treated grey water. To avoid the regrowth, disinfection is necessary prior to reuse, especially for the cases treated grey water is stored for a period of time. [38]

Since the literature data on characterization of grey water from households vary widely, within the scope of this work, a summary table is generated with the method given in Appendix A. In Table 2.5, typical concentration ranges for mixed, weak, and bathroom grey water is presented in comparison with typical compositions of domestic wastewater given by Metcalf & Eddy [39] (Table 2.4).

Table 2.3: Characterization of bathroom grey water from households.

		Australia				Canada	Jordan	Israel		UK	Germany	T.R.
			[40]		*[26]*	*[27]*	*[22]*	*[41]*	*[8]*	*[8]*	*[29]*	*[28]*
pH		7.1 - 8.3	6.8 - 8.2	6.8 - 7.8	10	6.7 - 7.6	7.5	7.14	7.3	7.54		
EC	*µS/cm*	300 - 630	116 - 1,150	117 - 800	1088			1200	1130	64.8		
TDS	*mg/L*	192 - 403	74.24 - 736	74.88 - 512	205		980					
TSS	*mg/L*	68 - 86	78 - 163	88 - 110	374	313 - 543	436	78	153	58		
COD	*mg/L*	35 - 739	445 - 621	180 - 291	225	278 - 435	900	230	435	367	250 - 430	451 - 852
BOD	*mg/L*	24 - 200	40 - 180	90 - 130	76		536	173	44	129	150 - 250	165 - 213
T.N	*mg/L*	24 - 32	10 - 38	5.3 - 30					7.2	6.6		60 - 68
TKN	*mg/L*	19 - 25	1.12 - 35	1.33 - 20								
NH_4	*mg/L*	0.40 - 15	0.022 - 6.7	0.24 - 5.2		1.2 - 6.2		0.9	0.65			
NO_3	*mg/L*	0.04 - 2.1	0.01 - 0.4	0.01 - 0.3	0.3							
T.P	*mg/L*	0.23 - 2.4	3 - 20	0.22 - 6.7		0.24 - 1.02			2.8			5 - 7.5
T. Coliform	*cfu/100 mL*										1.00E+06 - 1.00E+08	1.00E+06 - 5.00E+09
Fecal Coli	*cfu/100 mL*					4.70E+04 - 8.30E+05				8.27E+01	1.00E+04 - 1.00E+06	
E.coli	*cfu/100 mL*						1.70E+05					

Table 2.4: Typical composition of domestic wastewater. [39]

		Low strength	Medium strength	High strength
BOD	*mg/L*	110	190	350
COD	*mg/L*	250	430	800
TSS	*mg/L*	120	210	400
NH_4-N	*mg/L*	12	25	45
TN	*mg/L*	20	40	70
TP	*mg/L*	4	7	17

Table 2.5: Summary of literature review on sub-streams of grey water from households.

	Parameter		Num. of Obser. (N)	Min	Max	Typical Range	
MIXED GREY WATER	**BOD**	*mg/L*	28	60	1149	170 - 606	med. - >high
	COD	*mg/L*	32	171	1178	347 - 827	med. - >high
	TSS	*mg/L*	33	34	543	78 - 280	low - high
	NH_4-N	*mg/L*	8	1	16.35	1.6 - 9.4	low
	TN	*mg/L*	15	8.8	75	11 - 39	low - med.
	TP	*mg/L*	20	0.36	9.8	3.9 - 9.8	low - high
WEAK GREY WATER	**BOD**	*mg/L*	17	50	300	78 - 200	low - high
	COD	*mg/L*	17	100	663	145 - 400	low - med.
	TSS	*mg/L*	11	30	216	41 - 148	low - med.
	NH_4-N	*mg/L*	2	0.8	2.04	0.8 - 2	low
	TN	*mg/L*	12	4	20	4.5 - 13.5	low
	TP	*mg/L*	13	0.11	4	0.2 - 1.9	low
BATHROOM GREY WATER	**BOD**	*mg/L*	11	24	250	56 - 195	low - high
	COD	*mg/L*	16	35	900	257 - 579	med. - high
	TSS	*mg/L*	12	58	543	78 - 276	low - high
	NH_4-N	*mg/L*	10	0.02	15	0.36 - 6.3	low
	TN	*mg/L*	10	5.3	68	7 - 44	low - high
	TP	*mg/L*	10	0.22	7.5	0.24 - 6.7	low - med.

2.2 Grey Water Treatment Methods

Characteristics of grey water from different origins differ from each other. Grey water collected from bathtub/showers and washbasins, which refers to weak grey water might be defined as easier-to-treat fraction, as it contains less organic matter. Not only the origins, but also the end-use purposes of grey water is essential to choose the most suitable treatment method. The end-use of treated grey water determines the required quality of the water and treatment procedures required to ensure safety and lowest possible cost of implementation.

In short, following factors should be considered in order to determine the treatment method:

- Characterization of grey water sources.
- End-use of treated grey water.
- Influent and end-use/demand flow rates.
- Availability of space for treatment system.

Physical Treatment

Even though physical treatment options such as filtration and sedimentation are usually applied as pretreatment to ensure the efficiency of biological and chemical processes, appropriate use of filtration technologies in grey water is effective in removal of particles and majority of organic load. More or less sophisticated filtration technologies could be used in order to achieve different levels of removal as shown in Figure 2.5. While coarse filtration is able to remove large particles and hair, membrane filtration systems could actively remove protozoan cysts or colloidal substances as well as reducing turbidity [8] [42].

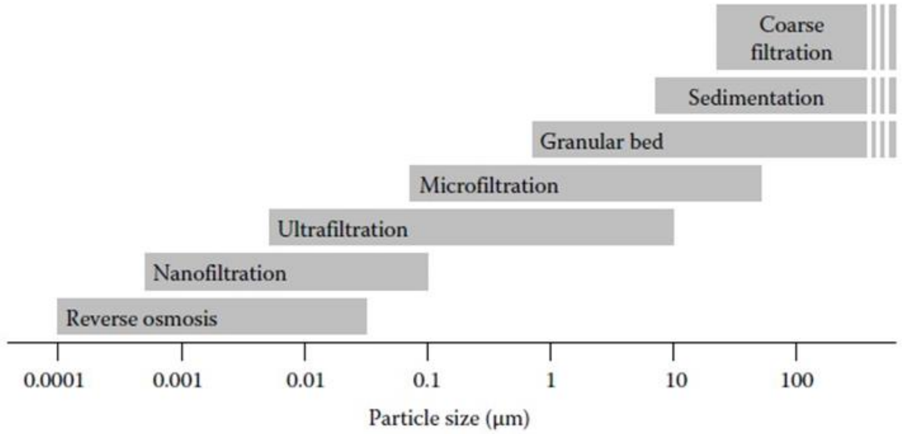

Figure 2.5: Size of the particle removed by different filtration technologies. [1]

Depending on the driving force and separation mechanisms, membrane systems categorized as flat films, hollow fibers, and tubular [43]. As given in Table 2.6, membranes are classified as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO) based on their pore sizes. Although in terms of initial investment, membrane systems are comparatively expensive, they provide outstanding performance depending on the pore size. While it is possible to eliminate protozoan oocysts and cysts, some bacteria and viruses via MF membranes, UF membranes with finer pore size could also contribute to disinfection by removing bacteria and some viruses.

Table 2.6: Membrane classification. [39]

Membrane type	Operating range (µm)	Permeate content	Constituents removed
Microfiltration (MF)	0.08-2.0	Water and dissolved solutes	TSS, turbidity, protozoan oocysts and cysts, some bacteria and viruses
Ultrafiltration (UF)	0.005-0.2	Water and small molecules	Macromolecules, colloids, most bacteria, some viruses, proteins
Nanofiltration (NF)	0.001-0.01	Water and very small molecules, ionic solutes	Small molecules, some hardness, viruses
Reverse Osmosis (RO)	0.0001-0.001	water and very small molecules, ionic solutes	Very small molecules, color, hardness, sulfates, nitrate, sodium, other ions

Biological Treatment

Because of the high organic matter content of grey water, treatment technologies that includes biological processes are usually preferred for grey water reclamation. However it should be noted that biodegradability of organic matter content should be considered as mentioned earlier in Chapter 2.1. By the implementation of biological treatment methods, it is possible to reach 60-98% and 51-88% of organic matter removal efficiency in terms of BOD and COD respectively [12]. Out of biological treatment methods such as constructed wetlands (CW), rotating biological contractors (RBC), sequenced batch reactors (SBR) and membrane bioreactors (MBR); membrane bioreactor is the most preferred option because of its space-efficient structure and removal-efficient performance. However, in design phase, the biodegradability of grey water should be considered case specifically [9].

Being a preferred process for grey water treatment, MBR systems combine biological and physical treatment methods in operation as well as their benefits. Biological part of an MBR system closely resembles an activated sludge system; microorganisms employed during biological treatment phase reduces nutrient and organic load of grey water, where aeration and mixing is supplied by air diffusers at the bottom of the tank. After biological treatment is complete, clarification is done by a membrane module, which can be placed inside or outside of biological treatment tank, in order to accommodate space needs. Such systems are known as submerged MBRs and side stream MBRs respectively. [8]

Effluent quality of MBR systems usually meet the reuse requirements for most purposes, since the typical effluent concentrations are reported as 5 mg/L and 1 NTU for TSS and turbidity respectively [8]. Since MF and UF type membranes are commonly in MBR configurations, the pore size do not allow bacteria passing to permeate. Even in some cases, it is possible for viruses to be held due to the biological biofouling layer that is formed on membrane surface [32].

However, MBR systems do not come without any disadvantages. Operation usually requires a skilled person and aeration and mixing as well as high pressure pumps that require significant amount of energy to function. Unavoidably, membranes are prone to fouling due to possible suspended solid and sludge accumulation, causing reduced flux, filtration capacity and lowered effluent water quality [8] [44].

Treatment Challenges

Grey water is usually treated in decentralized systems as later discussed with the examples in Chapter 3.2.2. Unlike the large scale conventional treatment plants, influent volume and quality of these localized systems might have fluctuations more often, depending on the daily consumption of the residents, possible contamination with urine, or one-time use of specific personal care and cleaning products [8].

2.3 Grey Water End-Use Purposes

Introducing grey water to a reuse scenario might greatly reduce fresh water demand, especially for water scarce areas where alternative water sources are needed or remote areas where pumping costs are significant. In this type of locations, as well as in urban areas, grey water could serve as an alternative water source for non-potable uses such as; car wash, urban/street cleaning, ornamental ponds, landscape and agricultural irrigation, swimming pools, and groundwater discharge. It could also be utilized in-building water consuming activities such as laundry and toilet flushing. Although the industrial reuse of grey water is case specific, the general industrial reuse options could be listed as process and cooling water, chemical preparation, on-site cleaning, dust control, construction.

Irrigation is a high-volume reuse scenario, where various levels of treatment might be required depending on irrigation method and area that is irrigated. The number of end user that might have possible contact with grey water varies depending on the area irrigated. While it is very few for a small garden, entire community could expose when a park is irrigated. For landscape irrigation, irrigation method gains significance as it might create water spray/aerosols, water accumulation on the surface, and surface runoff as well [8]. For the cases where water demand for irrigation is met by grey water, percolation through the soil and contamination to groundwater should be considered [8]. When irrigation scale is larger, such as parks and recreational areas, system might necessitate usage of storage tanks, which in turn might lower the water quality [45]. In such cases, storage tank should be designed considering the seasonal changes. In this step, for irrigational reuse of grey water combined with rainwater harvesting, the rain trends and climate should also be regarded.

When grey water reuse for toilet flushing is the case, Gross and others [8] mentioned about engineering challenges to prevent cross-connections between the potable water and treated greywater feed to toilet reservoirs. A widely utilized method, which involves directing grey water from hand wash basin to the reservoir, can remedy this issue. Such setups known as "Greywater Toilet Systems" are readily available [46] on market.

Some other possible end-use purposes could be find under Chapter 2.4, where quality criteria for water reuse specifically discussed in terms of reuse areas.

2.4 Reuse Standards and Guidelines

As a result of increasing water demand for alternative water sources, several international institutions and different countries publish guidelines or regulations on water reuse. While some of these standards is related to general reuse of domestic wastewater, some others address directly reclamation of grey water. As given in Appendix B1, which is a complete list of these guidelines for both wastewater and grey water reuse depending on the regions, some states in USA have the very first examples of standards covering grey water reuse such as South Dakota, Washington, and Florida. Together with US Environmental Protection Agency (USEPA), great majority of the states have their own standards that includes grey water reuse for different purposes like toilet flush, irrigation, firefighting, urban cleaning, or cooling. Likewise, each state of Australia also publish their own codes and guidelines that makes Australia one of the leader countries in grey water reclamation.

Evaluating the existing standards all over the world, most of them published in the regions suffering from water scarcity or stress such as Singapore, Israel, and Jordan. Singapore has the most clear criteria for grey water reuse around the world that covers general washing, cooling tower, toilet flush, and irrigation. While Israel applies quality criteria determined based on British Standards, there are some limits mostly about the microbiological quality in Jordan published by World Health Organization [47].

Around Europe, Germany is the initiator country specifically for grey water reuse criteria, followed by United Kingdom with specific code of practices on grey water systems. There other countries in Europe with wastewater reclamation standards that might be considered in the absence of grey water reclamation guidelines or regulations; such as Spain, Portugal, France, Italy, and Greece. In addition to these, China, Japan, Korea, Saudi Arabia, Brazil, Cyprus, and just a few of the States also have quality limits for wastewater reuse like T.R.; where the wastewater reuse standards address specifically irrigational purposes given in Technical Procedure Communication for Wastewater Treatment Plants determined by Ministry of Environment and Forestry (now named as Ministry of Environment and Urbanization) [48].

2.4.1 Criteria for toilet flush

Among all areas of reuse for grey water, toilet flush is the most common end-use option that has quality criteria defined by almost 40 guidelines, where 28 of those for grey water and 11 for wastewater. As shown in Appendix B2, most of grey water quality limits given for toilet flush are defined by USA and Australia. There is also a specific guideline for reclaimed grey water use in toilet and urinal flushing, even there is no other regulation or guideline for other end use options. The toilet flushing standards and guidelines (for grey water) are mostly about the organic matter content, total suspended solid and turbidity, microbiological quality, and accordingly residual chlorine. However, odor and color is also limited in Singapore, which is supposed to be under 15 HU. Unlike the others, two states of USA, Massachusetts and Washington, have limit of 10 mg/L for total nitrogen concentration in treated grey water.

In Table 2.7, min and max values are given for all parameters limited by grey water and wastewater guidelines. Additionally regulations all over the world and a full list of toilet flushing criteria based on region are given in Appendix B2. In the view of this information, BOD concentration should be at least 30 mg/L (by Nevada and New Mexico, USA) for grey water while it is defined as max 20 mg/L for wastewater (Florida, USA). However, most of the guidelines restricted BOD concentration in grey water with 10 mg/L and to meet the tightest requirements it should be lower than 5 mg/L.

Similarly, TSS concentration in both grey and wastewater is commonly determined as 10 mg/L, however the tightest limit is reported as 5 mg/L for grey water, and in some cases weekly and monthly averages are also required. Contrary to expectations, maximum turbidity criteria reported is higher for grey water reuse, in comparison with wastewater. Another unexpected point, there is no total nitrogen limits for wastewater reuse, while it is stated as 10 mg/L for grey water. There are also other additional chemical parameters (Fe, Mn, and detergents) restricted in wastewater, while there is no criteria for grey water reuse in toilet flushes.

In terms of microbiological quality, the max single sample limits given for grey water is unexpectedly higher than the ones reported wastewater as shown more in detail in Appendix B2.

Table 2.7: Reclaimed water quality criteria for toilet flushing.

Parameter	Units	Grey Water		Wastewater	
		Min	Max	Min	Max
Odor		Non (1)		Non (1)	
pH		5 (2)	9.5 (2)	5.5 (2)	9 (3) (4)
Color	*HU*	15 (1)		30 (5)	
Turbidity	*NTU*	1 (3)	20 (4)	2 (3) (6) (4) (7)	10 (8)
Residual Cl	*mg/L*	0.1 (5)	4 (5) (6)	0.1 (4)	2 (7)
BOD (max single sample)	*mg/L*	5 (1) (7) (8)	30 (9) (10)	5 (10)	20 (11)
BOD (7d mean)	*mg/L*			15 (9)	
BOD (30d mean)	*mg/L*			10 (9)	
TSS (max single sample)	*mg/L*	5 (5) (7) (11)	30 (10) (12) (13)	10 (6) (7) (11)	
TSS (7d mean)	*mg/L*			15 (9)	
TSS (30d mean)	*mg/L*	10 (12)		5 (11)	10 (9)
TOC	*mg/L*	1 (7)		5 (11)	
T.N	*mg/L*	10 (7) (11)			
NH_4-N	*mg/L*			10 (5)	
T.N	*mg/L*			10 (5)	12 (11)
TDS	*mg/L*			1500 (5)	
Detergents	*mg/L*			1 (5)	
Fe	*mg/L*			0.3 (5)	
Mn	*mg/L*			0.1 (5)	
T. Coliform (max single sample)	*cfu/100 mL*	2.2 (14)	1000 (2)	10 (1) (4)	
T. Coliform (7d mean)	*cfu/100 mL*	2.2 (7)			
T. Coliform (30d mean)	*cfu/100 mL*	2.2 (15)			
E.Coli (max single sample)	*cfu/100 mL*	0 (1)	200 (12) (16)	0 (4) (6)	75 (10)
E.Coli (30d mean)	*cfu/100 mL*	0 (16)	2.2 (12)	20 (10)	
E.Coli (1y mean)	*cfu/100 mL*	1 (3) (17)			

Table 2.7 (continued): Reclaimed water quality criteria for toilet flushing.

Parameter	Units	Grey Water Min	Grey Water Max	Wastewater Min	Wastewater Max
Faecal Coli. (max single sample)	*cfu/100 mL*	10 (8) (18)	400 (19)	3 (5)	500 (8)
Faecal Coli. (7d mean)	*cfu/100 mL*	0 (11)	2.2 (20)	2.2 (9)	
Faecal Coli. (30d mean)	*cfu/100 mL*	23 (20)		0 (3)	20 (10)
Faecal Coli. (1y mean)	*cfu/100 mL*	100 (19)			
Enterococci (max single sample)	*cfu/100 mL*			4 (10)	
Intestinal Nematodes	*egg/10 L*			1 (6) (9)	
Thermotolerant Coli.	*cfu/100 mL*	10 (3)	200 (16)	10 (2)	
Coliphages	*pfu/100mL*	1 (17)		1 (7)	
Clostridia	*cfu/100mL*	2 (17)		1 (7)	

(1) Singapore; (2) United Kingdom; (3) Queensland, Australia; (4) Israel; (5) Wisconsin, USA; (6) Colorado, USA; (7) Washington, USA; (8) Germany; (9) Nevada, USA; (10) New Mexico, USA; (11) Massachusetts, USA; (12) Texas, USA (13) New South Wales, Australia; (14) Oregon, USA; (15) California, USA; (16) Canada; (17) Northern Territory, Australia; (18) Jordan; (19) Israel; (20) Hawaii, USA

(1) Korea; (2) Tasmania, Australia; (3) EPA; (4) Japan; (5) China; (6) Spain; (7) Western Australia, Australia; (8) Brazil; (9) Saudi Arabia; (10) Texas, USA; (11) Florida, USA

2.4.2 Criteria for irrigation

In terms of guidelines and regulations, irrigation is the one of the most popular area of reuse after toilet flushing. Even the quality criteria for different type of irrigation defined by more than 40 different guidelines, almost half of those are determined for irrigational reuse of wastewater. As shown in Appendix B1 and B2, most of grey water quality limits for any type of irrigational reuse are defined by USA, Australia, Singapore, Israel, Jordan, followed by Germany and United Kingdom in Europe. These quality criteria is listed under two main groups which are generally landscape and agricultural irrigation. Irrigation of green areas is later examined in subgroups according to the possibility of human contact (unrestricted, restricted areas) or method of irrigation (subsurface, drip, sprinklers, etc.). The quality criteria is generally defined in terms of BOD, TSS, turbidity, and microbiological parameters for grey water, while TDS is also limited in reclaimed wastewater in four different countries including T.R.

The Turkish Technical Procedure Communication for Wastewater Treatment Plants [48] is the only standard that mentions wastewater reclamation only for irrigational purposes, while there is no other quality criteria specifically on grey water. In comparison with all irrigational standards given in Appendix B2, the scope of this procedure is pretty wider as it covers additional parameters such as sodium adsorption ratio (SAR), heavy metals and toxic elements and irrigation periods as shown in Table 2.8.

BOD concertation required for urban irrigation in T.R. (20 mg/L) is higher in comparison with other wastewater reuse standards, which generally ranges between 5 – 10 mg/L. While standard limits for TSS and turbidity are in line with other criteria for wastewater; TDS limit is the tightest among all four values reported by other countries. Similarly for the only microbiological parameter, faecal coliform concentration is pretty lower than most of the other limits.

Table 2.8: Reclaimed wastewater quality criteria for irrigation in T.R.

<table>
<tr><th></th><th>pH</th><th>BOD
mg/L</th><th>Turb. *
NTU</th><th>TSS
mg/L</th><th>Faecal Coliform
cfu/100mL</th><th>H_2S
mg/L</th><th>Residual Chlorine
mg/L</th><th>Cl
mg/L</th><th>Cond.
us/cm</th><th>TDS
mg/L</th><th>Na
mg/L</th><th>B
mg/L</th></tr>
<tr><td>Urban irrigation</td><td>6-9</td><td>20</td><td>2</td><td></td><td>14</td><td></td><td>>1</td><td></td><td rowspan="8">700</td><td rowspan="8">500</td><td></td><td rowspan="8">0.7</td></tr>
<tr><td>Agricultural irrigation
(raw-edible food stuff)</td><td>6-9</td><td>20</td><td>2</td><td></td><td>14</td><td></td><td>>1</td><td></td><td></td></tr>
<tr><td>Agricultural irrigation
(processed food stuff, industrial plants)</td><td>6-9</td><td>30</td><td></td><td>30</td><td>800</td><td></td><td>>1</td><td></td><td></td></tr>
<tr><td>Irrigation of limited contact areas.</td><td>6-9</td><td>30</td><td></td><td>30</td><td>800</td><td></td><td>>1</td><td></td><td></td></tr>
<tr><td>Surface irrigation</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>140</td><td>3</td></tr>
<tr><td>Drip irrigation</td><td>7</td><td></td><td></td><td>50</td><td></td><td>0.5</td><td>>0.5</td><td>100</td><td>70</td></tr>
<tr><td>Sprinklers</td><td></td><td></td><td></td><td>30</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Distribution system</td><td></td><td></td><td></td><td></td><td></td><td></td><td>>0.5</td><td></td><td></td></tr>
</table>

	Al mg/L	As mg/L	Be mg/L	Cd mg/L	Cr mg/L	Co mg/L	Cu mg/L	F mg/L	Fe** mg/L	Pb mg/L
Continuous irrigation	5	0.2	0.1	0.01	0.1	0.05	0.2	1	5	5
Duration: <24 years; soil pH: 6,0-8,5	20	2	0.5	0.05	1	5	5	15	20	10

**Recommended: 5 NTU, ** Drip irrigation Fe: 0.1 mg/L*

2.4.3 Criteria for cooling

In comparison to toilet flushing and irrigation, reuse of grey water for cooling is not a prevalent end-use since there is 16 standards currently available. While nine of these quality criteria defined for grey water and the rest is determined for wastewater reuse. As shown in Appendix B1 and B2, all of grey water quality limits given for cooling purposes are defined by USA, Australia, and Singapore. Except couple of states from USA, Spain is the only country that published standard limits for wastewater reuse on cooling.

The cooling standards and guidelines (for grey water) are mostly about the organic matter content, total suspended solid and turbidity, and microbiological quality in the case of aerosol generation. However, odor and color is only limited in Singapore, which is supposed to be under 15 HU. Unlike the others, two states of USA, Massachusetts and Washington, have limit of 10 mg/L for total nitrogen concentration in treated grey water, while unexpectedly there is no total nitrogen limits for wastewater reuse.

In Table 2.9, min and max values are given for all parameters limited by grey water and wastewater guidelines. Additionally regulations all over the world and a full list of cooling criteria based on region are given in Appendix B2.

In the light of this information, it is stated that microbiological quality requirement should be determined depending on the type of cooling systems. In the example of Washington State given in Appendix B2, total coliform concentration goes down to 23 cfu/100 mL if aerosol generation happens to be the case, while the limit is as high as 240 cfu/100 mL for cooling systems without aerosols.

Table 2.9: Reclaimed water quality criteria for cooling.

Parameters	Units	Grey Water Min	Grey Water Max	Wastewater Min	Wastewater Max
Odor		Non [1]			
pH		6 [1] [2]	9 [1] [2]	5.5 [1]	9 [2] [3] [4]
Color	*HU*	15 [1]			
Turbidity	*NTU*	2 [1] [3] [4] [5]	10 [7]	1 [3]	5 [5]
Residual Cl	*mg/L*	0.2 [6]	10 [2]	0.2 [5]	2 [5]
BOD	*mg/L*	5 [1] [5]	50 [2]	5 [4]	80 [1]
TSS	*mg/L*	5 [4] [5]	30 [2] [6]	5 [3] [4]	30 [2] [5]
TOC	*mg/L*	1 [5]			
T.N	*mg/L*	10 [4] [5]			
T. Coliform (max single sample)	*cfu/100 mL*	10 [1]	240 [5]		
T. Coliform (7d mean)	*cfu/100 mL*	2.2 [8]	23 [5]		
E.Coli (max single sample)	*cfu/100 mL*	0 [1]		0 [3]	800 [6]
E.Coli (30d mean)	*cfu/100 mL*			200 [6]	
E.Coli (1y mean)	*cfu/100 mL*	10 [6]			
Faecal Coliform (max single sample)	*cfu/100 mL*	14 [4]	200 [7]	100 [4]	800 [6]
Faecal Coli. (30d mean)	*cfu/100 mL*	23 [7]		23 [4]	200 [2] [6]
Faecal Coli. (7d mean)	*cfu/100 mL*	0 [4]	2.2 [7]	46 [4]	
Enterococci (max single sample)	*cfu/100 mL*			89 [6]	
Enterococci (30d mean)	*cfu/100 mL*			35 [6]	
T.Legionella	*cfu/L*	1,000 [1]			
Thermotolerant Coliforms	*cfu/100 mL*			10,000 [1]	
Intestinal Nematodes	*egg/10 L*			1 [3]	
		[1] Singapore; [2] Wisconsin, USA; [3] California, USA; [4] Massachusetts, USA; [5] Washington, USA; [6] Northern Territory, Australia; [7] Hawaii, USA; [8] Oregon, USA		*[1] Tasmania, Australia; [2] EPA; [3] Spain; [4] Georgia, USA; [5] Western Australia, Australia; [6] Texas, USA*	

2.4.4 Criteria for car wash

As one of the rare end-use areas of grey water or wastewater, quality criteria for car wash is determined in 16 different locations where more than half of them are specifically for grey water. As shown in Appendix B1 and B2, great majority of grey water quality limits given for this purpose is defined by USA and Australia. On top of these two expectable locations, United Kingdom and Jordan define limits.

While the grey water standards and guidelines set limits for the organic matter content, total suspended solid and turbidity, and microbiological quality like the other reuse areas; it is completely prohibited to utilize reclaimed grey water for car wash in Victoria, Australia.

A full list of car wash criteria (for both grey water and wastewater) based on region are given in Appendix B2. Additionally, min and max values are represented for all parameters limited by grey water in Table 2.10. As is seen, BOD concentration restricted as 10 mg/L by all the regions where standards are currently available.

Table 2.10: Reclaimed grey water quality criteria for car wash.

Parameters	Units	Min	Max
pH		5 (1)	9.5 (1)
Turbidity	*NTU*	1 (2)	10 (1)
Residual Cl	*mg/L*	0.2 (2)	10 (3)
BOD	*mg/L*	10 (2) (4) (5) (6) (7)	
TSS	*mg/L*	5 (5) (6)	10 (2) (4) (7)
T.N	*mg/L*	10 (5)	
T. Coliform (max single sample)	*cfu/100 mL*	10 (1)	23 (4) (8)
T. Coliform (7d mean)	*cfu/100 mL*	2.2 (4)	
E. Coli (max single sample)	*cfu/100 mL*	10 (2)	
E. Coli (1y mean)	*cfu/100 mL*	1 (2)	
Faecal Coli. (max single sample)	*cfu/100 mL*	10 (7)	23 (9)
Faecal Coli. (7d mean)	*cfu/100 mL*	0 (5)	
Thermotolerant Coliforms	*cfu/100 mL*	1 (2)	

(1) United Kingdom; (2) Queensland, Australia; (3) Wisconsin, USA; (4) Oregon, USA; (5) Massachusetts, USA; (6) Wisconsin, USA; (7) Jordan; (8) California, USA; (9) Arizona, USA

Similarly, most of the TSS concentration requirements are in line with each other, where it usually reported as 10 mg/L in most cases and 5 mg/L by two of the standards.

2.4.5 Criteria for urban cleaning

Likewise car wash, urban cleaning (which mainly refers to street cleaning) is not a wide-spread end-use in terms of grey water or wastewater reuse standards as it is only mentioned in the standards by several states in USA such as Washington, Oregon, Hawaii, Arizona, and Massachusetts.

Grey water quality standards for urban cleaning are most likely about the organic matter content, total suspended solid, and microbiological quality. As shown in detail in Appendix B2, Washington State has different limits for street sweeping and spray washing of streets. Spray washing requires tighter limits which is 5 mg/L for both BOD and TSS concentrations, while there is no BOD, TSS, and turbidity limits for street sweeping. The maximum BOD concentration requirement is determined by Massachusetts with 30 mg/L.

While Oregon and Washington States set limits for total coliform which is 23 cfu/100 mL for both; Hawaii, Arizona and Massachusetts measures microbial quality with faecal coliform which ranges between 100-800 cfu/100 mL for a single sample.

3. CURRENT WASTEWATER MANAGEMENT SYSTEM IN TURKISH REPUBLIC

Similar to all developing countries, consumption rate of natural resources, especially fresh water reserves, is increasing in Turkish Republic (T.R.) as a result of growing population and urbanization. However, Ministry of Environment and Urbanization stated that 36% of 112 billion m^3 of total water reserve in T.R. is available to be utilized. While 16% (7 billion m^3) of total water consumption (44 billion m^3) is consumed for potable purposes, 11% (5 billion m^3) is used in industrial facilities and the rest (73%, 32 billion m^3) for irrigation [49].

3.1 Conventional Wastewater Management

Conventional wastewater management consists of combined or separate sewer systems and a combination of physical, chemical, and biological operations to remove basically solids, organic matter, and nutrients from wastewater [50]. Combined sewer system is large pipe networks that convey domestic sewerage, industrial wastewater and storm water run-off in the same pipe to treatment facilities. While rain water is collected together with urban wastewater in combined systems, separate sewer systems are designed to convey wastewater and surface run-off in different pipe networks as illustrated in Figure 3.1. In separated systems, storm water, which is less polluted in comparison with wastewater, is discharged into the receiving environment without any treatment operation. Also without any pumps, rain water flow to receiving bodies is driven by gravity. Considering these two aspects of separate systems, pumping and treatment cost of urban wastewater decreases as wastewater becomes denser in smaller volumes. Similarly, investment cost of wastewater treatment facilities reduces as they receive only wastewater instead of an influent that contains surface water run-off [51].

Recently in T.R., sewer systems are being built as separate systems. However, some of the previously built combined sewerage networks are still in use. This is because the investments for sewerage networks started in 1970s and focused on city centers at the beginning and extended to smaller residential areas afterwards. [52] Due to the fact that many provinces in T.R. are still served by combined network, great number of treatment plant are receiving diluted wastewater which leads to higher energy consumption and lower biological growth rate [51].

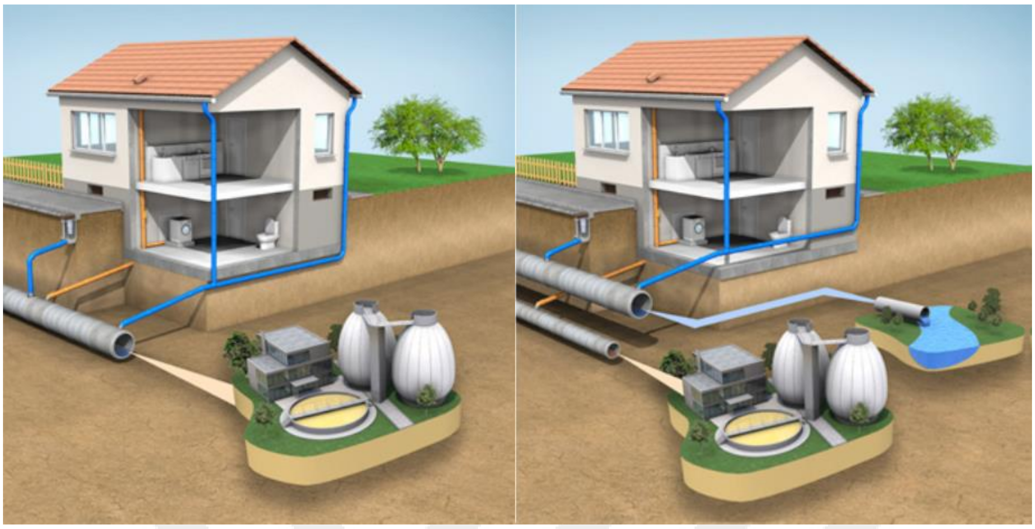

Figure 3.1: Combined and separate sewer systems. [51]

Figure 3.2 shows that the population receives sewerage services (no matter if combined or separate) was 69% of municipal population in 1994, while it reached up to 90% in 2014. The decline between 2012 and 2014 is explained by Ministry of Environment and Urbanization that some smaller municipalities were village/neighborhood status Municipality Law numbered 6360. [49]

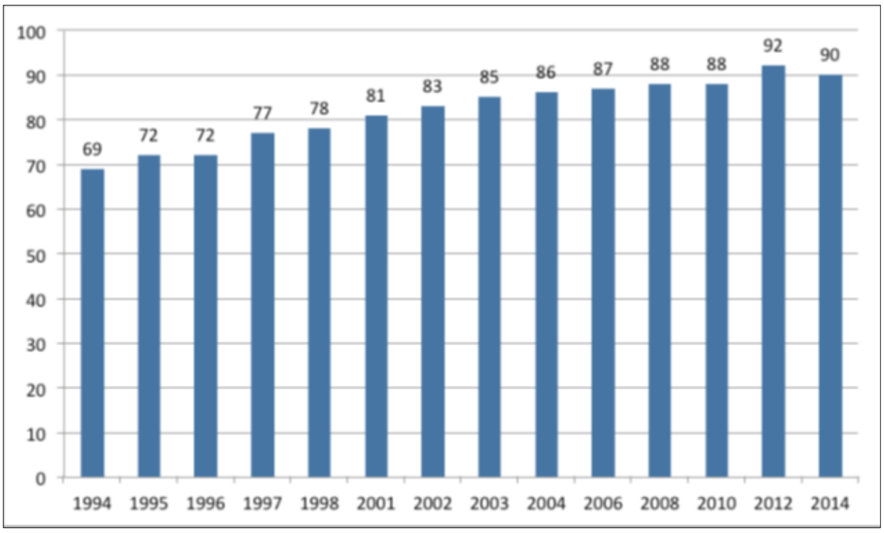

Figure 3.2: % Population served with a sewerage system in T.R. [49]

Similarly Figure 3.3 represents that only 13% of population in T.R. received wastewater treatment services in 1994, while this percentage raised up to 68% in 2014 [49].

According to the Wastewater Treatment Plant Inventory published by Ministry of Environment and Urbanization in February 2017, there are 919 municipal wastewater treatment plants in T.R. [53]. The capacities of these facilities are ranging between 50 - 971,136 m^3/d [51].

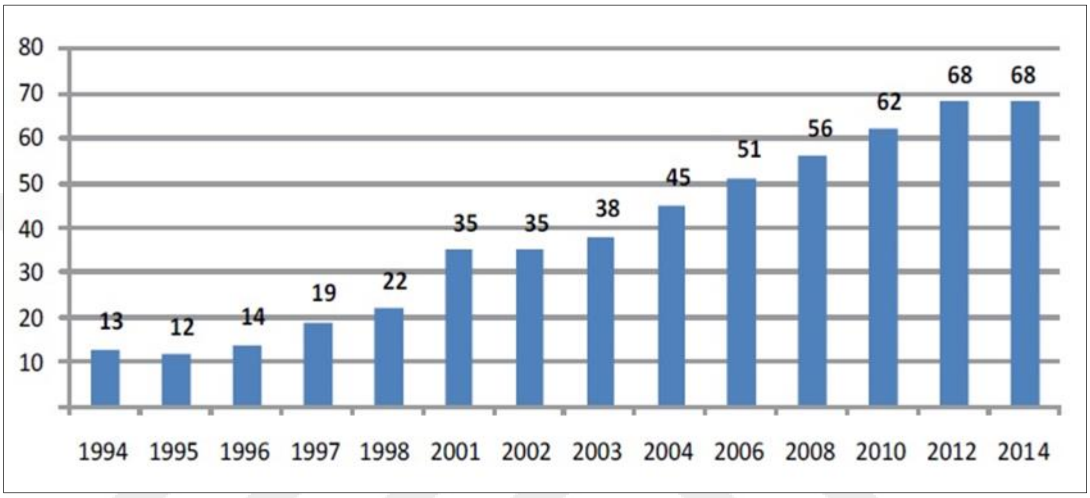

Figure 3.3: % Population served with a treatment system in T.R. [49]

As given in Figure 3.4, 11% of existing plant have advanced treatment, while great majority of facilities (48%) have secondary treatment which refers to the systems composed of coarse grid, pump station, fine grid, oil and sand catcher, primary sedimentation tank, aeration tank, and clarifiers. Modular treatment plants that covers 13% are preferred in remote and comparatively smaller locations, while natural treatment (19%) is applied in case that the climatic conditions are suitable.

In recent years, advanced biological treatment plants became widespread, as wastewater reclamation is gaining popularity. The processes that is able to eliminate nutrient is preferred for the facilities constructed after 2005 [52]. For reclamation, sand filter and disinfection units are commonly combined to advanced biological processes after secondary sedimentation tanks. The details of wastewater reclamation in Turkish Republic is mentioned in Chapter 3.2.

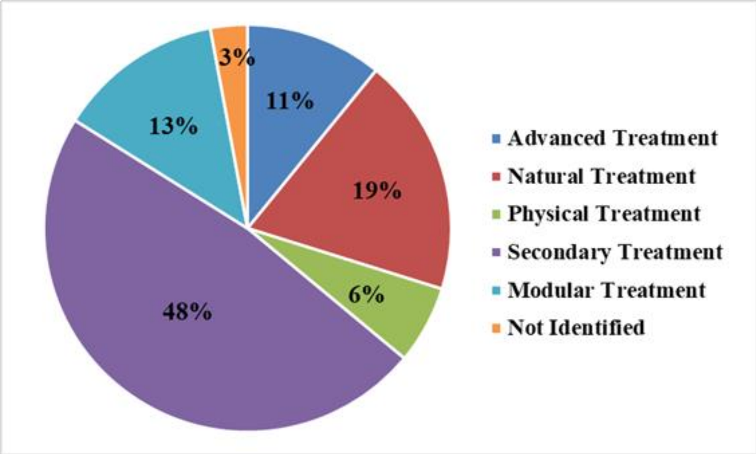

Figure 3.4: % Distribution of treatment methods in T.R.
(Based on [53])

3.2 Wastewater Reclamation

As a result of growing water demand and difficulty of reaching fresh water resources, sustainable management of water and interests in alternative water sources have increased all over the world, as well as in T.R. Wastewater and its segregated streams/sub-streams are considered as one of those alternative water sources which encourages the development of new technologies and applications of secure reuse practices. In terms of water recycling, domestic wastewater reclamation is generally applied on a large scale in centralized systems, while industrial wastewater and grey water recycling are commonly applied on a comparatively smaller scale in localized/decentralized systems.

3.2.1 Conventional wastewater reclamation

Considering T.R. as a country under water stress, it is significant to recycle and reuse wastewater for conservation of fresh water resources. Recently, 126,400 m^3/d wastewater is reclaimed out of 10,453,315 m^3 overall in T.R. While this volume refers to 1.2% of wastewater treated in T.R., this ratio is around 2.4% in Europe, 19% in Australia, and as high as 70% in Israel [54]. As it is shown in Figure 3.5, wastewater is reclaimed by 55 wastewater treatment plants (out of 919 in total) located in 19 provinces of T.R. Most of this centralized systems are operated in Kocaeli, which will be mentioned more in detail in Chapter 3.3. Out of 55 reclamation units operated, three highest capacity plants are Istanbul Pasakoy WWTP with 84,000 m^3/d, Kocaeli Dilovasi WWTP with 40,000 m^3/d, Afyon Sandikli WWTP with 7,000 m^3/d [54] [3].

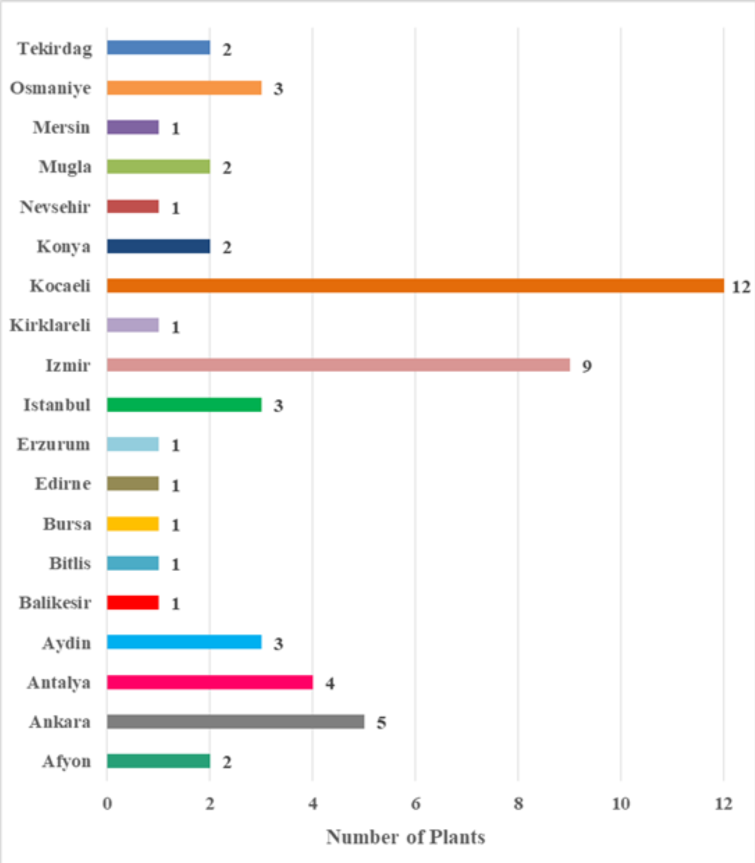

Figure 3.5: Number of wastewater treatment plants with reclamation units in T.R. (Based on [3] and [54])

Wastewater reuse applications are generally materialized by public sector by the adoption of centralized reclamation units after conventional treatment. The reclamation units are located following secondary sedimentation tanks, which are usually consisting of sand filter, UV disinfection, and chlorination as given in Figure 3.6. After treatment, 84% of treated wastewater is reused for irrigation of green areas, 4% is utilized for agricultural irrigation and 12% for industrial purposes [54]. As around 72% of water in T.R. is utilized for irrigational purposes, treated wastewater is primarily revaluated in order to prevent consumption of available fresh water resources [49].

Wastewater recycling is not only beneficial in terms of environmental sustainability, but also financial feasibility. Wastewater reclamation could be feasible in the regions such as Marmara, where water expenses are higher for the industrial facilities in comparison with households [49]. Industrial wastewater reclamation could be implemented in two ways; reclamation of industrial wastewater by organized industrial zones or reuse of reclaimed domestic wastewater in industrial processes. Bursa and Izmir Tekeli organized industrial zones are posing examples of good practices of industrial wastewater reclamation. While 8,000 m^3/d industrial wastewater is treated via MBR system in Izmir Tekeli OIZ, RO system with the capacity of 50,000 m^3/d is used in Bursa OIZ [55]. Kocaeli, as discussed in Chapter 3.3, is one of the examples of practices for domestic wastewater reclamation for industrial purposes.

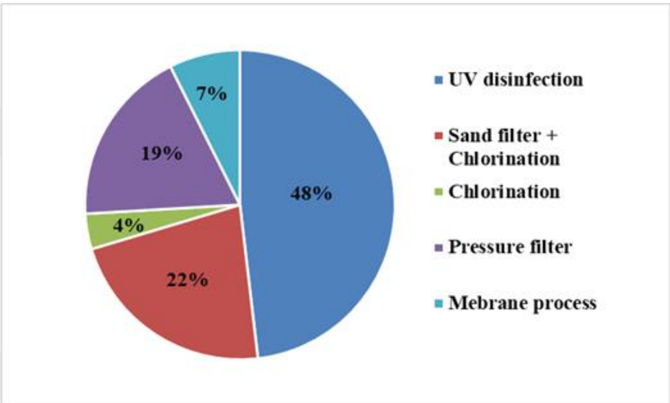

Figure 3.6: Treatment processes applied in wastewater reclamation in T.R. [54]

In Aegean and Mediterranean Regions of T.R., where tourism oriented water consumption is pretty high, reuse of domestic wastewater became common for irrigation of landscape areas around the hotels. In this context, the "Project for Determining Bathing Water Profiles on the Coasts of Turkey" is carried out by TUBITAK. Within the scope of the project, a research was conducted on recycling of wastewater and rain water from selected tourism facilities [49].

3.2.2 Grey water reclamation

Grey water reclamation is significant, since it enables the reuse of up to 75% of domestic wastewater by volume. Although it contributes to sustainability of water management, the number of the practices in T.R. is so limited. Starting in 2000s, green buildings started to emerge, mostly as LEED compliant projects; a US certification program that focuses primarily on sustainability of new, building projects, where points are awarded for factors such as sustainability, materials used, energy, and water efficiency as given Table 3.1. Based on the scoring chart given by US Green Building Council [56], water related points could be gained from the criteria depending on rain water management, water use reduction, water metering, and cooling water use, which is equal to 14 points out of 110 possible points in total.

Table 3.1: Scoring of LEED certificate. (Based on [56])

Criteria	Possible Points
Integrative process	1
Location, transportation	16
Sustainable sites	10
Rainwater management	*3*
Water efficiency	11
Outdoor water use reduction	*required*
Indoor water use reduction	*required*
Building level water metering	*required*
Outdoor water use reduction	*2*
Indoor water use reduction	*6*
Cooling tower water use	*2*
Water metering	*1*
Energy, atmosphere	33
Material, resources	13
Indoor environmental quality	16
Innovation	6
Regional priorities	4
TOTAL	**110**
Water related points	***14***
(Possible) grey water related points	***10***

Eliminating the criteria related to water metering and rainwater management, 9% of total possible score (110) could possibly be gained by grey water reuse, meeting the criteria including water use reduction, and cooling water use.

As of November 2017, around T.R., there are 236 LEED certified projects, most of which are situated in the population-dense cities such as Istanbul and Ankara [57]. It has to be noted that a building having LEED certification does not imply a grey water system, it only encompasses attributes such as usage of innovative water technologies related to criteria given in Table 3.1. For certain applications that addresses grey water reuse are far more limited and for the most part applied in small scale, centralized systems. Most of grey water systems in T.R. are reported by Oructut [12] as shown in Table 3.2. and they mostly route grey water from hand wash basins and shower/bathtubs to flush reservoirs and landscape irrigation after treatment are more popular in household, office, and hotel projects in T.R.

Table 3.2: Grey water reclamation in T.R.

Project	Province	Greywater Source	Capacity (m^3/d)	Treatment Method	End-use Purpose
Dorm					
Develi Dormitories*	Kayseri	SH/BT, WB	30	MBR	IR, TF
Aysel-Abdullah Ogutucu Dorm**	Istanbul			MBR	TF
Mersin State Dormitory*	Mersin	SH/BT, WB	280	-	IR, TF
Industrial facilities					
TEI TUSAS Factory*	Eskisehir	SH/BT, WB	8.5	MBR	IR, TF
Hotel					
Taksim Peradys Hotel*	Istanbul	SH/BT, WB	1.5	MBR	TF
Polat Renaissance*	Istanbul	SH/BT, WB	17	MBR	TF
Istanbul Hilton Hotel*	Istanbul	SH/BT, WB	75	MBR	IR, TF
Bostanci Dedeman Hotel*	Istanbul	SH/BT, WB	45	Filt. & UF	IR, TF, CT
Gokceada Surf Training Center & Hotel***	Canakkale	SH/BT, WB		MBR	IR, TF
Levent Dedeman Hotel***	Istanbul	SH/BT, WB	30	Filt. & UF	IR, TF
Ozdilek Center***	Istanbul	SH/BT, WB	-	-	TF
Household					
Anthill Housing Complex*	Istanbul	SH/BT, WB	105	MBR	TF
Sinpas Antepia-1. Etap*	Gaziantep	SH/BT, WB	118	MBR	OP
AnkaNatura*	Ankara	SH/BT, WB	25	MBR	IR, TF
Zorlu Center*	Istanbul	SH/BT, WB	250	MBR	IR
Milpark Homes*	Istanbul	SH/BT, WB	60	MBR	TF
Yeni Hayat Homes*	Istanbul	SH/BT, WB	35	MBR	IR, TF
Astay Onalti Dokuz*	Istanbul	SH/BT, WB, SN	70	MBR	TF
Antteras***	Istanbul	-	-	-	TF
Aeropark Project*	Istanbul	SH/BT, WB	8.5	MBR	TF
Gulnar Koru Homes***	Istanbul	SH/BT, WB	-	-	IR, TF
Varyap Meridian*	Istanbul	SH/BT, WB	45	MBR	IR, TF
Urban Reneval Project in Kadikoy	Istanbul	SH/BT, WB	Applicable to plots with over 200 households		
Mistral Izmir***	Izmir	-	-	-	-
Office					
Eser Green Building*	Ankara	SH/BT, WB	8.5	MBR	TF
Atasehir Municipality Building Complex*	Istanbul	SH/BT, WB	3.5	Filt. & UF	TF
Zorlu Levent Plaza*	Istanbul	SH/BT, WB	45	Filt. & UF	TF
Özdilek Plaza*	Istanbul	SH/BT, WB	20	-	TF
AND Kozyatağı Office Tower***	Istanbul	WB	-	-	IR

Table 3.2 (continued): Grey water reclamation in T.R.

Project	Province	Greywater Source	Capacity (m^3/d)	Treatment Method	End-use Purpose
Office					
Kuveyttürk Banking Headquarters*	Gebze	SH/BT, WB	22	-	TF
Habom Project*	Istanbul	SH/BT, WB	50	-	IR, TF
Albaraka Türk Headquarters***	Istanbul	WB	-	-	TF
Prokon-Ekon Headquarters***	Istanbul	-	240	-	-
KOY Project Sales Office***	Istanbul	-	-	-	TF
Kucukcekmece Municipality Building***	Istanbul	SH/BT, WB	-	-	TF
Shopping mall					
ESAS 41 Burda***	Kocaeli	-	-	-	OP
Sport complex					
Atasehir Sporium***	Istanbul	-	80	-	-
Sivas Stadium***	Sivas	-	-	-	IR, TF
Eskisehir Tepebasi Municipality Water Sports Center***	Eskisehir	SH/BT, WB	-	-	IR
Orhangazi Convention, Education & Sports Center***	Bursa	SH/BT, WB	-	-	IR, TF
University, school					
Ozyegin University*	Istanbul	SH/BT, WB	60	Filt. & UF	TF
Piri Reis University*	Istanbul	SH/BT, WB	60	-	IR, TF
IELEV-125.Yıl Elementary School*	Istanbul	SN	10	MBR	IR
Other					
Nish Istanbul*	Istanbul	SH/BT, WB	150	-	IR
Mosque*	Ankara	Ablution	13	MBR	TF
Gunesev*	Antalya	SN	0.8	MBR	IR

Adopted from [12]; **Adopted from [9]; * Adopted from [58]*
Sources; SH/BT: Shower/Bathtub, WB: Wash basin, SN: kitchen sink
End-Use; IR: Landscape irrigation, TF: Toilet flushing, OP: Ornamental pond, CT: Cooling tower

Sustainable Urban Renewal (Super City System) Project

With the cooperation between Istanbul Technical University and Ministry of Environment and Urbanization, the protocol of "Cooperation for Rehabilitation of Urban Areas under Disaster Risk" was signed in 2016, which includes greywater reuse in a concept called "Super City System" that is going to be implemented initially at Kocakir district of Eskisehir, with the highest emphasis on sustainability. Four more pilot areas to be designated by the ministry after evaluating parameters such as location, size of the area and the population [59].

Urban Renewal of Fikirtepe Kadikoy

Before the protocol of Cooperation for Rehabilitation of Urban Areas under Disaster Risk between the Ministry of Environment and Urbanization and Istanbul Technical University, only Urban Renewal project with grey water system implementation was Fikirtepe.

In accordance to a report "Determining Requirements for Ecologically Conscious Sustainable Residential Areas" published by Kadikoy Municipality, source separation, treatment and reuse of greywater from shower and washbasins were required for 200 and higher as well as business only areas that are at least 10.000 m^2 with council decision 2012/55 of 09.05.2012 and Istanbul Metropolitan Municipality council decision 2012/1592 of 11.09.2012. Firefighting, flush reservoirs, landscaping, car washing are some of the anticipated reuse scenarios [60].

Zorlu Center Istanbul

With flow rate of 250 m^3/d Zorlu Center has the highest flow rate of grey water for housings complexes. A total of 584 dwellings are fitted with dual piping for grey water collection, which will be treated and used for landscape irrigation. Following the installation, on some flats, grey water is combined with kitchen sinks, which necessitated the installation of oil catchers.

Initially, grey water is treated by a diffusor aerated MBR system, followed by ultrafiltration while still being aerated, in order to reduce sludge cake accumulation on the ultrafiltration plates. Additionally, treatment system and treated greywater storage tank is separated from each other with distance of 50 cm to prevent contamination [12].

Istanbul Hilton Hotel

With the help of a submerged MBR system, approximately 75 m^3 of shower and hand wash basin acquired greywater with design BOD of 200 mg/L, COD of 400 mg/L and SS of 70 mg/L is treated to BOD less than 10 mg/L and SS less than 5 mg/L and used for landscaping and flush reservoirs [61].

3.3 Current Situation in Kocaeli

Kocaeli is a province of Turkish Republic located at the east of Marmara Sea, around Izmit Gulf. Kocaeli, with the surface area of 3,505 km^2, has borders to Istanbul and

Marmara Sea on the west, Black Sea on the north, Sakarya on the east, Bursa on the south and Yalova on the southwest [62]. Kocaeli Province is divided into 12 districts (Darica, Cayirova, Gebze, Dilovasi, Korfez, Derince, Kandira, Izmit, Kartepe, Basiskele, Golcuk, and Karamursel) with the capital district of Izmit as illustrated in Figure 3.7.

Figure 3.7: Districts of Kocaeli.

According to population count in 2016 with a total population of 1,830,772, Kocaeli is one the most populated provinces in Marmara Region [63]. Since the metropolitan area of Istanbul extends to the Kocaeli-Istanbul border and the Bay of Izmit allows for port facilities, most of the industrial plants are located here in Kocaeli. As the city hosts 13% of manufacturing industry in Turkish Republic, in terms of water consumption, industrial entities have the highest portion around 30% of total consumption in the province [3] [64]. As given in Table 3.3, 11% of this total consumption is met from municipal supply (potable water), the rest comes from wells and reclaimed wastewater equally [3]. Consumption profile also shows a distribution of 3% for landscaping and the remaining mainly for domestic use by homes, offices and small and medium size enterprises [3, 4]. %17 (≈22 million m^3/year or ≈60,000

m^3/d) of all domestic usage (≈88 million m^3/year or ≈240,000 m^3/d) accounts for flush water [3, 65]. When the data provided above considered, it addresses that around 50% of potable water is being used by various industrial establishments, for public or private landscape irrigation and as flushing water, which don't necessarily require potable water quality.

Table 3.3: Water consumption in Kocaeli.

	m^3/year	%
Domestic	70,083,262	54
Office	7,448,218	6
Public	10,465,335	8
Spring	93,628	0.1
Industry	≈42,834,669	≈33
Potable water	14,582,798	11
Well water	13,996,770	11
Reclaimed water	14,255,101	11
TOTAL	**130,925,112**	**100**

Figure 3.8 shows the water consumption in 12 districts, the highest consumption takes place in Izmit, Gebze, and Korfez as a result of the comparatively denser urbanization and industrialization. Most of this water demand is supplied by Yuvacik Dam, which is the main water source of Kocaeli with the capacity of 51,100,000 m^3 [5]. Sapanca Lake (120,000,000 m^3) (shared with Sakarya Province), Namazgah Dam (25,000,000 m^3), and Denizli Pond (15,000 m^3/d) are the other secondary water reserves of Kocaeli [66].

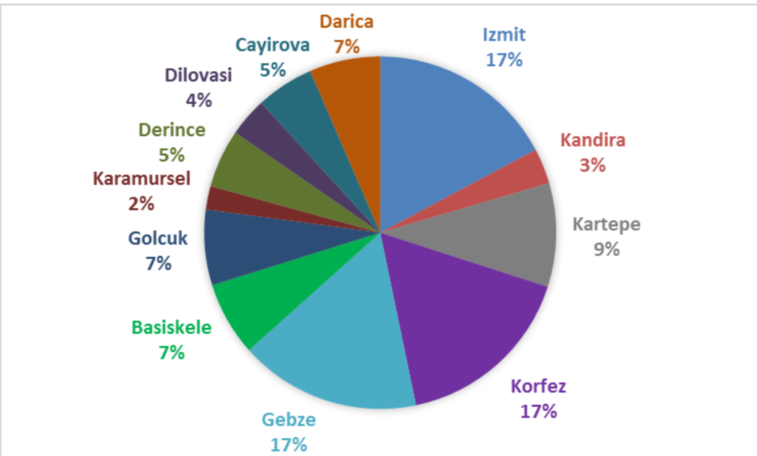

Figure 3.8: Water consumption in districts of Kocaeli.

The water abstracted from these sources are distributed by the water network after treatment in 14 different drinking water treatment plants (DWTP) as given in Figure 3.9. While four of them (Yuvacik Dam, Denizli Pond, Dudutepe, and Avluburun DWTP) are conventional, the rest is modular facilities with comparatively smaller capacity located in remote locations [3]. 90% of tap water is treated in Yuvacik Dam Drinking Water Treatment Plant and the quality of tap water is as given in Table 3.4.

Table 3.4: Tap water quality in Kocaeli.

Parameter	Unit	Tap Water[67]	Drinking water requirements [68]
pH		7.44	6.5 – 9.5
Cl	*mg/L*	0.52	0.2 – 0.5
Turbidity	*NTU*	0.17	1
Al	*mg/L*	0.04	0.2
Fe	*mg/L*	0.01	0.2
Mn	*mg/L*	0.01	0.05
NO_2	*mg/L*	0.01	0.5
NH_4	*mg/L*	0.01	0.5
T. Hardness	*mg/L*	113	
Coliform	*cfu/100mL*	0	0
E.coli	*cfu/100mL*	0	0

In recent years, Kocaeli is able to treat 99% of wastewater in 23 wastewater treatment plants shown in Figure 3.11. While five of those have advanced treatment processes that are able to remove nitrogen and phosphorus (Plajyolu, Gebze, Dilovasi, Kandira and Cebeci WWTPs), five have extended aeration activated sludge process (Kullar, 42 Evler, Yenikoy, Korfez, and Karamursel WWTPs). In addition to 11 modular wastewater treatment plants (Bagirganli, Validekopru, Akmese, Cavuslu, Hakkaniye, Tavsancil, Umuttepe, Cumakoy, Sarisu, Sucuali, and Seyrek Modular WWTPs), there is a constructed wetland located in Gebze district (Balcik CW). Kullar and 42 Evler WWTPs are to be combined into an advanced biological treatment plant.

In 12 of wastewater treatment plants (Gebze, Kandira, Cebeci, Plajyolu, Kullar, Korfez, Akmese, Umuttepe, Cumakoy, Dilovasi, Sucuali, and Seyrek WWTPs), conventionally treated wastewater is reclaimed by additional units consisting of sand filters and UV disinfection located after secondary sedimentation tanks. Wastewater

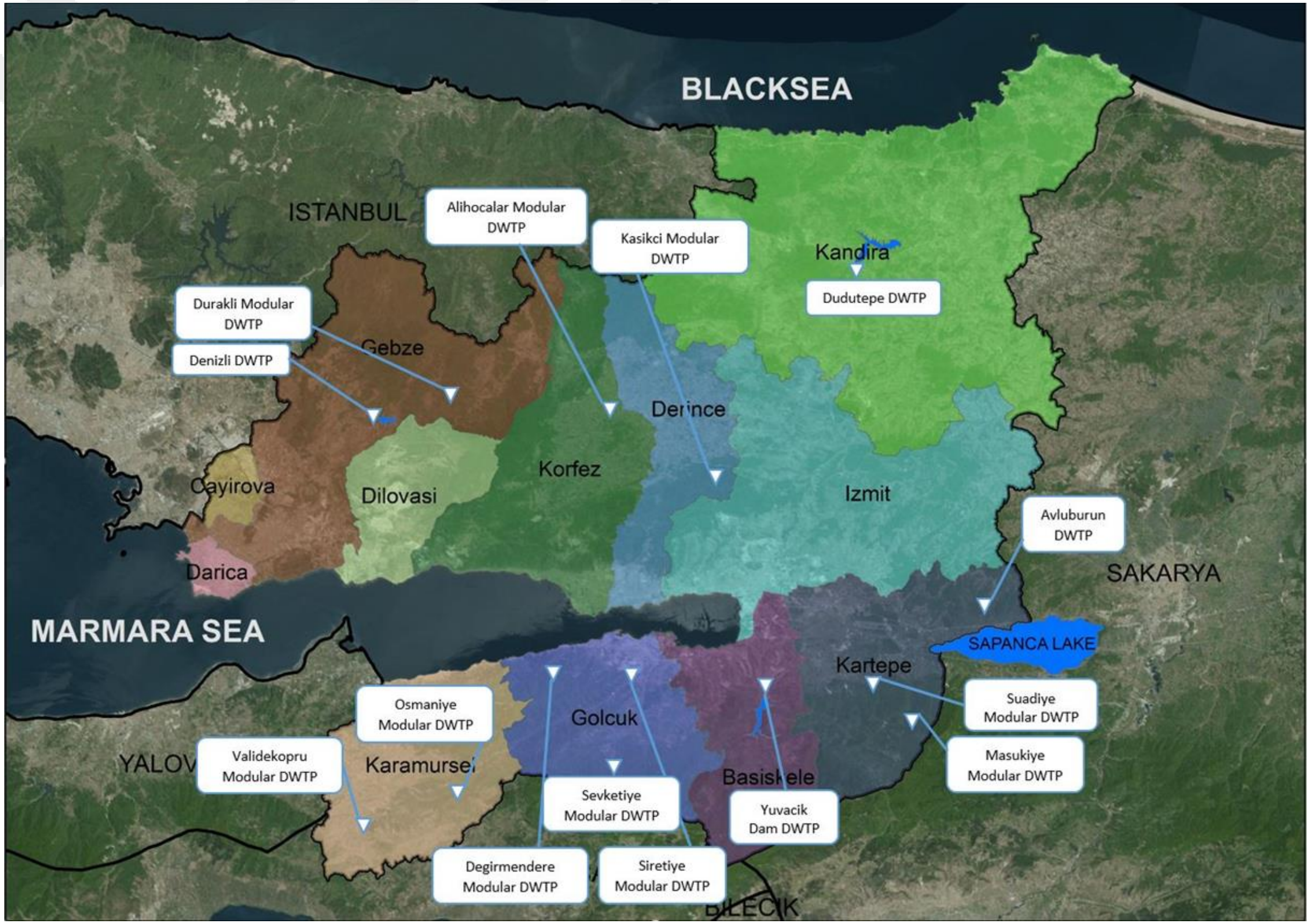

Figure 3.9: Drinking water treatment plants (DWTPs) in Kocaeli.

reclamation capacity of these plant (≈85,000 m^3/d) is equal to 14% of total wastewater treatment capacity (≈600,000 m^3/d) in Kocaeli [69] [70]. As given in Figure 3.10, recently 11% of total wastewater is reclaimed later to be reused for on-site cleaning and sludge dewatering (for chemical preparation) in treatment plants or landscape irrigation and street cleaning in some districts of the city. It is also provided to industrial facilities as an alternative source, to be used for landscape irrigation, cooling, and various washing functions [69]. Prior to reuse in these industrial entities, reclaimed wastewater is additionally treated by advanced treatment processes such as ultrafiltration and reverse osmosis. Reclaimed wastewater is pumped to these industrial end users that are located approximately 1 to 3 km away from relevant treatment plants, while it is transferred by water tankers for urban cleaning and some landscape irrigation.

The influent and effluent quality of conventional treatment plants are given in Table 3.5, together with reclaimed wastewater quality. When it is compared with the limits in T.R. Technical Procedure for WWTPs, (which is the only standard in Turkish Republic for water reuse) the quality of reclaimed domestic wastewater is not suitable for reuse for irrigational purposes in terms of conductivity, turbidity, and SAR parameters. For other industrial end-use purposes, it is also additionally treated prior to reuse.

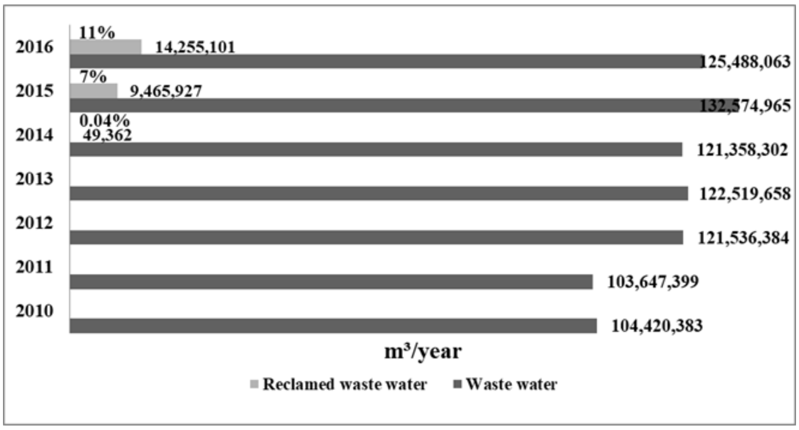

Figure 3.10: Wastewater treatment and reclamation in Kocaeli.

Table 3.5: Reclaimed water quality in Kocaeli.

		Kullar WWTP			Plajyolu WWTP			Gebze WWTP			T.R. Tech. Procedure for WWTPs
		Influent	Extended aeration	Rapid sand filter + UV	Influent	Advanced biologic.	Rapid sand filter + UV	Influent	Advanced biologic.	Pres. sand filter + UV	
pH		7.7	7.5	7.6	7.5	7.0	7.4	7.8	7.4	7.0	6-9
Conduct.	*µs/cm*			1377			1729			1929	700
Turbidity	*NTU*			2.16			5.11			3.42	2
NH_4	*mg/L*	35	3	0.27	15	0.5	0.40	40	3	0.44	
Hardness	*mg/L $CaCO_3$*			299			277			349	
Mn	*mg/L*			0.11			0.10			0.15	0.2
Cd	*mg/L*						0.01			0.01	0.01
Fe	*mg/L*			0.02			0.06			0.04	5
Ni	*mg/L*						0.04			0.02	0.2
Cr	*mg/L*						0.04			0.02	0.1
Cu	*mg/L*			0.01			0.05			0.02	0.2
Al	*mg/L*			0.02			0.11			0.02	5
B	*mg/L*			0.22			0.19			0.14	0.7
Zn	*mg/L*			0.02			0.06			0.06	2

Table 3.5 (continued): Reclaimed water quality in Kocaeli.

		Kullar WWTP			Plajyolu WWTP			Gebze WWTP			T.R. Tech. Procedure for WWTPs
		Influent	Extended aeration	Rapid sand filter + UV	Influent	Advanced biologic.	Rapid sand filter + UV	Influent	Advanced biologic.	Pres. sand filter + UV	
Pb	*mg/L*						0.07			0.01	5
T.P	*mg/L*	5	0.1		3	0.6	0.50	10	0.8	0.23	
NO_3-N	*mg/L*	7.5	5.5		5.5	5	3	7	5	4.03	
SO_4	*mg/L*			72			110			150	
Cl	*mg/L*			114			441			559	140*
T.N	*mg/L*	58	57		30	6	5	50	9	7	
SAR				3			14			6	
BOD	*mg/L*	210	8		150	5		230	7		20
COD	*mg/L*	540	50		330	30	25	530	25	19	
TSS	*mg/L*	300	20	10	190	10	7	350	25	15	30
T. Coli	*cfu/100mL*			7						0	14**
E.Coli	*cfu/100mL*			15						0	

**Only during surface irrigation; **Faecal coli.*

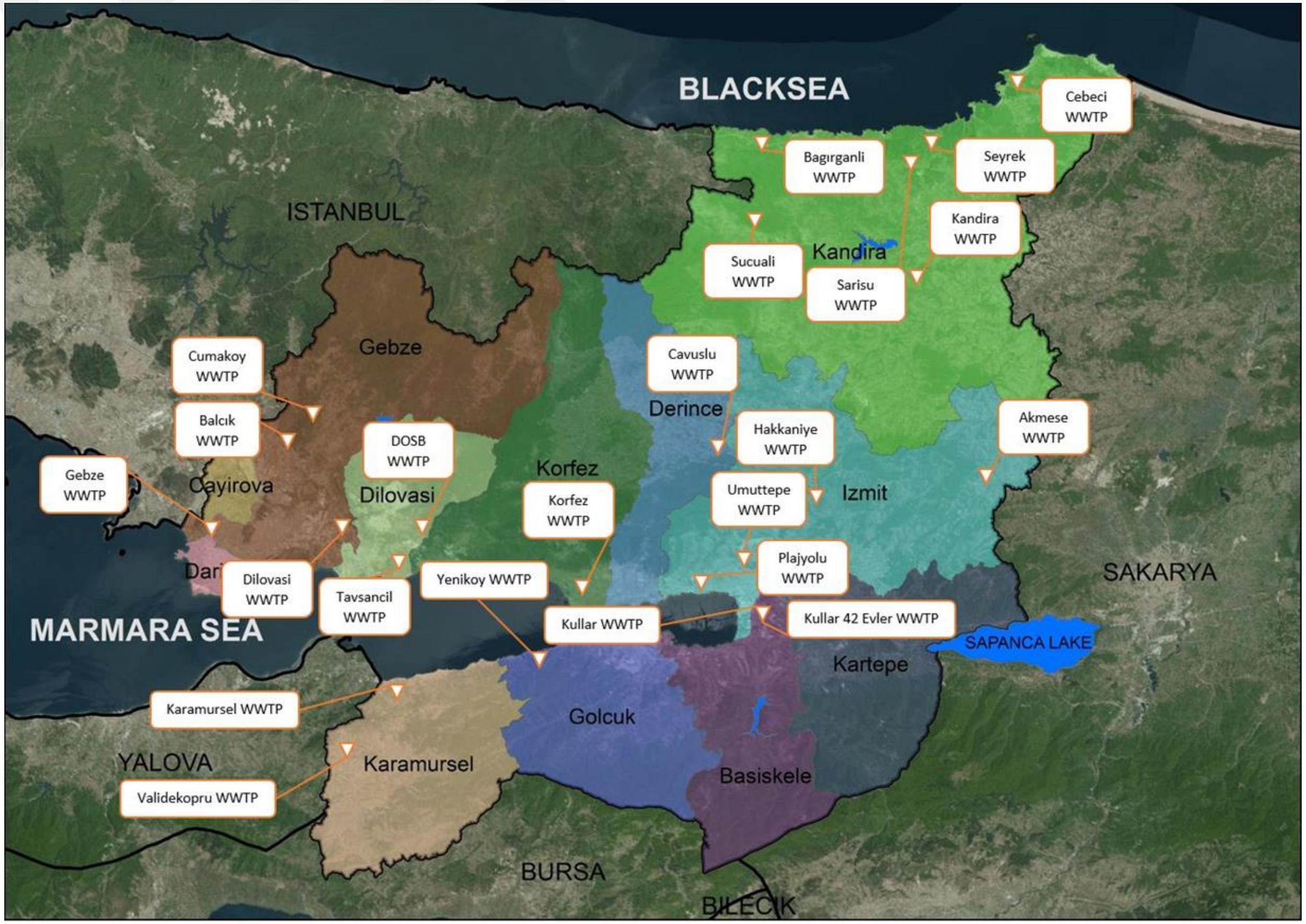

Figure 3.11: Wastewater treatment plants (WWTPs) in Kocaeli

4. METHOD AND SYSTEMATIC

4.1 Selection of Study Area: Yenikent Neighborhood

Selection of the study area is the initial step for the conversion of conventional wastewater management system into source separation of grey water. There are several criteria to take into consideration while selecting the relevant application area that are indicated below in order of priorities.

- Compactness and size of study area
- Grey water potential/volume
- Reuse potentials/Potential end-use areas
- Proximity between origin of grey water and potential reuse areas
- Existing water supply of potential reuse areas and proximity between

Considering all the selection criteria, compact residential areas surrounded by potential reuse areas are primarily determined in Kocaeli. The research mainly focused on planned urbanization sites consisting of building complexes. As a result of its comparatively regular urbanization and sufficient number of households, Yenikent is selected as a representative location. In order to confirm the suitability of the neighborhood, potential reuse areas are determined as Gebze Organized Industrial Site, Guzeller Organized Industrial Site, and Gaziler Natural Park, which are discussed more in detail in Chapter 5.3. Proximity between Yenikent Neighborhood and potential reuse areas, existing resource that supply water to these reuse areas and the proximity between are the other drivers for the selection of this neighborhood.

Yenikent

Yenikent is a neighborhood in Gebze district located on 1 km^2 (932,548 m^2) area, right across Gebze and Guzeller Organized Industrial Zones and near Gaziler Natural Park [71]. The number of residents in the neighborhood is estimated at 16,809 living in 105 buildings (each 8-10 stories high, each accommodating around 160 residents) [63] [72]. The neighborhood is started be built almost 20 years ago and still a developing field as result of growing industrial activities.

The water demand of neighborhood is supplied by main water source in Kocaeli, Yuvacik Dam, which is located approximately 50 km away as the cross flight as illustrated in Figure 4.1. However, raw water abstracted from the dam is firstly treated in Yuvacik Dam Treatment Plant situated 5 km away and prior to distribution, pumped to Gaziler potable water reservoir by 70-km-long pipeline [73].

Figure 4.1: Location of Yenikent and Yuvacik Dam.

The neighborhood is served by a separate conventional sewer system which ends up in Gebze Advanced Biological Wastewater Treatment Plant located around 6 km south west as shown in Figure 4.2. The average water consumption in the neighborhood is around 1,700 m^3 daily as later discussed in Chapter 5.1 and around 1,500 m^3/d is converted to wastewater.

Figure 4.2: Location of Yenikent and Gebze Wastewater Treatment Plant.

Guzeller Organized Industrial Zone

Guzeller is an organized industrial zone which is located on 1200-decare-land north of Gebze district [74]. As it can be observed from Figure 4.3, the distance from Yenikent is only 2 km (northeast), where the grey water is to be collected.

Figure 4.3: Location of Yenikent and Guzeller Organized Industrial Zone.

There are 32 companies actively carrying on a business in Guzeller OIZ, mostly metal and machine industry [75]. As stated by executive board of Guzeller OIZ, the primary water source is Yuvacik Dam (50 km) while Denizli Pond (12 km) is secondarily preferred [75]. According to the report by Ministry of Science, Industry and Technology, current water consumption from these sources is around 1,400 m^3 on a daily basis, where 8 m^3/d is consumed for landscape irrigation during dry season (May to September) [76] [77].

Gebze Organized Industrial Zone

Gebze Organized Industrial Zone is located on 4,030-decare-land north of Gebze district and northwest of Guzeller OIZ [76]. As shown in Figure 4.4. The distance from Yenikent is around 2.5 km (north). There are 164 production companies, mostly active in metal, automotive, chemical, and machine industry [78].

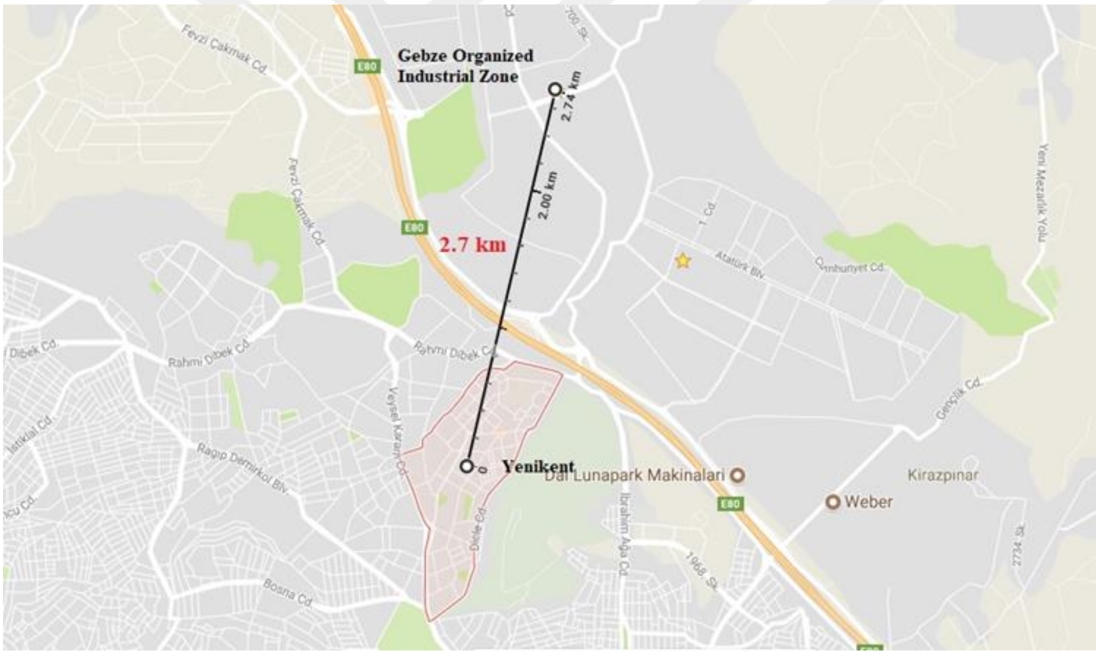

Figure 4.4: Location of Yenikent and Gebze Organized Industrial Zone.

As stated by Environmental Department of Gebze OIZ, the primary water source is Yuvacik Dam (50 km) and it is stored in 12,500-m^3-reservoir, where 6,000 m^3 of those is conserved for the purpose of fire protection. Similar to Guzeller OIZ, Denizli Pond (12 km) is also connected to water supply network as a secondary source [79]. Ministry of Science, Industry and Technology reports that current water consumption from these sources is approximately 60,000 m^3 per day [76]. Only 500 m^3 of this total consumption is used for landscape irrigation during the season [80].

Gaziler Natural Park

Gaziler Natural Park is a plantation area in Gebze district located on 101.36-hectare-land, right across organized industrial zones and next-to Yenikent Neighborhood as seen in Figure 4.5 [81].

The irrigational water demand of Gaziler Natural Park is fulfilled with potable water mainly extracted from Yuvacik Dam (50 km). Depending on the season, the daily water consumption in the area is around 50 m^3/d in the most rainy season and approximately 310 m^3/d during dry season [82].

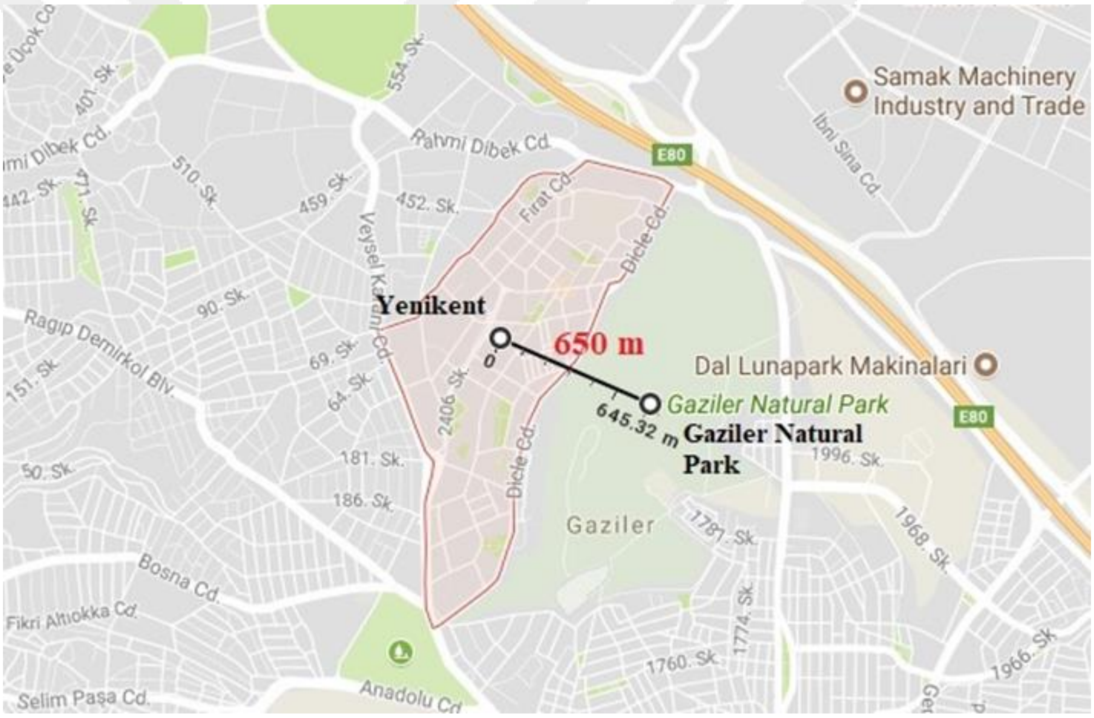

Figure 4.5: Location of Yenikent and Gaziler Natural Park.

4.2 Quantity of Grey Water

For the estimation of potential grey water volume in the selected study area, total water consumption of selected neighborhood is provided from IT Department of Kocaeli Water and Sewerage Administration (ISU) for the last two years. Depending on total water consumption and total treated wastewater flow given in annual reports by ISU, wastewater conversion ratio (refers to ratio of wastewater flow to tap water flow) is calculated.

$$\text{Conversion Ratio} = {}^{\text{Wastewater Flow}}/_{\text{Tap Water Flow}} \qquad (4.1)$$

The amount of wastewater generated is calculated by multiplying water consumption in selected neighborhood with wastewater conversion ratio.

$$\text{Wastewater Generation} = \text{Water Consumption x Conversion Ratio} \qquad (4.2)$$

Quantity of grey water and its sub-streams are estimated depending on wastewater generation and the domestic water usage percentages given before in Figure 2.3. Based on this percentages, mixed grey water generated from households covers 69% of total domestic wastewater, as it constitutes all wastewater sub-streams excluding toilet water [9]. 3% given for cleaning purposes in Figure 2.3 is assumed to be contained by black water.

While weak grey water constitutes 30% covering shower/bathtub and wash basin; this percentage rises up to 55% if it is collected together with washing machine grey water. Depending on these percentages, quantity of grey water and its sub-streams are calculated later in Chapter 5.1.

4.3 Quality of Raw Grey Water

Prior to selection and design of the suitable treatment option that meets the requirements for specific reuse areas, the quality of grey water and its sub-streams are estimated.

4.3.1 Mixed grey water quality

Table 2.5 shows that the typical ranges obtained from literature are too wide to make an assumption that realistically represents grey water characterization in a specific neighborhood as well as Yenikent. As the geographical conditions are one of the main factors that affects grey water characteristics, all characterization work from T.R. (given in Table 2.1) is reviewed to make the most appropriate estimation for grey water quality for this study.

In Table 2.1, several studies from Turkish Republic that are carried out close to the selected study area (Gebze district) are given with the other mixed grey characterization research. Atasoy [83], Hocaoglu [84], Baban [85], Barisci, and Turkay [86] [87] reported characteristics of mixed grey water collected from lodging houses of the TUBITAK MRC Campus which is located 5 km away from Yeniket. The plumbing system in this research is modified to allow segregation of black water and grey water streams in 2 buildings comprising a total of 28 apartments [44]. As a result of its close location to Yenikent Neighborhood in Gebze district, mixed grey water characterization for this study is adopted from studies conducted in TUBITAK MRC. Since it indicates the worst case quality for most of the parameters, the quality assumption is made depending on the study by Baban [85] as given in Table 4.1. Only the phosphorus concentration is at the upper limit of typical mixed grey water characteristics, while all the other parameters are at or close to lower limit. Higher phosphorus concentration is explained by the presence of phosphorus-containing soaps and detergents in grey water [83].

Table 4.1: Mixed grey water quality assumption for Yenikent Neighborhood.

Parameter	Unit	Mixed grey water (1)	Typical range (2)
BOD	*mg/L*	119	170 – 606
COD	*mg/L*	347	347 – 827
TSS	*mg/L*	79	78 – 280
Turbidity	*NTU*	103	
TKN	*mg/L*	8	
T.N	*mg/L*		11 – 39
T.P	*mg/L*	9.8	3.9 – 9.8

(1) Adopted from TUBITAK MRC [85]; (2) Typical ranges from Table 2.5

4.3.2 Weak grey water quality

Weak grey water quality data reported in Turkish Republic (T.R.) is presented in Table 4.2, where all of them are carried out for weak grey water originated from hotel, dorm, or university building; they are not suitable to make an assumption for the households in Yenikent Neighborhood. For this reason, the weak grey water quality is obtained from a study carried out in France by Chaillou and others [21] as given in Table 4.3, since it is a similar geographical location to T.R. and characteristics are suitable to be a representative of weak grey water. All the concentrations given in this study are close to lower limit of typical weak grey water characteristics presented earlier in Table 2.1.

Table 4.2: Weak grey water characterization in T.R.

		Hotel	**Dorm**	**University***
		[61]	*[9]*	*[44]*
Parameter	***Unit***	Hilton, Istanbul	Istanbul	Bogazici Uni, Istanbul
pH				7.4
BOD	*mg/L*	40	76	
COD	*mg/L*	113	226	428
TKN	*mg/L*	4.8	6.61	
NH_4-N	*mg/L*		0.64	0.45
NO_2-N	*mg/L*			0.04
T.P	*mg/L*	2.3	1.78	
TSS	*mg/L*	66	145	10
Al	*mg/L*			0.7
Fe	*mg/L*			0.4
Mn	*mg/L*			0.05
Turbidity	*ntu*			12
T. Coliform	*cfu/100mL*	1.00E+08	1.16E+07	
Faecal Coliform	*cfu/100mL*	1.00E+08	4.82E+06	
E. Coli	*cfu/100mL*		2.11E+06	

*Wash basin only.

Table 4.3: Weak grey water quality assumption for Yenikent Neighborhood.

Parameter	Unit	Weak grey water (1)	Typical range (2)
BOD	*mg/L*	81	78 – 200
COD	*mg/L*	145	145 – 400
TSS	*mg/L*	40.3	41 – 148
T.N	*mg/L*	6.2	4.5 – 13.5
T.P	*mg/L*	0.25	0.2 – 1.9

(1) Adopted from [21]; (2) Typical ranges from Table 2.5

4.3.3 Bathroom grey water quality

Great majority of the literature work reports the characteristics of washing machine/laundry grey water and shower/bathtub and wash basin grey water separately. However, bathroom grey water refers to shower/bathtub, wash basin together with washing machines within the scope of this study.

In Table 2.3, bathroom grey water characteristics are reviewed from the literature. It shows that there is only one study that indicates bathroom grey water characteristics in T.R. However, it does not reflect the possible characteristics of bathroom grey water properly; since it only covers washing machine and hand wash basin grey water (where showers/bathtubs are excluded) and total nitrogen concentration is pretty high in comparison with other literature data.

For this reason, the characteristics of grey water for this particular study is adopted from the research by Mohamed and others [40] since it contains all fractions of bathroom grey water (shower/bathtub, wash basin, washing machine) and also it is carried out in Australia where grey water applications are wide-spread. However, it should be noted that BOD concentration in this particular study is lower than expected as represented in Table 4.4, when it is compared with typical ranges.

Table 4.4: Bathroom grey water quality assumption for Yenikent.

Parameter	Unit	Bathroom grey water [1]	Typical range [2]
BOD	*mg/L*	40	56 – 195
COD	*mg/L*	445	257 – 579
TSS	*mg/L*	78	78 – 276
TKN	*mg/L*	1	
T.N	*mg/L*	10	7 – 44
T.P	*mg/L*	3	0.24 – 6.7

[1] Adopted from [40]; [2] From Table 2.5

4.4 Selected Quality Requirements

As mentioned earlier in Chapter 2.4, Turkish Technical Procedure Communication for Wastewater Treatment Plants is the only standard mentions wastewater reclamation. This standard addresses reuse of only wastewater and it is specifically for irrigational purposes. Even it refers directly to wastewater, the limits given in Table 2.8 (in Chapter 2.4) might be used because of the absence of grey water limits in T.R.

However, for the other end-use purposes such as toilet flushing, urban cleaning, car wash, and cooling, grey water guidelines and regulations presented in Appendix B1 and B2 are examined in detail in order to estimate grey water treatment requirements for this study.

In Table 4.5, quality requirement assumptions for selected reuse areas are given. All grey water reuse standard limits are reviewed. To make an assumption for the limits required for toilet flushing, urban cleaning, and car wash; the most common concentration limits are designated for pH, turbidity, BOD, TSS, and T.N. As a result, all these three end-use purposes are turned out to be equal to each other.

The same method is applied for cooling, while assumption for pH, BOD, T.N, and faecal coliforms are the same with the requirements for toilet flushing, urban cleaning, and car wash; the limits for turbidity and *Escherichia Coli* are tighter.

Table 4.5: Quality requirement assumptions for different end-use purposes.

		Toilet Flush		**Urban Cleaning**		**Car Wash**		**Cooling**		**Irrigation**
		*N.**	*Sc. 1A, 3*	*N.*	*Sc. 1B*	*N.*	*Sc. 1B*	*N.*	*Sc. 2, 4*	*Sc. 3*
pH		*3*	6.5 - 8.5	*1*	6.5 - 8.5	*2*	6.5 - 8.5	*2*	6.5 - 8.5	6 - 9
Turbidity	*NTU*	*5*	5	*1*	5	*2*	5	*5*	5	2
BOD	*mg/L*	*6*	10	*1*	10	*5*	10	2	10	20
TSS	*mg/L*	*5*	10	*2*	10	*3*	10	*2*	30	30
T.N	*mg/L*	*2*	10	*2*	10	*1*	10	*2*	10	
E.coli	*cfu/100 mL*	*3*	10			*1*	10	*1*	0	
Faecal Coli	*cfu/100 mL*	*1*	200	*1*	200			*1*	200	0

** N.: Number of standards that refers to that specific quality limit*

Even though there are T.N limits set by two different standards, it is not necessary to make an assumption for nitrogen concentration. Since the TKN concentration in mixed grey water for this study (11 mg/L) is expected to meet the requirements (10 mg/L for T.N) after proper treatment in order to remove organic matter and total suspended solids.

4.5 Treatment System Design

Depending on the possible influent character for each scenarios, membrane bioreactor and ultrafiltration systems are selected and designed.

4.5.1 Membrane bioreactor design

The MBR system is designed based on the feed flow characteristics given in Chapter 4.3 and limits given in Chapter 4.4 and in two distinct but interrelated phases:

- The membrane process design,
- The biological process design.

It is assumed that the MBR system is only able to remove carbon however; N-removal is not particularly required depending on the grey water characteristics and reuse criteria in this case. The calculations for biological process design for carbon removal are based on Monod Equations and for membrane process design, the method given by Judd [88] is followed.

In Table 4.6, the equations and assumption are given in the order of the steps followed for the design. From pilot studies and manufactural guidelines, a sustainable design flux is need to be chosen. The common flux range is defined between 15 – 30 LMH ($L/m^2.h$) by Judd [88]. Depending on this, mean flux value (J_{net}) of 11 different hollow fiber (HF) MBR applications is adopted.

According to calculated membrane area by using Equation 4.3, optimum UF-pore-sized membrane module available on market is selected and the specifications of the module are later given in Chapter 5.3. Minimum required membrane tank volume is designed based on the membrane area (A_m) and membrane packing density in membrane tanks (φ_{tank}) given by manufacturers [88] [89]. For biological process design, the same methods applied for the design of aeration tanks in conventional treatment systems could be followed. By using Equation 4.7, aeration tank volume is computed, where hydraulic retention time is adopted from similar MBR applications.

Table 4.6: Equations for MBR design.

		Unit	Equation	Eq. No.	Reference
Determination of membrane area					
A_m	Membrane area	m^2	$A_m = \frac{Q_{peak}}{J_{net,peak}}$	(4.3)	
$J_{net,peak}$	Maximum allowed flux	$L/m^2.h$ = LMH	$J_{net,peak} = 140\%\ J_{net}$	(4.4)	
J_{net}	Net Flux	$L/m^2.h$ = LMH	Assumption: 20 LMH (Operation Range: 15–30 LMH)		[88]
Q_{peak}	Peak influent flow rate	m^3/h	$Q_{peak} = 2Q$	(4.5)	[88]
Selection of membrane module available on market and determination of membrane tank volume					
$V_{m,min}$	Minimum required membrane tank volume	m^3	$V_{m,min} = \frac{A_m}{\varphi_{tank}}$	(4.6)	[88]
φ_{tank}	Membrane packing density in membrane tanks	m^2/m^3	Assumption: 150.5 m^2/m^3 (From manufacturer specifications)		[89]
Determination of aeration tank volume					
V_{aer}	Aeration tank volume	m^3	$HRT = \Theta = \frac{V_{aer}}{Q}$	(4.7)	[39]
HRT or Θ	Hydraulic retention time in aeration tank	h	Assumption: 10 h (Range: 7-22 h from similar applications)		[88]

4.5.2 Effluent quality estimation for membrane bioreactor

For the prediction of effluent quality of MBR systems, treatment efficiencies for both mixed and weak grey water in similar studies are reviewed as given in Table. 4.7 and 4.8. For MBR treatment of weak grey water, the data stated by Giresunlu [9] and Santasmanas and others [90] are comparable with the one selected for this study, since they treat the same fractions of weak grey water by the same pore-sized membrane (UF). However, the treatment efficiencies reported by Giresunlu [9] is chosen as it includes % efficiency of all parameters limited by standards.

Table 4.7: Weak grey water treatment efficiencies by MBR.

Membrane Type in MBR	GW Fraction	Parameter	% Efficiency	Reference
UF (0.05 µm)	Weak	BOD	95	[90]
		COD	90	
		Turbidity	98	
UF (30 kDa=0.01 µm)	Weak (Shower)	COD	70	[91]
		Turbidity	97	
UF (0.1 µm)	Weak (Shower)	BOD	93	[92]
		COD	86	
		Turbidity	98	
		T.N	63	
		NH_4-N	72	
		T.P	19	
UF (0.05 µm)	Weak (Wash basin)	COD	93	[44]
		NH_4-N	82	
		NO_2-N	80	
		Turbidity	95	
UF	**Weak**	COD	88	**[9]**
		BOD	95	
		TSS	97	
		VSS	97	
		TKN	78	
		T.P	40	

For MBR treatment of mixed grey water, the data stated by Atasoy et al. [58] is comparable with the designed treatment system for Yenikent Neighborhood, the characterization of mixed grey water for this study is adopted from the same location [83]. However, effluent T.P concentration is estimated based on the data reported by Lesjean and others [93] and turbidity based on the results reported by Jefferson [94], since there is no treatment efficiency or effluent quality given by Atasoy [83] for these parameters.

Table 4.8: Mixed grey water treatment efficiencies by MBR.

Membrane Type in MBR	GW Fraction	Parameter	% Efficiency	Reference
UF	**Mixed**	COD	85	[93]
		NH_4-N	96	
		T.P	**50**	
		T.N	52	
UF (0.04 µm)	**Mixed**	COD	94	[94]
		Turbidity	**100**	
MF (0.4 µm)	**Mixed**	BOD	>95	[83]
		COD	95	
		TSS	94	
		T.N	92	
		NH_4-N	82	
		T. Coli	100	
MF (0.5 µm)	Mixed (Wash basin, kitchen sink, washing machines)	BOD	97	[95]
		COD	86	
UF (0.03 µm)	Mixed (Wash basin, washing machine)	BOD	93	[28]
		COD	90	
		T.N	75	
		T.P	65	
		T. Coli	>6 Log	

Since the membrane pore sizes selected for the design in this study is smaller than the one used by Atasoy and others [83], the treatment efficiency of designed MBR is expected to be higher in comparison with the results reported in Table 4.8.

4.5.3 Ultrafiltration system design

Ultrafiltration module design project is produced by in-house software named Akualys v1.0, which is available for commercial membrane distributors.

4.5.4 Effluent quality estimation for ultrafiltration

To estimate possible effluent quality of ultrafiltration system in this study, the treatment efficiency reported by Giresunlu is assumed [9]. The study carried out by Giresunlu indicates a preliminary investigations on grey water treatment by UF membrane manufactured in laboratory, where the treatment efficiencies are 95%, 94%, 92%, 50% for BOD, TSS, TKN, and T.P respectively.

4.6 Financial Assessment of Scenarios

Financial assessment of the scenarios is investigated in three steps; calculation of capital expenditure (CAPEX), operational expenditure (OPEX), and pay-back period.

The capital expenditure of each scenario contains the investment cost of the selected treatment method, grey water collection system in buildings, and treated grey water distribution pipes to various reuse areas, that are calculated based on several price offers by private entities. The dimensions for plumbing system design are adopted from a mass housing project by Urban Housing Construction Department of Kocaeli Metropolitan Municipality [96].

While the capital cost of treatment systems are based on total expenditure for entire neighborhood, the cost of in-building-pipelines is given per apartment/household. Preliminary cost of treated grey water distribution system is roughly estimated based on average proximity to end-use locations.

For the analysis of operational expenditures, energy consumption of equipment (pumps and blowers) and chemical consumption for disinfection and chemical cleaning of membranes are considered. Unit cost of chemicals are also received from private entities and electricity prices are adopted from Turkish Electricity Distribution Corporation (TEDAS) [97]. All prices given in different monetary units are converted to US dollars by using European Commission currency converter (INFOREURO) [98]. The operational cost of grey water reclamation system designed for each scenario are compared with the cost of existing conventional wastewater management system presented in Table 4.9.

Table 4.9: Current unit cost of water in Yenikent Neighborhood.

	USD/m³
Potable water pumping	0.035
Potable water treatment	0.096
Wastewater pumping	0.009
Wastewater treatment	0.079
TOTAL	**0.219 USD/m³**

Depending on [99] and [3]

Lastly the pay-back period is calculated based on Equation 4.10. For the calculation, unit water price for households is adopted from prices determined by ISU [100] as given in Table 4.10.

$$\text{Savings} = \text{Water Reuse x Unit Water Price} \tag{4.8}$$

$$\text{USD/year} = \frac{\text{m}^3}{\text{d}} \text{ x } \frac{\text{USD}}{\text{m}^3} \text{ x } \frac{365\text{ d}}{1\text{ year}}$$

$$\text{Total Saving} = \text{Saving} - \text{OPEX} \tag{4.9}$$

$$\text{USD/year} = \frac{\text{USD}}{\text{year}} - \frac{\text{USD}}{\text{year}}$$

$$\text{Payback Period} = \frac{\text{CAPEX}}{\text{Total Saving}} \tag{4.10}$$

$$\text{year} = \frac{\text{USD}}{\text{USD/year}}$$

Table 4.10: Unit water price in Kocaeli.

Subscriber	*TL/m³*	*USD/m³*	Scenario
Industry	11.36	3.92	
Organized Industrial Zone	7.57	**2.61**	S-2, S-3
Reclaimed Wastewater (Industry)	3.26	1.12	
Reclaimed Wastewater (Organized Industrial Zone)	1.62	0.56	
House (0-10 m^3)	3.33	1.15	
House (>10 m^3)	6.09	**2.10**	S-1, S-4
Irrigation (0-10 m^3)	2.22	0.77	
Irrigation (0-10 m^3)	4.06	**1.40**	S-4
Well (Industry)	3.15	1.09	
Well (Industry)	3.79	1.31	

4.7 Public Acceptance towards Grey Water Reuse

For the investigation of grey water reuse applications in terms of social sustainability, a survey was conducted through face to face questionnaires to assess attitudes, acceptance and willingness regarding reuse of grey water as an alternative source. The survey questions were posed to 210 participants living in T.R.

Table 4.11 represents the demographic profile of the respondents who are mostly Turkish nationals with 95% Turkish, 5% other nationalities. The distribution of the participants based on gender is in half shares. The educational level is considered high as the great majority of the respondents were university graduates (with 10% 2-year, 44% bachelor's and 25% graduate degrees). Age ranges were set to represent employment status; <18 for children and adolescents, 18-24 for college students, 25-30 for new graduates, 31-50 for professionals, 51-65 for senior professionals, and >65 for retirees for this survey. 31-50 year old professionals, which constituted 42% of respondents, was the largest group that was to respond to this survey followed by new graduates with 28%. Most of the respondents in the survey majored in engineering with 41%, however there were also technicians (7%), students (8%), researchers/academicians/teachers (6%), operators/workers (6%), and others (32%) such as officers, housewives, housekeepers, accountants/bankers.

Table 4.11: Demographic profile of survey respondents.

		<18	**18-25**	**26-30**	**31-50**	**51-65**	**>65**
Age	*N*	4	32	58	88	26	2
	%	2	15	28	42	12	1
		Female			**Male**		
Gender	*N*	104			106		
	%	50			50		
		Turkish			**Other**		
Nationality	*N*	199			11		
	%	95			5		
		Primary Sch.	**High Sch.**	**2-Year Deg.**	**Undergrad**	**Master**	**Ph.D**
Education	*N*	11	34	20	92	44	9
	%	5	16	10	44	21	4
		Engin.	**Technician**	**Student**	**Academi.**	**Operator**	**Other**
Occupation	*N*	86	15	17	12	13	67
	%	41	7	8	6	6	32

****Other:** Americans (N. 3), Syrian (N. 3), Bangladeshi (N. 1), British (N. 1), Greek (N. 1), Bulgarian (N. 1), Russian (N. 1).*

The questionnaire consisted of a total of 27 questions given in Appendix C, which is composed of three parts:

- General questions about the demographic attributes of the participants,
- Questions to evaluate background knowledge and awareness of water scarcity in T.R. as well as grey water, motivations and concerns/drawbacks regarding grey water reuse including the reasons behind their perception,
- Questions regarding the origin and reuse areas of grey water to analyze the level of public acceptance for grey water reuse.

The data obtained were analyzed using simple head counts and percentages to reflect acceptance or motivations/concerns.

5. RESULTS AND DISCUSSION

5.1 Grey Water Volume in Study Area

Potential grey water volume in Yenikent Neighborhood is estimated following the method given in Chapter 4.2. By substituting the total water consumption and total treated wastewater flow (in Kocaeli) in Equation 4.1, wastewater conversion ratio (refers to ratio of wastewater flow to tap water flow) is calculated as 90% [3] [99].

Total water consumption of Yenikent Neighborhood is reported around 1,700 m^3/d by Information Technology Department of Kocaeli Water and Sewerage Administration (ISU) [101]. The amount of domestic wastewater generated in neighborhood is calculated based on Equation 4.2.

Depending on the percentages given before in Figure 2.3, volume of grey water and its sub-streams are calculated as indicated in Table 5.1. As a result of these findings, mixed grey water flow generated in Yenikent Neighborhood is assumed about 1,000 m^3/d, while the weak grey water flow is assumed as 460 m^3/d (shower/bathtub, wash basin) and 850 m^3/d for grey water originated from bathrooms (shower/bathtub, wash basin, washing machine). Potential grey water volume generated in bathrooms is estimated for this study, as it could be collected in a compact and practical way from a single point in a household.

Table 5.1: Quantity of grey water in Yenikent Neighborhood. *(Water consumption: 1,708 m^3/d)*

Grey Water Fractions	%	m^3/d 2015	m^3/d 2016
Water Consumption	110%	1,568	1,708
Domestic Wastewater *(Eq. 4.1&4.2)*	100%	1,412	1,537
Grey Water *(GW)*	69%	974	**1,061**
• **Shower/Bathtub** *(SH/BT)*	23%	325	354
• **Wash Basin** *(WB)*	7%	99	108
Weak Grey Water *(wGW) (SH/BT+WB)*	30%	423	**461**
• **Washing Machine** *(WM)*	25%	353	384
Bathroom *(SH/BT+WB+WM) (wGW+WM)*	55%	776	**846**
• **Sink** *(SN)*	11%	155	169
• **Dish Washer** *(DW)*	3%	42	46
Kitchen *(SN+DW)*	14%	198	215
Strong Grey Water *(sGW) (WM+SN+DW)*	39%	550	600

5.2 Areas of Reuse and Scenarios

Following the selection of study area, the next step is the evaluation of possible end-use purposes. In and around the selected neighborhood, several reuse areas that might not require potable water quality are determined. The water consumption for these areas are determined based on actual water consumptions obtained from local water authority and environmental management departments of industrial zones. In Table 5.2, all possible end-use purposes around the study area are given in detail together with seasonal changes.

Since proximity is one of the main concerns effecting the cost of grey water reuse systems, it is significant for treated grey water to be reused as close as possible to where it is originated from. For this reason, toilet flushes of Yenikent Neighborhood have one of the highest potential for on-site reuse of grey water. In order to determine the amount of water discharged for toilet flushing, it is assumed that 25% of domestic water consumption is used for toilet flushes [9].

As four of 13 organized industrial zones in Kocaeli are located in Gebze district, 35% of total industrial water consumption takes place here especially in Gebze Organized Industrial Zone and Gebze Guzeller Organized Industrial Zone [1] [3]. As mentioned earlier in Chapter 4.1, Yuvacik Dam is the main water reserve of these industrial sites which is located around 70-80 km away. This distance between source and demand legitimates the reuse of grey water for industrial purposes in the location where it is generated. In order to prevent health risks, food, pharmaceutical, and chemical industries are excluded from the scope of this study. As a result of discussions with Gebze and Guzeller Organized Industrial Zones, cooling is turned out to be the most possible industrial end-use with the highest water consumption as shown in Table 5.2.

Irrigation is another potential end use area, since landscape irrigation is applied not only around households in Yenikent, but also in organized industrial zones and Gaziler Natural Park. In Table 5.2, the water consumption for all possible irrigational purposes are given on a monthly basis to observe the seasonal changes.

For financial and environmental assessment of grey water reuse applications, different type of scenarios are developed based on these potential reuse areas. Determining the scenarios, quantity of grey water and its fractions (from Table 5.1) are compared with water demand for each end-use purpose (from Table 5.2). As proximity is one of the factors effecting cost of grey water reuse systems, proximity is also considered at the decision stage.

Table 5.2: End-use Potentials in Yenikent Neighborhood. (m^3/d)

Area of Reuse	January	February	March	April	May	June	July	August	September	October	November	December
TOILET FLUSH - Yenikent	447	420	404	464	426	425	422	430	449	399	457	427
IRRIGATION												
Yenikent	6	6	2	50	41	128	104	160	142	36	29	7
Gaziler Dagi	79	112	116	123	160	273	233	328	314	114	92	70
Gebze OIZ	-	-	-	-	500	500	500	500	500	-	-	-
Guzeller OIZ	-	-	-	-	8	8	8	8	8	-	-	-
Gebze WWTP	-	-	-	-	120	240	240	240	120	-	-	-
TOTAL	88	122	122	179	852	1,179	1,112	1,269	1,116	155	126	80
COOLING (and other												
Gebze WWTP-sludge dewatering	59	65	59	61	59	61	59	59	61	59	61	59
Gebze OIZ-cooling	791	902	770	978	808	1,235	916	1,326	764	641	999	808
Guzeller OIZ-cooling	42	46	42	43	42	43	42	42	43	42	43	42
TOTAL	919	1,048	897	1,117	936	1,382	1,048	1,471	895	764	1,138	937
URBAN CLEANING												
Gebze-streets	0.32	0.36	0.32	0.33	0.32	0.33	0.32	0.32	0.33	0.32	0.33	0.32
Gebze WWTP-onsite cleaning	39	43	39	40	39	40	39	39	40	39	40	39
TOTAL	39	43	39	40	39	40	39	39	40	39	40	39
CAR WASH - Yenikent	3	4	4	4	5	3	4	4	2	3	6	3
SWIMMING POOL - Yenikent	1.68	1.54	0.10	0.10	0.81	0.13	0.16	1.42	0.20	0.19	0.23	0.16

In Table 5.3, determined scenarios are illustrated with color and number codes, where Scenario 1 has two options, 1-A and 1-B. According to this table, scenarios are as follows;

- *Scenario 1-A:* Reuse of weak grey water for toilet flushing in Yenikent.

- *Scenario 1-B:* Reuse of weak grey water for toilet flushing, urban cleaning, and car wash in Yenikent.

- *Scenario 2:* Reuse of mixed grey water for cooling in Gebze and Guzeller Organized Industrial Zone

- *Scenario 3:* Reuse of bathroom grey water for cooling in Gebze Organized Industrial Zone.

- *Scenario 4:* Reuse of bathroom grey water for irrigation in Yenikent, Gaziler Natural Park, Gebze and Guzeller Organized Industrial Zone during dry seasons (5 months from May to September) and toilet flushing in Yenikent rest of the year (during 7 months).

In Figure 5.1, annual flow rate change for each scenario are illustrated. The graphs shows that water consumption for not only landscape irrigation, but also for cooling processes depends on the season which might conclude in need of tap water addition during dry seasons.

Table 5.3: Determination of scenarios.

Grey Water Fractions

	Avg. m^3/d	Scenario	
Shower/Bathtub (SH/BT)	354		
Wash Basin (WB)	108		
Weak Grey Water (SH/BT+WB)	**461**	1A	1B
Washing Machine (WM)	384		
Bathroom (SH/BT+WB+WM)	**846**	4	3
Sink (SN)	169		
Dish Washer (DW)	46		
Kitchen (SN+DW)	**215**		
Mixed Grey Water (SH/BT+WB+WM+SN+DW)	**1,061**	2	

Area of Reuse

	Prox. (km)	Avg. m^3/d	Scenario		
Yenikent	0	431			
TOILET FLUSH		**431**	1A	1B	4
Yenikent	0	59	4		
Gaziler Natural Park	0.65	168	4		
Gebze OIZ	2.7	500	4		
Guzeller OIZ	2.1	8	4		
Gebze WWTP	6.2	192			
IRRIGATION		**927**			
Gebze WWTP-sludge dewatering	6.2	60			
Gebze OIZ-cooling	2.7	911	3	2	
Guzeller OIZ-cooling	2.1	42		2	
COOLING (and other processes)		1,014			
Gebze-streets		0.33			
Gebze WWTP-onsite cleaning	6.2	39			
URBAN CLEANING		40	1B		
Yenikent		4			
CAR WASH		4	1B		
Yenikent		1			
SWIMMING POOL		1			

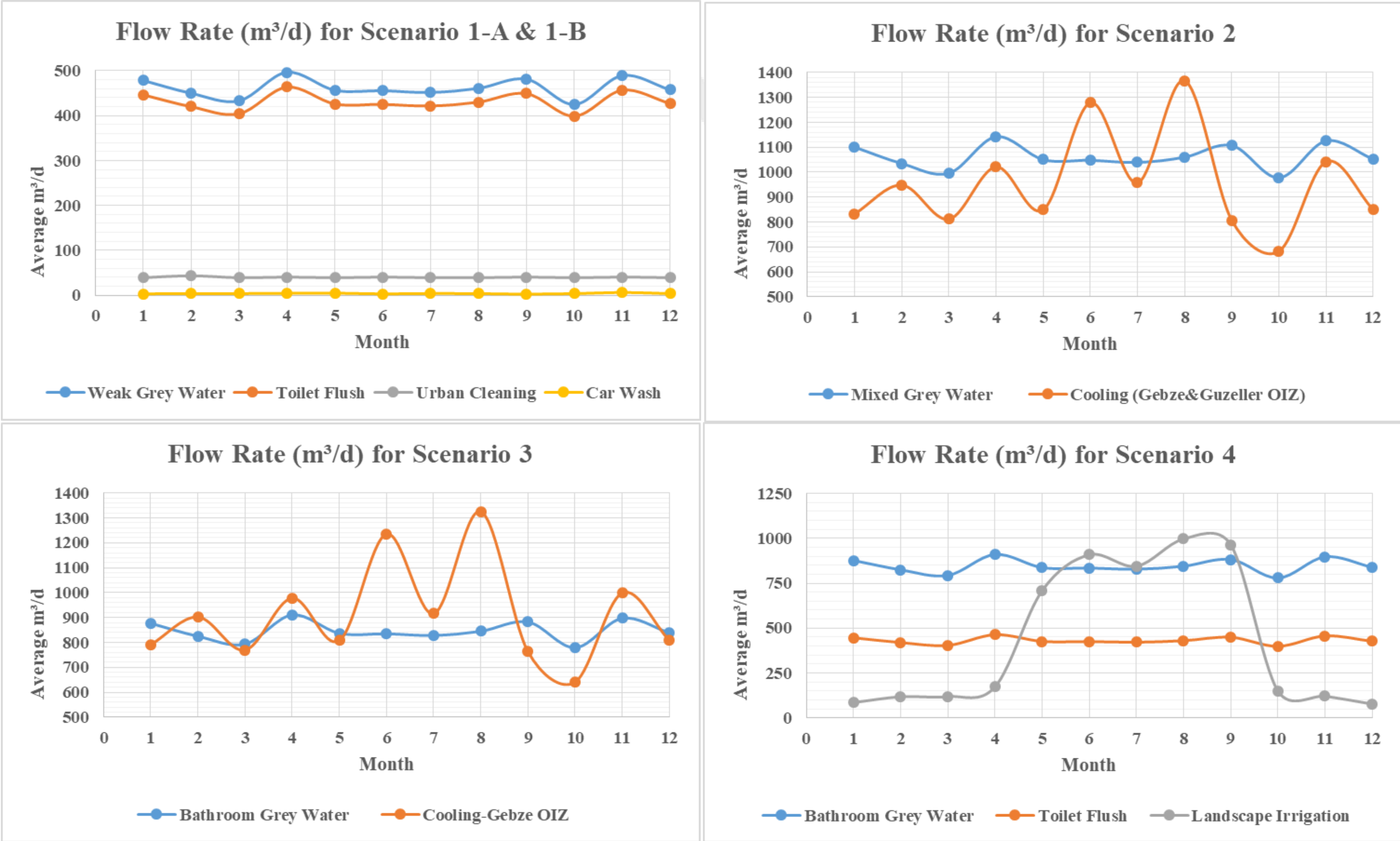

Figure 5.1: Seasonal water demand and grey water production for scenarios.

5.2.1 Scenario 1: Reuse of weak grey water for toilet flushing

Scenario 1-A refers to reuse of weak grey water for toilet flushing in Yenikent Neighborhood. In the cases where weak grey water generation is higher than the water demand for toilet flushing, it could be reused for urban cleaning and car wash in the neighborhood which is presented as Scenario 1-B.

Figure 5.2 illustrates the comparison of current situation with the implementation of Scenario 1, where the actual water volumes are given in black (from Table 5.1 and 5.3) and water balances are marked with red. The water balances are created assuming that the volume of domestic wastewater generated is equal to 100 units.

The first section of Figure 5.2 illustrates that all type of water demand in selected neighborhood is currently supplied by tap water, including toilet flushes. In other words toilet reservoirs are supplied by water which is in drinking water quality. Similarly, some of the water consumed for car wash and urban cleaning is met by tap water, which is conveyed by not pipelines but water trucks. Evaluation of the water balances are later discussed in Chapter 5.4.1.

In the case of implementation of Scenario 1, weak grey water collected from Yenikent Neighborhood is reused for toilet flushing in the same neighborhood where it is generated. For all the other purposes, potable water is still consumed. However, as grey water is separated from whole domestic wastewater, the volume of wastewater treated in conventional treatment plants is reduced to volume of black water and strong grey water.

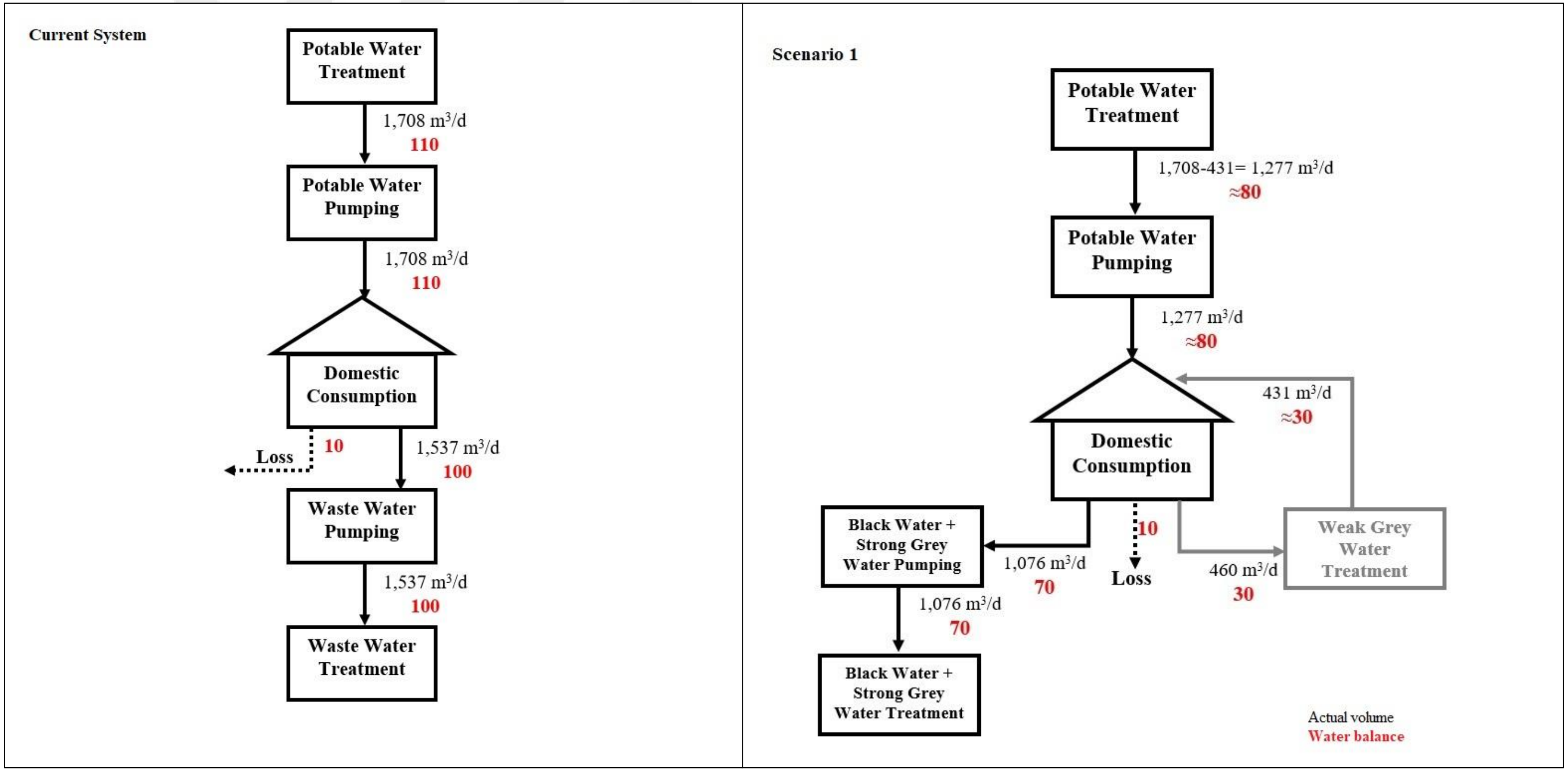

Figure 5.2: Comparison of current system with Scenario 1.

*(*water balances based on 100% wastewater volume)*

5.2.2 Scenario 2: Reuse of mixed grey water for cooling

Scenario 2 refers to reclamation of mixed grey water (collected from Yenikent) for cooling purposes in Gebze and Guzeller Organized Industrial Zones. Figure 5.3 illustrates the comparison of current situation with Scenario 2, where the actual water volumes are given in black (from Table 5.1 and 5.3) and the water balances are marked with red. Evaluation of the water balances are later discussed in Chapter 5.4.1.

The water demand for cooling in industrial zones is currently supplied by water resources in drinking water quality. In the case of implementation of Scenario 2, mixed grey water collected from Yenikent Neighborhood is reused for cooling in Gebze and Guzeller industrial zones that are situated 2.7 and 2.1 km respectively. As mixed grey water is collected separately, only black water originating from selected neighborhood is processed in existing wastewater treatment system. In other words, the volume of wastewater treated in conventional system is reduced to volume of black water. In the seasons where grey water generation is not sufficient to meet cooling water demands, grey water reclamation system could be supported by tap water from existing water network.

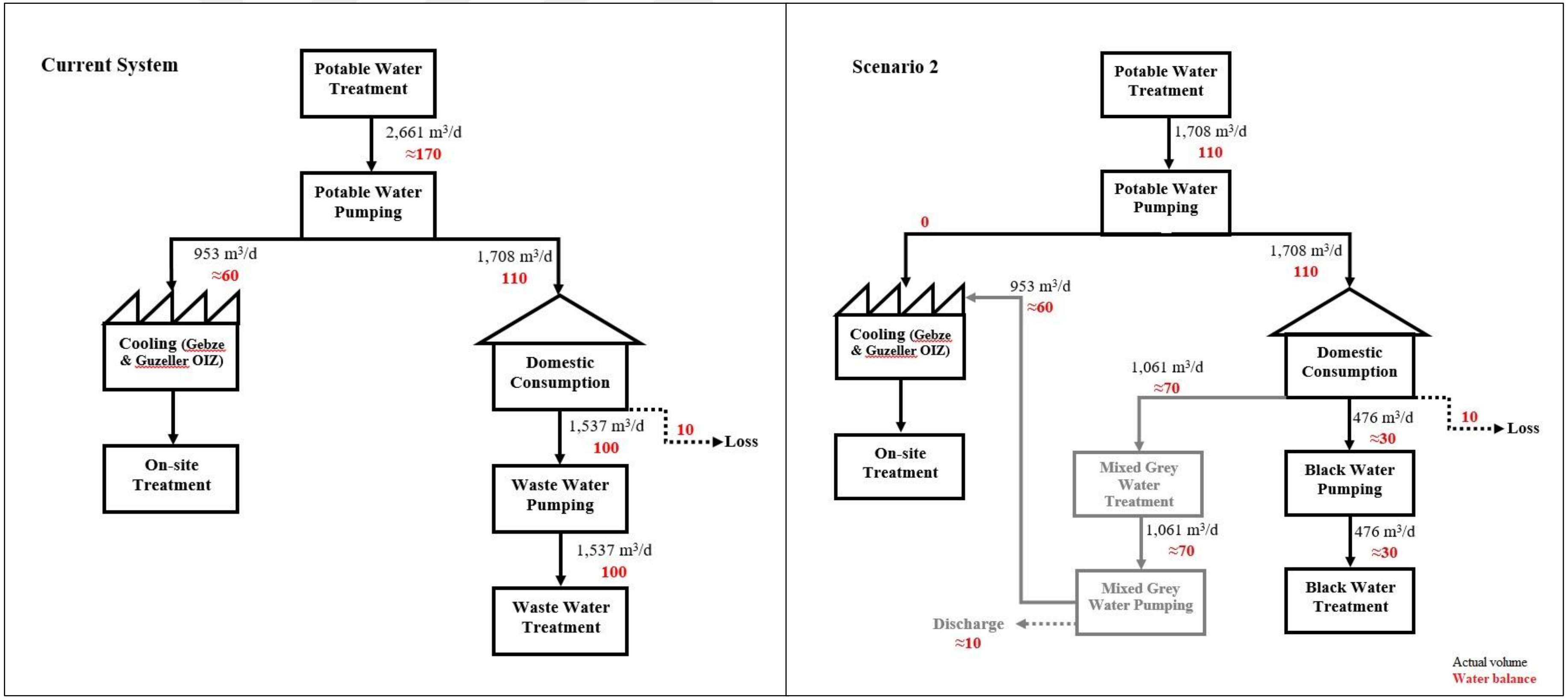

Figure 5.3: Comparison of current system with Scenario 2.

*(*water balances based on 100% wastewater volume*

5.2.3 Scenario 3: Reuse of mixed grey water for cooling

Similar to Scenario 2, Scenario 3 also contains reuse of grey water for cooling purposes in Gebze Organized Industrial Zone that is situated 2.7 km away. Different than Scenario 2, grey water is revaluated in only one location for the reduction of proximity between grey water source and reuse area. Since weak grey water volume is not sufficient to meet the demand for cooling, bathroom grey water is considered to be reclaimed for this scenario. Another reason for bathroom grey water to be chosen is its compactness to be collected as it is generated in one spot in a household.

Figure 5.4 illustrates the comparison of current system with the case of implementation of Scenario 3, where the actual water volumes are given in black (from Table 5.1 and 5.3) and the water balances are marked with red. Evaluation of the water balances are later discussed in Chapter 5.4.1.

The water demand for cooling in Gebze Industrial Zones is currently supplied from existing tap water network of the city. In the case of implementation of Scenario 3, as bathroom grey water is collected separately, black water and grey water originated from kitchens are processed in existing wastewater treatment system. In this scenario, during the seasons where grey water generation is not sufficient to meet cooling water demands, grey water reclamation system could be supported by tap water (the existing source of cooling water demand).

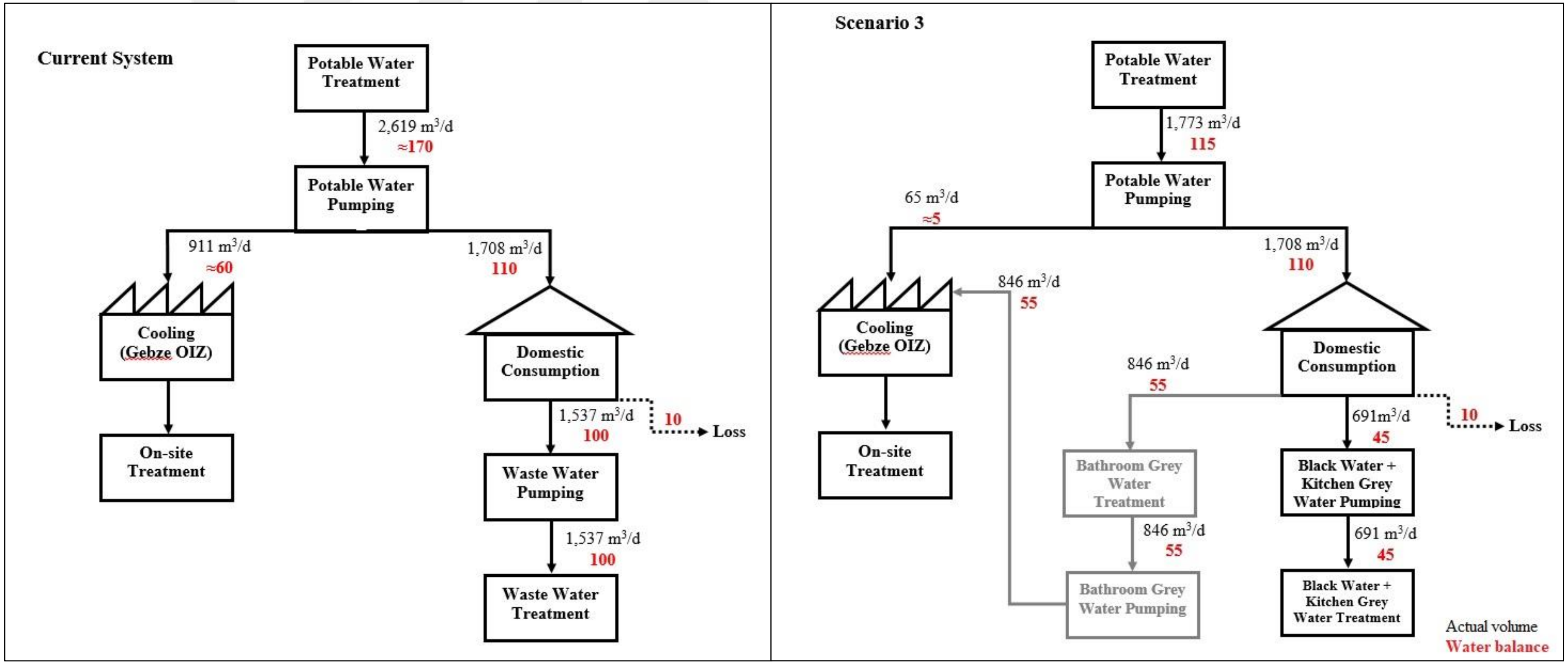

Figure 5.4: Comparison of current system with Scenario 3.

*(*water balances based on 100% wastewater volume)*

5.2.4 Scenario 4: Reuse of bathroom grey water for irrigation and toilet flushing

Scenario 4 refers to reuse of bathroom grey water (collected from Yenikent Neighborhood) for landscape irrigation in Yenikent, Gaziler Natural Park, Gebze and Guzeller Organized Industrial Zone and toilet flushing in Yenikent. While some of reclaimed grey water is reused on-site in Yenikent for irrigation, the rest is revaluated in areas situated 0.6 km (Gaziler Natural Park), 2.7 km (Gebze OIZ), and 2.1 km (Guzeller OIZ).

While bathroom grey water is reused for irrigation during dry seasons for 5 months from May to September, the rest of the year (during 7 months), it is reused for toilet flushing in the neighborhood.

While Figure 5.5 illustrates the current situation, Figure 5.6 represents the seasonal applications of Scenario 4, where the actual water volumes are given in black (from Table 5.1 and 5.3) and the water balances are marked with red. Evaluation of the water balances given for selected reuse areas are later discussed in Chapter 5.4.1.

The water demand for cooling in Gebze Industrial Zones is currently supplied by water in drinking water quality. In the case of implementation of Scenario 3, as bathroom grey water is collected separately, black water and grey water originated from kitchens are processed in existing wastewater management system. In this scenario, during the seasons where grey water generation is not sufficient to meet cooling water demands, grey water reclamation system could be supported by tap water as it is currently provided.

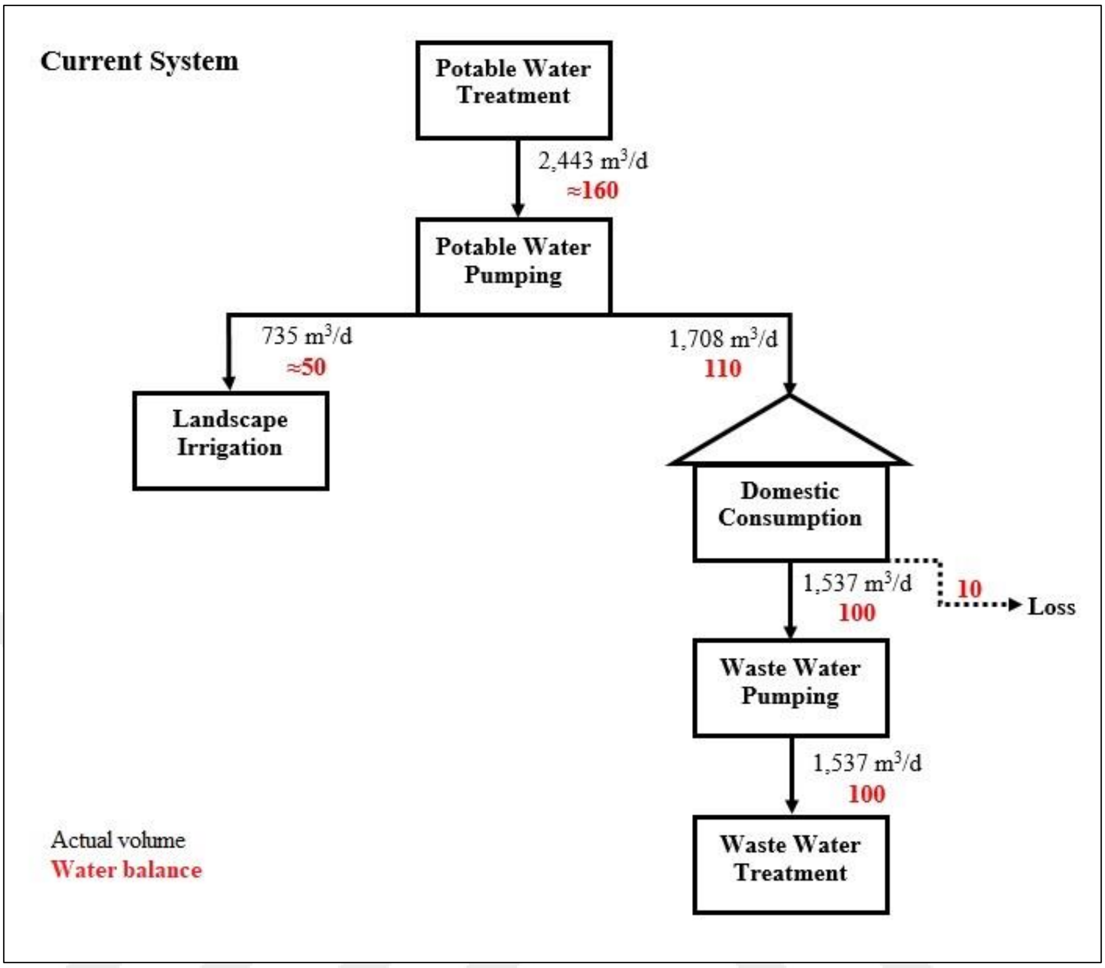

Figure 5.5: Current system (for Scenario 4).

*(*water balances based on 100% wastewater volume)*

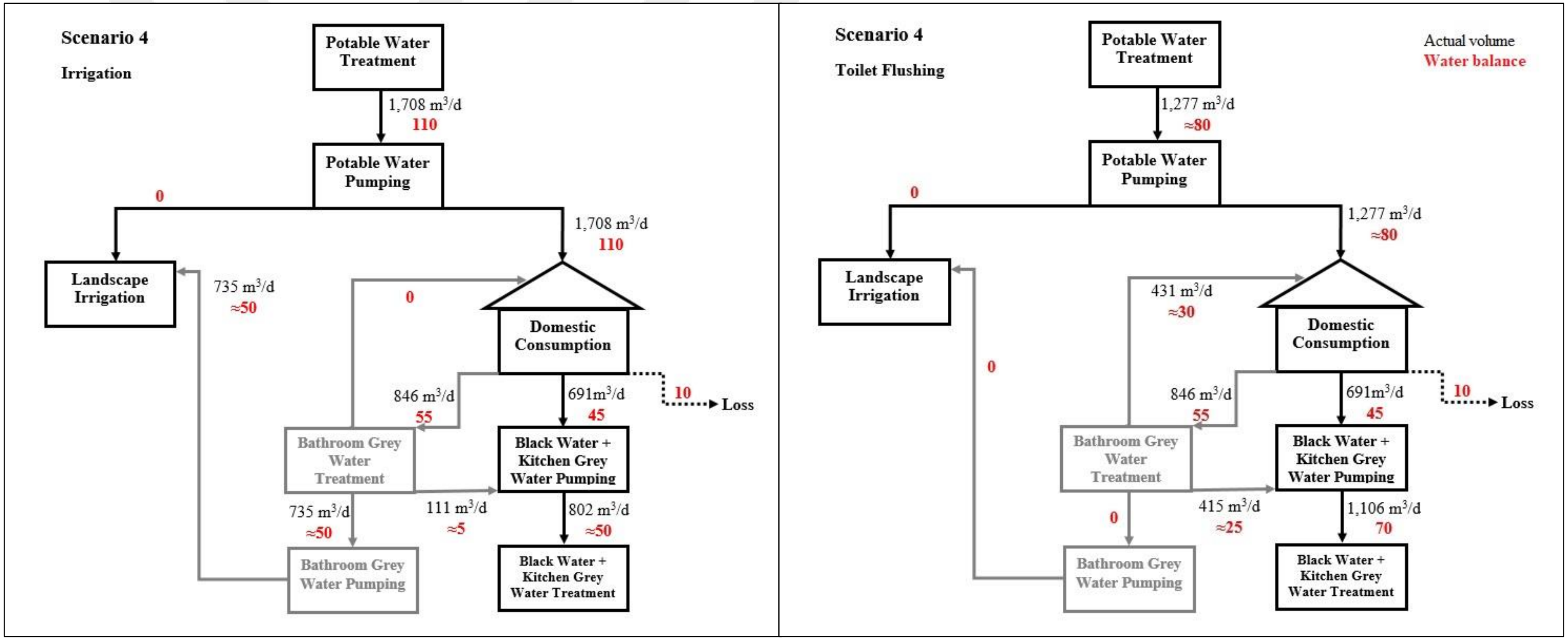

Figure 5.6: Seasonal implementation of Scenario 4.

*(*water balances based on 100% wastewater volume)*

5.3 Treatment Methods for Scenarios

The treatment method, which is selected in conformity with the end-use purpose, is generally a biological process as a result of high organic matter content of grey water. However biodegradability of the organic matter should be considered prior to selection of biological treatment process and C:N:P ratio in grey water is also essential in terms of the efficiency of treatment process. For this reason, COD/BOD and C:N:P ratios are calculated for each stream as given in Table 5.4.

Table 5.4: Biodegradability of grey water in Yenikent Neighborhood.

		Grey Water Fraction		
Parameter	**Unit**	**Mixed [(1)]**	**Weak [(2)]**	**Bathroom [(3)]**
BOD	*mg/L*	119	81	40
COD	*mg/L*	347	145	445
TKN	*mg/L*	8		1
T.N	*mg/L*		6.2	10
T.P	*mg/L*	9.8	0.25	3
COD/BOD		2.9	1.7	11
C:N:P [(4)]		100:6.7:8.2	100:7.6:0.3	100:25:7.5

(1) *Mixed GW refers to SH/BT, WB, WM, KS, DW*
(2) *Weak GW refers to SH/BT, WB*
(3) *Bathroom GW refers to SH/BT, WB, WM*
(4) *BOD:TKN:T.P for mixed grey water, BOD:T.N:T.P for weak and bathroom grey water*

In Table 5.4, the COD/BOD ratios are calculated as 2.9 and 1.7 for mixed and weak grey water respectively. Organic matter in mixed and weak grey water shows high biodegradability since COD/BOD ratios are similar to the ones that is reported in literature for biodegradable grey water (COD/BOD: 2.9 for bathroom grey water, 2.8 grey water from shower and bathtub, and 3.6 for hand wash basin grey water [8]). However, grey water originated from bathroom has non-biodegradable characteristic indicating COD/BOD ratio of 11 in this case. Considering all these information, biological treatment processes are suitable for mixed and grey water, while bathroom grey water in this case cannot be defined as easily biodegradable.

As mentioned before, one of the factors that affect the efficiency of biological treatment is the balance between nutrients and organic substances. In this context, biodegradable mixed and weak grey water streams are evaluated. The average ratio of BOD:TKN:T.P for mixed grey water is computed as 100:6.7:8.2, which is lower in nitrogen but higher in phosphorus in comparison with optimum C:N:P ratio (100:20:5) for biological treatment reported in literature [8]. These ratios indicate that both mixed and weak grey water are nitrogen limited for microbial growth.

In the light of the above findings, MBR system is selected and designed for Scenario 1 and 2 as they address mixed and weak grey water reuse. Treatment system without a biological process is found appropriate for the treatment of grey water originating from bathroom. In other words, UF system is selected for Scenario 3 and 4 that indicate bathroom grey water reuse.

5.3.1 Membrane bioreactor for scenario 1

The nitrogen load of weak grey water in this study is too low to require particular treatment for N-removal as given in Table 5.5. Depending on the limits presented in

Table 5.5: Influent and effluent quality for Scenario 1.

		Influent (1)	**Effluent** (1)			**% Treat. Req.**
Flow	*m^3/d*	460	431	40	4	
		Yenikent (2)	Reuse Standards (3)			
		Weak GW	**Toilet Flushing**	**Urban Cleaning**	**Car Wash**	
pH			6.5 - 8.5	6.5 - 8.5	6.5 - 8.5	
Turbidity	*NTU*		5	5	5	
BOD	*mg/L*	81	10	10	10	88
COD	*mg/L*	145				
TSS	*mg/L*	40.3	10	10	10	75
T.N	*mg/L*	6.2	10	10	10	0
T.P	*mg/L*	0.25				
T.Coliform	*cfu/100m*					
E.Coli	*cfu/100m*		10		10	
Faecal Coli	*cfu/100m*		200	200		

(1) Table 5.3; (2) Table 4.3; (3) Table 4.5

Table 5.5, nitrogen concentration in weak grey water already meets the grey water reuse limits for toilet flushing, urban cleaning, and car wash.

The MBR system with the capacity of 460 m^3/d is designed based on influent and effluent quality in Table 5.5 by following the method given in Chapter 4.5. Required membrane area (A_m) is determined as 1,370 m^2 as given in Table 5.6. According to calculated membrane area, 1 of 1,500 m^2 UF-pore-sized membrane module available on market is selected for Scenario 1. The specifications of this module is as given below in Table 5.7.

Table 5.6: MBR design - Scenario 1.

Design Parameter	Result	Ref.
Flow (Q)	460 m^3/d	Scenario 1
Peak influent flow rate (Q_{peak})	920 m^3/d = 38,333 L/h	Eq. (4.5)
Net Flux (J_{net})	20 LMH	Table 4.6
Maximum allowed flux ($J_{net,peak}$)	28 LMH	Eq. (4.4)
Membrane area (A_m)	1,370 m^2	Eq. (4.3)
Available membrane module area on market	1,500 m^2	[89]
Membrane packing density in membrane tanks (φ_{tank})	150.5 m^2/m^3	[89]
Minimum required membrane tank volume ($V_{m,min}$)	9.96 ≈ 10 m^3	Eq. (4.6)
Hydraulic retention time in aeration tank (HRT or Ө)	10 h	Table 4.6
Aeration tank volume (V_{aer})	190 m^3	Eq. (4.7)

Following the method given in Chapter 4.5.2, estimated effluent quality is calculated as presented in Table 5.8 and it indicates that designed MBR system meets the requirements for reuse areas selected for Scenario 1.

Table 5.7: Membrane module specifications – Scenario 1&2.

Product Description		
Manufacturer		KOCH
Product		PSH 1500
Membrane Type		HF
Nominal Pore Size	*µm*	0.03
Area	m^2	1500
Module Dimensions		
Length	*mm*	2,244
Width	*mm*	1,755
Height	*mm*	2,530

Adopted from [89]

Table 5.8: Estimated effluent quality of MBR - Scenario 1.

	Influent (1)	% Efficiency (2)	Effluent
BOD	81	95	4
TSS	40.3	97	1.2
T.N	6.2	78	1.4
T.P	0.25	40	0.1

(1) Weak grey water in Yenikent Neighborhood; (2) Adopted from [9]

5.3.2 Membrane bioreactor for scenario 2

The same method explained in Chapter 4.5 is followed for the MBR design for Scenario 2, where mixed grey water is planned to be reused for several cooling purposes. As the nutrient load of mixed grey water in this study is also too low (almost under the limits given for cooling in Table 5.9), MBR system doesn't include particular treatment for N-removal.

The design results for 1,000 m^3/d capacity MBR are given in Table 5.10. The required membrane area (A_m) is determined as 2,976 m^2. According to calculated membrane area, 2 of the same membrane module selected for Scenario 1 is chosen, since it provides 3,000 m^2 area in total. (Module specifications: Table 5.7.)

Table 5.9: Influent and effluent quality for Scenario 2.

		Influent (1)	Effluent (1)	% Treat. Require.
Flow	*m^3/d*	1,000	953	
		Yenikent (2) Mixed Grey Water	Reuse Standards (3) Cooling	
pH		7.1	6.5 - 8.5	
Turbidity	*NTU*	103	5	95
BOD	*mg/L*	119	10	92
COD	*mg/L*	347		
TSS	*mg/L*	79	30	62
T.N	*mg/L*		10	0
TKN	*mg/L*	8		
NH4-N	*mg/L*	2.2		
T.P	*mg/L*	9.8		
E.Coli	*cfu/100*		0	
Faecal Coli	*cfu/100*		200	

(1) Table 5.3; (2) Table 4.3; (3) Table 4.5

Table 5.10: MBR design – Scenario 2.

Design Parameter	Result	Ref.
Flow (Q)	1,000 m^3/d	Scenario
Peak influent flow rate (Q_{peak})	2,000 m^3/d = 83,333 L/h	Eq. (4.5)
Net Flux (J_{net})	20 LMH	Table 4.6
Maximum allowed flux ($J_{net,peak}$)	28 LMH	Eq. (4.4)
Membrane area (A_m)	2,976 m^2	Eq. (4.3)
Available membrane module area on market	1,500 x 2 m^2	[89]
Membrane packing density in membrane tanks (φ_{tank})	150.5 m^2/m^3	[89]
Minimum required membrane tank volume ($V_{m,min}$)	19.9 ≈ 20 m^3	Eq. (4.6)
Hydraulic retention time in aeration tank (HRT or Θ)	10 h	Table 4.6
Aeration tank volume (V_{aer})	420 m^3	Eq. (4.7)

Following the method given in Chapter 4.5.2, estimated effluent quality is calculated as presented in Table 5.11 and it indicates that designed MBR system meets the requirements for reuse areas selected for Scenario 2.

Table 5.11: Estimated effluent quality of MBR - Scenario 2.

	Influent [1]	% Efficiency [2]	Effluent
BOD	119	95	6
TSS	79	94	5
Turbidity	103	100	0
TKN	8	92	0.6
TP	9.8	50	4.9

[1] Mixed grey water in Yenikent ;[2] Adopted from [83], [94], and [93]

5.3.3 Ultrafiltration for scenario 3 and scenario 4

Removal efficiencies and effluent quality for Scenario 3 and 4 are estimated to be the same as the influent grey water fraction (bathroom grey water) and the treatment systems are identical. Following the method given in Chapter 4.5.4, estimated effluent quality is calculated as presented in Table 5.12 and it indicates that designed UF system meets the requirements for reuse areas selected for Scenario 3 and 4.

Table 5.12: Estimated effluent quality of UF - Scenario 3&4.

	Influent [1]	% Efficiency [2]	Effluent
BOD	40	95	2
TSS	78	94	5
T.N	10	92	0.8
T.P	3	50	1.5

[1] Mixed grey water in Yenikent Gebze; [2] Adopted from [9]

5.4 Assessment of the Scenarios

Within the scope of this study, each scenario is investigated in terms of environmental, financial and social sustainability through an appraisal of technical and economical applicability and public acceptance.

5.4.1 Examining the water balances and savings

Scenario 1

Water demands for toilet flushing, car wash and urban cleaning in Yenikent Neighborhood which is selected as end-use purpose for Scenario 1 is compared with reclaimable weak grey water volume. As a result, additional tap water feed and water savings are calculated as presented in Table 5.13.

As estimated weak grey water flow is higher than the water consumption in selected neighborhood, there would no need for potable water use for toilet flushes. Due to the implementation of Scenario 1-A, potable water saving would be 100% and additional treated weak grey water would be available for other uses.

The water demand for reuse purposes estimated for Scenario 1-B is currently supplied by tap water in Yenikent Neighborhood. In the case of implementation of Scenario 1-B, the water demand for toilet flushing and car wash could be supplied by treated grey water completely. Together with urban cleaning, great majority of water demand for these specific end-use purposes could be met by reclaimed grey water collected in the neighborhood. The consumption of potable water (which is extracted from the main water reserve located almost 50 km away) would decrease to approximately 13 m^3/d. In other words, daily potable water saving for Scenario 1-B would be at least 96%.

Table 5.13: Water balance for Scenario 1-A&B.

	Water Consumption (m^3/d)				Water Source (m^3/d)		% Water Saving
	Toilet Flushing	Urban Cleaning	Car Wash	Total	Weak Grey Water	Tap Water	S 1-B
Jan.	447	39	3	489	478	10	98
Feb.	420	43	4	467	450	17	96
Mar.	404	39	4	447	433	14	97
Ap.	464	40	4	508	497	11	98
May	426	39	5	470	457	13	97
June	425	40	3	469	456	13	97
July	422	39	4	465	452	13	97
Au.	430	39	4	473	461	12	97
Sep.	449	40	2	492	481	11	98
Oct.	399	39	3	441	425	16	96
Nov.	457	40	6	503	489	14	97
Dec.	427	39	3	470	458	12	97

Scenario 2

For the assessment of Scenario 2 in terms of water savings, water demand for cooling is compared monthly with reclaimable mixed grey water flow in Yenikent Neighborhood. As a result, possible tap water need and water savings are calculated as presented in Table 5.14.

If Scenario 2 is implemented in selected study area of Scenario 1-A, cooling water demand could be met by separation of mixed grey water generated pretty close to reuse area during 10 months in a year. In other words, during 10 months, it is possible to consume reclaimed grey water for all cooling purposes in study area instead of potable water. During only 2 months in dry season, around 200-300 m^3/d tap water addition is needed. Even in these premises, potable water consumption would drop about 78 and 82%.

Table 5.14: Water balance for Scenario 2.

	Water Consumption (m^3/d)			Water Source (m^3/d)		% Water Saving
	Cooling-Gebze OIZ	Cooling-Guzeller OIZ	Total	Mixed Grey Water	Tap Water	
Jan.	791	42	833	1,100		>100
Feb.	902	46	948	1,035		>100
Mar.	770	42	811	996		>100
Ap.	978	43	1,021	1,142		>100
May	808	42	849	1,050		>100
June	1,235	43	1,278	1,048	230	82
July	916	42	957	1,039		>100
Au.	1,326	42	1,367	1,060	307	78
Sep.	764	43	807	1,107		>100
Oct.	641	42	682	977		>100
Nov.	999	43	1,042	1,126		>100
Dec.	808	42	850	1,052		>100

Scenario 3

Water balance for Scenario 3 given in Table 5.15 shows that grey water collected from bathroom is sufficient to meet cooling water demand in Gebze Organized Industrial Zone. While water consumption for cooling water could be met by bathroom grey water during half of the year, water saving ranges between 64% and 94% during the months when tap water addition is needed.

Table 5.15: Water balance for Scenario 3.

	Water Consumption (m^3/d)	Water Source (m^3/d)		% Water Saving
	Cooling - Gebze OIZ	Bathroom Grey Water	Tap Water	
Jan.	791	877		>100
Feb.	902	825	77	91
Mar.	770	794		>100
Ap.	978	911	68	93
May	808	837		>100
June	1,235	835	400	68
July	916	828	88	90
Au.	1,326	845	481	64
Sep.	764	882		>100
Oct.	641	779		>100
Nov.	999	897	102	90
Dec.	808	839		>100

Scenario 4

For Scenario 4, treated grey water originating from bathroom is planned to be reused in landscape irrigation during 5 months of dry season and rest of the year (7 months) it is planned to be revaluated for toilet flushing.

During the period that grey water is utilized for toilet flushing, it is possible to meet all water demand with reclaimed water as shown in Table 5.16. However, during irrigational use, tap water addition to reclaimed grey water is necessary to meet all demand for landscape irrigation. While water savings are as high as 98% in the beginning of dry season (May), the saving ranges between 67 to 79%.

Table 5.16: Water balance for Scenario 4.

	Water Consumption (m^3/d)		Water Source (m^3/d)		% Water Saving
	Toilet Flushing	Irrigation	Bathroom Grey Water	Tap Water	
Jan.	447		877		>100
Feb.	420		825		>100
Mar.	404		794		>100
Ap.	464		911		>100
May		852	837	15	98
June		1,179	835	344	71
July		1,112	828	284	74
Au.		1,269	845	424	67
Sep.		1,116	882	234	79
Oct.	399		779		>100
Nov.	457		897		>100
Dec.	427		839		>100

5.4.2 Financial assessment

Financial assessment of each scenario is investigated in three steps; calculation of capital expenditure (CAPEX), operational expenditure (OPEX), and pay-back period. While the capital expenditure of each scenario contains the investment cost of the selected treatment method, grey water collection system in buildings, and treated grey water distribution pipes to various reuse areas; the operational expenditures indicate the energy and chemical consumptions.

5.4.2.1 Financial assessment of scenario 1

Scenario 1-A indicates the reclamation of weak greywater and reuse for toilet flushing after MBR treatment and disinfection. As treated grey water is reused in the neighborhood where it is generated, investment cost of Scenario 1 doesn't cover the expenditures arising from treated grey water distribution pipes to different reuse locations, however in-building treated grey water pipes should be considered for financial assessment.

Capital Expenditure (CAPEX) of Scenario 1

For Scenario 1-A and 1-B, weak grey water should be collected separately in Yenikent Neighborhood, since weak grey water stream is considered to be reclaimed by an MBR system. While current in-building pipelines could be used for the collection of black water and strong grey water, a new pipeline needs to be installed in order to collect weak grey water originated from shower, bathtub, and wash basin. Similarly, a new plumbing system is necessary to feed treated grey water to toilet flushes. Taking into account all of these factors, a new plumbing system is designed to convert the conventional one into grey water-friendly version as illustrated in Figure 5.7. and the cost of grey water plumbing system per apartment/household is given in Table 5.17.

Table 5.17: Plumbing system cost for Scenario 1-A & B

	USD/household	
	Conversion cost in existing buildings	**Extra cost in new building projects**
Bathroom	**1,100**	**-**
Pipe (Toilet flush feed, 32Ø)	30	
Tiles	730	
Construction and Labor Costs	340	
Lavatory	**700**	**-**
Pipe (Toilet flush feed, 32Ø)	20	
Tiles	540	
Construction and Labor Costs	140	
Void	**30**	**30**
Pipe (Grey water collecting, 150Ø)	20	20
Pipe (Toilet flush feed, 50Ø)	10	10
TOTAL	**1,830**	**30**

While the cost of plumbing system conversion in an existing building is estimated as 1,830 USD per household/apartment, the total capital expenditure for Scenario 1 is also related to selected treatment system. In this case, capital cost of 460 m^3 capacity MBR system followed by chlorine disinfection is 230,000 USD. Considering that there are approximately 5,000 domestic subscribers in Yenikent Neighborhood, the capital cost of treatment system is computed as 46 USD per household which covers of 2.4% of total investment cost for an household [101]. For the implementation of grey water reuse systems, it could be indicated that conversion of current plumbing systems in an existing neighborhood is not financially feasible as almost 98% of total investment cost is spent for in-building implementations. Table 5.17 shows that investment cost of grey water plumbing systems is reduced to approximately 30 USD per household, if it is implemented in new building projects. Assuming that there are 5,000 households in neighborhood capital cost of grey water plumbing and treatment system is 380,000 USD in total (treatment system: 230,000 USD, plumbing system: 150,000 USD).

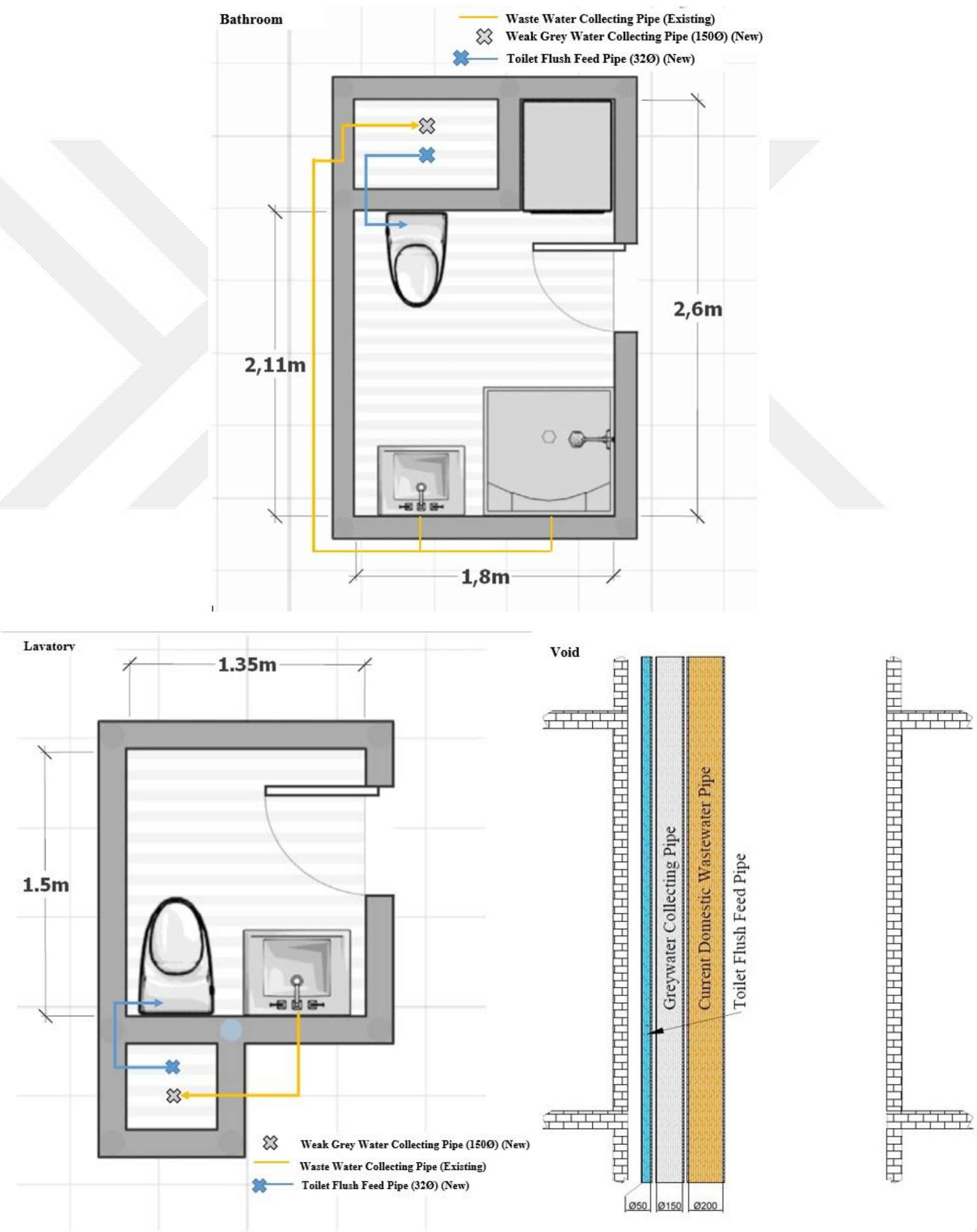

Figure 5.7: Plumbing system for Scenario 1-A & B.

Operational Expenditure (OPEX) of Scenario 1

Operational expenditure of this MBR system is calculated based on energy consumption by pumps and blowers, chemical consumption for disinfection and cleaning of membranes. For the calculation of energy expenditures, the capacities of each equipment, operating times, and unit energy cost are required. One operation cycle of the MBR system is defined as 14 mins of filtration followed by backwash for a minute. Chemical cleaning of membranes is assumed to be applied 3 times a year for an hour, which is enhanced with sodium hypochlorite.

The capacities of the pumps and blowers are given in Table 5.18 depending on the manufacturer specifications available on market. Depending on these capacities and estimated operating times, the energy consumption together with the costs is calculated. Due to their marginal capacities, the chemical dosing pumps are neglected in OPEX estimation. Covering 68% of energy cost, the blowers used for membrane scouring and biological treatment consumes the highest amount of energy as shown in Table 5.18.

Table 5.18: Energy cost of MBR system for Scenario 1.

Equipment	**Available Capacity on Market**	**Operating Time**	**Daily Consumption**	**Daily Cost**	**Annual Cost**
	kW	*h/d*	*kWh/d*	*USD/d*	*USD/year*
Influent Pump	2.2	24	52.8	4.75	1,734
Recirculation Pump	2.2	24	52.8	4.75	1,734
Effluent and Backwash Pump	1.5	24	36	3.24	1,183
Chemical Cleaning-Dosing Pump	0.37	0.008			
Disinfection-Dosing Pump	0.37				
Membrane Tank Blower	7.5	22	165	14.85	5,420
Aeration Tank Blower	5.5	24	132	11.88	4,336
TOTAL				**14,408 USD/year**	

In contradiction to the energy cost, chemical consumption comprises a pretty small part of total operational expenditure. The consumption and cost for chemical cleaning is calculated based on the chemically enhanced backwash procedure mentioned earlier. Chemical consumption for disinfection unit also contributes to total cost. Depending on treated grey water quality requirements mentioned in Chapter 2.4, the residual chlorine is assumed as 0.5 mg/L. The consumption and the cost of sodium hypochlorite are calculated as given in Table 5.19.

Table 5.19: Chemical cost of MBR system for Scenario 1-A & B.

Chemical		**Cost**	
NaOCl (12%)	*kg/year*	*USD/kg*	***USD/year***
Disinfection	177.97	0.224	**39.90**
Chemical Cleaning	90	0.224	**20.17**
TOTAL			**60.07 USD/year**

In total, annual operational cost of MBR system is equal to 14,468 USD/year. Depending on the daily grey water flow, unit cost of the treatment process could be computed as the following.

$$460\ \frac{\mathrm{m^3}}{\mathrm{d}}\ \mathrm{x}\ 365\ \frac{\mathrm{d}}{\mathrm{year}} = 167{,}900\ \mathrm{m^3/year}$$

$$\text{Unit Treatment Cost} = \frac{\text{Annual OPEX}}{\text{Treated Water}} = \frac{(14{,}408 + 60.07)\ \text{USD/year}}{167{,}900\ \ \mathrm{m^3/year}}$$

$$= \frac{14{,}468\ \text{USD}}{\text{year}}\ \mathrm{x}\ \frac{\text{year}}{167{,}900\ \mathrm{m^3}} = \mathbf{0.09\ USD/m^3}$$

Payback Period of Scenario 1

For the comparison of current wastewater management system with the implementation of Scenario 1, the current situation in the study area needs to be analyzed in terms of potable water pumping, potable water treatment, wastewater pumping, and wastewater treatment expenditures as illustrated in Figure 5.8. As mentioned earlier in Chapter 5.2, in the flow charts, actual water volumes are represented in black, while the water balances are marked with red and operational costs in green.

In Table 5.20, total operational costs of current system and Scenario 1 are calculated depending on the actual volumes of water (m^3/d) and the unit cost (USD/m^3) of each operation applied to water (including all pumping, water and wastewater treatment costs). As a result, total operational expenditure of current system in the neighborhood (water consumption: 1,708 m^3/d) is calculated around 360 USD per day [99] [3].

Table 5.20: OPEX analysis of Scenario 1-A & B

		Current	Scenario 1
Potable water treatment	Unit	110	80
	Volume (m^3/d)	1,708	1,277
	Unit cost (USD/m^3)	0.096	0.096
	Total cost (USD/d)	**164**	**123**
Potable water pumping	Unit	110	80
	Volume (m^3/d)	1,708	1,277
	Unit cost (USD/m^3)	0.035	0.035
	Total cost (USD/d)	**60**	**45**
Wastewater pumping	Unit	100	70
	Volume (m^3/d)	1,537	1,076
	Unit cost (USD/m^3)	0.009	0.009
	Total cost (USD/d)	14	10
Wastewater treatment	Unit	100	70
	Volume (m^3/d)	1,537	1,076
	Unit cost (USD/m^3)	0.079	0.079
	Total cost (USD/d)	**121**	**85**
Weak grey water treatment	Unit		30
	Volume (m^3/d)		461
	Unit cost (USD/m^3)		0.090
	Total cost (USD/d)		**41**
	TOTAL (USD/d)	**359**	**303**
	Saving %		**15%**

If Scenario 1 is implemented in Yenikent, around 460 m^3 would be treated via grey water treatment system in the location where it is generated. As a consequence of this on-site treatment, some of the potable water treatment and pumping cost would be eliminated as given in Table 5.20 (and Figure 5.8). Similarly, the cost of wastewater pumped and treated by the existing conventional system would be reduced. Following the same method, the total operational cost of Scenario 1 is calculated and compared with existing conventional system. As a result, total saving is found as 15% in terms of operational costs.

Lastly the payback period is calculated for Scenario 1 following the method given Chapter 4.6. For the calculation, unit water price for households is adopted from prices determined by ISU [100].

$$\text{Saving} = \text{Water Reuse x Unit Water Price} = 460\ \frac{\text{m}^3}{\text{d}}\ \text{x}\ 2.10\ \frac{\text{USD}}{\text{m}^3} \tag{4.8}$$

$$= 966\ \text{USD/d} = 352{,}590\ \text{USD/year}$$

$$\text{Total Saving} = \text{Saving} - \text{OPEX} = 352{,}590\ \frac{\text{USD}}{\text{year}} - 14{,}468\ \frac{\text{USD}}{\text{year}} \tag{4.9}$$

$$= 338{,}122\ \text{USD/year}$$

$$\textbf{Payback Period} = \frac{\text{CAPEX}}{\text{Total Saving}} = \frac{380{,}000\ \text{USD}}{338{,}122\ \text{USD/year}} = \mathbf{1.1\ year} \tag{4.10}$$

$$\cong 1\ \text{year}$$

As a result, the payback period of 460 m^3/d grey water reclamation system is calculated as 1 year. In terms of payback period, the results obtained for Scenario 1 is in line with cost analysis reported in literature. Oructut stated that redemption period of grey water treatment systems is shorter than 2 years if grey water is collected from 200 households or more [12]. The more number of households leads to reduction in capital and operational expenditures per household.

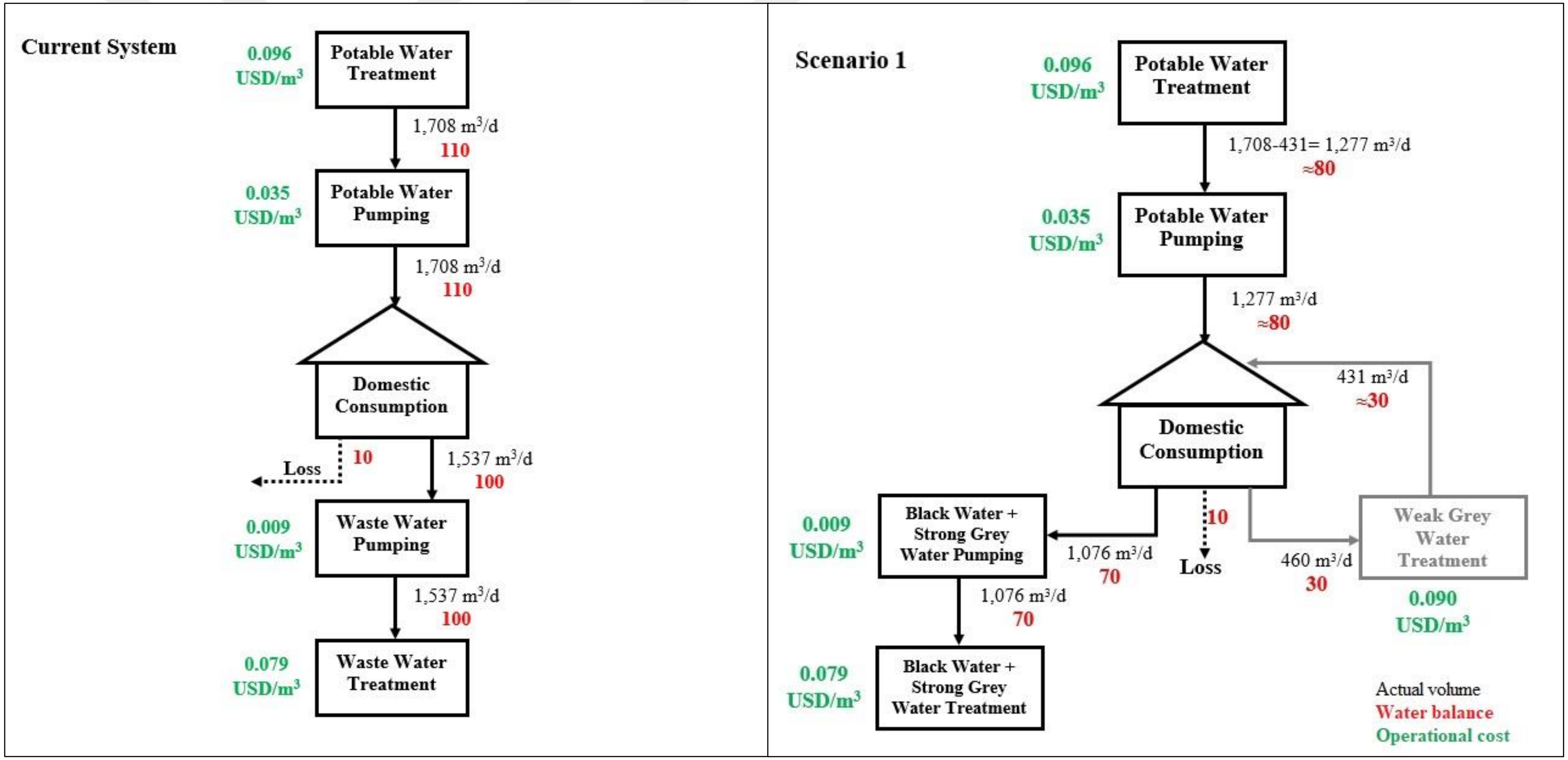

Figure 5.8: Financial comparison of Scenario 1.

*(*water balances based on 100% wastewater volume)*

5.4.2.2 Financial assessment of scenario 2

Scenario 2 indicates the reclamation of mixed greywater and reuse for cooling after MBR treatment and disinfection. As treated grey water is reused in Gebze and Guzeller Organized Industrial Zones that are situated 2.7 and 2.1 km respectively, investment cost of Scenario 2 includes the expenditures arising from treated grey water distribution pipes to locations together with in-building grey water collecting pipes. For the same reason, pumping cost of treated grey water also contributes to operational cost.

Capital Expenditure (CAPEX) of Scenario 2

For the segregated collection of mixed grey water, a new pipeline needs to be installed, while existing in-building pipelines could be used for the collection of black water. Considering that, a new pipe is added to the void as illustrated in Figure 5.9. The cost of grey water plumbing system given in Table 5.21, only covers the cost of additional raw grey water pipeline without any construction work, since treated grey water is not used for in-building purposes such as toilet flushing. However, for the distribution of treated grey water to Gebze and Guzeller Organized Industrial Zones, approximately 3.5 km pipeline should be installed. In terms of investment expenditure of grey water distribution network, 97% is covered by construction and labor costs.

Table 5.21: CAPEX of Scenario 2.

	Cost *(USD)*
Grey water collection (indoor) (1)	**100,000**
Pipe (Grey water collecting, 150Ø)	100,000
Grey water distribution (outdoor) (2)	**300,000**
Pipe	10,000
Construction and labor costs	290,000
Grey water treatment (3)	**470,000**
TOTAL	**870,000**

(1) 20 USD/household and 5,000 households; (2) 300 TL/m and 3.5 km; (3) MBR + disinfection

Considering that there are approximately 5,000 domestic subscribers in Yenikent Neighborhood, the capital cost of treatment system is computed as 94 USD per household [101]. For the cases where grey water is reused not in-building but in another reuse area, it could be indicated that plumbing system expenditures would be reduced. However, the capital cost of grey water distribution pipeline would contribute to total CAPEX in around 35%.

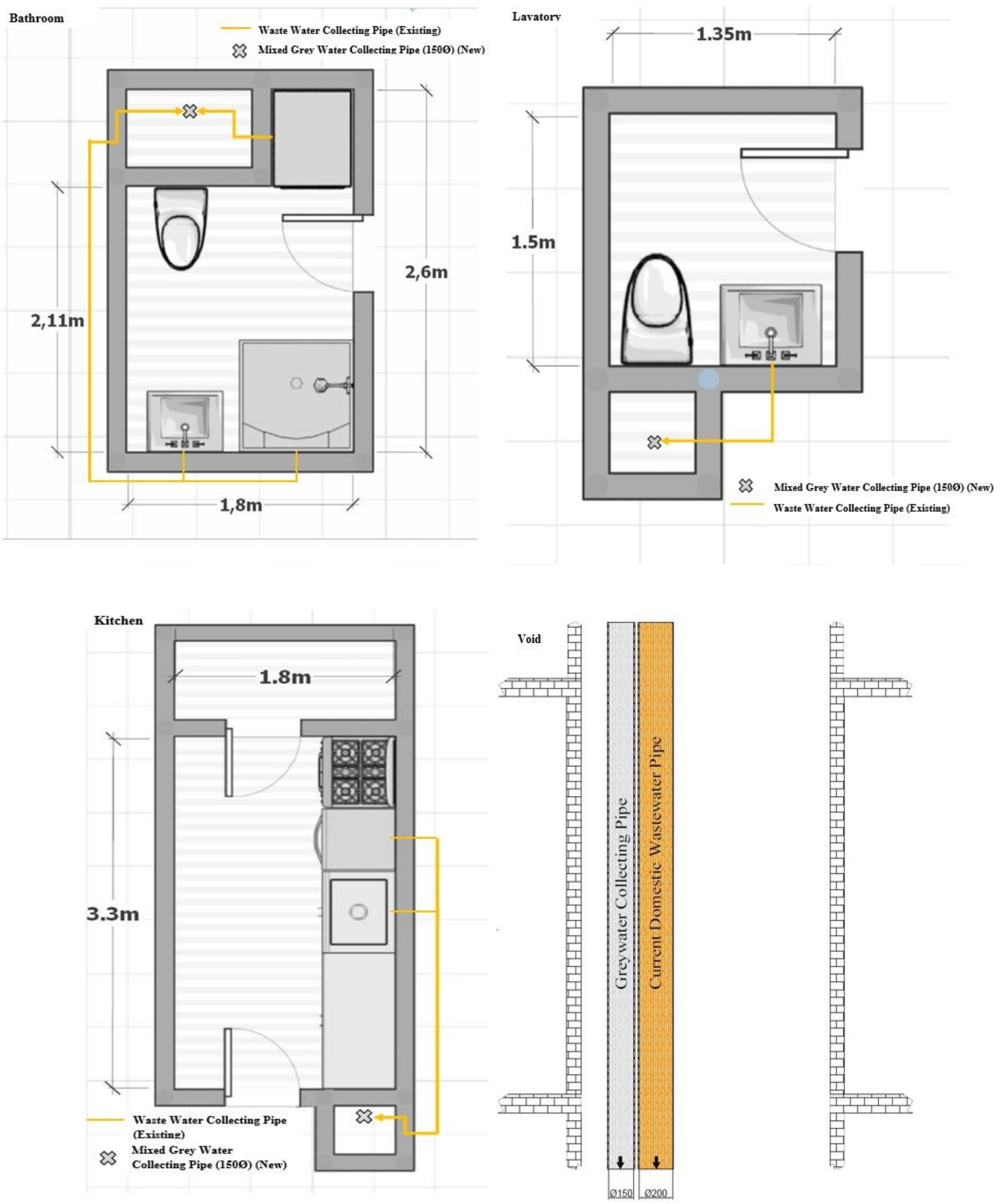

Figure 5.9: Plumbing system for Scenario 2.

Operational Expenditure (OPEX) of Scenario 2

Operational expenditure of this MBR system for Scenario 2 is calculated following the same method applied for Scenario 1. Based on the energy consumption by pumps and blowers, total energy cost of grey water treatment system is calculated as in Table 5.22. Due to their marginal capacities, the chemical dosing pumps are neglected in OPEX estimation.

Table 5.22: Energy cost of MBR system for Scenario 2.

Equipment	Available Capacity on Market	Operating Time	Daily Consumption	Daily Cost	Annual Cost
	kW	*h/d*	*kWh/d*	*USD/d*	*USD/year*
Influent Pump	2.2	24	52.8	4.75	1,734.48
Recirculation Pump	4.4	24	105.6	9.50	3,468.96
Effluent and Backwash Pump	2.2	24	52.8	4.75	1,734.48
Chemical Cleaning-Dosing Pump	0.37	0.01	0.00	0.00	0.12
Disinfection-Dosing Pump	0.37	0	0	0	-
Membrane Tank Blower	18	22	396	35.64	13,008.60
Aeration Tank Blower	7.5	24	180	16.2	5,913.00
Total				**25,859.64 USD/year**	

Considering chemical consumption for disinfection and chemical cleaning of membranes, total chemical expenditures are calculated as shown in Table 5.23. In total, annual operational cost of MBR system with 1,000 m^3 capacity is equal to 25,959 USD/year.

Table 5.23: Chemical cost of MBR system for Scenario 2.

Chemical			Cost	
NaOCl (12%)	*kg/day*	*kg/year*	*USD/kg*	***USD/year***
Chemical Cleaning	0.7	264.00	0.224	**59.14**
Disinfection	0.5	182.5	0.224	**40.88**
TOTAL				**100.02 USD/year**

Depending on the daily grey water flow for Scenario 2, unit cost of the treatment process could be computed as the following.

$$1000\ \frac{\mathrm{m}^3}{\mathrm{d}}\,\mathrm{x}\,365\,\frac{\mathrm{d}}{\mathrm{year}} = 365{,}000\ \mathrm{m}^3/\mathrm{year}$$

$$\text{Unit Treatment Cost} = \frac{\text{Annual OPEX}}{\text{Treated Water}} = \frac{(25{,}859.64 + 100.02)\ \mathrm{USD/year}}{365{,}000\ \mathrm{m}^3/\mathrm{year}}$$

$$= \frac{25{,}959\ \mathrm{USD}}{\mathrm{year}}\ \mathrm{x}\ \frac{\mathrm{year}}{365{,}000\ \mathrm{m}^3} = \mathbf{0.07\ USD/m^3}$$

Payback Period of Scenario 2

To compare Scenario 2 with the existing system in the study area, the current situation should be analyzed considering all the processes applied to water that is currently consumed for cooling. Depending on the unit costs of potable water pumping, potable water treatment, wastewater pumping, and wastewater treatment, the existing system is analyzed as shown in Figure 5.10. The results revealed that total cost of water consumption is currently around 480 USD per day in the neighborhood [99] [3].

If Scenario 2 is implemented in Yenikent, 1,000 m^3 of water would be treated in a closer location in comparison with potable water. As a result of this on-site treatment, some of the potable water treatment and pumping cost would be eliminated, however, pumping cost of treated grey water would still contribute to operational cost as given Figure 5.10. In Table 5.24, the most of the savings in terms of operational cost are arising from the reduces volume of wastewater treated in conventional plants, and as a result the total saving is 28% in terms of operational costs for Scenario 2.

Table 5.24: OPEX analysis of Scenario 2.

		Current	Scenario 2
Potable water treatment	Unit	≈170	110
	Volume (m^3/d)	2,661	1,708
	Unit cost (USD/m^3)	0.096	0.096
	Total cost (USD/d)	**255**	**164**
Potable water pumping	Unit	≈170	110
	Volume (m^3/d)	2,661	1,708
	Unit cost (USD/m^3)	0.035	0.035
	Total cost (USD/d)	**93**	**60**
Wastewater pumping	Unit	100	≈30
	Volume (m^3/d)	1,537	476
	Unit cost (USD/m^3)	0.009	0.009
	Total cost (USD/d)	**14**	**4**
Wastewater treatment	Unit	100	≈30
	Volume (m^3/d)	1,537	476
	Unit cost (USD/m^3)	0.079	0.079
	Total cost (USD/d)	**121**	**38**
Mixed grey water treatment	Unit		≈70
	Volume (m^3/d)		1,061
	Unit cost (USD/m^3)		0.070
	Total cost (USD/d)		**74**
Mixed grey water pumping	Unit		≈70
	Volume (m^3/d)		1,061
	Unit cost (USD/m^3)		0.009
	Total cost (USD/d)		**10**
	TOTAL (USD/d)	**484**	**349**
	Total Saving %		**28%**

Lastly the payback period is calculated for Scenario 2 following the method given Chapter 4.6 by using unit water price for organized industrial sites [100]. The payback period of Scenario 2 is shorter when it is compared with Scenario 1. Since Scenario 1 and 2 have the same treatment methods applied to different fractions of grey water, it could be stated that payback period is getting shorter for the reclamation of higher capacities. As it was 1.1 year for weak grey water reclaiming scenario, it is calculated as 0.9 year in this case for mixed grey water reclamation.

$$\text{Saving} = \text{Water Reuse x Unit Water Price} = 1{,}000\ \frac{\text{m}^3}{\text{d}}\ \text{x}\ 2.61\ \frac{\text{USD}}{\text{m}^3} \tag{4.8}$$

$$= 2{,}610\ \text{USD/d} = 952{,}650\ \text{USD/year}$$

$$\text{Total Saving} = \text{Saving} - \text{OPEX} = 952{,}650\ \frac{\text{USD}}{\text{year}} - 25{,}959\ \frac{\text{USD}}{\text{year}} \tag{4.9}$$

$$= 926{,}691\ \text{USD/year}$$

$$\textbf{Payback Period} = \frac{\text{CAPEX}}{\text{Total Saving}} = \frac{870{,}000\ \text{USD}}{926{,}691\ \text{USD/year}} = \textbf{0.9 year} \tag{4.10}$$

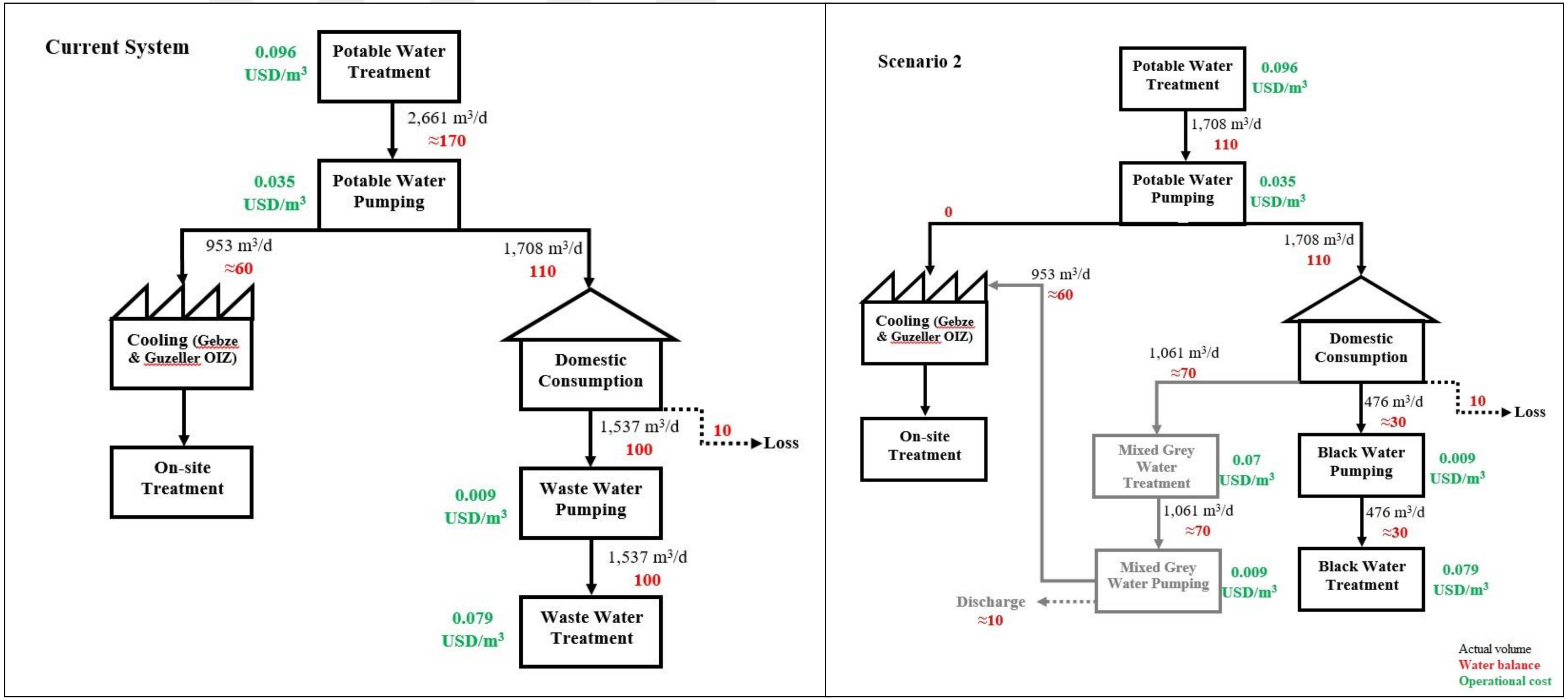

Figure 5.10: Financial comparison of Scenario 2.

5.4.2.3 Financial assessment of scenario 3

Capital Expenditure (CAPEX) of Scenario 3

Scenario 3 indicates the reclamation of bathroom greywater and reuse for cooling after UF treatment. As treated grey water is reused for cooling in Gebze Organized Industrial Zone, the investment cost of Scenario 3 includes the 2.7 km-long pipeline. As given in Table 5.25, UF treatment and in-building grey water collecting pipes are also included in total capital cost of Scenario 3. As illustrated in Figure 5.11, grey water plumbing system only contains the installation of grey water collecting pipes without any construction work.

Table 5.25: CAPEX of Scenario 3.

	Cost *(USD)*
Grey water collection (indoor) (1)	**100,000**
Pipe (Grey water collecting, 150Ø)	100,000
Grey water distribution (outdoor) (2)	**230,000**
Pipe	8,000
Construction and Labor Costs	222,000
Grey water Treatment (3)	**65,000**
TOTAL	**395,000**

(1) 20 USD/household and 5,000 households; (2) 300 TL/m and 2.7 km; (3) UF

In comparison with MBR system selected for first two scenarios, the investment cost of UF treatment is comparatively low. As in Scenario 2, grey water distribution pipes to industrial zone covers most of the capital expenditures, which is 395,000 USD in total.

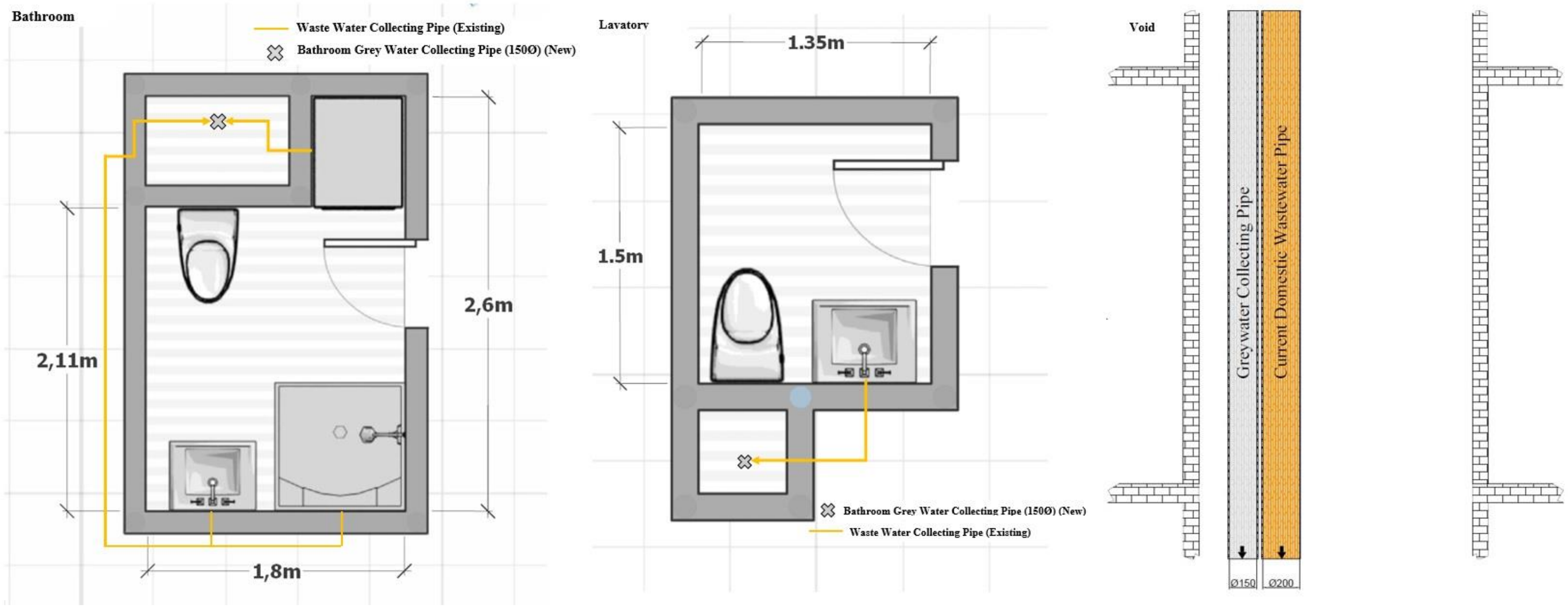

Figure 5.11: Plumbing system for Scenario 3.

Operational Expenditure (OPEX) of Scenario 3 and 4

Operational expenditure of UF system for Scenario 3 and 4 is calculated based on energy consumption by pumps and chemical consumption for chemical cleaning of membranes.

The capacities of the equipment are given in Table 5.26, depending on the manufacturer specifications available on market. Depending on these capacities and operating times, the energy consumption costs is calculated.

Table 5.26: Energy cost of UF system for Scenario 3 & 4.

Equipment	Available Capacity on Market		Operating Time	Annual Consumption	Annual Cost
	m^3/h	*kW*	*h/year*	*kWh/year*	*USD/year*
Pump (Influent)	42	2.2	8,760	19,272	1,734
Pump (CIP Tank)	72	2.2	6	13	1.19
Pump (Backwash)	12	1.1	438	482	43
Pump (BW NaOCl Dosing)	315 L/h	0.37	438	162	15
Pump (CEB NaOCl Dosing)	120 L/h	0.37	15	6	0.50
Pump (CEB Acid/HCl Dosing)	44 L/h	0.37	2.50	1	0.08
Pump (CEB Alkali/NaOH Dosing)	4.5 L/h	0.37	17.5	6	0.58
TOTAL					**1,795 USD/year**

The cost for chemically enhanced backwash is calculated in Table 5.27. Considering chemical and energy consumptions, annual operational cost of UF system is equal to 4,221 USD/year in total. In comparison with MBR treatment in Scenario 1 and 2, the total operational cost of UF treatment is pretty low since it doesn't include energy consumption for aeration of membranes and biological treatment.

Table 5.27: Chemical cost of UF system for Scenario 3 & 4.

Chemical	**Consumption**		**Cost**	
	kg/d	kg/year	USD/kg	USD/year
HCl (30%)	2.22	810.30	0.24	195.61
NaOH (46%)	2.79	1,018.35	0.67	684.84
NaOCl (12%)	18.89	6,894.85	0.22	1,545.59
TOTAL				**2,426.04 USD/year**

Depending on the daily grey water flow originated from bathrooms in Yenikent Neighborhood, unit cost of the treatment process could be computed as the following.

$$850\ \frac{\mathrm{m^3}}{\mathrm{d}}\,\mathrm{x}\,365\,\frac{\mathrm{d}}{\mathrm{year}} = 310{,}250\ \mathrm{m^3/year}$$

$$\mathrm{Unit\ Treatment\ Cost} = \frac{\mathrm{Annual\ OPEX}}{\mathrm{Treated\ Water}} = \frac{(1{,}795 + 2{,}426.04)USD/year}{310{,}250\ \mathrm{m^3/year}}$$

$$= \frac{4{,}221\ \mathrm{USD}}{\mathrm{year}}\,\mathrm{x}\,\frac{\mathrm{year}}{310{,}250\ \mathrm{m^3}} = \mathbf{0.01\ USD/m^3}$$

Payback Period of Scenario 3

In order to evaluate the implementation of Scenario 3, the current situation in the study area needs to be analyzed considering potable water pumping, potable water treatment, wastewater pumping, and wastewater treatment expenditures as illustrated in Figure 5.12. Depending on the unit cost of each operation currently applied to water, total cost of water consumption for current situation is around 480 USD per day as given in Table 5.28 [99] [3].

After the reclamation of bathroom grey water for reuse in cooling, 850 m^3 of water would be treated in a closer location in comparison with potable water. For this reason, some of the potable water treatment and pumping cost would be eliminated, however, pumping cost of treated grey water would still contribute to operational cost as shown in Figure 5.12. In Table 5.28, the most of the savings in terms of operational cost are arising from the reduced volume of wastewater treated in conventional plants, and as a result, the total saving is 35% in terms of operational costs for Scenario 3.

Table 5.28: OPEX analysis of Scenario 3.

		Current	Scenario 3
Potable water treatment	Unit	≈170	115
	Volume (m^3/d)	2,619	1,773
	Unit cost (USD/m^3)	0.096	0.096
	Total cost (USD/d)	**251**	**170**
Potable water pumping	Unit	≈170	115
	Volume (m^3/d)	2,619	1,773
	Unit cost (USD/m^3)	0.035	0.035
	Total cost (USD/d)	**92**	**62**
Wastewater pumping	Unit	100	45
	Volume (m^3/d)	1,537	691
	Unit cost (USD/m^3)	0.009	0.009
	Total cost (USD/d)	14	6
Wastewater treatment	Unit	100	45
	Volume (m^3/d)	1,537	691
	Unit cost (USD/m^3)	0.079	0.079
	Total cost (USD/d)	**121**	**55**
Bathroom grey water treatment	Unit		55
	Volume (m^3/d)		846
	Unit cost (USD/m^3)		0.010
	Total cost (USD/d)		**8**
Bathroom grey water pumping	Unit		55
	Volume (m^3/d)		846
	Unit cost (USD/m^3)		0.009
	Total cost (USD/d)		**8**
	TOTAL (USD/d)	**478**	**309**
	Total Saving %		**35%**

Following the same method applied for first two scenarios, the payback period of reclamation system for Scenario 3 is calculated as 0.5 year as explained below. Since the investment cost of UF system is lower in comparison with MBR systems, the payback period for this scenario is lower than Scenario 1 and 2.

$$\text{Savings} = \text{Water Reuse x Unit Water Price} = 850\ \frac{\text{m}^3}{\text{d}}\ \text{x}\ 2.61\ \frac{\text{USD}}{\text{m}^3} \quad (4.8)$$
$$= 2{,}219\ \text{USD/d} = 809{,}752\ \text{USD/year}$$

$$\text{Total Saving} = \text{Savings} - \text{OPEX} = 809{,}752\ \frac{\text{USD}}{\text{year}} - 4{,}221\ \frac{\text{USD}}{\text{year}} \quad (4.9)$$
$$= 805{,}531\ \text{USD/year}$$

$$\textbf{Payback Period} = \frac{\text{CAPEX}}{\text{Total Saving}} = \frac{395{,}000\ \text{USD}}{805{,}531\ \text{USD/year}} = \mathbf{0.5\ year} \quad (4.10)$$

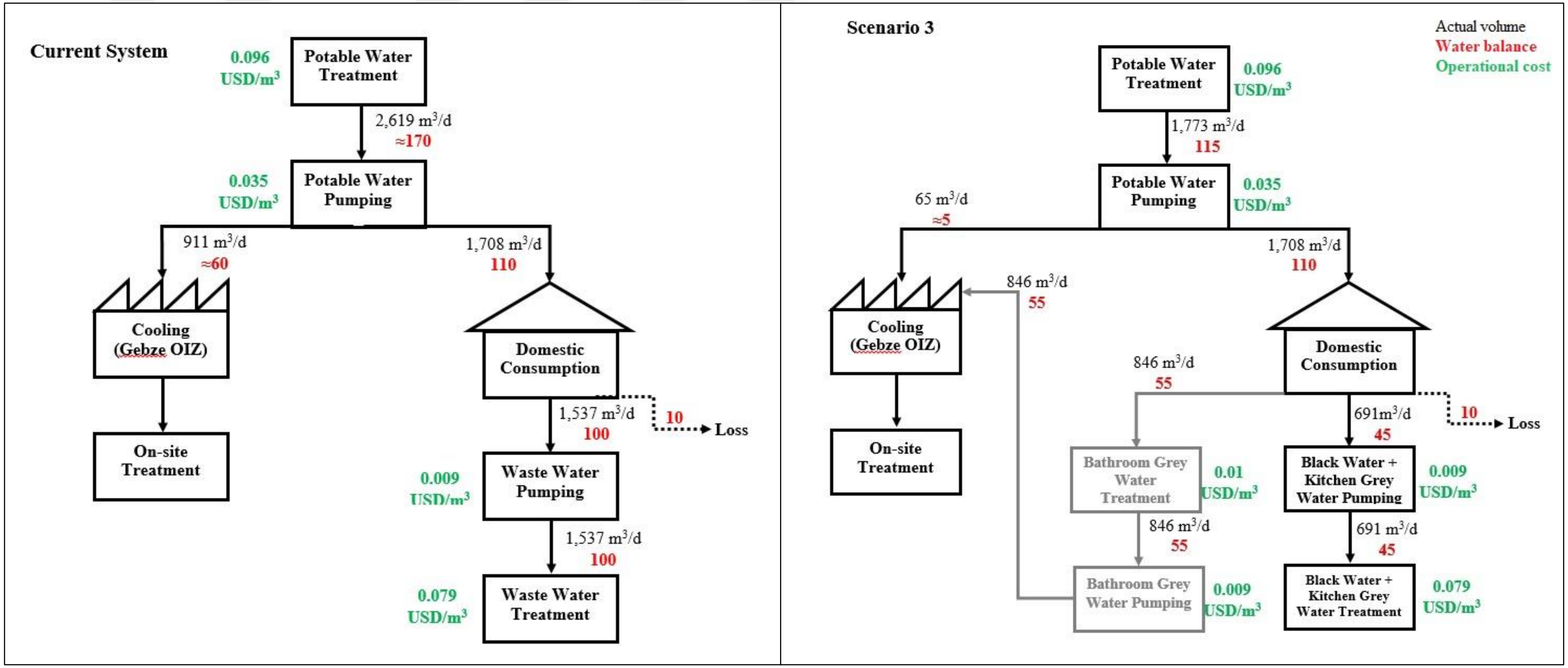

Figure 5.12: Financial comparison of Scenario 3.

*(*water balances based on 100% wastewater volume)*

5.4.2.4 Financial assessment of scenario 4

Capital Expenditure (CAPEX) of Scenario 4

Scenario 4 indicates reuse of bathroom greywater for landscape irrigation during dry season and for toilet flushing during the rest of the year. As treated grey water is reused after UF treatment for irrigational purposes, not only in Yenikent, but also in Gaziler Natural Park and industrial zones, the capital expenditure of Scenario 4 includes the cost of treatment units together with plumbing and distribution pipelines. Table 5.29 summarizes the cost of each item contributes to total CAPEX, where total investment cost is 575,000 USD and almost half of it is for grey water distribution network to various reuse areas.

Table 5.29: CAPEX of Scenario 4.

	Cost *(USD)*
Grey water collection (indoor) $^{(1)}$	**150,000**
Pipe (Grey water collecting, 150Ø)	100,000
Pipe (Toilet flush feed, 50Ø)	50,000
Grey water distribution (outdoor) $^{(2)}$	**360,000**
Pipe	12,000
Construction and Labor Costs	348,000
Grey water Treatment $^{(3)}$	**65,000**
TOTAL	**575,000**

$^{(1)}$ 30 USD/household and 5,000 households; $^{(2)}$ 300 TL/m and 4.2 km; $^{(3)}$ UF

The capital cost of plumbing system of Scenario 4 includes grey water collecting pipes and grey water feed pipes to toilet flushes as illustrated in Figure 5.13. For the determination of the cost of treated grey water network, it is assumed that a common 3.5-km-long pipeline delivers grey water to organized industrial zone and another 0.7-km-pipeline to the Natural Park. The operational expenditure of Scenario 4 is as calculated for Scenario 3 since they both have reclamation of grey water generated from bathrooms. (See Chapter 5.4.2.3)

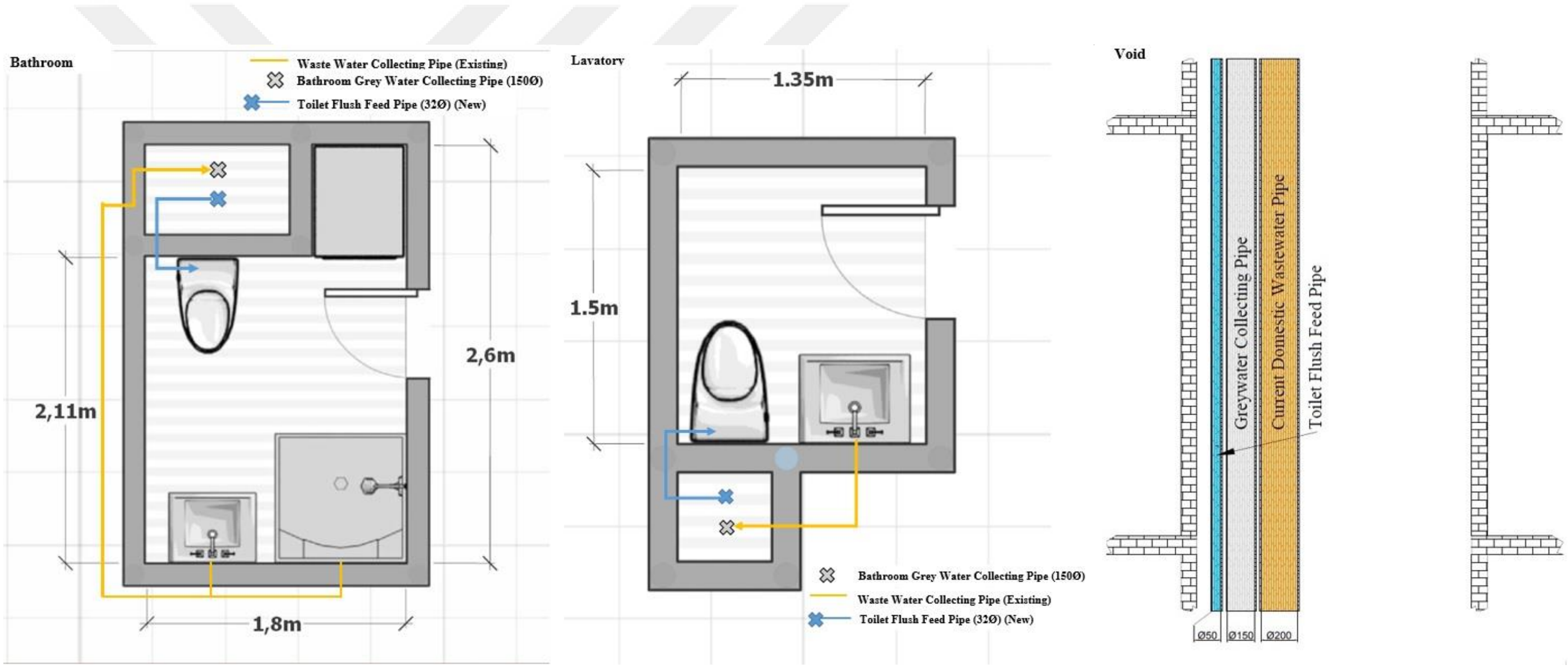

Figure 5.13: Plumbing system for Scenario 4.

Payback Period of Scenario 4

For the evaluation of total savings in terms of operational expenditures, current situation in the study area is calculated and compared with seasonal implementation of Scenario 4. The total OPEX of existing conventional system is consisting of the costs of potable water pumping, potable water treatment, wastewater pumping, and wastewater treatment expenditures as illustrated in Figure 5.14. Depending on the unit cost of each operation currently applied to water, total cost of water consumption for current situation is 455 USD per day as given in Table 5.30 [99] [3].

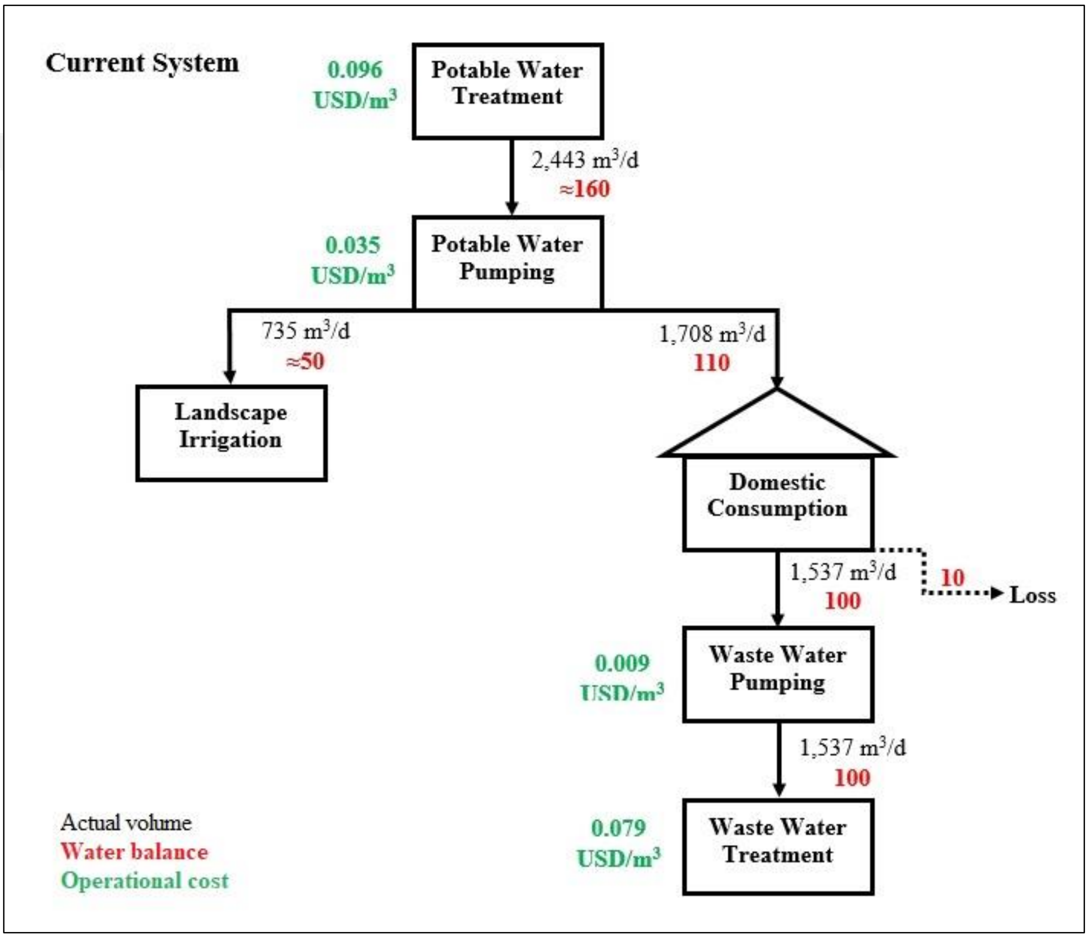

Figure 5.14: Evaluation of current system for Scenario 4.

*(*water balances based on 100% wastewater volume)*

In Figure 5.15, the water balances for seasonal implementations of Scenario 4 are illustrated and used for the calculation of operational cost of each application in order compare with the current system analyzed in Figure 5.14. After the reclamation of bathroom grey water for irrigational reuse during 5 months of dry season, 850 m^3 of water would be treated in a closer location in comparison with potable water. For this reason, some of the conventional water treatment and pumping cost would be eliminated and in terms of operational costs, the total saving is calculated as 32% during 5 months of irrigational reuse, while it is 34% during 7 months when it is reused for toilet flushing.

Table 5.30: OPEX analysis of Scenario 4.

		Current	Scenario 4	Scenario 4
Potable water treatment	Unit	≈150	≈80	110
	Volume (m^3/d)	2,443	1,277	1,708
	Unit cost (USD/m^3)	0.096	0.096	0.096
	Total cost (USD/d)	**235**	**170**	**164**
Potable water pumping	Unit	≈150	≈80	110
	Volume (m^3/d)	2,443	1,277	1,708
	Unit cost (USD/m^3)	0.035	0.035	0.035
	Total cost (USD/d)	**86**	**62**	**60**
Wastewater pumping	Unit	100	70	≈50
	Volume (m^3/d)	1,537	1,106	802
	Unit cost (USD/m^3)	0.009	0.009	0.009
	Total cost (USD/d)	14	6	7
Wastewater treatment	Unit	100	70	≈50
	Volume (m^3/d)	1,537	1,106	802
	Unit cost (USD/m^3)	0.079	0.079	0.079
	Total cost (USD/d)	**121**	**55**	**63**
Bathroom grey water treatment	Unit		55	55
	Volume (m^3/d)		846	846
	Unit cost (USD/m^3)		0.01	0.01
	Total cost (USD/d)		**8**	**8**
Bathroom grey water pumping	Unit			≈50
	Volume (m^3/d)			735
	Unit cost (USD/m^3)			0.009
	Total cost (USD/d)			**7**
	TOTAL (USD/d)	**455**	**302**	**309**
	Total Saving %		**34%**	**32%**

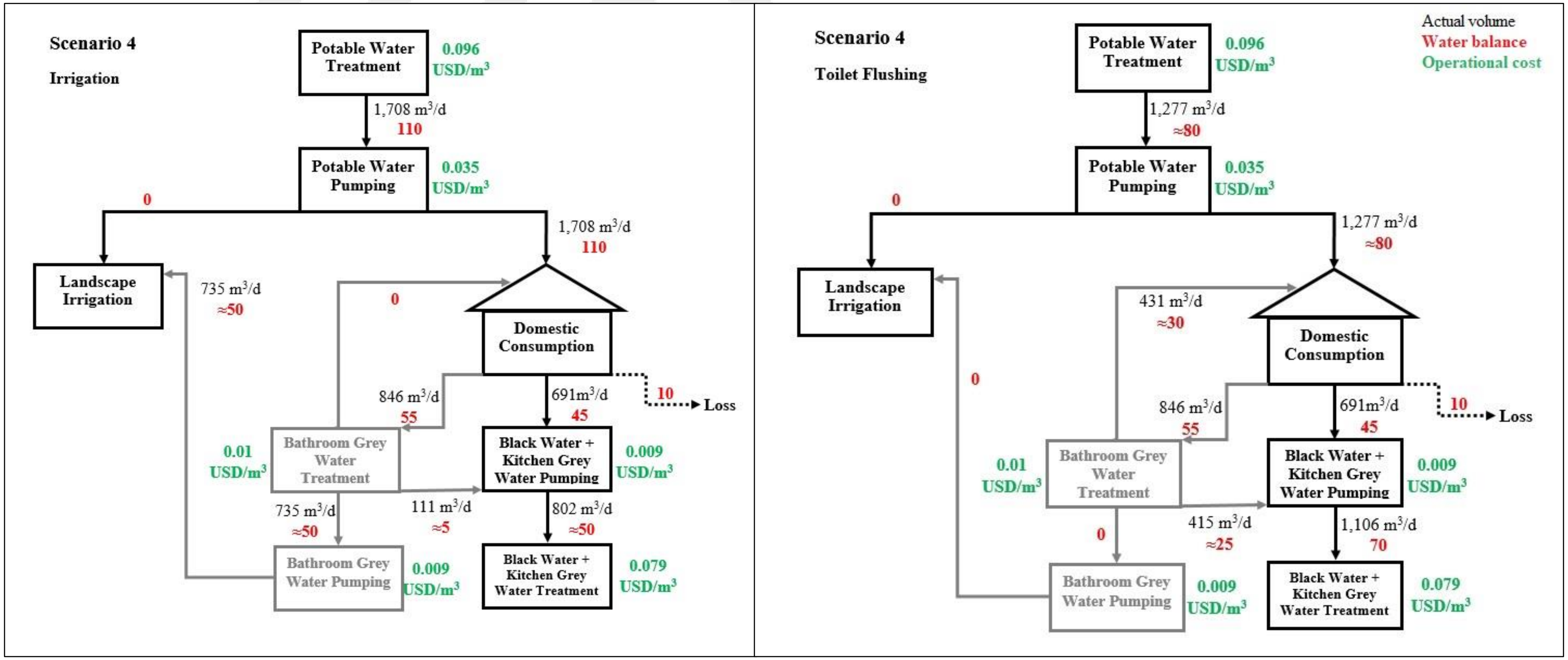

Figure 5.15: Seasonal implementation of Scenario 4.

*(*water balances based on 100% wastewater volume)*

Following the same method applied for the other scenarios. The payback period for the implementation of Scenario 3 is calculated as 1.2 year as given below. Although the investment cost of UF system is low, the payback period of Scenario 4 is the longest compared to the ones computed for the first three scenarios, since the capital cost of the system includes expenditures for both indoor and outdoor pipelines.

$$\text{Water Saving} = 850\ \frac{\text{m}^3}{\text{d}}\ \text{x}\ 1.40\ \frac{\text{USD}}{\text{m}^3} = 1{,}190\ \text{USD/d} \\ = 434{,}350\ \text{USD/year} \tag{4.8}$$

$$\text{Total Saving} = \text{Water Saving} - \text{OPEX} = 434{,}350\ \frac{\text{USD}}{\text{year}} - 4{,}221\ \frac{\text{USD}}{\text{year}} \\ = 430{,}129\ \text{USD/year} \tag{4.9}$$

$$\textbf{Payback Period} = \frac{\text{CAPEX}}{\text{Total Saving}} = \frac{510{,}000\ \text{USD}}{430{,}129\ \text{USD/year}} = \mathbf{1.2\ year} \tag{4.10}$$

In Table 5.31, financial assessment of each scenario is summarized in detail. The capital cost of treatment system, in-building plumbing system, and reclaimed grey water distribution network are the main contributors of investment expenditure of grey water reclamation systems. The results of this work showed that UF systems are far more advantageous in comparison with MBR systems, not only in terms of its CAPEX, but also its compactness and comparatively less area requirement.

In the grey water implementations that includes conversion of already-existing buildings, as in Scenario 1, the capital cost of plumbing systems were way too high covering around 98% of total investment cost. In such cases, it was assumed that current wastewater plumbing system could be kept for the collection of grey water in buildings, while additional raw grey water pipe and treated grey water feed pipe to the toilet reservoirs would be installed from the void for each floor. In new building projects, the extra cost of plumbing systems consisting of separate grey water collection and treated grey water feed pipes to toilet reservoirs were around 1/3 of total CAPEX.

The scenarios that address the reuse of grey water not in building where it is generated, but in surroundings of the selected neighborhood had high capital expenditure for the installation of the network that distributes treated grey water to various reuse-areas.

The CAPEX of distribution pipes were even higher than CAPEX of plumbing and treatments systems for Scenario 3 and 4, where UF treatment was preferred. In such cases, proximity between the origin and reuse area of grey water becomes an issue. For this work, the maximum proximity to selected reuse areas (Gebze OIZ) was 2.7 km, which still shorter than the average proximity (3 km) between existing domestic wastewater reclamation units and end-users of reclaimed wastewater in Kocaeli.

Table 5.31: Summary of financial assessment.

Scenario	**1**	**2**	**3**	**4**
Grey water fraction	Weak grey water	Mixed grey water	Bathroom grey water	Bathroom grey water
End-use purpose	Toilet flushing, car wash, urban	Cooling	Cooling	Irrigation, toilet flushing
Treatment method	MBR	MBR	UF	UF
Capacity	460 m^3/d	1,000 m^3/d	850 m^3/d	850 m^3/d
CAPEX-treatment	230,000 USD	470,000 USD	65,000 USD	65,000 USD
CAPEX-plumbing	150,000 USD	100,000 USD	100,000 USD	150,000 USD
CAPEX-distribution	-	300,000 USD	230,000 USD	360,000 USD
CAPEX-TOTAL	380,000 USD	870,000 USD	395,000 USD	575,000 USD
CAPEX-savings %	75%	42%	74%	62%
OPEX-treatment system	0,09 USD/m^3	0,07 USD/m^3	0,01 USD/m^3	0,01 USD/m^3
OPEX-current situation	360 USD/d	497 USD/d	478 USD/d	455 USD/d
OPEX-scenarios	300 USD/d	377 USD/d	309 USD/d	IR: 309 USD/d
OPEX-savings %	15%	28%	35%	IR: 32% TF: 34%
Payback period	1.1 year	0.9 year	0.5 year	1.2 year

When the total capital costs of each scenario are compared with the investment cost of existing conventional systems located in Kocaeli (that consists of a similar capacity modular drinking water and wastewater treatment plants). If the same amount of water consumed for each scenario was treated by on-site systems instead of conventional treatment systems, 42-75% saving of capital cost could be achieved. However, it should be considered that the capital cost of conventional systems are higher for the modular plants with smaller capacities in comparison with conventional treatment systems designed for an entire city.

5.5 Assessment of Public Acceptance towards Grey Water Reuse

The success of implementation and widespread use of grey water reclamation systems are closely related to the awareness and acceptance of the community it will serve. To gain insight about readiness and willingness of respondents living in T.R., for grey water reuse, a preliminary survey was conducted. The questions (given in Appendix C) were basically focusing upon awareness regarding water stress/scarcity in T.R. and grey water as an alternative source, and acceptance with regard to the reuse of different fractions of grey water and possible end uses. Motivations and concerns for grey water reuse were also questioned.

The demographic profile of the respondents are summarized in Table 4.11. Following the general questions regarding demographic attributes, questions were asked to gain insight about background knowledge and awareness of the respondents about water scarcity and grey water. Currently, T.R. is experiencing water stress with a water availability of about 1500 m^3/capita.year [1], which indicates water stress [102]. As given in Figure 5.16, the survey results revealed that 87% of the participants are aware that water scarcity is a problem at this time or it might be within 10 to 15 years. However, 13% of the respondents were not aware of this fact as they stated that there were plenty of water or they did not know. This indicates that 86% of the respondents were aware that there is a shortage problem, showing that awareness with regard to water stress/scarcity was high.

When the participants were asked if they know about the meaning of grey water, 71% did not know the exact meaning before the survey. When the definition of grey water was provided to all participants, 59% of those thought that grey water could be collected separately out of whole domestic wastewater. Of the entire respondents, only 6% stated that they didn’t know if separate collection of grey water is technically possible or not, since they had no knowledge about how to segregate the streams of conventional domestic wastewater. The results revealed that awareness with regard to grey water was rather low and providing information would be helpful to public.

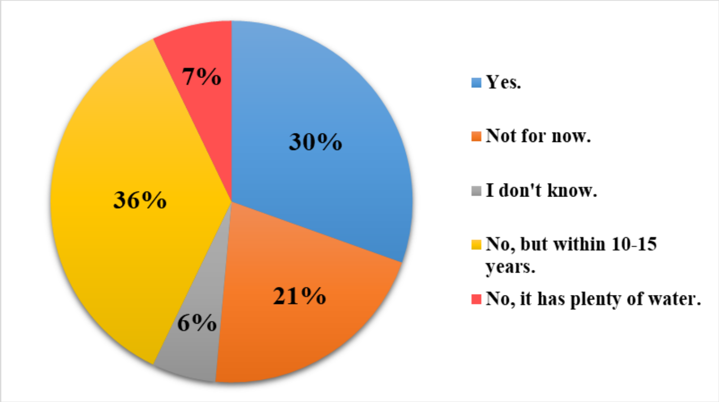

Figure 5.16: Awareness regarding water stress/scarcity in T.R.

(Do you think T.R. has a water shortage problem?)

When the participants were asked about acceptance towards five different origins of grey water in a household, hand wash basins (68%) and kitchen sinks (68%) equally received the highest acceptance as illustrated in Figure 5.17. While washing machines got the lowest preference with 43%, because of the dense detergent content of grey water originated from laundry. None of the respondents had a complete rejection against the reuse of the grey water origins, at least 43% of the participants accepted to use one of the sub-streams. In a similar study Beler Baykal and others [103] with 300 respondents showed that under all circumstances over half of the participants accepted to use grey water from different origins in the household. In other words, grey water originating from dishwasher, washing machine, and shower/bathtubs received around 10% higher acceptance in comparison with this study.

Together with the responses for the origins of grey water, participants expressed their concerns about the detergents and personal care products which they thought might come from washing machines and dishwashers and possible contact with human excreta in shower and bath tub water. It is to be noted that some of these concerns do not reflect the real situation as for example in the case of possible human excreta problem, which may be more significant in the fraction from washing machines rather than showers/baths especially due to underwear that are washed in washing machines, while personal care products would be expected to be more predominant in wastewater from wash basins, showers and bath tubs as compared to washing machines and dish washers. These provide supporting proof of the significance of informing/educating communities in terms of grey water, its contents and the ways of dealing with those constituents.

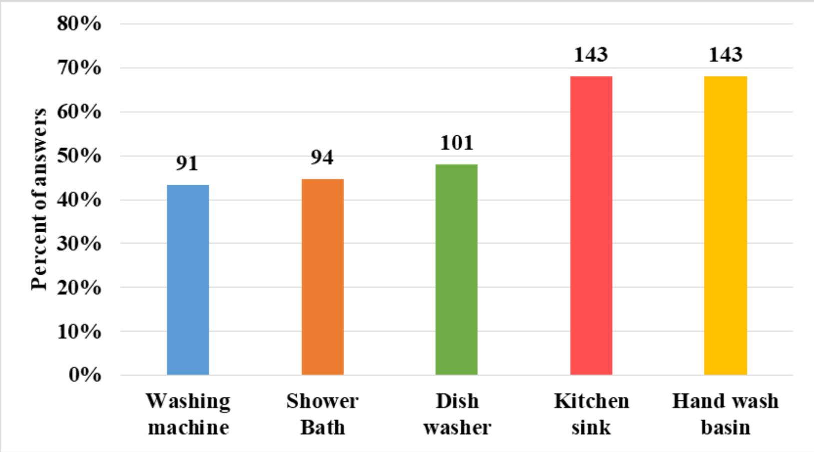

Figure 5.17: Acceptance of grey water origins.

(Which sources of greywater would you consider to be suitable for reuse in your house?)

The survey results shown in Figure 5.18 reveals that of the seven different end use purposes questioned, the top three choices were toilet flushing (91%), fire protection (86%), and irrigation (82%). Even though it was clearly stated as 'after proper treatment', only 19% was ready to reuse grey water for potable purposes and 29% for laundry, mainly as a result of concerns regarding hygienic safety. Preference for those two end uses was apparently lower as compared to the other end uses questioned that received acceptances between 76–91%.

In addition to the end uses listed in the question, 10% of the respondents also mentioned about possible additional reuse areas such as street washing, groundwater injection, cleaning of industrial plants, cleaning of chemical tanks, ponds and swimming pools, dust control in construction and mines, household and carpet cleaning, and others like air conditioning, heating, etc. Even if it is only 3%, some participants stated extreme end-use purposes such as swimming pools hand wash, and shower/bath tubs.

It was interesting that the results indicate that one of the most widespread current end use of grey water reuse, toilet flushing, received the highest preference in the survey, which was a motivating outcome. As indicated in Scenario 1, only weak grey water, which in general requires the least level of treatment, is sufficient to cover the water demand for toilet flushes. Using reclaimed grey water for this purpose is a meaningful step in contributing to sustainability of water resources through the "fit for purpose" use of this alternative water source, which will help cut back "wasting" of drinking water quality water, the cleanest, for sweeping away human excreta, the most polluted. Willingness of people involved with irrigation to use grey water as an alternative source was also apprehended as encouraging as Scenario 4 indicates seasonal reuse of grey water for landscape irrigation.

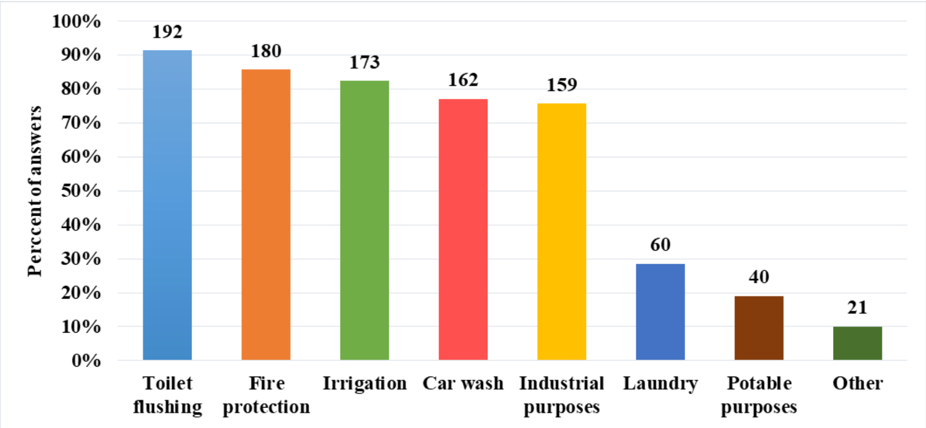

Figure 5.18: Acceptance of grey water reuse areas.
(Which purposes would you reuse treated grey water for?)

Acceptance for irrigational reuse of grey water was investigated in three categories: food stuff, green areas, and industrial plants. Six different group of food stuff were chosen to represent specific features, for example potato, eggplant, and spinach are selected as one group that is consumed after cooking. In contrast, lettuce and cucumber were chosen to represent uncooked vegetables. The group consisting of hazelnut, pecan, and almond, is selected as nuts that covered by shells as a protection against possible contact with grey water. Lastly, groups that includes fruits grown on soil and fruits grown on trees are questioned as listed in Figure 5. 19.

Among six different groups of food stuff, the fruits grown on trees received the highest preference (67%) followed by vegetables consumed after cooking (65%), while "none of them" was ticked only four times showing that there is considerable acceptance. As illustrated in Figure 5.19, cooked vegetables received twice more acceptance in comparison with the uncooked ones. Similarly, the acceptance towards fruits on soil was almost half of the acceptance for fruits grown on trees. This result shows that acceptance of food stuff irrigation increased with the proximity between the product and grey water, most probably as a reflection of concerns about hygienic safety. The attitude towards this question was different than the results of the study carried out by Beler Baykal and others [103], since the most preferred food stuff was cooked vegetables with around 70%.

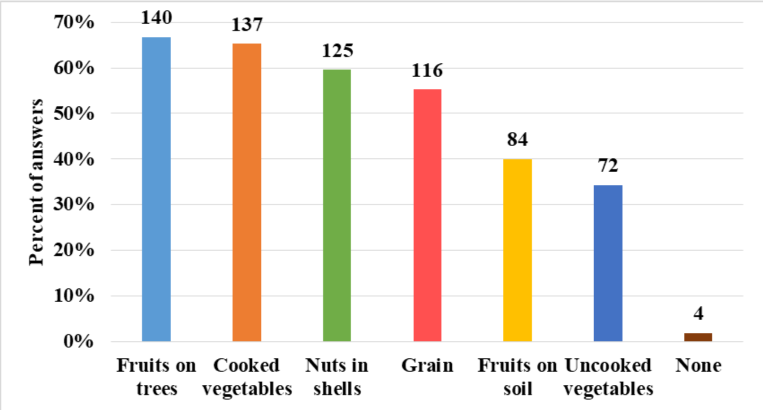

Figure 5.19: Acceptance of food stuff irrigated with reclaimed grey water. *(Which one do you prefer to eat if irrigated with treated grey water?)*

Acceptance towards irrigational reuse of grey water in green areas, in general are higher in comparison with food stuff. Among seven different green areas, landscape areas (90%), stadiums (89%), and parks (86%) received the highest acceptance; while playgrounds for children (60%) and school gardens (59%) had lowest acceptance as a result of possible contact which might occur with a higher possibility with younger children to lead to health problems, as can be observed from Figure 5.20. Similar to toilet flushing, survey results with 90% of acceptance for landscape irrigation is pretty motivating, since financial assessment of Scenario 4 revealed that 32% saving are possible if grey water is seasonally reused for landscape irrigation (See Chapter 5.4).

In general, acceptance towards irrigational reuse of grey water for industrial plants are lower in comparison with irrigation of green areas and surprisingly it was even lower than acceptance towards food stuff. Figure 5.21 shows the results of four different industrial products produced from plants irrigated with treated grey water. Wearing clothes produced from cotton grown upon grey water received the highest acceptance with 53%. While 31% of respondents accepted to use industrial products produced from plants irrigated with grey water, 13% said they would not use any one of them. Interestingly, fruit juice produced from fruits grown upon trees irrigated with grey water received higher acceptance (30%) in comparison with tobacco (13%). Irrigation of sugar canes were also lower than fruits used in juice production, since sugar cane is an herbaceous plant that is directly processed for sugar production. The acceptances towards tobacco and cotton were around 30% lower in comparison with the study carried out by Beler Baykal and others [103].

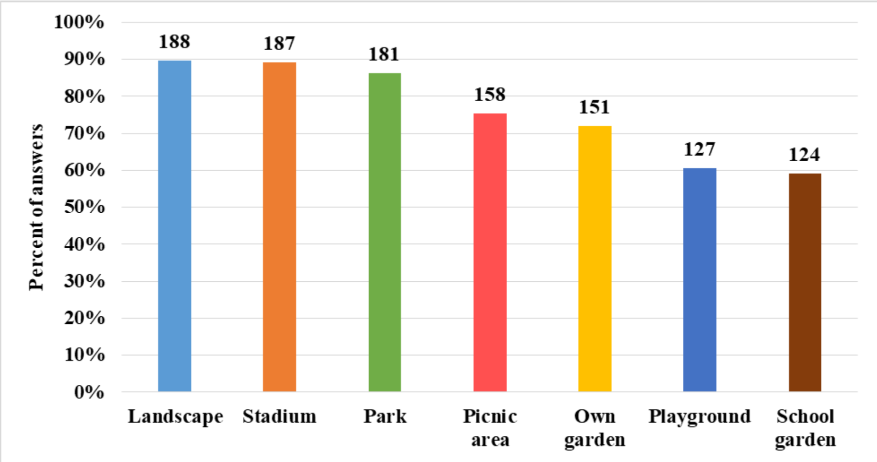

Figure 5.20: Acceptance of green areas irrigated with reclaimed grey water.

(Which of the following do you think would be acceptable to be irrigated with treated grey water?)

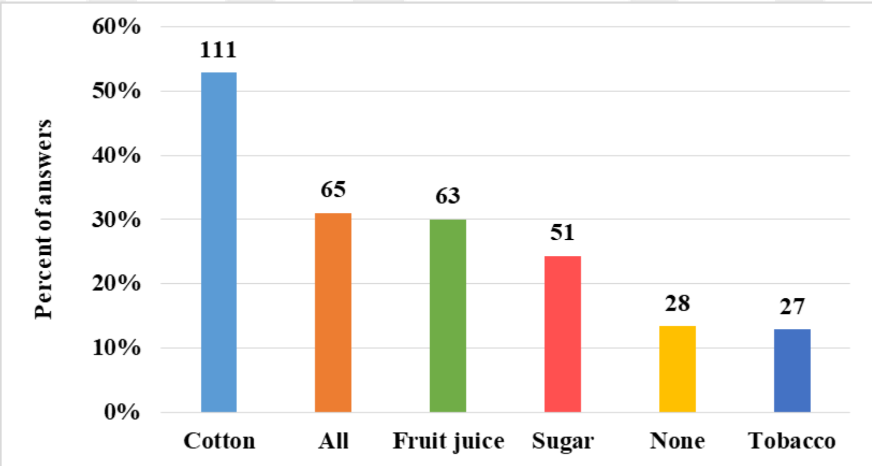

Figure 5.21: Acceptance of industrial plants grown upon reclaimed grey water.

(Which of the following do you think would be acceptable to be irrigated with treated grey water?)

As illustrated in Figure 5.22 and 5.23, the top three motivations for grey water reuse were lower environmental impacts (78%), water savings (71%), and lower water bills (50%), while the top most concerns were insufficient data on hygienic safety (55%), reluctance to pay for installation (40%), and lack of known success stories related to this practice (39%). Differently in the study carried out by Beler Baykal and others [103], the top most motivation was water savings.

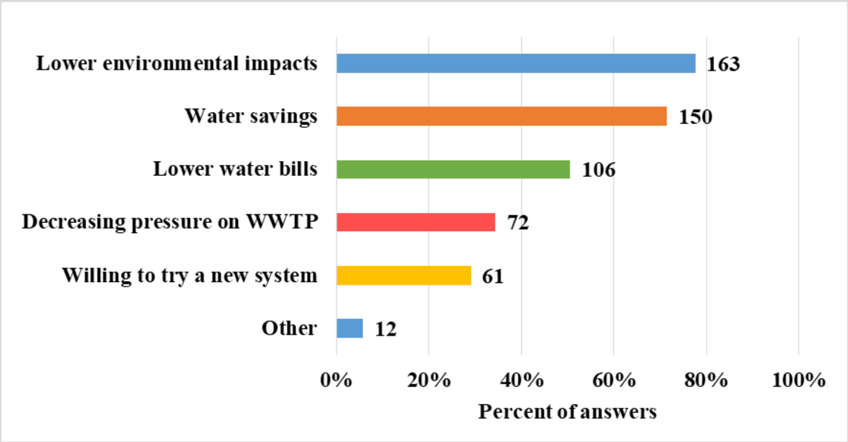

Figure 5.22: Motivations for grey water reuse.

(What would motivate you to install separate grey water collection system to your house?)

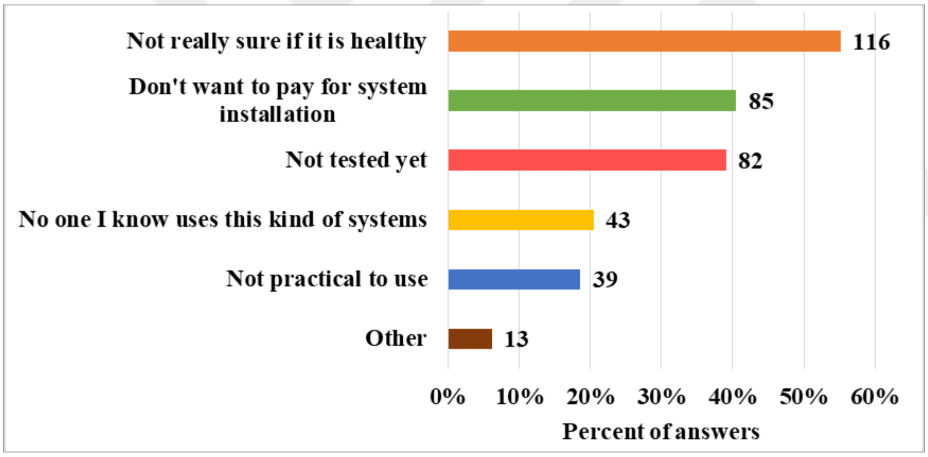

Figure 5.23: Concerns/drawbacks for grey water reuse.

(What would discourage you to install separate grey water collection system to your house?)

Additionally, 6% of the respondents mentioned about other reasons that might encourage to reclaim grey water, such as social responsibility, more sterile effluent of sophisticated treatment methods applied to grey water. Some indicated that they would ecclesiastically feel better if food containing wastewater was not discharged to the sewer system together with human excreta. Some others stated separate grey water collection systems would be an opportunity to receive a grant from the government. Some others only thought that segregation was necessary just to catch up the recent technological developments in the world.

Similar to additional motivations, some other concerns and drawbacks are stated by 6% of the participants, such as the efficiency of treatment system, fate of micro-pollutants. Another concern was stated as dilution of industrial wastewater with domestic wastewater would decrease because of separated collection of grey water. Despite all negative statements, 3% of participants pointed out there is no reason discouraging them to reuse grey water by selecting none of the options.

Reusing grey water for toilet flushes is the most logical and probably the most common areas of domestic reuse. As flush water constitutes about 1/4 of domestic water use [10], participants were asked if they would accept or reject reuse of grey water for toilet flushing if the water bill shows 25% reduction. 91% of participants accepted to reuse grey water for flushes if it can decrease the water bills, while only 15 rejected the idea. The responses revealed that showing measurable monetary benefits had positive effects on public opinion and acceptance.

To test the financial impacts further, participants were first asked for extra payment for the installation of grey water systems in their current houses. Of the entire respondents, only 7% indicated definite acceptance and 16% rejected the extra payment in their current houses completely as given in Figure 5.24. While 30% needed a proof of an environmental benefit, 20% of respondents stated that they needed a proof of a future financial benefit to pay for grey water system installation in their current houses. When the question was changed to free installation in their current houses, 28% of participants were still not sure. However, definite acceptance towards grey water installation was raised from 8% to 68% and only 4% of answers remained as no, which shows that conditionally acceptance from the previous question was changed to definite acceptance. These results revealed that the major drivers for willingness to pay extra were environmental and financial benefits, and more importantly economic instruments in the form of free installations would be a major factor for public acceptance and willingness to use grey water systems. The increase from 8% to 68% in terms of acceptance is perceived to be remarkable, and that such an incentive would be a major positive instrument/driver in the implementation of this practice (especially at the initial stages).

For the participants who still have objection even for the free installation, to measure effect of the rejection against an alteration, the participants were asked if they have any objection to these systems in a new house. In this case 81% of the participants didn't have any rejection for grey water plumbing systems in a new house as illustrated in Figure 5.25.

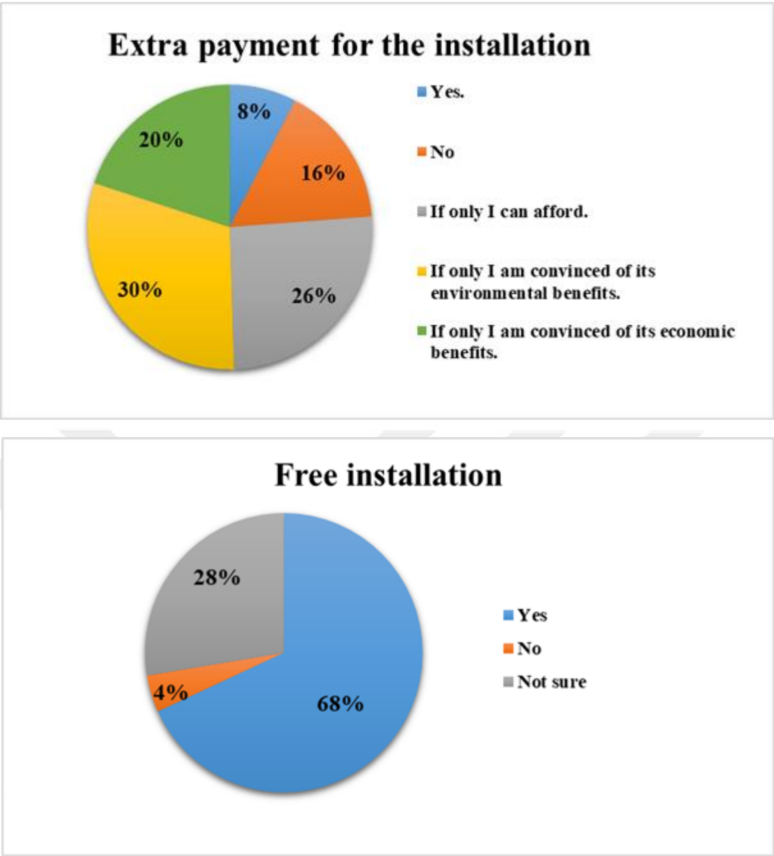

Figure 5.24: Financial drivers for installation of grey water plumbing systems in a current household.

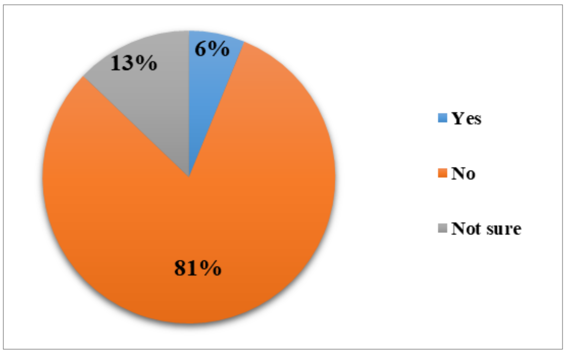

Figure 5.25: Installation of grey water plumbing systems in a new household.

(If you are buying a new house, would you have any objections to separate grey water collection system?)

Lastly, to assess motivations towards reusing grey water, participants were asked from whom they will be inspired. 60% of respondents thought public sector would be the most encouraging group followed by scientist and academicians, as shown in Figure 5.26, while public sector got around 20% lower acceptance in the study carried out by Beler Baykal and others [103]. This information may be useful in getting a clue in terms of with who to start the grey water reuse action in Turkish Republic.

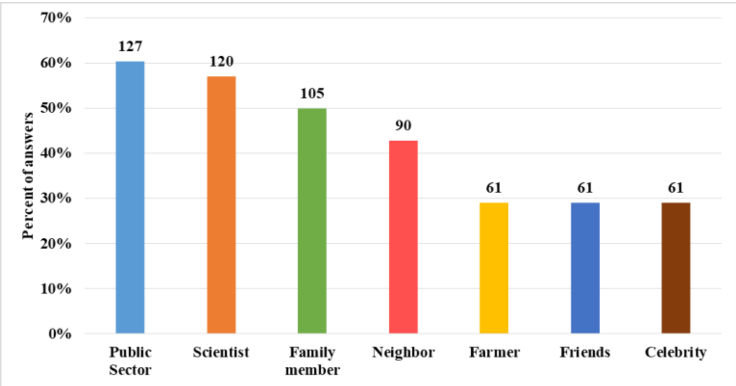

Figure 5.26: Possible role models to encourage grey water reuse.

(Whose reuse of grey water would courage you to reuse as well?)

5.6 Other Subjects to Consider

In addition water balances, grey water characteristics, quality criteria for reuse options, treatment options, and environmental, financial, and social drivers, there are other subjects to take into consideration for the implementation of grey water reclamation systems, such as the effects of grey water reuse on existing conventional sewer and treatment systems.

Although there are some studies stating that on-site grey water reuse has almost no effect on municipal sewer system, the scope of existing research is so far limited with small scale scenarios [104]. The study by Penn and others [104] indicated that, in the case of grey water reuse, the velocity of wastewater that remains in conventional sewer meets the minimum velocity requirement for movement of black water in the pipeline (The min velocity requirement for solid movement is stated as 0.6 - 1.0 m/s [105] [106]). When the flow velocity is low for black water movement, the grey water reuse implementations might end up with blockage, H_2S production and correspondingly odor problem in drains. The results of the same study showed that the current diameters of the sewer system and calculated pipe diameters for the cases where grey water is reclaimed, are the same when it is compared with commercial sewer pipe diameters available on the market.

Although the small scale grey water reuse practices don't affect the flowrate, they considerably change the concentrations of observed pollutant in sewer pipes [104]. It is not necessary to recycle entire grey water streams, since the grey water reuse demand is lower in comparison with grey water production in urban areas. Therefore it should be preferred to focus on less polluted weak grey water stream and to discharge the more polluted dark grey water to sewer system together with black water. The effects of grey water reuse on conventional wastewater management systems and receiving environments, some simulation software such as SIMBA might be used. In its version 6, SIMBA allows the analysis of sewer system, wastewater treatment plant, sludge treatment and receiving environments.

6. CONCLUSION AND RECOMMENDATIONS

In spite of the rapid population increase and urbanization, available water sources remain the same and undoubtedly global water scarcity will pose a risk all over the world, as well as in Turkish Republic (T.R.). This global water related challenge necessitates the development of new sustainable concepts to recover water resources including non-conventional practices. Instead of recovering entire domestic wastewater, stream segregation and ecological sanitation focuses on grey water as an alternative source of water, which is covers 70-75% of domestic wastewater by volume and less polluted in comparison with conventional wastewater.

Approximately 50% of potable water in Kocaeli is used by various industrial establishments, for public or private landscape irrigation and as flushing water, which don't necessarily require potable water quality. However they are all currently supplied by Yuvacik Dam, the primary water reserve of Kocaeli that is treated to drinking water quality and distributed to the edges of the city via 70-80 km-long-transmission line.

If conventional domestic wastewater across Kocaeli was separated into two streams as grey water and black water, possible water to be reclaimed as grey water would be around 55 million m^3/year, which is almost equal to the usable volume of Yuvacik Dam (51 million m^3). For this reason, the effects of the reuse of grey water as an alternative source is analyzed and assessed in this work in a smaller scale with the development of scenarios in the selected neighborhood, Yenikent, Kocaeli.

The results of this study revealed that around 1,000 m^3 grey water could be reclaimed specifically in Yenikent Neighborhood and five major end-use purposes, which do not require drinking water quality, were detected. The scenarios were developed based on the balance between possible grey water generation and water demand for potential reuse areas. The water balances gain importance in order to optimize the reuse of grey water and to consider the seasonal change of water demand for potential end-use purposes (such as landscape irrigation and cooling). Assessment of the water balances revealed that 64-100% saving of potable water (which goes into these end uses) is possible with the implementation of decentralized grey water reclamation systems in the study area. Among all, reuse of grey water on toilet flushes was the most advantageous scenario in terms of water savings, since only weak grey water is sufficient to meet the water demand for toilet reservoirs and >100% of water saving could be achieved, meaning that there is a surplus of treated grey water. Reuse of grey water for industrial purposes (such as cooling in this study) also turned out to be a legitimate implementation if water balances developed properly together with acceptable proximity.

The quality standard defined for water reuse applications in general is highly limited in T.R., since Turkish Technical Procedure Communication for Wastewater Treatment Plants is the only standard that mentions water reclamation, which only addresses irrigational purposes and there are no other quality standards defined specifically for grey water. However, the worldwide overview of reuse standards and determination of quality standards has shown that different end-uses have different quality criteria. Different end-use purposes selected for this study were pretty close to each other. Consequently, the same level of treatment process could be applied to grey water which would later be reused for different purposes.

The total capital costs of each scenario were compared with the investment cost of conventional system that consists of a similar capacity modular drinking water and wastewater treatment plants. The results of this study revealed that if water demand for various end use purposes was supplied/treated by on-site systems instead of conventional treatment systems, 42-75% saving of capital cost could be possible. However, it should be considered that the capital cost of conventional systems are higher for the modular plants with smaller capacities in comparison with conventional treatment systems designed for an entire city.

In terms of payback periods, each scenario showed reasonable period ranging between 6 months to 1.2 years. It should be noted that unit prices of potable water differs depending on the type of subscribers and it affects directly the length of payback period, as well as the volume that is reused. It legitimates the reuse of grey water in industrial facilities located nearby, since unit price of water for industrial subscribers are higher in comparison with households and irrigation.

Overall operational expenditures were calculated in USD per day basis for each scenario and compared with the operational cost of current conventional system (consisting of potable water treatment, potable water pumping, wastewater pumping, and wastewater treatment steps respectively). The results of financial assessment of this work revealed that 35% total savings in terms of OPEX could be achieved case-specifically, which showed that decentralized grey water reclamation systems were reasonable to be implemented for industrial reuse areas that were located nearby. Savings were calculated for toilet flushing as 15% for MBR treatment and 34% for UF treatment in terms of operational costs.

Within the scope of this study, the responses of public acceptance survey revealed that awareness regarding water stress/scarcity in T.R. is high and the general opinion seems to be positive regarding grey water reuse as in most cases acceptances were high, especially for non-potable uses including toilet flushing (91%) and irrigation (82%). Potable use of grey water received the lowest level of acceptance mainly due to hygienic safety and health concerns, which seem to be the most significant barrier for wide spread implementation of grey water reuse overall. In terms of the origin of grey water, all sub-streams of grey water received reasonable acceptance ranging between 43-68% acceptances. However the possible health risks seem to constitute the main concern in acceptance of the origins of grey water. Lower environmental impacts including water savings and economic benefits such as lower water bills were observed as the top drivers for grey water reuse. The results of the survey indicated that economic incentives will most likely increase willingness to adopt grey water systems. Increasing efforts of awareness raising, education and publicity, successful examples of practices, and financial benefits will most likely raise the level of acceptance and popularity of this sustainable practice.

Although the results of this study was motivating in terms of financial and social assessment of implementation of grey water reclamation systems, there are some other significant points to be a subject for further research. It should be considered that micropollutants in grey water, mainly arising from personal care products, should be monitored, since the long-term effect of these endocrine disruptors are still discussed. Additionally, the effects of grey water reclamation systems on existing conventional sewer and treatment systems should be examined in detail.

This work revealed that awareness regarding water stress in T.R. is pretty high and the opinion regarding grey water reuse is generally positive, especially for non-potable uses including toilet flushing and irrigation as indicated in the scenarios. However, the number of successful practices are not sufficient for public recognition or installation of these sustainable systems. The results of this work gave a clue that public sector, scientist, and academicians could convince/encourage the end user for widespread reuse of grey water in T.R. These result of the work bring forward the idea of legislative regulations and incentives on grey water reuse might serve as initial step where to start the grey water reuse action in T.R., and the effect of decision makers on promoting grey water reclamation cannot be denied. The installation of these systems could become compulsory for new building projects that generate reasonable amount of grey water. Within the scope of future legislative regulation on grey water reclamation in T.R., the number of the households could be estimated as 200 or more, since the results of studies in literature reported extremely short payback periods for this scale neighborhoods, as well as in this work.

As a summary, implementation of grey water reclamation systems revealed considerable savings in terms of not only capital and operational expenditures, but also consumption of fresh water reserves. It is possible to take the best adventages out of grey water reuse with a proper water balance and proximity assessment. For this reason, installation of grey water plumbing systems in new building projects is highly recommended to optimize the possible savings and promote the widespread use of these sustainable systems.

REFERENCES

[1] DSI (State Hydraulic Works of Turkey). *Toprak ve Su Kaynakları. (Soil and Water Resources)* [cited 2017 11 March 2017]; Available from: http://www.dsi.gov.tr/toprak-ve-su-kaynaklari.

[2] United Nations Educational Scientific and Cultural Organization (UNESCO), *Managing Water under Uncertainty and Risk: UN World Water Developement Report 4*. 2012: France.

[3] Kocaeli Water and Sewerage Administration, I., *2016 Annual Report*. 2017: Kocaeli.

[4] Kocaeli Water and Sewerage Administration, I., *2014 Annual Report.* 2015.

[5] ISAS. *Yuvacik Dam*. [cited 2017 19 October]; Available from: http://www.izmitsu.com.tr/sayfa.asp?ID=15&PID=2.

[6] United Nations, *World Population Prospects: 2017 Revision*. 2017: New York.

[7] 2030 Water Resources Group, *Charting Our Water Future: Economic frameworks to inform decision-making*. 2009.

[8] Amit Gross, et al., *Grey Water Reuse*, ed. C. Press. 2015, Boca Raton, FL: Taylor & Francis Group.

[9] Giresunlu, E., *Characterization and Analysis of Urban Weak Grey Water.pdf*, in *Department of Environmental Engineering*. 2015, Istanbul Technical University: Istanbul, Turkey.

[10] Beler Baykal B., *Stream Segregation in Household Use: A Review of Grey Water as an Alternative Source of Water and Yellow Water as an Alternative Source of Fertilizers.* Water Quality, Exposure and Health, 2014. **7**(1): p. 27-37.

[11] Giresunlu E. and Beler Baykal B., *An appraisal of microbiological indicators for grey water reuse as a priority issue*, in *CEST2015*. 2015: Rhodes, Greece.

[12] Oructut, N., *Grisu Yonetimi ve Kentsel Agirlikli Uygulamalarin Degerlendirilmesi*, in *Department of Environmental Engineering*. 2013, Istanbul Technical University: Istanbul, Turkey.

[13] Halalsheh, M., et al., *Grey water characteristics and treatment options for rural areas in Jordan.* Bioresour Technol, 2008. **99**(14): p. 6635-41.

[14] Ammari, T.G., et al., *An evaluation of the re-circulated vertical flow bioreactor to recycle rural greywater for irrigation under arid Mediterranean bioclimate.* Ecological Engineering, 2014. **70**: p. 16-24.

[15] Hernandez Leal, L., et al., *Characterisation and biological treatment of greywater.* Water Sci Technol, 2007. **56**(5): p. 193-200.

[16] Antonopoulou, G., A. Kirkou, and A.S. Stasinakis, *Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods.* Sci Total Environ, 2013. **454-455**: p. 426-32.

[17] Wurochekke, A.A., et al., *Constructed Wetland of Lepironia Articulata for Household Greywater Treatment.* APCBEE Procedia, 2014. **10**: p. 103-109.

[18] Casanova, L.M., C.P. Gerba, and M. Karpiscak, *Chemical and microbial characterization of household graywater.* Environmental Science and Health, 2001: p. 395-401.

[19] Palmquist, H. and J. Hanaeus, *Hazardous substances in separately collected grey- and blackwater from ordinary Swedish households.* Sci Total Environ, 2005. **348**(1-3): p. 151-63.

[20] Rodda, N., et al., *Use of domestic greywater for small-scale irrigation of food crops: Effects on plants and soil.* Physics and Chemistry of the Earth, Parts A/B/C, 2011. **36**(14-15): p. 1051-1062.

[21] Chaillou, K., et al., *Bathroom Greywater Characterization and Potential Treatments for Reuse.* Water, Air, & Soil Pollution, 2010. **215**(1-4): p. 31-42.

[22] Ghrair, A.M., et al., *Influence of grey water on physical and mechanical properties of mortar and concrete mixes.* Ain Shams Engineering Journal, 2016.

[23] Abdel Kader, A.M., *Studying the Efficiency of Greywater Treatment by Rotating Biological Contactors System*, in *Fifteenth International Water Technology Conference*. 2011: Alexandria, Egypt.

[24] Assayed, A., J. Chenoweth, and S. Pedley, *Assessing the efficiency of an innovative method for onsite greywater treatment: Drawer compacted sand filter – A case study in Jordan.* Ecological Engineering, 2015. **81**: p. 525-533.

[25] Ronen, Z., A. Guerrero, and A. Gross, *Greywater disinfection with the environmentally friendly Hydrogen Peroxide Plus (HPP).* Chemosphere, 2010. **78**(1): p. 61-5.

[26] Chin, W.H., F.A. Roddick, and J.L. Harris, *Greywater treatment by UVC/H2O2.* Water Res, 2009. **43**(16): p. 3940-7.

[27] Sara Finley, Suzelle Barrington, and D. Lyew, *Reuse of Domestic Greywater for Irrigation of Food Crops.* Water Air Soil Pollution, 2009.

[28] Asan, C., *Grisularin Yeniden Kullaniminda Membran Biyoreaktor (MBR) Uygulamalari*, in *Department of Environmental Engineering*. 2013, Ondokuz Mayis University: Samsun, Turkey.

[29] Nolde, E., *Greywater reuse systems for toilet fushing in multi-storey buildings - over ten years experience in Berlin.* Urban Water Journal, 2000: p. 275-284.

[30] Christova-Boala, D., R.E. Edenb, and S. McFarlaneC, *An investigation into greywater reuse for urban residential properties.* Desalination, 1996: p. 391-397.

[31] Friedler, E., R. Kovalio, and N.I. Galil, *On-site greywater treatment and reuse in multi-storey buildings.* Water Science & Technology, 2005. **51**: p. 187-194.

[32] Gilboa, Y. and E. Friedler, *UV disinfection of RBC-treated light greywater effluent: kinetics, survival and regrowth of selected microorganisms.* Water Res, 2008. **42**(4-5): p. 1043-50.

[33] Friedler, E. and Y. Gilboa, *Performance of UV disinfection and the microbial quality of greywater effluent along a reuse system for toilet flushing.* Sci Total Environ, 2010. **408**(9): p. 2109-17.

[34] Penn, R., M. Hadari, and E. Friedler, *Evaluation of the effects of greywater reuse on domestic wastewater quality and quantity.* Urban Water Journal, 2012. **9**(3): p. 137-148.

[35] J.G. March, M. Gual, and F. Orozco, *Experiences on greywater re-use for toilet flushing in a hotel (Mallorca Island, Spain).* Desalination, 2004: p. 241-247.

[36] Eriksson, E., et al., *Greywater pollution variability and loadings.* Ecological Engineering, 2009. **35**(5): p. 661-669.

[37] Nolde, E. *Greywater Reuse in Households-Experience from Germany*. in *Second International Conference on Ecological Engineering for Wastewater Treatment*. 1995. Zurich, Switzerland.

[38] Giresunlu E. and Beler Baykal B., *Tracking pathogenic indicators in the grey water cycle for reuse in flushes*, in *IWA Alternative Water Resources Conference*. 2014: Nanjing, China.

[39] Metcalf & Eddy, *Wastewater Engineering: Treatment and Reuse*. 2003, New York, NY, USA: Mc Graw Hill.

[40] Mohamed, R.M., et al., *A monitoring of environmental effects from household greywater reuse for garden irrigation.* Environ Monit Assess, 2013. **185**(10): p. 8473-88.

[41] Friedler, E., *Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities.* Environmental Technology, 2004. **25**: p. 997-1008.

[42] National Environmental Engineering Research Institute Nehru Marg, *Greywater Reuse In Rural Schools: Wise Water Management Guidance*. 2007: India.

[43] Sirkar, K.K., *Separation of molecules, Macromolecules and Particles: Principle, Phenomena and Processes*. 2014, United Kingdom: Cambridge University Press.

[44] Sarioglu, S., *Low load greywater and municipal wastewater treatment by membrane bioreactor*, in *Institute of Environmental Science*. 2011, Bogazici University: Istanbul, Turkey.

[45] A. Dixon, D.B., A. Fewkes, M. Robinson, *Measurement and modelling of quality changes in stored untreated grey water.* Urban Water Journal, 2000. **1**: p. 293-306.

[46] Radcliffe, J.C., *Evolution of water recycling in Australian cities since 2003.* Water Sci Technol, 2010. **62**(4): p. 792-802.

[47] World Health Organization (WHO), *Overview of greywater management: Health considerations in Jordan*, J. Regional Office for the Eastern

Mediterranean Centre For Environmental Health Activities in Amman, Editor. 2006.

[48] T.R. Ministry of Environment and Forestry (Ministry of Environment and Urbanization), *Technical Procedure Communication for Wastewater Treatment Plants*, in *27527*. 20 March 2010.

[49] Ministry of Environment and Urbanization, *State of the Environment Report for Republic of Turkey*. 2016.

[50] FAO. *Wastewater Treatment and Use in Agriculture*. [cited 2017 10 October].

[51] Nas, B., *Atıksu Arıtma Tesislerinde İşletme Sorunları ve Çözümleri*, ed. TC Çevre ve Şehircilik Bakanlığı Çevre Yönetimi Genel Müdürlüğü. 2017, Ankara, Turkiye: Selçuk Üniversitesi Basım Evi.

[52] Ministry of Environment and Urbanization, *Waste Water Treatment Action Plan (2015-2023)*. 2015.

[53] Ministry of Environment and Urbanization, *2017 Waste WaterTreatment Plant Inventory* W.W.P. Inventory, Editor. 2017.

[54] Nas, B. *Türkiye Genelindeki Evsel/Kentsel Atıksu Arıtma Tesislerinin Mevcut Durumunun Tespiti, Revizyon İhtiyacının Belirlenmesi Projesi (TÜRAAT)*. in *Türkiye Genelindeki Evsel/Kentsel Atıksu Arıtma Tesislerinin Mevcut Durumunun Tespiti, Revizyon İhtiyacının Belirlenmesi Projesi (TÜRAAT) Kapanis Toplantisi*. 2017.

[55] Ozcan, E. *Turkiye'de Atiksu Yonetimi*. in *Turkiye Kiyilarinda Yuzmesuyu Profillerinin Belirlenmesi ve Turizmde Atiksu Yonetimi*. 25 September 2014. Gebze, Turkey.

[56] US Green Building Couincil, U. *Scorecard of LEED Certificate*. 2017 [cited 2017 12 November]; Available from: https://www.usgbc.org/credits.

[57] The Green Building Information Gateway, G., *Explore Green Buildings*. 2017.

[58] Ceyhan, İ., in *Yesil Bina: Surdurulebilir Yapi Teknolojileri Dergisi*. June 2010.

[59] Ministry of Environment and Urbanization. *Sürdürülebilirlik Performanslı Kentsel Dönüşüm (Süper Kent Sistemi) Projesi*. 9 November 2015 [cited 2017 27 April]; Available from: http://www.csb.gov.tr/gm/altyapi/index.php?Sayfa=haberdetay&Id=20704.

[60] Su ve Cevre Dergisi, *Kadikoy "Cevre"ye Odaklandi*, in *Su ve Cevre*. Aralik 2012: Istanbul.

[61] Beler Baykal B. *Atiksularin Akimlarina Ayrilmasi ve Gri Su Geri Kazanimi*. in *Turkiye Kiyilarinda Yuzme Suyu Profillerinin Belirlenmesi ve Turizmde Atiksu Yonetimi*. 2014. Gebze, Turkey: Ministry of Environment and Urbanization.

[62] Governorate of Kocaeli. *Geography of Kocaeli*. [cited 2017 05 November]; Available from: http://www.kocaeli.gov.tr/geography-of-kocaeli.

[63] TURKSTAT. *Adrese Dayali Nufus Kayit Sistemi*. August 2017 [cited 2017 08 April]; Available from: https://biruni.tuik.gov.tr/medas/?kn=95&locale=tr.

[64] Governorate of Kocaeli. *Production Center of Nation's Industry*. Available from: http://www.kocaeli.gov.tr/sanayi-kenti-kocaeli.

[65] Otterpohl R., Braun U., and Oldenburg M., *Innovative technologies for decentralised wastewater management in urban and periurban areas.* Water Science and Technology, 2003. **48 (13)**: p. 23-31.

[66] Saski Water and Sewerage Administration, S. *Sapanca Lake*. [cited 2017 10 October]; Available from: https://www.sakarya-saski.gov.tr/icerik/detay.aspx?Id=49.

[67] ISAS. *Analysis Results*. [cited 2017 17 October]; Available from: http://www.izmitsu.com.tr/teknikveriler.asp?Yil=2017&ID=53&PID=8.

[68] Ministry of Health, *İnsani Tüketim Amaçlı Sular Hakkında Yönetmelik*, in *RG-7/3/2013-28580*. 07 March 2013.

[69] Kocaeli Water and Sewerage Administration, I. *Kullanilmis Su Geri Donusumu*. [cited 2017 7 September]; Available from: https://www.isu.gov.tr/icerik/detay.aspx?Id=329.

[70] Kocaeli Water and Sewerage Administration, I. *Wastewater Treatment Plants in Kocaeli*. [cited 2017 10 November]; Available from: https://www.isu.gov.tr/icerik/detay.aspx?Id=208.

[71] Municipality of Kocaeli. *Sanayi Kenti Kocaeli*. [cited 2017 20 July 2017]; Available from: http://www.kocaeli.gov.tr/sanayi-kenti-kocaeli.

[72] Yenikoy Neighborhood Unit, H. Efe, Editor.

[73] ISU Department of Real Estate and Expropriation. August 2016: Kocaeli.

[74] Gebze Guzeller Organized Industrial Zone. 2017 September 2017]; Available from: https://www.ggosb.com.tr/hakkimizda/.

[75] Gebze Guzeller Organized Industrial Zone. September 2017]; Available from: https://www.ggosb.com.tr/firma-rehberi.

[76] Ministry of Science Industry and Technology, *OIZ Information System*. 2014.

[77] Gebze Guzeller Organized Industrial Zone, *Water Consumption in Gebze Guzeller Organized Industrial Zone*. 2016: Gebze, Turkey.

[78] Gebze Organized Industrial Zone. *List of Production Companies in Gebze OIZ*. September 2017]; Available from: http://www.gosb.com.tr/firmalar/uretimdeki-firmalar.

[79] Gebze Organized Industrial Zone. *Infrastructure Services in Gebze OIZ*. September 2017]; Available from: http://www.gosb.com.tr/hizmetler/altyapi-hizmetleri/su.

[80] Gebze Guzeller Organized Industrial Zone, *Water Consumption in Gebze Organized Industrial Zone*. 2017: Gebze, Turkey.

[81] Ministry of Forestry and Water Affairs. 2 August 2013 September 2017]; Available from: http://kocaeli.ormansu.gov.tr/kocaeli/anasayfa/resimlihaber/13-08-02/Tabiat_Park%C4%B1_Say%C4%B1m%C4%B1z_7_oldu.aspx?sflang=tr.

[82] ISU Gebze Branch, *Water Consumption in Gebze District.* 2016.

[83] Atasoy, E., et al., *Membrane Bioreactor (MBR) Treatment of Segregated Household Wastewater for Reuse.* CLEAN – Soil, Air, Water, 2007. **35**(5): p. 465-472.

[84] Murat Hocaoglu, S., et al., *COD fractionation and biodegradation kinetics of segregated domestic wastewater: black and grey water fractions.* Journal of Chemical Technology & Biotechnology, 2010. **85**(9): p. 1241-1249.

[85] Baban, A., et al., *Grey water treatment and reuse by using RBC: A kinetic approach.* Desalination and Water Treatment, 2010. **23**(1-3): p. 89-94.

[86] Barisci, S., *Electrochemical ferrate (VI) and research of its pottential use for greywater treatment*, in *Department of Environmental Engineering*. 2017, Gebze Technical University: Gebze, Turkey.

[87] Barışçı, S. and O. Turkay, *Domestic greywater treatment by electrocoagulation using hybrid electrode combinations.* Journal of Water Process Engineering, 2016. **10**: p. 56-66.

[88] Simon Judd, C.J., *The MBR BOOK*. 2011, Oxford, UK: Elsevier.

[89] Membranes, K. *Hollow Fiber Submerged Membrane Modules for MBR Applications Data Sheet (PSH1500)*. [cited 2017 10 April]; Available from: http://www.kochmembrane.com/PDFs/Data-Sheets/Hollow-Fiber/UF/puron-mbr-modules-psh250-500-1500-datasheet.aspx.

[90] Santasmasas, C., et al., *Grey water reclamation by decentralized MBR prototype.* Resources, Conservation and Recycling, 2013. **72**: p. 102-107.

[91] Ramona, G., et al., *Low strength graywater characterization and treatmentby direct membrane filtration.* Desalination, 2004. **170**(3): p. 241-250.

[92] Merz, C., et al., *Membrane bioreactor technology for the treatment of greywater from a sports and leisure club.* Desalination, 2007. **215**(1-3): p. 37-43.

[93] Lesjean, B. and R. Gnirss, *Grey water treatment with a membrane bioreactor operated at low SRT and low HRT.* Desalination, 2006. **199**(1-3): p. 432-434.

[94] B. Jefferson, et al., *Membrane bioreactors and their role in wastewater reuse.* Water Science & Technology, 2000. **41**: p. 197-204.

[95] Jefferson, B., et al., *Technologies for domestic wastewater recycling.* Urban Water Journal, 1999: p. 285-292.

[96] Urban Housing Construction Department of Kocaeli Metropolitan Municipality. *Completed Housing Projects*. [cited 2017 15 May]; Available from: http://www.kentkonut.com.tr/projeler.

[97] Turkish Electricity Distribution Corporation (TEDAS). July 2016 [cited 2017 11 April]; Available from: http://www.tedas.gov.tr/#!tedas_tarifeler.

[98] European Commission. *Inforeuro Currency Converter*. [cited 2017 11 April]; Available from: http://ec.europa.eu/budget/contracts_grants/info_contracts/inforeuro/index_en.cfm.

[99] Kocaeli Water and Sewerage Administration, I., *2015 Annual Report.* 2016.

[100] Kocaeli Water and Sewerage Administration, I. *Unit water prices*. 2017 [cited 2017 11 April]; Available from: https://isu.gov.tr/sufiyatlari/index.aspx.

[101] Information Technology Department of ISU, *Water Consumption in Yenikent District*. 2015 - 2016.

[102] UNDP (United Nations Development Programme). *Coping with Water Scarcity*. [cited 2017 07 July 2017]; Available from: http://www.tr.undp.org/content/turkey/en/home/presscenter/news-from-new-horizons/2007/04/coping-with-water-scarcity.html.

[103] Beler Baykal B., et al. *A preliminary survey on public attitude for the reuse of grey water as an alternative source of water in Turkey*. in *IWA Conference on Sustainable Solutions for Small Water and Wastewater Treatment Systems (S2Small2017)*. 2017. Nantes, France: IWA.

[104] Penn, R., M. Schutze, and E. Friedler, *Modelling the effects of on-site greywater reuse and low flush toilets on municipal sewer systems.* J Environ Manage, 2013. **114**: p. 72-83.

[105] Bong, C.H.J., *A Review on the Self-Cleansing Design Criteria for Sewer System.* UNIMAS e-Journal of Civil Engineering, 2014.

[106] Walski, T., Edwards, B., Helfer, E., Whitman, B.E.,, *Transport of large solids in sewer pipes.* Water Environmental Research, 2009. **81**: p. 709-714.

[107] Griffiths, D., *Head First Statistics*. 2009, USA: O'REILLY.

[108] Alfred A. Bartolucci, K.P.S., and Sejong Bae., *Introduction to Statistical Analysis of Laboratory Data*. 1st ed. 2016: John Wiley & Sons, Inc.

[109] USEPA, *Guidelines for Water Reuse*, in *EPA/600/R-12/618*, O.o.W.M.O.o.W. U.S. Environmental Protection Agency (USEPA), Editor. September 2012: Washington, D.C.

[110] Government of Western Australia, D.o.H., *Guidelines for the Non-potable Uses of Recycled Water in Western Australia*, D.o.H. Government of Western Australia, Editor. August 2011.

[111] Department of Primary Industries Water and Environment (DPIWE), *Environmental Guidelines for the Use of Recycled Water in Tasmania* D.o.P.I.W.a.E. (DPIWE), Editor. December 2002.

[112] Texas Commission on Environmental Quality, *Texas Administrative Code Title 30, Chapter 210: Use of Reclaimed Water - Subchapter C: Quality Criteria and Specific Uses for Reclaimed Water-Type 1*, in *210.31 - 210.36*, T.C.o.E. Quality, Editor. 26 November 2009.

[113] Florida Department of Environmetal Protection, *Reuse of Reclaimed Water and Land Application: Chapter 62-610* F.D.o.E. Protection, Editor. 1999.

[114] Qasim Akhtar, Katherine Hyde, and T. Yearley. *Greywater: a study of greywater characteristics and treatment feasibility at the University of Reading*. in *WATEF -Water Efficiency Conference*. 26 March 2013.

[115] Ernst, M., et al., *An integrated wastewater treatment and reuse concept for the Olympic Park 2008, Beijing.* Desalination, 2007. **202**(1-3): p. 293-301.

[116] Spanish Association of Sustainable Water Reuse, *Spanish Regulations for Water Reuse: Royal Decree*, in *1620/2007*, S.A.o.S.W. Reuse, Editor. September 2011.

[117] A. Tajima, M.Y., K. Sakurai, M. Minamiyama, *Establishment of Guidelines for Reuse of Treated Wastewater*, in *4th Japan-U.S. Governmental Conference on Drinking Water Quality Management and Wastewater Control*. 22 January 2007: Okinawa.

[118] Surendran, S., *Grey-Water Reclamation for Non-Potable Re-Use*, in *CIWEM's East Midlands and West Midlands Branches,*. 1998: Nottingham.

[119] Al-Hajri, M.A. *Wastewater Reuse Regulations in Saudi Arabia*. in *Water Arabia*. 2-4 March 2009.

[120] Couto, E.d.A.d., et al., *Greywater treatment in airports using anaerobic filter followed by UV disinfection: an efficient and low cost alternative.* Journal of Cleaner Production, 2015. **106**: p. 372-379.

[121] Canada Mortgage and Housing Corporation (CMHC), *Water Reuse Standards and Verification Protocol*. 2005.

[122] Singapore National Water Agency, *Technical Guides for Grey Water Recyling System*, S.N.W. Agency, Editor. 2014.

[123] Singapore National Water Agency. *Guidelines for Treated Greywater Quality*. [cited 2017 19 February]; Available from: https://www.pub.gov.sg/Documents/greywaterRequirements.pdf.

[124] Queensland Government Department of Housing and Public Works, *Queensland Plumbing and Wastewater Code*. 26 October 2017.

[125] Victoria, E., *Code of Practice-Onsite Wastewater Management*, in *891.4,* E. Victoria, Editor. 2016.

[126] Government of Western Australia, D.o.H., *Code of Practice for the Reuse of Greywater in Western Australia 2010*, D.o.H. Government of Western Australia, Editor. 2010.

[127] NSW Government, D.o.W.a.E., *Guidelines for Greywater Reuse in Sewered, Single Household Residential Premises*, D.o.W.a.E. NSW Government, Editor. May 2008.

[128] Government, N.T., *Draft Guidelines Wastewater Works Design Approval for Recycled Water Systems*, D.o. Health, Editor. 9 July 2014.

[129] Committee), C.M.o.H.F.P.T., *Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing*, C.M.o.H.F.P.T. Committee), Editor. 2010, Minister of Health.

[130] California Department of Public Health. *California Code of Regulations - Title 22 -Division 4 - Chapter 3 - Article 3. Uses of Recycled Water*. Available from: https://govt.westlaw.com/calregs/Browse/Home/California/CaliforniaCodeofRegulations?guid=IF08AF390D4B911DE8879F88E8B0DAAAE&originationContext=documenttoc&transitionType=Default&contextData=(sc.Default).

[131] Colorado Department of Public Health and Environment: Water Quality Control Commission, *Greywater Control Regulation*, in *Reg. #86, 5 CCR 1002-86*, C.D.o.P.H.a. Environment, Editor. 30 December 2015.

[132] Oregon Department of Environmental Quality, *340-053-0050 Division 53 Graywater Reuse and Disposal Systems* Oregon Department of Environmental Quality, Editor. 2011.

[133] New Mexico Environmental Improvement Board, *Environmental Protection: Chapter 7 Wastewater and Water Supply Facilities: PART 3 Liquid Waste Disposal and Treatment*, in *20*, N.M.E.I. Board, Editor. 2013.

[134] Hawaii State Department of Health Wastewater Branch, *Guidelines for Treatment and Reuse of Recycled Water*, H.S.D.o.H.W. Branch, Editor. 15 May 2002.

[135] Guidelines Committee (Merger University, E., BOAG, Georgia Department of Community Affairs, University of Georgia),, *Georgia Gray Water Recycling Systems Guidelines.* 2009.

[136] Arizona Department of State, *Arizona Administrative Code: Environmental Quality - Chapter 9, 11*, in *18*, A.D.o. State, Editor. 2016.

[137] Department of Environmental Protection. *310 CMR 15.262: Grey Water Systems*. [cited June 24 2016]; Available from: http://www.mass.gov/courts/docs/lawlib/300-399cmr/310cmr15.pdf.

[138] Massachusetts Department of Environmental Protection. *314 CMR 20.00: Reclaimed Water Permit Program and Standards*. 20 March 2009 [cited 2017 January 2]; Available from: https://www.mass.gov/regulations/314-CMR-2000-reclaimed-water-permit-program-and-standards.

[139] South Dakota Legislative Research Council. *74:53:01:38. Requirements for graywater system*. 1996 [cited 2017 8 March]; Available from: http://www.sdlegislature.gov/Rules/DisplayRule.aspx?Rule=74:53:01:38.

[140] Montana Secretary of State, *Grey Water Reuse*, in *17.36.319*, M.S.o. State, Editor. 2009.

[141] Office of the Secretary of Texas State, *Title 30, Chapter 210: Use of Reclaimed Water - Subchapter F: Use of Grey Water Systems*, in *30*, Office of the Secretary of Texas State, Editor. 2016.

[142] Washington State Department of Health & Ecology, *Water Reclamation and Reuse Standards*, Washington State Department of Health & Ecology, Editor. September 1997.

[143] Wisconsin Legislative Reference Bureau, *Wisconsin Administrative Code - Chapter SPS 382 - Design, Construction, Installation, Supervision, Maintenance and Inspection of Plumbing*, Wisconsin Legislative Reference Bureau, Editor. 2016.

[144] Oron, G., et al., *Greywater use in Israel and worldwide: standards and prospects.* Water Res, 2014. **58**: p. 92-101.

[145] New Jersey Department of Environmental Protection (NJDep), *Technical Manual: Reclaimed Water for Beneficial Reuse*, New Jersey Department of Environmental Protection (NJDep), Editor. 2005.

[146] Georgia Department of Natural Resources, *Guidelines for Water Reclamation and Urban Water Reuse*, Georgia Department of Natural Resources, Editor. 2012.

[147] Laura Alcalde Sanz and Bernd Manfred Gawlik, *Water Reuse in Europe Relevant guidelines, needs for and barriers to innovation*, in *JRC Science and Policy Reports*. 2014, European Commission.

[148] Utah Office of Administrative Rules. *Utah Administrative Code: Rule R317-401. Graywater Systems*. 1 November 2017; Available from: https://rules.utah.gov/publicat/code/r317/r317-401.htm.

[149] Department of Public Health Environmental Health Section, *Manual for On-site Sewage Management Systems*. 2016.

[150] TURKSTAT. *Belediye Su İstatistikleri*. 2015 22 December 2015 [cited 2017 15 November 2017]; Available from: http://www.tuik.gov.tr/PreHaberBultenleri.do?id=18779.

APPENDICES

APPENDIX A: Method for Outlier Analysis

APPENDIX B1: List of Guidelines and Regulations on Wastewater and Grey Water Reuse

APPENDIX B2: Quality Criteria for Wastewater and Grey Water Reuse

APPENDIX C: Survey on Public Willingness and Acceptance for Grey Water Reuse

APPENDIX D: Pathway for Grey Water Reuse Implementations

APPENDIX A: Method for Outlier Analysis

In this study, boxplot method is used for the analysis of outliers from the literature data on characterization of mixed, weak and bathroom grey water. After the removal of outliers, minimum and maximum values of the observations are found and typical ranges for each parameter are detemined by the the calculation of interquartile range (IQR).

A boxplot is a graph used to show the shape of a distribution as given in Figure A.1. The elements of the graph are its central value, its spread, and the minimum and maximum values of the data. Any data that lies beyond these values are treated as outliers. The box plot rule has been applied to detect outliers for univariate and multivariate data in chemistry data. As it is shown in Figure A.1, the upper and lower boundaries of the box define the interquartile range (IQR) or the values between the 25th and 75th percentiles. These values are known as the lower quartile or first quartile (Q1), and the upper quartile, or third quartile (Q3) repectively. The line within the box is the quartile in the middle (Q2) which is the median, as it splits the data in half. The horizontal lines below and above the box are the minimum and maximum values of the data without the outliers, where outlier marked with asterisk [107] [108].

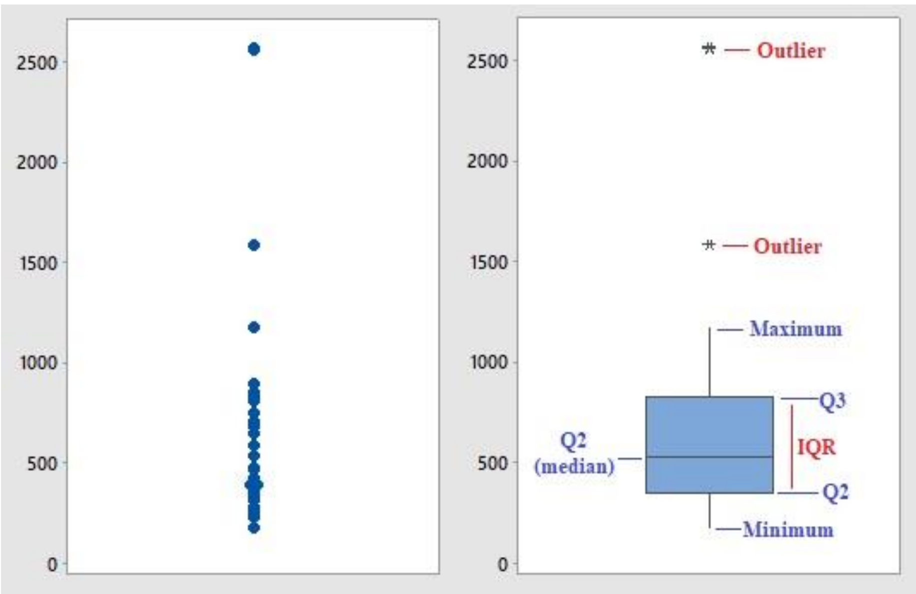

Figure A.1: Individual value and boxplot presentation of the same data set.

The box plot can capture more than one suspected outlier at a time. If a graph is not available, a rule of thumb is to compute the IQR, which is; Q3–Q1 = IQR. One then takes 1.5 times the IQR (1.5 x IQR). One then takes the first quartile minus this value Q1 - (1.5 x IQR) and if any points lie below this value, then it is considered an outlier candidate. On the other end, take the third quartile plus this value Q3 + (1.5 x IQR) and if any points lie above this value it is considered an outlier as well. Oftentimes if the data is normal, the multiplier is taken as 1.35 instead of 1.5 [108].

In this study the box plots are created in Minitab 18 which is statistical software that allows the calculation of outliers together with Q1 and Q3, median (Q2) and mean.

APPENDIX B1: List of Guidelines and Regulations on Wastewater and Grey Water Reuse

Table B1.1: Guidelines and regulations on wastewater and grey water reclamation.

Related Regulation/Guideline	Country	Date	Ref.
WASTEWATER to TOILET FLUSHING			
Guidelines for Water Reuse (Table 4-4: Unrestricted Urban Reuse)	EPA	2012	[109]
Guidelines for the Non-potable Uses of Recycled Water in Western (Table 7, 8)	Western Australia, Australia	2011	[110]
Environmental Guidelines for the Use of Recycled Water in Tasmania (Table 2-1)	Tasmania, Australia	2002	[111]
Title 30, Chapter 210: Use of Reclaimed Water - Subchapter C: Quality Criteria and Specific Uses for Reclaimed Water-Type 1	Texas, USA	2009	[112]
Chapter 62-610 Reuse of Reclaimed Water and Land Application	Florida, USA	1999	[113]
Chinese Water Quality Standards for Reclamation (GB/T18920-2002, GB/T18921-2002)	China	2002	[114, 115]
Spanish Regulations for Water Reuse: Royal Decree 1620/2007 (Appendix A)	Spain	2011	[116]
Guidelines for the Reuse of Treated Wastewater from the Ministry of Land, Infrastructure and Transport of Japan	Japan		[117]
Water Quality Criteria for Toilet Flushing in Japan	Japan		[118]
Rules of Implementations for the Regulations of Treated Sanitary Wastewater and Its Reuse by Ministry of Water and Electricity (MOWE) (Table 3)	Saudi Arabia	2005	[119]
Brazilian standard NBR 13969	Brazil	1997	[120]
Water Reuse Standards in Korea	Korea		[121]
GREY WATER to TOILET FLUSHING			
Technical Guideline for Greywater Recycling System (Table 1)	Singapore	2014	[122]
Guidelines for Treated Greywater Quality	Singapore	2014	[123]
Queensland Plumbing and Wastewater Code (Table T1A, T1B)	Queensland, Australia	2017	[124]
Code of practice - onsite wastewater management (Section 2.2.3)	Victoria, Australia	2016	[125]
Code of Practice for the Reuse of Greywater in Western Australia (Table 1, 2)	Western Australia, Australia	2010	[126]
Guidelines for Greywater Reuse in Sewered, Single Household Residential Premises	New South Wales, Australia	2008	[127]
Draft Guidelines for Wastewater Works Design Approval of Recycled Water Systems (Table 6, 7)	Northern Territory, Australia	2014	[128]
Canadian Guidelines for Domestic Reclaimed Water for Use in Toilet and Urinal Flushing-Table 1	Canada	2010	[129]
Service Water Reuse Criteria	Berlin, Germany	1999	[29]
California Code of Regulations - Title 22 -Division 4 - Chapter 3 - Article 3. Uses of Recycled Water (60307. Use of Recycled Water for Other Purposes)	California, USA		[130]

Table B1.1 (continued): Guidelines and regulations on wastewater and grey water reclamation.

Related Regulation/Guideline	Country	Date	Ref.
Grey Water Control Regulation	Colorado, USA	2015	[131]
340-053-0050 Division 53 Graywater Reuse and Disposal Systems	Oregon, USA	2011	[132]
TITLE 20 Environmental Protection: Chapter 7 Wastewater and Water Supply Facilities: PART 3 Liquid Waste Disposal and Treatment	New Mexico, USA	2013	[133]
Guidelines for the Treatment and Use of Recycled Water (Type R1)	Hawaii, USA	2002	[134]
Georgia Gray Water Recycling Systems Guidelines	Georgia, USA	2009	[135]
Arizona Administrative Code - Title 18: Environmental Quality - Chapter 9, 11 - Class A	Arizona, USA	2016	[136]
Senate bill 126–Senator Care BDR 48-394	Nevada, USA	2009	[12]
248 CMR 10.00: Massachusetts Uniform State Plumbing Code	Massachusetts, USA		
310 CMR 15.262: Grey Water Systems		2016	[137]
314 CMR 20.00: Reclaimed Water Permit Program and Standards (Class A)		2009	[138]
74:53:01:38. Requirements for graywater system	South Dakota, USA	1996	[139]
17.36.319 Grey Water Reuse	Montana, USA	2009	[140]
Title 30, Chapter 210: Use of Reclaimed Water - Subchapter F: Use of Grey Water Systems	Texas, USA	2016	[141]
Water Reclamation and Reuse Standards (Article 4 - Section 11, Table 2)	Washington, USA	1997	[142]
Wisconsin Administrative Code - Chapter SPS 382 - Design, Construction, Installation, Supervision, Maintenance and Inspection of Plumbing	Wisconsin, USA	2016	[143]
BS-8525-1 Greywater systems: Code of practice	UK	2010	[9]
Reuse Criteria for Greywater by the Standards Institute of the State of Israel (Quality C)	Israel		[144]
Overview of greywater management: Health considerations in Jordan	Jordan	2006	[47]
WASTEWATER to LANDSCAPE IRRIGATION			
Guidelines for Water Reuse (Table 4-4: Unrestricted Urban Reuse)	EPA	2012	[109]
Technical Manual: Reclaimed Water for Beneficial Reuse (Appendix A: RWBR Public Access Systems)	New Jersey, USA	2005	[145]
Chapter 210: Use of Reclaimed Water - Subchapter C: Quality Criteria and Specific Uses for Reclaimed Water-Type 1	Texas, USA	2009	[112]
Guidelines for Water Reclamation and Urban Water Reuse (Chapter 3.2., Appendix A)	Georgia, USA	2012	[146]
Technical Procedure Communication for WWTPs (Reg. No.27527)	Turkish Republic	2010	[48]
Guidelines for the Non-potable Uses of Recycled Water in Western Australia (Table 7, 8)	Western Australia, Australia	2011	[110]
Environmental Guidelines for the Use of Recycled Water in Tasmania (Table 2-1)	Tasmania, Australia	2002	[111]

Table B1.1 (continued): Guidelines and regulations on wastewater and grey water reclamation.

Related Regulation/Guideline	Country	Date	Ref.
Brazilian standard NBR 13969	Brazil	1997	[120]
Decree no: 296/03.06.05	Cyprus		[9]
DL 236/98 & ERSAR Technical Guide no 14: Wastewater reuse	Portugal		[147]
Art 24 Decret 94/469	France	1994	[147]
JMD 145116/11	Greece		[147]
Spanish regulations for Water Reuse: Royal Decree 1620/2007 (Appendix A)	Spain	2011	[116]
Rules of Implementations for the Regulations of Treated Sanitary Wastewater and Its Reuse by Ministry of Water and Electricity (MOWE) (Table 3)	Saudi Arabia	2005	[119]
Water Reuse Standards in Korea	Korea		[121]
Guidelines for the Reuse of Treated Wastewater from the Ministry of Land, Infrastructure and Transport of Japan	Japan	2007	[117]
Chinese Water Quality Standards for Reclamation (GB/T18920-2002, GB/T18921-2002)	China	2002	[115]
GREY WATER to LANDSCAPE IRRIGATION			
California Code of Regulations - Title 22 -Division 4 - Chapter 3 - Article 3. Uses of Recycled Water (60304. Use of Recycled Water for Irrigation)	California, USA		[130]
340-053-0050 Division 53 Graywater Reuse and Disposal Systems (Type 1, 2, 3)	Oregon, USA	2011	[132]
Title 20 Environmental Protection: Chapter 7 Wastewater and Water Supply Facilities: PART 3 Liquid Waste Disposal and Treatment	New Mexico, USA	2013	[133]
Grey Water Control Regulation	Colorado, USA	2015	[131]
Guidelines for the Reuse of Grey Water	Hawaii, USA	2009	
Guidelines for the Treatment and Use of Recycled Water (Type R1, R2)		2002	[134]
Arizona Administrative Code - Title 18: Environmental Quality - Chapter 9, 11 - Class A	Arizona, USA	2016	[136]
314 CMR 20.00: Reclaimed Water Permit Program and Standards (Class A)	Massachusetts, USA	2009	[138]
Utah Administrative Code: Rule R317-401. Graywater Systems	Utah, USA	2017	[148]
74:53:01:38. Requirements for graywater system	South Dakota,	1996	[139]
Senate bill 126–Senator Care BDR 48-394	Nevada, USA	2009	[12]
17.36.319 Grey Water Reuse	Montana, USA	2009	[140]
Title 30, Chapter 210: Use of Reclaimed Water - Subchapter F: Use of Grey Water Systems	Texas, USA	2016	[141]
Manual for On-site Sewage Management Systems (pg. 143)	Georgia, USA	2016	[149]
Water Reclamation and Reuse Standards (Article 1 - Section 4, Table 2)	Washington, USA	1997	[142]
Code of Practice for the Reuse of Greywater in Western Australia (Table 1, 2)	Western Australia, Australia	2010	[126]
Code of practice - onsite wastewater management (Section 2.2.2, 2.2.3)	Victoria, Australia	2016	[125]

Table B1.1 (continued): Guidelines and regulations on wastewater and grey water reclamation.

Related Regulation/Guideline	Country	Date	Ref.
Guidelines for Greywater Reuse in Sewered, Single Household Residential Premises	New South Wales, Australia	2008	[127]
Draft Guidelines for Wastewater Works Design Approval of Recycled Water Systems (Table 6, 7)	Northern Territory, Australia	2014	[128]
Queensland Plumbing and Wastewater Code (Table T1A, T1B)	Queensland, Australia	2017	[124]
Technical Guideline for Greywater Recycling System (Table 1)	Singapore	2014	[122]
Guidelines for Treated Greywater Quality			[123]
Service Water Reuse Criteria	Berlin, Germany	1999	[29]
BS-8525-1 Greywater systems: Code of practice	UK	2010	[9]
Reuse Criteria for Greywater by the Standards Institute of the State of Israel (Quality D)	Israel		[144]
Overview of greywater management: Health considerations in Jordan (Table 10)	Jordan		[47]
WASTEWATER to CAR WASH			
Guidelines for Water Reuse (Table 4-4: Unrestricted Urban Reuse)	EPA	2012	[109]
Technical Manual: Reclaimed Water for Beneficial Reuse (Appendix A: RWBR Public Access Systems)	New Jersey, USA	2005	[145]
Chinese Water Quality Standards for Reclamation (GB/T18920-2002, GB/T18921-2002)	China	2002	[114, 115]
Brazilian standard NBR 13969	Brazil	1997	[120]
Spanish regulations for Water Reuse: Royal Decree 1620/2007 (Appendix A)	Spain	2011	[116]
Guidelines for the Non-potable Uses of Recycled Water in Western (Table 7, 8)	Western Australia, Australia	2011	[110]
GREY WATER to CAR WASH			
California Code of Regulations - Title 22 -Division 4 - Chapter 3 - Article 3. Uses of Recycled Water	California, USA		[130]
340-053-0050 Division 53 Graywater Reuse and Disposal Systems (Type 3)	Oregon, USA	2011	[132]
Arizona Administrative Code - Title 18: Environmental Quality - Chapter 9, 11 - Class A	Arizona, USA	2016	[136]
314 CMR 20.00: Reclaimed Water Permit Program and Standards (Class A)	Massachusetts, USA	2009	[138]
Wisconsin Administrative Code - Chapter SPS 382 - Design, Construction, Installation, Supervision, Maintenance and Inspection of Plumbing	Wisconsin, USA	2016	[143]
BS-8525-1 Greywater systems: Code of practice	UK	2010	[9]
Overview of greywater management: Health considerations in Jordan (Table 10)	Jordan	2006	[47]
Queensland Plumbing and Wastewater Code (Table T1A, T1B)	Queensland, Australia	2017	[124]
Code of practice - onsite wastewater management (Section 4.4.1)	Victoria, Australia	2016	[125]

Table B1.1 (continued): Guidelines and regulations on wastewater and grey water reclamation.

Related Regulation/Guideline	Country	Date	Ref.
Code of Practice for the Reuse of Greywater in Western Australia (Table 1, 2)	Western Australia, Australia	2010	[126]
GREY WATER to SWIMMING POOL			
Code of practice - onsite wastewater management (Section 4.4.1)	Victoria, Australia	2016	[125]
WASTEWATER to COOLING			
Guidelines for Water Reuse (Table 4-4: Industrial Reuse)	EPA	2013	[109]
Title 30, Chapter 210: Use of Reclaimed Water - Subchapter C: Quality Criteria and Specific Uses for Reclaimed Water-Type 2	Texas, USA	2009	[141]
Technical Manual: Reclaimed Water for Beneficial Reuse (Appendix A: RWBR Industrial Systems)	New Jersey, USA	2005	[145]
Guidelines for Water Reclamation and Urban Water Reuse (Chapter 3.2)	Georgia, USA	2012	[146]
Spanish regulations for Water Reuse: Royal Decree 1620/2007 (Appendix A)	Spain	2011	[116]
Guidelines for the Non-potable Uses of Recycled Water in Western (Table 7, 8)	Western Australia, Australia	2011	[110]
Environmental Guidelines for the Use of Recycled Water in Tasmania (Table 2-1)	Tasmania, Australia	2002	[111]
GREY WATER to COOLING			
California Code of Regulations - Title 22 -Division 4 - Chapter 3 - Article 3. Uses of Recycled Water	California, USA		[130]
340-053-0050 Division 53 Graywater Reuse and Disposal Systems (Type 3)	Oregon, USA	2011	[132]
Guidelines for the Treatment and Use of Recycled Water (Type R1)	Hawaii, USA	2002	[134]
314 CMR 20.00: Reclaimed Water Permit Program and Standards (Class A)	Massachusetts, USA	2009	[138]
Water Reclamation and Reuse Standards (Article 4 - Section 15, Table 2)	Washington, USA	1997	[142]
Wisconsin Administrative Code - Chapter SPS 382 - Design, Construction, Installation, Supervision, Maintenance and Inspection of Plumbing	Wisconsin, USA	2016	[143]
Technical Guideline for Greywater Recycling System (Table 1)	Singapore	2014	[122]
Guidelines for Treated Greywater Quality			[123]
Code of Practice for the Reuse of Greywater in Western Australia (Table 1, 2)	Western Australia, Australia	2010	[126]
Draft Guidelines for Wastewater Works Design Approval of Recycled Water Systems (Table 6, 7)	Northern Territory, Australia	2014	[128]
Code of practice - onsite wastewater management (Section 4.4.1)	Victoria, Australia	2016	[125]

Table B1.1 (continued): Guidelines and regulations on wastewater and grey water reclamation.

Related Regulation/Guideline	Country	Date	Ref.
WASTEWATER to FIRE FIGHTING			
Guidelines for Water Reuse (Table 4-4: Unrestricted Urban Reuse)	EPA	2012	[109]
Rules of Implementations for the Regulations of Treated Sanitary Wastewater and Its Reuse by Ministry of Water and Electricity (MOWE) (Table 3)	Saudi Arabia	2005	[119]
Spanish regulations for Water Reuse: Royal Decree 1620/2007 (Appendix A)	Spain	2011	[116]
Title 30, Chapter 210: Use of Reclaimed Water - Subchapter C: Quality Criteria and Specific Uses for Reclaimed Water-Type 1	Texas, USA	2009	[141]
Chapter 62-610 Reuse of Reclaimed Water and Land Application	Florida, USA	1999	[113]
Guidelines for Water Reclamation and Urban Water Reuse (Chapter 3.2., Appendix A)	Georgia, USA	2012	[146]
Technical Manual: Reclaimed Water for Beneficial Reuse (Appendix A: RWBR Public Access Systems)	New Jersey, USA	2005	[145]
Environmental Guidelines for the Use of Recycled Water in Tasmania (Table 2-1)	Tasmania, Australia	2002	[111]
Guidelines for the Non-potable Uses of Recycled Water in Western (Table 7, 8)	Western Australia, Australia	2011	[110]
GREY WATER to FIRE FIGHTING			
Guidelines for the Treatment and Use of Recycled Water (Type R1, R2)	Hawaii, USA	2002	[134]
314 CMR 20.00: Reclaimed Water Permit Program and Standards (Class A)	Massachusetts, USA	2009	[138]
TITLE 20 Environmental Protection: Chapter 7 Wastewater and Water Supply Facilities: PART 3 Liquid Waste Disposal and Treatment	New Mexico, USA	2013	[133]
Draft Guidelines for Wastewater Works Design Approval of Recycled Water Systems (Table 6, 7)	Northern Territory, Australia	2014	[128]
Code of practice - onsite wastewater management	Victoria, Australia	2016	[125]
Arizona Administrative Code - Title 18: Environmental Quality - Chapter 9, 11 - Class A	Arizona, USA	2016	[136]
Water Reclamation and Reuse Standards (Article 4 - Section 11, Table 2)	Washington, USA	1997	[142]

APPENDIX B2: Quality Criteria for Wastewater and Grey Water Reuse

Table B2.1: Regulations for water reuse in toilet flushing.

Table B2.2: Regulations for water reuse in cooling.

Table B2.3: Regulations for water reuse in landscape irrigation.

Table B2.4: Regulations for water reuse in car wash.

Table B2.5: Regulations for water reuse in urban cleaning.

FROM GREY WATER TO URBAN CLEANING												
PARAMETER		**pH**	**Turb.**	**BOD**	**TSS**	**TOC**	**T.N**	**T. Coli (max single)**	**T. Coli (7d mean)**	**Faecal Coli. (max single)**	**Faecal Coli. (30d mean)**	**Faecal Coli. (7d mean)**
COUNTRY			***NTU***	***mg/L***	***mg/L***	***mg/L***	***mg/L***	***cfu/100 mL***		***cfu/100 mL***		
Washington, USA	**Street sweeping**							23	2.2			
	Spray washing of streets		0.1	5	5	1	10	23	2.2			
Oregon, USA				10	10			23	2.2			
Hawaii, USA			5 - 10							200	23	2.2
Arizona, USA										800		200
Massachusetts, USA		6.5 - 8.5		30	10		10			100		14

Table B2.6: Regulations for water reuse in fire protection.

APPENDIX C: Survey on Public Willingness and Acceptance for Grey Water Reuse

PART 1. GENERAL QUESTIONS

1. **Age**
   ◯ <18
   ◯ 18-25
   ◯ 25-30
   ◯ 30-50
   ◯ 50-65
   ◯ >65
2. **Gender**
   ◯ Female
   ◯ Male
3. **Nationality**
   ◯ Turkish
   ◯ Other: ……….
4. **Educational Status**
   ◯ Primary Education
   ◯ High School
   ◯ Two-year Degree
   ◯ Undergraduate
   ◯ Master
   ◯ Ph.D
5. **Occupation**
   ◯ ……….
6. **Where do you live?**
   ◯ Urban
   ◯ Suburban
   ◯ Rural
7. **How long have you been living in your current location?**
   ◯ ……….
8. **Have you ever lived in a rural area?**
   ◯ Yes, for ……….. years.
   ◯ No.
9. **How many people live in your house?**
   ◯ ……….
10. **Do you have a garden?**
    ◯ Yes, I have my own garden.
    ◯ Yes, I have a common garden with my neighbors. (Apartments, building complex etc.)

◯ No.

11. Which purposes do you use your garden for?

◯ Personal agriculture
◯ Commercial agriculture
◯ Landscape / Green field
◯ I don't use my garden.

PART 2. GREYWATER

12. Do you think Turkish Republic has a water shortage problem?

◯ Yes.
◯ Not for now.
◯ I don't know.
◯ No, but within 10-15 years.
◯ No, it has plenty of water.

13. Do you know the meaning of grey water?

◯ Yes.
◯ No.

If no; Grey water is wastewater fraction mainly from various washing functions such as shower, bath, hand wash basin, kitchen sink, washing machine and dish washer etc. which can be used as an alternative water supply after proper treatment.

14. Do you think that grey water can be collected separately out of whole domestic wastewater body?

◯ Yes.
◯ No.
◯ Maybe, but I don't know how.

15. What would motivate you to install separate grey water collection system to your house? *(You can select multiple options)*

◯ Lower environmental impacts
◯ Lower water bills
◯ Water savings
◯ Decreasing pressure on wastewater treatment plants
◯ Willing to try a new system
◯ Other: ……….

16. What would discourage you to install separate grey water collection system to your house? *(You can select multiple options)*

◯ It is not tested yet.
◯ It is not practical to use.
◯ No one I know uses this kind of systems.
◯ I don't want to pay for installation of the system.
◯ I am not really sure if it is healthy.
◯ Other: ……….

17. **Would you pay extra for the installation of separate grey water collection system to your <u>current house</u>?**
   ◯ Yes.
   ◯ If only I am convinced of its environmental benefits.
   ◯ If only I am convinced of its economic benefits.
   ◯ If only I can afford.
   ◯ No.
18. **Would you allow for the installation of separate grey water collection system to your <u>current house</u> for free?**
   ◯ Yes.
   ◯ Not sure.
   ◯ No.
19. **If you are buying a <u>new house</u>, would you have any objections to separate grey water collection system?**
   ◯ Yes.
   ◯ Not sure.
   ◯ No.
20. **Who do you think should be responsible for the installation of grey water collection and treatment systems?**
   ◯ Individuals
   ◯ Private companies
   ◯ Water authorities
   ◯ High volume users
   ◯ Industrial consumers

PART 3. GREYWATER REUSE

21. **Which sources of greywater would you consider to be suitable for reuse in your house? *(You can select multiple options)***
   ◯ Kitchen sink
   ◯ Hand wash basin
   ◯ Shower/Bath
   ◯ Washing machine
   ◯ Dish washer
22. **Which purposes would you reuse treated grey water for? *(You can select multiple options)***
   ◯ Irrigation
   ◯ Toilet flushing
   ◯ Laundry
   ◯ Car wash
   ◯ Potable purposes after proper treatment
   ◯ Fire protection

◯ Industrial purposes
◯ Other: ……….

23. Which one do you prefer to eat if irrigated with treated grey water? *(You can select multiple options)*

◯ Wheat, rye, oat, etc. *(Grains)*
◯ Hazelnut, pecan, almond, etc. *(Nuts in shells)*
◯ Strawberry, etc. *(Fruits on soil)*
◯ Apple, orange, peach, etc. *(Fruits on trees)*
◯ Potato, eggplant, spinach, etc. *(Cooked vegetables)*
◯ Lettuce, cucumber, etc. *(Uncooked vegetables)*

24. Which of the following do you think would be acceptable to be irrigated with treated grey water? *(You can select multiple options)*

◯ Your own garden
◯ Picnic area
◯ Landscape
◯ Park
◯ Stadium
◯ Playground
◯ School garden

25. Which of the following do you agree? *(You can select multiple options)*

◯ I would wear clothes produced from cotton irrigated with treated grey water.
◯ I would smoke a cigarette produced from tobacco irrigated with treated grey water.
◯ I would drink juice produced from fruits irrigated with treated grey water.
◯ I would eat sugar produced from sugar beet irrigated with treated grey water.
◯ All of the above options.
◯ None of the above options.

26. Would you agree to use grey water if a reduction of 25% in water bills could be achieved by using it as flush water?

◯ Yes.
◯ Maybe.
◯ No.

27. Whose reuse of grey water would courage you to reuse as well? *(You can select multiple options)*

◯ Family member
◯ Friends
◯ Neighbor
◯ Scientist / Academician
◯ Government
◯ Farmer
◯ Celebrity

APPENDIX D: Pathway for Grey Water Reuse Implementations

Step 1-Study area:

- If the area is going to be selected for the implementation of grey water reclamation systems, there are several criteria to take into consideration such as;

- Compactness and size of study area,
- Grey water potential in terms of volume,
- Potential end-use purposes and reuse areas,
- Proximity between origin of grey water and potential reuse areas,
- Existing water supply of potential reuse areas and its proximity.

Step 2-Volume of grey water and its fractions:

- *If possible;* measure daily domestic water consumption in the study area.
- *If not;* consider that daily domestic water consumption in T.R. is 200 L per person per day [150] [12] and multiply by the number of inhabitants in the study area, that could be obtained from the population databases (i.e. TURKSTAT [63]).

$$\text{Total Water Consumption} = 200 \ \text{L/capita.d} \times \text{Population}$$

- Convert total water consumption to wastewater generation in the study area.

$$\text{Wastewater Generation} = \text{Total Water Consumption} \times \text{Conversion Ratio}$$

If exact conversion ratio is not available, assume that conversion ratio (which refers to ratio of wastewater flow to tap water flow) is 0.90-0.95.

- Calculate grey water volume by using the following percentages given for T.R. (For the example see Table 5.1)

$$\text{Grey Water Generation} = \text{Wastewater Generation} \times \text{Grey Water Fraction \%}$$

Grey Water Fractions		%
Domestic Wastewater	WW	100%
Grey Water	GW	69%
• **Shower/Bathtub**	SH/BT	23%
• **Wash Basin**	WB	7%
• **Washing Machine**	WM	25%
• **Sink**	SN	11%
• **Dish Washer**	DW	3%
Weak Grey Water	SH/BT+WB	30%
Strong Grey Water	WM+SN+DW	39%

Step 3-Characteristics of grey water and its fractions:

- Monitor the characterization of grey water, if possible.
- If not, check the characteristics of raw grey water from reclamation practices that is located nearby.
- If not, make an assumption from the typical quality range given in Table 2.5.

Step 4-End-use purposes and quality requirements:

- Determine potential end-use purposes, at an acceptable proximity, that do not require potable water quality.
- List water consumptions for these potential end-uses.
- Find quality requirement in Appendix B2.

End-use Purposes	Table No.
Toilet flushing	Table B.2.1
Cooling	Table B.2.2
Landscape irrigation	Table B.2.3
Car wash	Table B.2.4
Urban cleaning	Table B.2.5
Fire Protection	Table B.2.6

- The quality requirements for toilet flushing, cooling, car wash, landscape irrigation, and urban cleaning could be adopted from Table 4.5.

Step 5-Matching Step 2 & Step 4:

- Compare and match grey water generation with demand in terms of quality and quantity. (For the example see Table 5.3)

Step 6-Treatment method and infrastructure:

- If the raw grey water quality is monitored, calculate COD/BOD ratio to decide if biological treatment is needed.
- For the plumbing systems; existing pipes could be used for the collection of grey water in buildings, while the remaining is being discharged to municipal sewer together with black water. However an additional grey water collection pipeline should be installed from the void. If grey water is reused for toilet flushing, another additional pipe should be installed for feeding treated grey water to the reservoirs.
- For the distribution of reclaimed grey water, a pipeline to reuse areas could be installed depending on the proximity or treated grey water could be conveyed by water trucks for end-use purposes such as street cleaning.

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Publications/Presentations **:**

- Beler Baykal, B., Efe, H., Afacan, E., Arslan, E. 2017. A preliminary survey on public attitude for the reuse of grey water as an alternative source of water in Turkey. 14th IWA Specialized Conference on Small Water and Wastewater Systems, 22-26 October 2017, Nantes, France