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UAEU College of Engineering

جامعة الإمارات العربيـة المتحدة
United Arab Emirates University

United Arab Emirates University

College of Engineering

Department of Architectural Engineering

# Water Recycling in Green Buildings: Grey Water Treatment and Reuse benefits in Al-Wagan Residential Neighborhood in Al-Ain City

Al Dehaim Nassib Suhail Yatba AlAmeri

This thesis is submitted in partial fulfillment of the requirements for the Master of Science in Architectural Engineering degree

Under the direction of Doctor Rashed Khalifa Al Shaali

June 2014

# DECLARATION OF ORIGINAL WORK

I, Al Dehaim Nassib Suhail Yatba AlAmeri, the undersigned, a graduate student at the United Arab Emirates University (UAEU) and the author of the thesis titled "Water Recycling in Green Buildings: Grey Water Treatment and Reuse benefits in Al-Wagan Residential Neighborhood in Al-Ain City", hereby solemnly declare that this thesis is an original research work done and prepared by me under the guidance of Dr. Rashed Khalifa Al Shaali, in the College of Architectural Engineering at UAEU. This work has not been previously formed as the basis for the award of any academic degree, diploma or similar title at this or any other university. The materials borrowed from other sources and included in my thesis/dissertation have been properly cited and acknowledged.

Student's Signature ............................................ Date ..12/6/2014.............

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# ABSTRACT

Water scarcity is a worldwide problem that called for a wiser and more sustainable resources' management. Grey waste water treatment is considered a widely spread technology that dominates water management in order to substitute the potential deficiencies.

Water use in the last three decades in the UAE has witnessed both a great increase and pressure on groundwater and desalinated water. This consequently has called for continuous, serious and diversified efforts to simultaneously improve the supply and sustain the water use by treatment and recycling. Besides UAE's natural population growth, the demand for water is also expected to increase significantly in UAE following the announcement of the award to Dubai to host the World Expo 2020 as it estimated that the event would help create 277,000 jobs and attract 25 million visitors from outside of the UAE. This therefore warrants the need for sustainable water resources to cater for this anticipated demand. Further, Expo 2020 would have a domino effect on trade, investment, technology, construction, and other related sectors and sub-sectors in Dubai and the UAE. This will also add to the need for additional water resources for construction activities. Without adequate supply of water the projected economic benefits associated with the Expo 2020 cannot be realized.

The main goal of this study was to provide an estimate of the benefits in Dirham's in cost savings through investigating recycling grey water so as to reduce water consumption within in Al Wagan residential neighborhood of Al Ain city in the Emirate of Abu-Dhabi. An extended objective was related to the energy savings which will be a byproduct and is resulted from reducing the amount of the pumped water to the neighborhood and to Sewage Treatment Plant (STP) by the government.

Within this context, the author adopted mixed research methodology. Theoretical background was highlighted for water resources in the UAE, Abu Dhabi Emirates and the Al-Wagan district. Water treatment systems were handled using a qualitative research approach while considered the case study in Al-Wagan District using the quantitative methodology.

The study revealed the escalation of the water supply by the TRANSCO for the residential sector in particular. An amount of 1,200,000 gallon was registered to be provided by TRANSCO for the whole district. Consuming 40.75 % in the residential and 40% as a grey water resulted from ablution, hand wash basins and showers gave a huge potential towards the recycling and reusing the treated resulted grey water.

Using a local water treatment company, a decentralized system with physical treatment technology revealed the savings of more than two million Dirhams on an annual basis that can be devoted for other developmental activities in Al Wagan district. This research gave a considerable weight for other relevant studies in other destinations that potentially sustain the water resources in the UAE and the gulf countries as well.

# DEDICATION

To my Parents, Brothers, Sisters, Husband and my children Mubarak, Hind and Hamad for their guidance, support, love and passion. Without these things this research could not have been possible.

# ACKNOWLEDGMENTS

I would like to express my deep gratitude to Dr. Rashed Al-Shaali as my advisor and committee chairman for his constant guidance and support in reviewing and revising my thesis. His assistance has been essential to the development of my thesis.

I would also like to thank the Faculty of Engineering and Department of Architectural Engineering for continuous support during this research work. I would also like to thank Mr. Ahmed Hayajneh and Mr. Khamees Khabour (METITO Company) for their support and flexibility during the long months it has taken to research and write up this dissertation. Further, I have to recognize the support and encouragement provided by my parents, my husband, brothers and sisters.

Special thanks are also accorded to Mr. Mutahar Abddullah the Central Region Operation and Maintenance Manager at Al Ain Distribution Company (AADC), Eng. Bader Al Shamsi, Engineer at TRANSCO, for their support in data collection stage, and Eng.Maysara El Essy for her guide and support.

Finally, I would like to acknowledge the inputs of those who assisted me in one way or the other towards the final realization of the goals of the entire master's program.

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# CHAPTER 1: INTRODUCTION

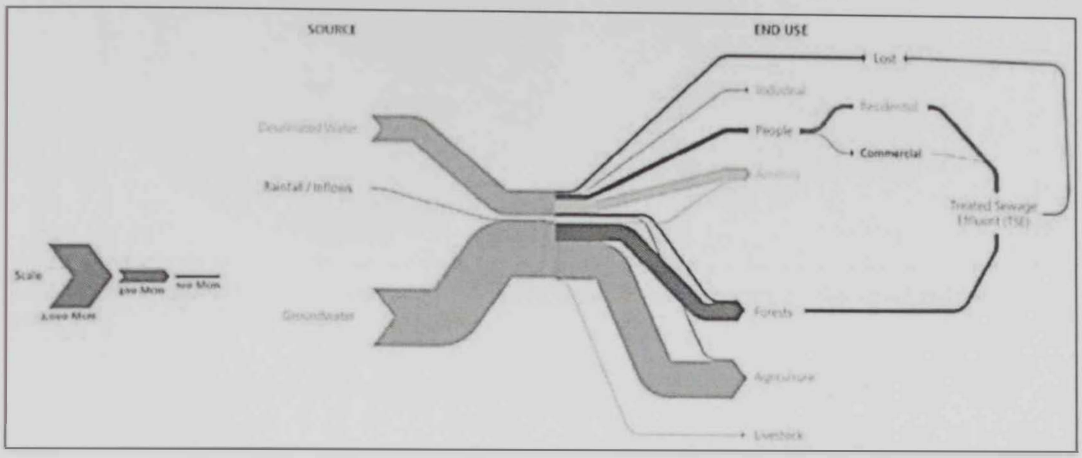
## 1.1 Background

The Abu Dhabi Vision 2030 recognizes water scarcity and lays important steps to a sustainable model of growth and development. In order to deliver the leadership vision of evolving Abu Dhabi as a global capital city and Emirate, Abu Dhabi must develop a comprehensive set of sustainable water management policies (Columbia-University, 2010). As a practical and strategic step towards the fulfillment of this vision, the State of the Environment Reporting (2011) has set a target for water consumption in domestic sector to be 250 litres/person/day (Columbia-University, 2010). In recognition of Vision 2030, Abu Dhabi leadership do emphasize the importance of water in UAE and the whole region as well and accords higher importance for water than oil. In his own words the Crown Prince of Abu Dhabi has been quoted as: "we must find ways to meet the current needs and preserve natural resources for future generations"(Al-Etihad, 2011 ).

Besides UAE's natural population growth, the demand for water is also expected to increase significantly in UAE following the announcement of the award to Dubai to host the World Expo 2020 as it estimated that the event would help create 277,000 jobs and attract 25 million visitors from outside of the UAE (Oxford Economics, 2013). This therefore warrants the need for sustainable water resources to cater for this anticipated demand. Further, Expo 2020 would have a domino effect on trade, investment, technology, construction, and other related sectors and sub-sectors in Dubai and the UAE. This will also add to the need for additional water resources for construction activities. Without adequate supply of water the projected economic benefits associated with the Expo 2020 cannot be realized.

Abu Dhabi gets its needs of water from three main sources i.e., groundwater, desalinated water and treated sewage water. As presented in Figure 1.1, water from these sources find application in various purposes. About 47% of the Emirate's total water supply (approximately 1,816 million cubic meters; Mcm) is groundwater comprising of water historically stored in the ground and the rainfalls/inflows into these reserves. The vast majority (96%) of groundwater is used for agriculture (64%)

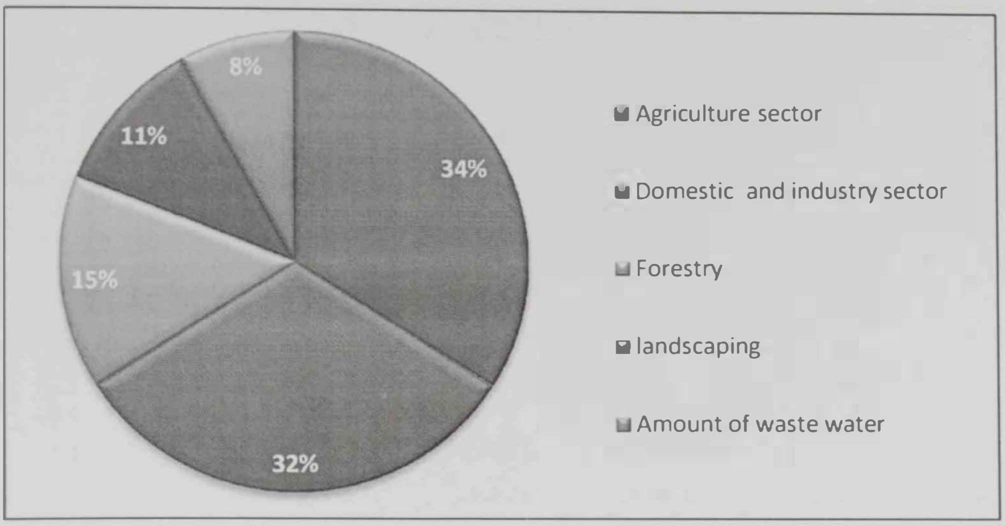
and forestry (32%), which also makes them potential sectors for water conservation strategies. Desalinated water from the Arabian Gulf accounts for about 36% of the Emirate's total water supply. Eighty three percent (83%) of desalinated water, 856 Mcm, comes directly from desalination plants while the remaining 17% (182 Mcm) comes from water reuse via treated sewage effluent (Columbia-University, 2010).




*Source: Sustainable Water Management Assessment and Recommendations for Abu Dhabi Emirate's, 2010

Figure 1.1: Water sources and uses in Abu Dhabi

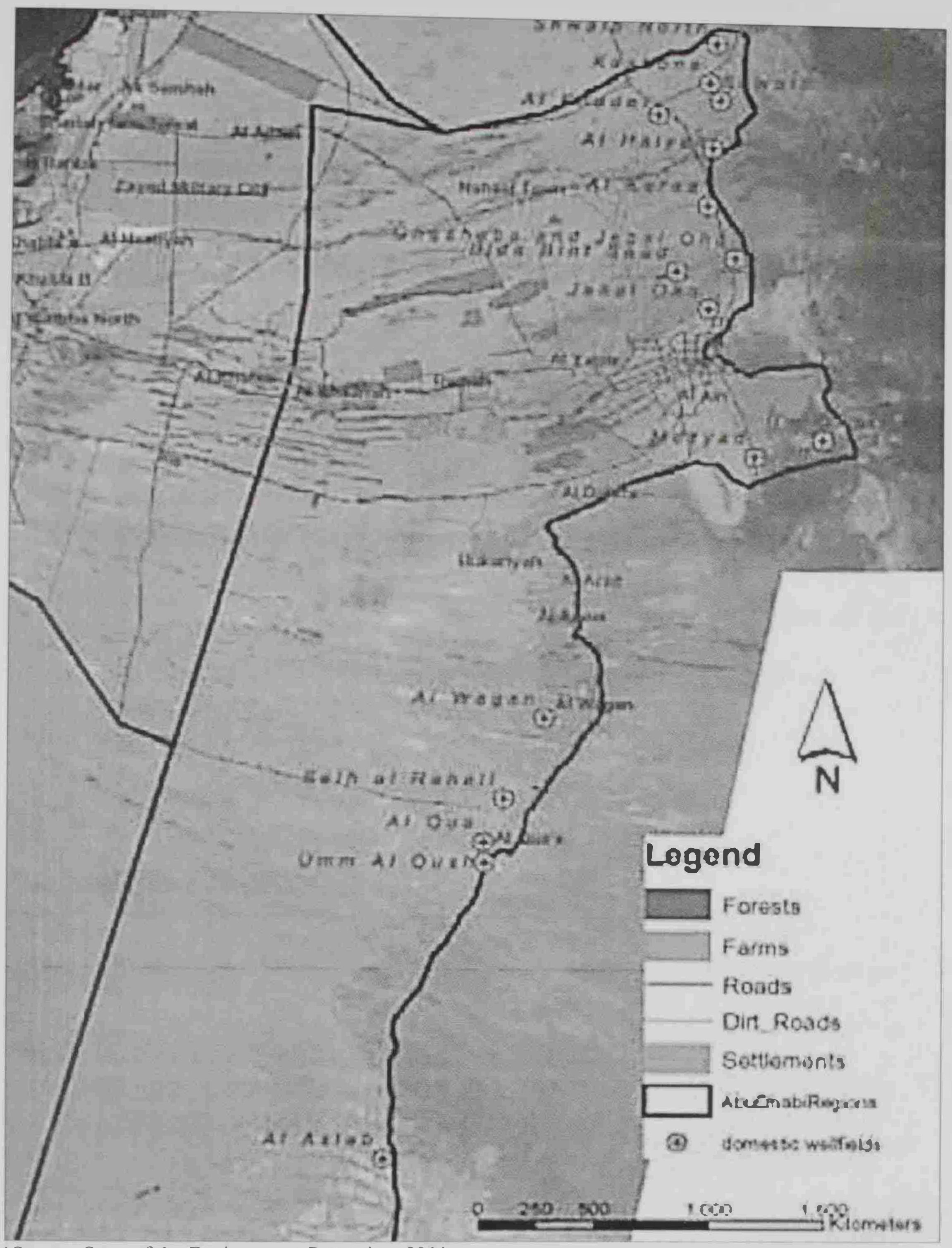
Although the UAE can get its needs of the water through desalination besides the groundwater, however, the leadership do recognize that this is not sustainable and therefore calls for research and studies that focus much more on sustainable creation of practical, economic and healthy alternatives that can provide the region's needs. Over the last three decades, however, rapid economic development, coupled with sharp population increase and the development of a large agriculture sector, have led to a large increase in water demands. This considerable increase in water consumption occurred mainly in government sponsored housing development schemes and agricultural activities especially farming and forestry. As shown in Figure 1.2, in 2003, 15.5% of all the consumed water in AD was in the domestic sector where 96% from desalination and the rest of 4% from groundwater well fields. However, since 1998, production from the domestic well fields has decreased by over 85%, and in 2005 it had reduced to only 10Mcm/yr, which met a small fraction of the total requirements in the eastern region as provided in Figure 1.3 (Dawoud, 2008).




*Source: Sustainable Water Management Assessment and Recommendations for Abu Dhabi Emirate's, 2010

Figure 1.2: Desalinated water in Emirate of Abu Dhabi

Al Ain city's domestic water requirements are met from well fields. There are 16 production well fields as shown in Figure.1.3, and they contain 600 wells, where 333 only are operating wells and are located in the eastern region. However, the massive increases in domestic demands represented by a 8% annual population growth rate, mean that the well fields are subjected to increasing stress, resulting in the declination of water levels, the increase in groundwater salinity and a resultant decrease in total production (Dawoud, 2008).




*Source: State of the Environment Reporting, 2011

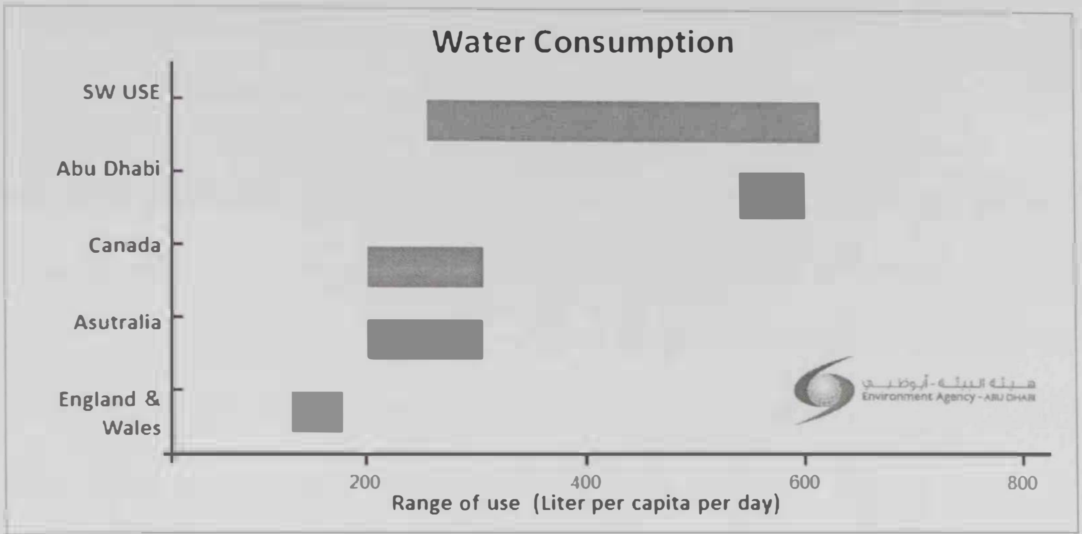
Figure 1.3: Municipal well fields in the Eastern Region

There is an increasing pressure on the governmental efforts to retain the proper provision in order to meet growing demands of population, simultaneously with the foreseeing sustainability for the future requirements and the climate change consequences.

There is a great need to develop and promote new techniques to work on reducing the use of the fresh water in addition to handling the grey water of all urban uses. It is against this backdrop that there needs a shift towards the Grey Water (GW) treatment and reuse as this can on one hand create potential improvements in domestic water provision, and on the other hand reduce water desalination expenses as it is the major provider for the fresh water.

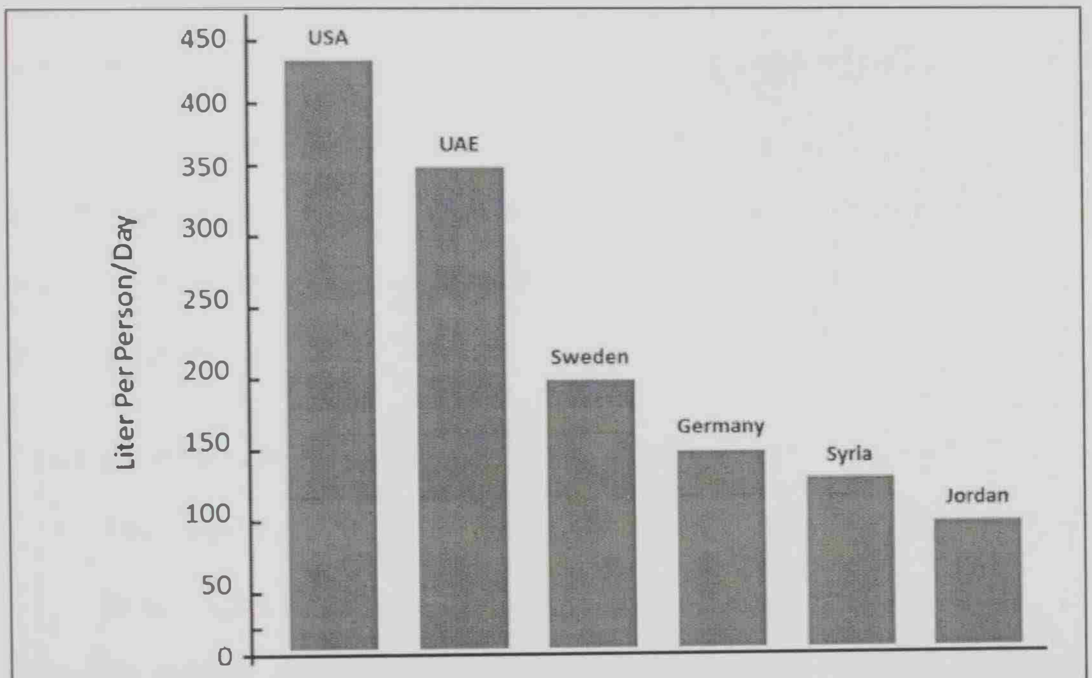
## 1.2 Problem Statement and Importance

The Emirate of Abu Dhabi (AD) is one of the seven Emirates which comprise the United Arab Emirates (UAE). It occupies an area of 67,340 km² - approximately 87% of the UAE land, excluding the Islands. AD exhibits an arid/hyper arid climatic conditions with less than 100 mm of rainfall annually. It also has a low groundwater recharge rate of less than 4% of total annual water consumption without reliable or recurrent surface water resources (Dawoud, 2008). With a current population of about 1.3million, AD is considered one of the highest per capita water consumption places in the world. As shown in Figure 1.4, is ranked as the second highest among the whole world countries following the United State of America (USA) (ADWEA, 2005). According to AD Environmental Agency (2011), its domestic water consumption increased from 350 litres/person/day in 2003 to 550 litres/person/day in 2007 as illustrated in Figure 1.5, which presents a serious warning.




*Source: State of the Environment Reporting, 2011

Figure 1.4: Water consumption l/c/d in different countries in 2003




*Source: State of the Environment Reporting, 2011

Figure 1.5: Water consumption l/c/d in different countries in 2007

## 1.3 Goals and Objectives

Treatment of grey water and reuse of treated effluent for irrigation around homes, parks, street landscape and toilet flushing are new practice in UAE. The main goal of this study is to provide an estimate of the benefits in Dirham's of the saving cost of water through investigating a recycling system in Al Wagan residential neighborhood as a selected case study in Al Ain city in the Emirate of Abu-Dhabi.

The major goal of this study was to investigate the possibility of recycling grey water so as to reduce water consumption within neighborhoods. An extended objective is related to the energy savings which will be a byproduct and is resulted from reducing the amount of the pumped water to the neighborhood and to Sewage Treatment Plant (STP) by the government.

The impact of the water reuse system on the environment, energy, health, society and economy will be assessed. The understanding of the dynamics of the community where the project will be implemented will both put forward a pilot system that illustrates how the relations work in this specific context and assess the GW recycling system. The research focuses mainly on the estimated percentage of saving of both water and energy and how it could be decrease after applying the selected GW recycling system.

To achieve these goals, the following specific objectives were investigated:

- To determine the current water use and sources in Al-Ain City and particularly in Al Wagan.
- To estimate the quantities of gray water generated in typical Al Wagan households.
- To focus on the GW recycling and reuse systems and study the manufacturers systems to decide the best choice which helps in recommending the proper one for each context and target.
- To evaluate the appropriate GW recycling and reuse systems.

- To Study and calculate the benefits of the cost of water in Dirham's to AD government.

### 1.4 Research Question and Hypothesis

The achievement of the research goals and objectives considered the following question.

- Will the applied system for GW recycling and reuse be a conventional and efficient practice to be implemented in Al Wagan and then generalized in other neighborhoods considering the privacy of the urban context?

The considered hypothesis statement was as follows:

GW recycling and reuse system can be applied in Al Wagan neighborhood as residential uses. It might be an accepted solution to overcome both of overconsumption and water scarcity. A significant reduction in governmental payments for water supply will result. Reviewing the real size of this neighborhood shows that the adopted system can cope with neighborhood size of about 400-600 inhabitants.

### 1.5 Research Significance

This research is the first of its kind in UAE that tackles the GW recycling and reuse in residential context when viewed in terms of sustainability and consistent with the UAE leaders' vision for development.

While there are already efforts for water conservation that took several actions in different fronts, this research is considered to test new practices and technologies in different water consumers' areas other than the residential sector. New irrigation methods, sheltered agriculture, different landscaping, alternative crop selection and test innovations are all considered in order to achieve water conservation (Environment-Agency-Abu-Dhabi). Furthermore, this research will be a unique study that will focus on residential water use as one of the most significant consumer of water in Abu Dhabi.

## 1.6 Research Outcome

The study outcome focused on the implementation of the GW recycling and reuse in one of the five residential neighborhoods of Al Wagan District in Al Ain City. From this study, design aspects and performance evaluation of the GW treatment system and reuse will be directed towards using the treated effluent in irrigation of the neighborhood landscape as well as toilet flushing. The study will end up by recommendations of the optimal grey water system that meets the local conditions of Al-Wagan District and Al Ain City as well.

The application of the GW treatment systems is currently limited although the separate fittings are already fixed but are not operational. The concept of house/neighborhood onsite wastewater management systems is very promising however the provision of proper technical solutions is very important. It is expected to find out the savings that could result by using this GW treatment and reuse system, and the positive environmental impacts as well.

## 1.7 Thesis Outline

This thesis report consists of 6 chapters including Appendices. Chapter 1 provides the study background, defines the study problems and the scope and objectives of this research while Chapter 2 contains the findings from a comprehensive review of the literature that is relevant to this study.

Chapter 3 provides the methodology followed in this research including the procedure, participants, data collection locations, methods used in analyzing collected data, and the equipment used in the data collection process. Chapter 4 covers the overall detailed data collection of the Al Wagan district as a case study, more explanation of grey water system and details of the analysis methodology. Chapter 5 provides the results of the data analysis and Chapter 6 provides conclusions and recommendations for further study.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

Water industry is facing challenging situations in many parts of the world. Water scarcity and ensuring sustainable water supply present a significant challenge globally making water scarcity one of the most pressing problems of the 21st century (Pinto et al., 2010). Further, existing potable water supplies are fast reaching their limits while at the same time water demand continues to rise rapidly. Population growth, changing lifestyles to more water-intensive uses and climate change are all of the primary factors that lead to the growing deficit between the available water resources and the increasing demands.

Grey water (GW) reuse is one of the ways to reduce the globally shrunk fresh water resources. According to the World Health Organization's (WHO) guidelines for safe use of wastewater, excreta and grey water, the GW reuse is affordable, implementable and safe solutions to alleviate water problems. GW can contribute to this as it is:

a) still water;

b) makes up the largest volume of the waste flow from households

c) has nutrient content that, although low, can be beneficially used for crop irrigation;

d) has low pathogen content; and,

e) can be used to reduce the demand for first use (fresh) water (WHO, 2006).

Grey water (GW) is waste water that includes water from showers, bathtubs, sinks (Li et al., 2009, Memon et al., 2005, AL-Hamaiedeh and Bino, 2010, Al-Jayyousi, 2003, Jefferson et al., 1999, Kariuki et al., 2011) excluding water from dishwashers, laundry tubs, washing machines, toilet water (black water) and kitchen. It commonly contains soap, shampoo, toothpaste, food scraps, cooking oils, detergents and hair. GW constitutes the largest proportion of the total wastewater flow from households in terms of volume. It constitutes 50-80% of indoor household water use (Kariuki et al., 2011, AL-Hamaiedeh and Bino, 2010, Al-Jayyousi, 2003). The installation of GW treatment systems should act in accordance with the national (local) technical regulations for drinking water installations, drainage and wastewater treatment. A strict separation of the drinking water and GW pipes and clear labeling of the taps and devices is mandatory for all types of reuse ( AL-Hamaiedeh and Bino, 2010).

The typical volume of grey water varies from 90 to 120 l/p/d depending on lifestyles, living standards, population structures (age, gender), customs and habits, water installations and the degree of water abundance. However the volume of grey water in low income countries with water shortage and simple forms of water supply can be as low as 20–30 l/p/d (Li et al., 2009). The residential sector represents the most important setting for reducing per capita consumption of water (Abu Dhabi Sustainable Water Council, 2010). Therefore, housing grey water treatment will only be considered as it is less contaminated and easiest to treat, in addition, the frequent use for using wash basins, showers and ablution, if any.

Appropriate GW treatment could significantly reduce water pollution and therefore, contribute to protecting the environment and improving public health and living conditions of communities relying on freshwater sources. The experience in several countries indicates that GW can be a cost effective alternative source of water (Kariuki et al., 2011). Gardening and forestation often use large amounts of tap water as it is the case in an arid and water deficient urban area, such as Xi'an in the northwest region of China (Wang et al., 2008). Three main concerns related to current and future water resources are water scarcity, poor water quality and water-related disasters (Kariuki et al., 2011).

New urban extensions and developments as well ask for water supply to cater new housing. Higher quality of living conditions and environmental friendly become principles for housing development. They are requiring no less than 35% of the area for greenery in addition to artificial water surfaces. Water consumption is then an important issue that the developer has to consider. For this reason, there are many calls for treated grey water reuse for non-potable purposes as far as possible (Wang et al., 2008).

The recycled and reused GW should act in accordance with the local relevant regulations and fulfill the minimal specifications. They include water quality (physical, chemical, biological), water monitoring, water fittings and water regulations schemes in the country. GW systems also should be cost effective; the amount of money depend on the volume of saved water, price of the mains water replaced and the cost of installing and running and maintaining the system (Environment-Agency-Abu-Dhabi, 2011). Therefore, it is worth considering all of those issues and calculating the expected savings in the water and energy bills early enough in order to decide about the established system.

## 2.2 Previous Studies Related to the Research

GW can be used for various purpose includes toilets flushing, landscaping and car washing. In Australia, GW reuse has reduced freshwater demand, strain on wastewater treatment plants and energy consumption. In Lebanon, GW is a valuable resource for encouraging plant growth from nutrients that may otherwise have been wasted. Palestine shares similar climate and water scarcity conditions with most arid sub-Saharan African countries, yet utilizes GW in production of crops and citrus fruits (Godfrey et al., 2009).

In Arizona USA, it is documented that an average household can generate about 30,000 to 40,000 gallons of GW per year (Al-Jayyousi, 2003). It has also been estimated that 30% of the total household water consumption could be saved by reusing grey wastewater for flushing toilets. For example reusing grey water in Los Angeles city for irrigation saves about 12-65% of annual used freshwater (Mourad et al., 2011). Also (Ghisi and Ferreira, 2007) found out that using grey water for toilet flushing saves between 29 and 35% of consumed water.

In arid regions, a significant part of the water requirements for the landscape around homes is consumed using fresh water. However, this use and other uses can be met with the grey water generated within the household. Many studies highlight this concept and examine the potential of grey water reuse to save fresh water supplies. The studies reported savings in the range of 50–80% upon reusing the grey-water for toilet flushing and irrigation (AL-Hamaiedeh and Bino, 2010). Some surveying studies in capital cities of different countries have identified an average grey water flow of 400 liter per day per household and grey water ratio is 68 % of total wastewater. For example, in Oman, the percentage of grey water was estimated as 82 % of total domestic fresh water consumption (Mourad et al., 2011). In Sana'a it is about 87% of total domestic fresh water consumption (Mughalles et al., 2012). A study conducted by Abbood and others found that an average the volume of water use in a house per day in Baghdad is 116L/person/day which approximately 70% (83 L/person/day) of this water can be captured and recycled from the gray water (Abbood et al., 2012).

Residential GW recycling and reuse received an increased attention by many authors for cases in global, regional and local contexts. On the global scene, Japan, the US and Australia maintain the highest profile in GW reuse. Other countries involved in active GW research and applications include Canada, UK, Germany and Sweden. At the regional level, Saudi Arabia, Cyprus, Jordan, Syria, Oman, Yemen and Palestine have introduced GW systems to optimize water use. Several articles that addressed the use of the treated GW in toilet flushing and irrigation among other potential uses and its impacts on plant growth and soil specifications will be summarized.

Hurlimann and McKay in 2006 addressed the "attributes of recycled water to make it fit for residential purposes" in Mawson Lakes in South Australia. The authors investigated the Australian community's perspective and addressed the importance of various attributes of recycled water for various uses using a 30-minutes survey. The purpose of this paper is to give greater support to the understanding of the social aspects of water recycling project considerations. The color, odor, salt, pressure, availability, and nutrients are chosen for analysis for the potential uses of garden watering, toilet flushing and clothes washing. The study concluded that respondents rated the attributes of 'no color' and 'no odor' of extreme importance for clothes washing, but they were not rated as important for toilet flushing or garden watering. The variation in attribute and use combinations suggests that the parameters of recycled water quality and delivery should be determined 'fit for purpose.' It is recommended that the parameters to be established in consultation with the community involved in order fulfilling satisfaction criteria (Hurlimann and McKay, 2006).

Li, Wichmann and Otterpohl (2009) reviewed the technological approaches for grey water treatment and reuses. A non-potable urban grey water reuse standard is proposed and the treatment alternatives and reuse scheme for grey water reuses are evaluated according to grey water characteristics and the proposed standards. They considered the characterizations of the World Health Organization WHO guidelines which were published in 2006. These guidelines outline the microbiological requirements without considering the physical and chemical parameters. The case revealed that all types of grey water show good biodegradability in terms of the chemical oxygen demand (COD): bio-chemical oxygen demand (BOD) ratios. Li, Wichmann and Otterpohl's study addressed the physical processes for the GW, and found they are alone not sufficient to guarantee an adequate reduction of the organics, nutrients and surfactants. It revealed also that the biological treatment is needed when the kitchen GW is mixed with other streams to avoid the deficiency of both macronutrients and trace nutrients. The chemical processes can efficiently remove the suspended solids, organic materials and surfactants in the low strength grey water. They concluded that anaerobic processes are not recommended for the grey water treatment while aerobic biological processes can be applied for medium and high strength grey water treatment (Li et al., 2009). The authors concluded that the combination of aerobic biological process with physical filtration and disinfection is considered to be the most economical and feasible solution for grey water recycling. The membrane bio reactor (MBR) appears to be an attractive solution for medium to high strength grey water recycling. This is particularly applied in collective urban residential buildings that are serving more than 500 inhabitants. This can help in determining the size of the urban neighborhood that is proper to establish the GW recycling and reuse system.

Residential grey water systems also were addressed by Mahmoud and Mimi in 2008. At the household level, using a questionnaire, the study has two main goals. It targets the assessment the impacts of a model project of 47 house onsite source separated wastewater management systems on the environment, health, society and economy. It aims at investigating the drivers and barriers of implementing those non-conventional sanitation systems (Mahmoud and Mimi, 2008). The results of Mahmoud and Mimi review reveal the importance of the big incentives for applying GW treatment system for irrigation purposes, which is socially accepted. The application of those systems is currently limited and tied to the availability of external funds. The main concerns that people have regarding the constructing of the house onsite systems are health risks, flooding, and odor emissions. Accordingly, the system of house onsite wastewater management systems is increasingly accepted and very promising, but provision of proper technical solutions is very important.

GW reuse in residential schools in Madhya, Pradesh, India was discussed in view of the cost-benefit analysis (Godfrey et al., 2009). The article addressed the case of about 200 GW treatment and reuse systems constructed in residential schools (Schools) in Madhya Pradesh, India. The treated GW is mostly used for toilets flushing, cleaning of school floors and small-scale irrigation. The economic feasibility through cost–benefit analysis was done and indicated that the benefits of GW reuse system are significantly higher than the cost of GW reuse system. It also revealed that the benefit to cost ratio is higher than those for water resource projects.

Another case in an urban household in India for the grey water collection, treatment and reuse system as designed and implemented was discussed by Mandal and others. The context reflected families that have a water requirement of 165 lpcd and a GW generation rate of 80 lpcd in house consists of five people with age group of 12-50 years. The GW treatment plant includes a screening, sedimentation, filtration and disinfection as major treatment processes is constructed. The treated GW is used for toilet flushing and to irrigate the vegetables in the backyard of the household. GW characterization indicates that COD and BOD are sufficiently reduced during the treatment and there is also substantially reduction in Escherichia coli count. The payback period of this GW treatment and reuse system is estimated to be 1.6 year (Mandal et al., 2011).

AL-Hamaiedeh and Bino (2010) investigated the effects of treated grey water reuse in irrigation on soil and plants. The quality of treated and untreated GW was studied in order to evaluate the performance of treatment units and the suitability of treated GW for irrigation according to Jordanian standard. The treated GW produced from 4-barrel and confined trench (CT) treatment units are used for irrigation of olive trees and some vegetable crops. Study results showed that salinity, sodium adsorption ratio (SAR), and organic content of soil increased as a function of time. Therefore leaching of soil with fresh water was highly recommended. Research also revealed that chemical properties of the irrigated olive trees and vegetable crops were not affected, while the biological quality of some vegetable crops was adversely affected.

The relationship between urban development and GW recycling and reuse has been considered by examining the role of GW treatment in alleviating poverty in the context of Jordan. The paper outlines both water reuse and the impact of an untreated GW reuse project on poverty in southern Jordan. This has been addressed through the description of a pilot project that allowed the poor in Tufileh, Jordan, to reuse untreated household GW in home gardens. They also, discussed the benefits of GW reuse within urban agriculture as a means for alleviating poverty (Faruqui and Al-Jayyousi, 2001).

The article raised another social issue where women in this community used small loans to implement simple GW treatment systems. Feelings of independency and pride for being involved in income generating activities were reported taking into consideration their new acquired skills. It also helps to set-up gardens which help to allow the community to compensate food purchases. Women were able to generate income by selling surplus production where the savings formed an average of 10 percent income. Environmentally, untreated GW did not show negative impacts when reused on soil and crops, however this could change if greater volumes of GW are reused (Faruqui and Al-Jayyousi, 2001).

Sustainable water management is an important topic that Al-Jayyousi tackled in an article entitled as "grey-water reuse: towards sustainable water management" which was published in 2003. A case study on GW reuse in Jordan is demonstrated to shed some lights on its role in sustainable water management as an example for the arid regions. The conceptual framework for GW reuse is based on the closed-loop concept. This implies that GW is being managed and reused in a decentralized manner within the household, neighborhood, and/or community. The main idea was to match water quality with appropriate water uses. The review concludes that current environmental policies should aim to control pollution and to maximize recycling and reuse of GW within households and communities. Decentralized GW/wastewater management offers more opportunities for maximizing recycling opportunities.

Grey water and sustainable urban development has also been examined by Fidar et al., (2010). Environmental implications of water efficient micro-components in residential buildings were considered. The Code for Sustainable Homes (CSH) in England determines several water efficiency levels. These levels form a part of a comprehensive environmental performance criteria to measure the sustainability of a building. The CSH code is performance based; it requires reduction in per capita water consumption in households. Water efficiency can be met using a range of water-efficient micro-components such as (WC, showers, kitchen taps, basin taps, dishwashers, washing machines, and baths).

CSH aims at reducing environmental implications by reducing water consumption in dwellings. however. little is known about the energy consumption and the environmental impacts (e. g. carbon emissions) resulting from water efficient end uses. Therefore. the paper describes a methodology to evaluate the energy consumption and carbon emissions associated with the CSH's water efficiency levels. Authors found that. about 96% of energy use and 87% of carbon emissions which associated with urban water provision are referred to in-house consumption. In addition. achieving water efficiency level does not automatically save energy or reduce carbon emissions. Recycling and conservation of water in urban areas is therefore an essential contribution to the future environmental sustainability.

In UAE. a few GW treatment studies have also been done. A study of "Sustainable Water Management Assessment and Recommendations for the Emirate of Abu Dhabi" was prepared for the "Abu Dhabi Urban Planning Council" in 2010 by the Columbia University. It assessed the Abu Dhabi water demands and available resources and supplies.

The study concluded that grey water treatment and reuse has strong potentials in reducing the consumed water for the residential uses. Experiences showed sustainable impacts for GW recycle and reuse in relationship to several dimensions. GW recycle and reuse can replace the fresh water resources for several uses such as the toilet flushing. limited irrigation and cleaning houses.

In addition, the study explained that characterization of the resulted treated GW indicates that screening. sedimentation. filtration and disinfection as major treatment processes that can be able to obtain a satisfactory COD and BOD. showing a relatively short payback period. In relation to socio-economic impact for the grey water, literature reflected the ability of women to generate income by selling surplus production where the savings may account for an average of 10 percent income (Columbia-University, 2010).

## 2.3 The Context of Growing Awareness on Water Resources Management and Water Use in Abu Dhabi

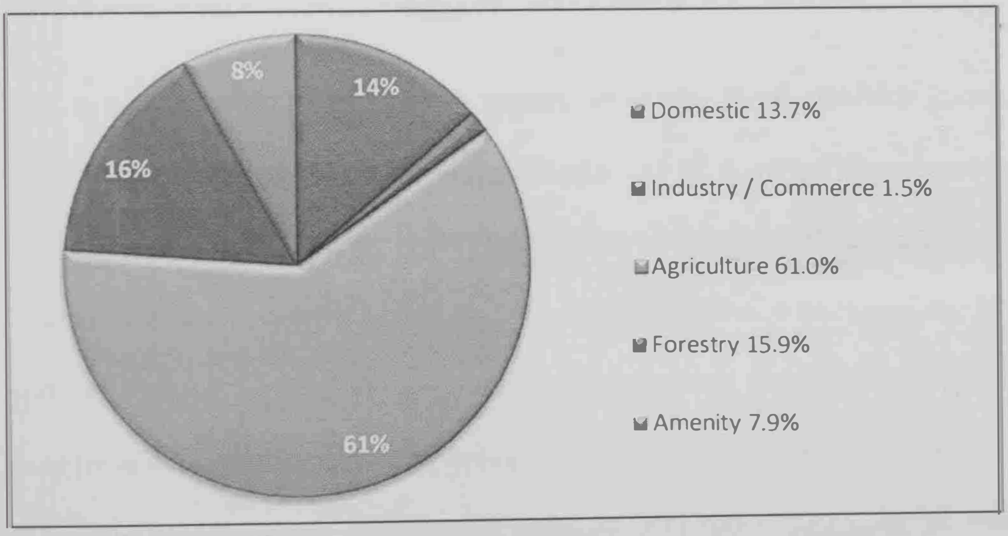
Abu Dhabi Emirate occupies 87% of the total area of the UAE. The total population of the Emirate at the end of 2002 was 1,215,218, an increase of 8% over the previous year (ERWDA, 2002).

In United Arab Emirates, water is considered as a precious national resource and a natural capital for each of the underground reservoirs or basins surface or the sea. It needs a comprehensive management and planning to reduce the depletion and to increase its benefits. By the year 2030, the UAE water demand is expected to double from about 5.4 billion cubic meters per year at present to about 9.0 billion cubic meters in the case of the continued pace of water demand growth at the current rate (Al-Khalij, 2011).

According to 2007 population statistics, Abu Dhabi Emirate has an average per capita daily domestic water consumption of 550 liters, which was one of the highest in the world (Columbia-University, 2010 and Environment-Agency-Abu-Dhabi, 2008). The average consumption per capita daily water consumption dropped to 364 liters in 2008. This average is still higher than average consumption of some developed countries with a climate similar to the UAE. It is also higher than the world average water consumption which is about 200 liters per person per day (Al-Khalij, 2011). Water is over-consumed in Abu Dhabi given the current supply. Among many reasons for this high water consumption is related to a non-integrated approach to water resources management across agencies and governing bodies in Abu Dhabi.

Inconsistent and unreliable data to properly quantify and understand the issue of water resources, consumption and waste, and the general absence of awareness about the need for and desirability to reduce consumption as an essential component in water sustainability. Finally, the absence of a price for water in Abu Dhabi is a significant contributor in this overconsumption while water may have a high normative value among the populace. Consumption needs to be informed by both economic and environmental value (Columbia-University, 2010).

The largest user of water is the agricultural sector which uses 61% of the total water consumption in over 20,000 small farms owned by the citizens and few large state farms. Water used in this sector is mostly brackish in quality. The second largest user of water is the forestry sector, (15.9%), which irrigates over 250,000 hectares distributed amongst 247 separate plantations. Amenity irrigation for parks, gardens and recreational areas, accounts for 7.9% total water use. This sector relies mostly on treated effluent as a source. Finally, the industrial/commercial sector is accounts for only 1.5% of all water consumed (ERWDA, 2002) as presented in Figure 2.1.




*Source: ERWDA, 2002

Figure 2.1: Abu Dhabi water consumption in 2002

However, treated grey water and the reuse of the treated effluent are new practices in the UAE which is generally to irrigate parks and streets (Abu Dhabi Sustainable Water Council, 2010). Treated water until the current time is used for Wetlands and Reserves, and this constitutes only 7% of the water resources which utilized in Abu Dhabi. UAE has 18 Plants with capacity of 200 MCM/year due to tertiary treatment. This percentage has the potential to increase gradually in the light of recycling and reuse of the treated grey water in residential uses (Environment-Agency-Abu-Dhabi, 2008).

## 2.4 Consideration for the Use of Treated Grey Water

Grey water reuse can result in cost savings to both the consumer and state, reduced sewage flows and potable water savings of up to 38% (Al-Jayyousi, 2003). On-site GW treatment reduces the volume of wastewater that must be diverted to more expensive sewage and septic treatments. The use of GW for irrigation reincorporates nutrients from the waste stream into the land-based food chain, rather than contributing to surface and ground water pollution via sewers and septic systems (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007).

The non-potable reuse of treated sewage in urban areas provides considerable conservation of potable supplies through water use efficiency. Effluent reuse is also an inevitable requirement in novel decentralized wastewater systems (Fane et al.). Few of potential uses involve a high risk of human exposure such as spray irrigation and car washing while others are low risk options such as toilet flushing. Pathogen transfer is considered the most pressing alarm; it is however important to ensure that the lack of information in the chemical pollutant dynamics of GW does not lead to the dominance of sub-optimal treatment or inappropriate reuse practices (Revitt et al., 2011).

GW may be also used in groundwater recharge, landscaping, and plant growth (Al-Jayyousi, 2003). Regarding urban irrigation, the conventional GW treatment could be utilized with effluent reused on playing fields, golf courses and public parks where a relatively low level of exposure is expected. From the other hand, urban recycling involves advanced levels of wastewater treatment with effluent recycled back to households via dual reticulation. A recycled effluent forms a secondary supply for all non-potable uses; garden watering, laundry and toilet (Fane et.al, 2001). In Kenya for example, GW use is practiced on an informal basis for irrigation in urban gardens either in middle or upper income suburbs. It also used in food gardens in lower income informal, periurban and rural areas (Kariuki et al., 2011). However, the use of GW from recycling systems should fulfill four criteria: hygienic safety, aesthetics, environmental, sustainability, technical and economic feasibility (Al-Jayyousi, 2003; Li et al., 2009; Dott, 1991; Cook et al., 2009).

## 2.5 Perceptions and Attitudes Regarding the Use of the Treated Grey Water

The use of the treated grey water is impacted by the perceptions of the users. People's attitude for the recycled and reused GW is affected by whether there is a direct or indirect contact. Studies revealed that users prefer to reuse their own GW rather than someone else's (Environment-Agency-Abu-Dhabi, 2011). Perception of water reuse and the risk associated with it dictates the quality standards of produced water and the appropriateness of treatment technologies. Thus, a holistic approach and efficient technologies to water treatment and reuse is crucial and must be precisely evaluated (Jefferson et al., 1999).

Grey water systems have to be assessed for suitability in specific households as water use patterns vary widely between them. Some households may use a large amount of water for showering and bathing in the morning and evening, and spend most of the day at work where other toilet facilities are available. This pattern would produce an excess of GW then water savings would be minimal. Instead, occupants may have a low use of water for bathing; being at home for the majority of the day lead to large use of water for toilet flushing. This would create a higher demand for treated GW than the quantity available and minimal water savings (Environment-Agency-Abu-Dhabi, 2011).

## 2.6 Grey Water Treatment and Recycling Approaches

The various systems of grey water reuse could be approached through two main categories; diversion systems and treatment systems. From one hand, diversion systems direct GW from the source to the garden for immediate use in restricted irrigation, without making changes to its quality. In this case, water is not stored for more than a few hours, if any. From the other hand, treatment systems improve the quality of the GW by filtering, treating and disinfecting it. Treated GW is higher quality and can be stored for longer periods for several uses (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007).

Grey water treatment systems can be addressed from different perceptions. They may be considered in terms of the level of treatment; either centralized or decentralized; type of treatment; either physical, biological or mixed and according to the complexity of the applied system technology (low, complex) as presented in Figure2.2.

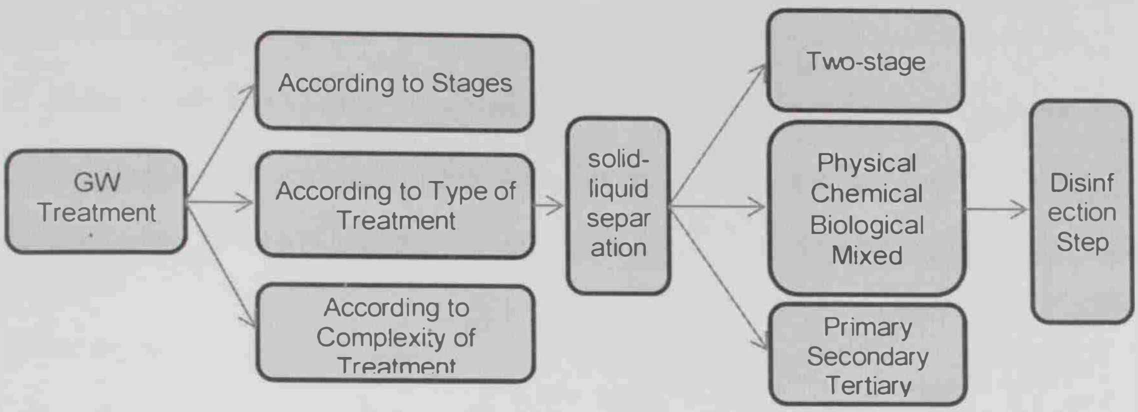



Figure 2.2: Classification of the GW treatment Systems

The simple systems may route GW directly to applications such as toilet flushing and garden irrigation, while the complex are incorporating sedimentation tanks, membranes, bioreactors, filters, pumps and disinfections units (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007) that allows for storage for long times and wider range of uses. In developing countries, a high percentage of the population (90%) is connected to centralized wastewater treatment systems (Bernal and Restrepo, 2012). Simple systems offer minimal both treatments and storage while more complex systems treat GW to a standard sufficient to allow extended storage. Some simple systems have technical limitations while complex systems have other trade-offs such as energy use for high-tech options and space for intensive biological options (Environment-Agency-Abu-Dhabi, 2011).

### 2.6.1 Centralized and Decentralized GW Treatment Systems

The choice of either centralized or decentralized GW treatment type is governed by the drivers and constrains for each that will be discussed according to (Bernal and Restrepo, 2012). Water related drivers to decentralization are water crises and water scarcity, other new societal demands on the infrastructure, droughts and water supply shortages, water quality and habitat degradation. Society related drivers are quality of life in urban and rural communities, population growth, resource constraints, increased demand, new ideas and design concepts, and innovations by entrepreneurs. In addition, climate change, aging infrastructure costs - repairs and expansion, pervasive grey infrastructure, alternatives to sprawl development and available technology.

However, several potential constraints are mainly related to government, economy and society. Government policies and regulations related to centralized infrastructure, fragmentation of the water and sanitation agencies, civil society based on the conventional, minimum investment in research, institutional constrains lack of acceptance public and lack of economic evaluations procedures are the major issues. Segregation of actors (entrepreneurs, professionals, and academics) in three different areas: supply, storm water and wastewater is hindering the shift to decentralization.

Centralized GW treatment systems provide considerable benefits to modern society, particularly for the safe and reliable supply of water, improved public health through removal and treatment of wastewater and flood mitigation (Wang et al., 2008, Cook et al., 2009). They collect and treat the GW from several apartments or houses in a treatment plant outside the house. Those systems usually have a larger space requirements (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007). Centralized treatment plants, disposal and reuse of the treated effluent, are usually many miles far from the point of origin (Cook et al., 2009).

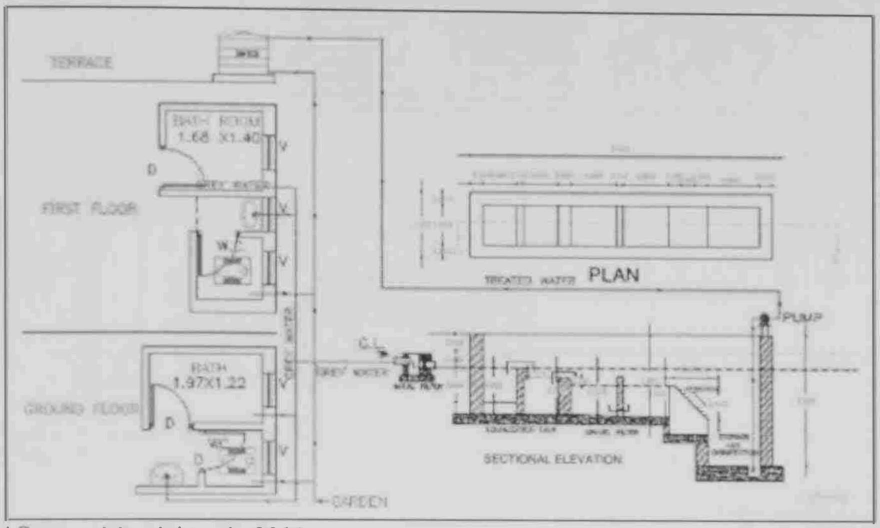
In the centralized approach, the construction cost of transferring and distributing pipelines often becomes more expensive compared with the construction cost for the tertiary treatment facility and the operation costs. This shortcoming has restricted the application of centralized systems in many cases (Wang et al., 2008). However, centralization in collecting and treating GW restrict opportunities to exploit this potentially valuable resource (Cook et al., 2009). It implies that conventional centralized systems are not always the most appropriate solution for urban development.

Decentralized approaches are defined as the technologies that enable the collection, treatment and reuse of alternative water sources such as rainwater, GW, wastewater and storm water. These systems could be applied at different spatial scales; individual homes, clusters of homes, urban communities, industries, or built facilities. They also could be portions of existing communities either independent from or as part of a larger system (Cook et al., 2009). Decentralized systems have the possibility to reduce treatment costs in the long term (Bernal and Restrepo, 2012). Decentralized systems have been provided in semi-urban, rural and remote areas, where the provision of centralized systems is not technically, economically or environmentally feasible. Decentralized systems based on integrated urban water management (IUWM) and water sensitive urban design (WSUD) principles are being planned and implemented for urban developments. They can act either as separate facilities or in combination with a centralized system and can be managed as stand-alone systems. Treated water is partially or completely utilized at or close to the point of generation (Cook et al., 2009). Advantages of decentralization correspond to the individual solutions, so it fits in the locations with low density and scattered population such as peri-urban areas. Onsite scale is a type of decentralized approach in treating GW, which offer technologies and systems that provide water and wastewater services at the scale of an individual lot, cluster or development scale. These systems are owned by allotment holders and operate under some form of common ownership model (Cook et al., 2009).

In New Haven, South Australia, the onsite treatment considered 65 units lay on $20,000m^2$. In Japan, about 2,500 decentralized systems are associated with large buildings that treat and reuse their own GW. By regulations, all institutions, schools and hotels with a construction area larger than $30,000m^2$ have their own water recycling system (Bernal and Restrepo, 2012). Another guidance shows decentralization scale which can serve up to 1000 population, and considering an average household size of 2.6 persons, it can provide a development of about 380 dwellings (Cook et al., 2009). Cluster scale for decentralized GW services can be applied either at different scale. The larger scale cluster system, compared to centralized approach, offers a greater level of control of the quality and quantity of water/wastewater entering the systems, which increases the flexibility and simplicity of the treatment process. It also offers economies of scale; it will often be more efficient for a number of households to invest in and run a decentralized technology than for each one to have its own system (Cook et al., 2009). However, onsite and cluster systems are commonly used in combination, as it is the case in combining the centralized and decentralized approaches together.

Decentralization provides greater flexibility in selecting and setting the types of facilities for GW treatment. It is more reliable and less prone to failure and outside intervention. Decentralization holistically considers the benefits of reducing the amount of waste at source and the option of recycling or reuse at the site. Further, decentralized approaches keep the collection components of the system as minimal as possible and stress on the necessary treatment and disposal of wastewater. The fee collection costs can be reduced down to more than 60% of the total budget for wastewater management in a centralized system, particularly in small communities with low population densities (Bernal and Restrepo, 2012). However, the on-site

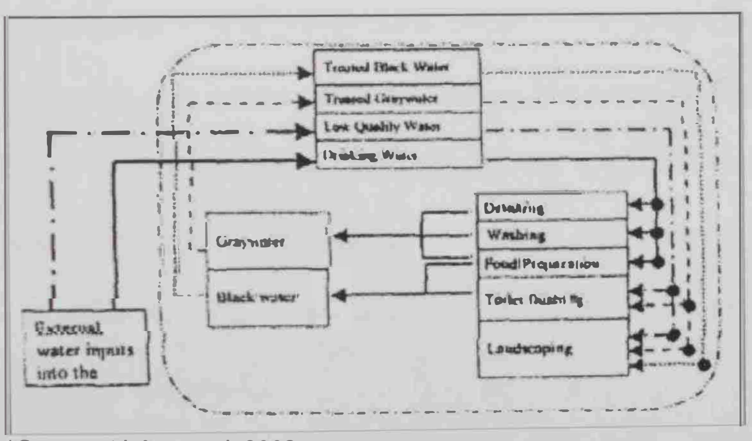
MBR-based GW treatment system has verified to be economically realistic and feasible for the high buildings that exceeds 37 storey's with about 148 flats (Li et al., 2009). Figures 2.3 to Figure 2.5 show the details of the on-site treatment.




*Source: Mandal et al., 2011

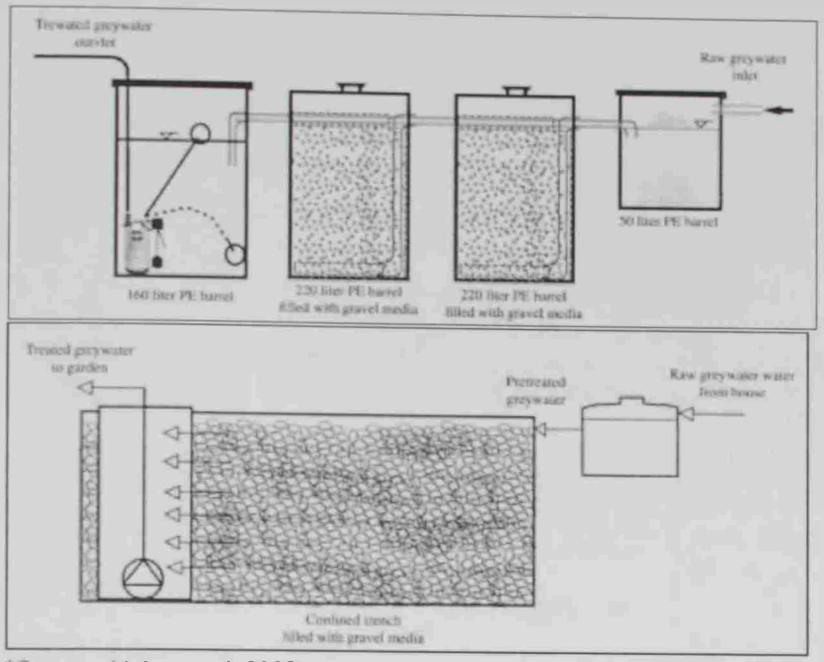
Figure 2.3: On site system for GW collection, treatment and reuse

House onsite treatment of GW and the reuse of treated effluent is increasingly accepted and practiced. The conceptual framework for GW reuse is based on the closed-loop concept Figure (2.4), demonstrated in Figure (2.5). This implies that GW is being managed and reused in a decentralized manner within the household, neighborhood, and/or community. The main idea here is to match water quality with appropriate water uses(Mahmoud and Mimi, 2008).




*Source: Al-Jayyousi, 2003

Figure 2.4: A closed water loop for a residential building



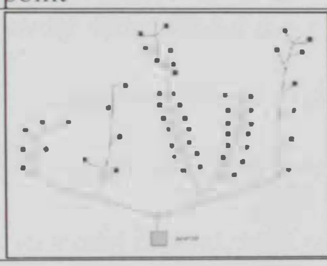
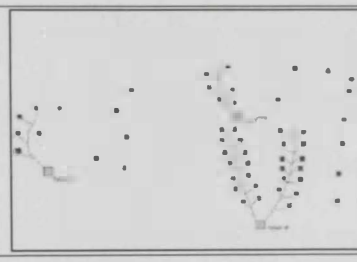

*Source: Al-Jayyousi, 2003

Figure 2.5: A 4-barrel treatment unit and confined trench filled with gravel

In summary, decentralized approaches, they are more financially affordable, more socially responsible, and more environmentally benign than conventional centralized systems. They are bridging the gap between onsite, centralized, and the semi-centralized (satellite) systems. They minimize the environmental impacts and facilitate resources recovery. Decentralized systems can offer a profitable long-term option to guarantee the execution of public health and water quality objectives. These approaches, however, engage changes in planning and deciding about the management of water resources regarding infrastructure, operation, and maintenance. Moreover, they consider climate change and environment, and highly emphasize the concerns about the pressures on urban water systems. Their infrastructure spreads the risks of drought and extreme events and so it is often more climate resilient (Bernal and Restrepo, 2012). A comparison between the centralized and decentralized is provided in Table.2.1.

Table 2.1: Centralized and decentralized schemes

*Source: Bernal and Restrepo, 2012, Cook et al., 2009

| Parameter | Centralized | Decentralized |
|---|---|---|
| **Collecting system** | Large diameters long distances | Small diameters short distances |
| **Requirements space** | Large area in one place | Small areas in many places |
| **Operation and maintenance** | Full time technical staff requirements | Less demanding, can be monitored remotely |
| **Uniformity of water** | Many types of water | More uniform water |
| **Risk** | Risk on a larger scale | Risk distributed |
| **Water transfer** | Increase the needs for water transfer | Water is used and reused in the same area |
| **Social control** | Social control is lost | More social control |
| **Ease of expansion** | High costs, more complexity to implement | Low cost, less complexity to implementation |
| **Potential to reuse** | All water is concentrated in one point | Water can be reused locally |
| **Schematic diagram shows the two systems modified from (Cook et al., 2009).** |  |  |

The application of either centralized or decentralized approach has been elaborated in a case examined by Wang and others in China, 2008. Reclaimed water distribution pipelines in Xi'an are designed to supply water mainly to some potential users such as industries, water bodies and large municipal facilities. Housing developers are facing difficulties in getting easy access to the centralized reclaimed water supply. Therefore, there are cases, where long pipelines have to be constructed by the developers themselves or by the government for the acquisition of the reclaimed water (Wang et al., 2008). However, an assessment study was carried in order to decide which system to choose in the housing development in Xi'an urban area. A critical distance considers the distance from the housing development site to the access point of the centralized reclaimed water supply system and denoted it as L. The construction cost of a pipeline to the access point depends on both L and the design flow rate Q.Under a given Q, L0 is the distance where the cost for pipeline construction equals to that for DESAR (decentralized wastewater treatment and reuse system) system installation and can be called the critical distance. If L< L0 then using the centralized system is economically more feasible, and if L>L0 then DESAR system is economically more feasible (Wang et al., 2008). This comparison assumed that the tariff of the reclaimed water is the same. Construction cost of the decentralized system in housing development in Xi'an urban area in China was reasonable. It was considered for the wastewater treatment system which was installed in the basement of one building. The total construction cost was equivalent to constructing 3.4km pipeline of 100mm diameter while the real distance to the nearest central system was about 8km. About a quarter of the cost was for the civil works while the rest is for equipment and installation. Moreover, estimated operation and maintenance cost for the DESAR unit is found to be (0.82RMB-1.06RMB)/$m^3$ water production which is less than current tariff of 1.17RMB for reclaimed water from the centralized system (Wang et al., 2008). The designer therefore should analyze the existing conditions and carry a feasibility study in order to decide either centralized or decentralized, or work together.

## 2.7 Grey Water Treatment Systems

GW treatment systems range from on-site septic tanks to complex treatment including secondary treatment, membrane filtration and UV disinfection, where the selection of which depends on the reuse and disposal conditions (Cook et al., 2009). This classification considers both centralized and decentralized treatment based on location and site conditions among other several factors. Choosing the proper system for treating the grey water in order to be recycled and reused is crucial. It could be reflected on health, environment, and economy. Most of GW treatment are preceded by solid-liquid separation step and ended by a disinfection step (Li et al., 2009). GW treatment systems' designs vary based on the site conditions and GW characteristics. From the one hand, the technology utilized in a GW reuse systems can be differentiated into primary, secondary and tertiary levels (Mandal et al., 2011).

The primary treatment process comprises of absorbing soap suds using a synthetic sponge, sedimentation settlement tank. The secondary treatment involves filtration of the treated water by gravel (10–60mm size) and sand. Tertiary treatment treats effluent using aeration and chlorination before being pumped to an overhead tank for use in toilet flushing (Godfrey et al., 2009). However, the adopted GW systems might be direct reuse systems which show no treatment and short retention systems. Treatment also might be carried using basic physical and chemical (basic two-stage) systems, biological systems, bio-mechanical systems and integrated systems (Environment Agency, 2011).

Grey Water treatments are classified into three main categories; physical, chemical and biological. The physical treatments include coarse sand and soil filtration and membrane filtration, followed mostly by a disinfection step (Li et al., 2009). Current treatment options vary widely in sophistication from simple filter systems to constructed wetlands, multi-stage biological treatment systems, and membrane bioreactors. All systems are based on a combination of chemical, physical and biological processes such as adsorption, coagulation, precipitation, filtration, aeration, biodegradation, and disinfection (Revitt et al., 2011). However, low cost technologies have been used for GW recycling ranging from simple two-stage processes to more complex treatment processes (Kariuki et al., 2011).

Most of GW treatment technologies are preceded by a solid-liquid separation step and followed by a disinfection step as post treatment. To avoid the obstruction of the later treatment, the pre-treatments such as septic tank, filter bags, screen and filters are applied to reduce the amount of particles, oil and grease. The disinfection step is used to meet the microbiological requirements (Li et al., 2009). All GW treatment processes should have a separate GW plumbing. The choice of the technology for GW recycling depends on several factors such as planned site, available space, user needs, investment and maintenance costs (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007).

Several factors may influence the choice of GW reuse treatment systems (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007). These include budget, existing plumbing, existing garden area if any, elevation of garden beds compared with GW sources. Budget considers the costs for GW treatment which range from simple, relatively inexpensive diverters to complex treatment, storage and irrigation systems which are more costly. However, some states offered on GW recycling systems in households and industry such as Germany. Existing garden area may be affected by the space required by the treatment and irrigation systems. Garden design and the choice of plants will also determine the watering needs. Elevation of garden beds compared with GW sources will partly determine whether the force of gravity alone is enough to push the treated GW through the system to where it is needed or it requires a pump. The following section discuss the various GW treatment systems.

### 2.7.1 Direct Reuse Systems (no treatment) and Short Retention Systems

These two systems apply the simplest GW reuse. Direct reuse system help to reuse GW without any treatment and water is should not be stored for a long time before use. For example, once bath water has cooled it can be reused directly to water the garden. This can be applied using a hose pipe with a small hand pump to create a siphon. However, short retention systems take wastewater from the bath or shower and apply a very basic treatment. They remove debris off the surface and allow particles to settle to the bottom of the tank. The short retention systems use a simple level of treatment hence they are relatively cheap to buy, run and repair. They can be located in the same room as the source of GW reducing the need for costly plumbing (Environment-Agency-Abu-Dhabi, 2011).

### 2.7.2 Basic Physical and Chemical Systems

These systems known as basic two-stage systems carry the treatment process with two stages including a coarse filtration and disinfection (Kariuki et al., 2011, Al-Jayyousi, 2003, Jefferson et al., 1999). It represents one of the most common technologies used for domestic grey water reuse in the UK. These systems are designed to meet the less restricted reuse standards (Jefferson et al., 1999). Filters are used to physically remove waste from GW before storing. Chemical disinfectants such as chlorine or bromine are used in order to stop bacterial growth during storage. In this system, reliability varied and filters required regular cleaning to avoid blockages (Environment-Agency-Abu-Dhabi, 2011).

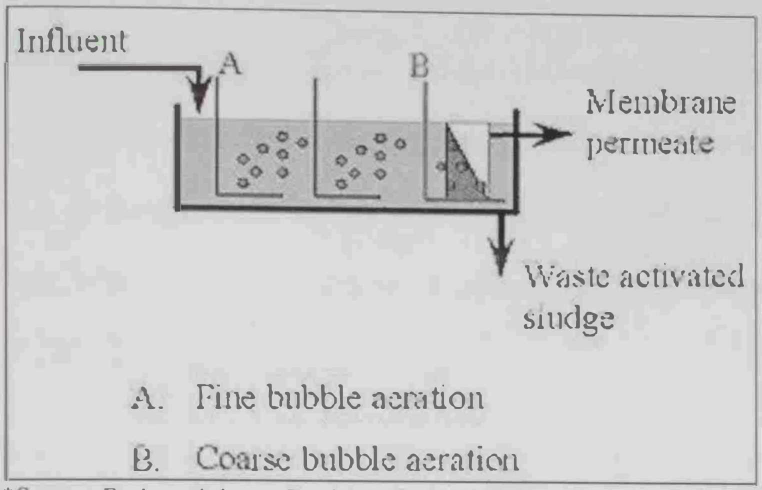
Physical processes can achieve substantial clarification of water. They are reasonably effective in decreasing the organic pollutant load of GW prior to reuse. The aesthetic quality of water is thus increased and problems associated with downstream disinfection encountered in the coarse filtration systems substantially ameliorated (Al-Jayyousi, 2003). Moreover, physical processes such as sand and membrane filtration can be applied as post-treatments for polishing purposes in order to achieve non-restricted non-potable reuse standard in terms of the BOD and the turbidity requirements (Li et al., 2009). Simple filtration based on fibrous, cloth, a metal strainer or granular depth filters presents no complete barrier to suspended matter, resulting in coli-form breakthrough. Systems have shown water saving levels ranging from 3.4% to 33.4%. Such systems are commercially available at reasonable price offering minimum payback periods of around 8 years for a four-person household. Even though little or no removal of the chemical and biological pollution was reported for such systems, the treated GW was free of all indicator organisms making it potentially safe for reuse. However the system also suffered periodic failure of the disinfection process, such that coliform levels occasionally exceeded quality standards(Jefferson et al., 1999). However, this should be considered seriously when handling a site with evidences showing the existence of infection in a neighborhood or district in a way that may threaten the general health.

Chemical processes include coagulation, photo-catalytic oxidation, ion exchange and granular activated carbon. They, followed by a filtration and/or disinfection stage, are able to reduce the suspended solids, organic substances and surfactants and turbidity in grey water. Coagulation with either aluminium salt or ferric salt gave similar results in terms of reducing the COD, the BOD, the turbidity, TN and phosphate ion (PO43-). Magnetic ion exchange resin process can reduce the turbidity and the BOD. Chemical processes are not sufficient to meet the non-potable reuse standards for high strength GW unless they are combined with other processes such as polishing using sand or membrane filtration. The effluent from the sand filtration stage shall be disinfected to meet the non-restricted reuse standards (Li et al., 2009). However, disinfection by chlorine generates byproducts such as chloramines and tri-halo-methanes, which have a lower disinfectant capability and adversely affect human health(Al-Jayyousi, 2003).

### 2.7.3 Biological treatments Technologies

The concept in GW biological treatment is to remove (digest) contamination by bacteria from organic material using oxygen. Supply of oxygen could be through the use of pumps to draw air into the water in the GW storage tanks or the use of plants to aerate the water. Reed beds are generally used to add oxygen to GW and allow naturally occurring bacteria to remove organic matter. GW can be passed through the soil or gravel where the reeds are growing (Environment-Agency-Abu-Dhabi, 2011). Biological treatment is used in particular for systems that include large distribution networks such as hotels or community-based recycling schemes (Jefferson et al., 1999).

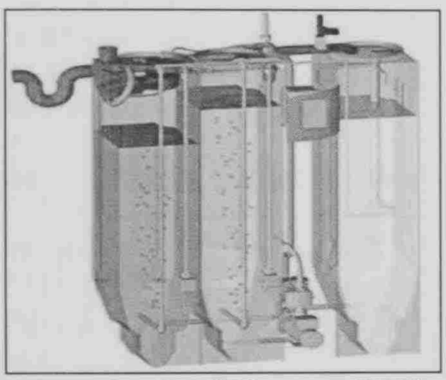
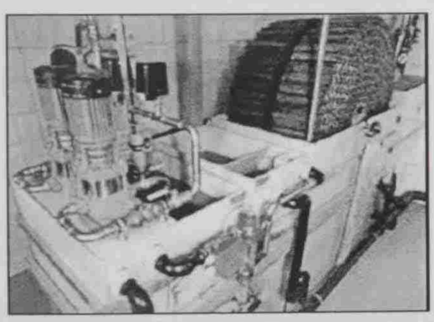
Biological processes include rotating biological contactor (RBC), sequencing batch reactor (SBR), anaerobic sludge blanket (UASB), constructed wetland (CW), membrane bioreactors (MBR) (Li et al., 2009) and biologically aerated filters (BAFs) as illustrated and described in Figure 2.6 and Table 2.2. The BAF are capable of producing high-quality effluents (Jefferson et al., 1999). Biological treatments are often preceded by a physical pre-treatment step such as sedimentation, usage of septic tanks or screening. Except the MBR, most of the biological processes are followed by a sand filtration step and/or a disinfection step (Li et al., 2009). However, filtration in itself is not considered sufficient to guarantee an adequate reduction in organic contamination that can prevent biological re-growth in distribution systems(Jefferson et al., 1999). Therefore, some biological systems allow for another step of treatment as the filtered water passes through an Ultra-Violet (UV) filter to kill any remaining bacteria and is dyed green to distinguish it from potable water (Environment-Agency-Abu-Dhabi, 2011).




*Source: Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007

Figure 2.6: Membrane Bio-Reactors (MBR)

Table 2.2: SBR and RBC as biological GW treatments

| | |
|---|---|
|  Sequencing Batch Reactor (SBR) | The Sequencing Batch Reactor (SBR) is a variant of the activated sludge process, however it is operated (filled and emptied) discontinuously. There are four stages to treatment; fill, aeration, settling and decanting. It consists of a primary sedimentation tank, an aerated flow-bed reactor in which the bacterial biomass is mainly fixed on foam cubes or other carrier material, and a storage tank. SBR are available in modular design such that single modules can be added dependent on the amounts of generated GW to be treated. |
|  Rotating Biological Contactors (RBC) | Rotating Biological Contactors (RBC) is a multi-stage system that has been also used for wastewater treatment following primary treatment. RBCs have been successfully employed for GW treatment. These are usually preceded by a primary sedimentation stage with a final clarification stage for biomass removal. UV disinfection of the treated GW yields a high-quality water for non-potable uses. RBC systems can be placed in the cellar as they have a low space requirement. |

Biological treatment varies widely in their ability to remove suspended solids and pollutants such as Pb and 4-NP from GW. The composition and condition of the microbial community or biofilm in biological systems will significantly affect the likely biodegradation for organic micro-pollutants. This treatment can take some time to mature and establish reliable performance. It may be hampered by pollutants such as a predominance of bleach or other cleaning products. Efficiencies may vary over time, which impact the system effectiveness and urban water cycle as well (Revitt et al., 2011).

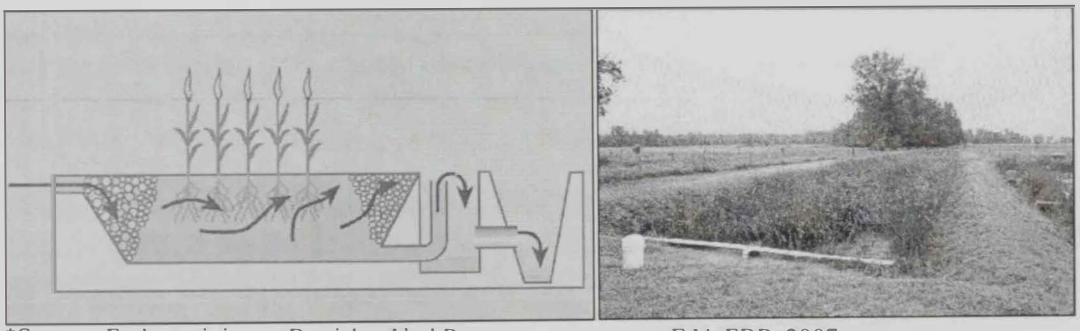
Membrane Bio-Reactor (MBR) system combines biodegradation with membrane filtration for solid liquid separation in the GW treatment. The MBR is able to remove pathogens with high stability(Li et al., 2009). The MBR is a suspended growth activated sludge system that utilizes micro-porous membranes for solid/liquid separation. The system consists of a pre-treatment settling tank, an aerated settling tank which also stores the irregularly produced GW and the aerated activated sludge tank. The sludge is held back by the submerged membrane filter module installed in the aeration tank. The treated GW passes through the membrane under a pressure of 0.1-0.3 bars yielding a bacteria-free effluent. MBRs require less space since less hydraulic residence time is needed to achieve a given solids retention time (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007).

The MBR process can be configured with the membrane placed within the reactor which could be either submerged or side-stream MBR. They both show similar biological performance but membrane permeation differentiates them. External systems are run at higher trans-membrane pressures. They produce high flow rates which intensify fouling problems that is necessitating regular cleaning. However, internal systems are hydraulically operated, and generate stable but much lower flow rates. In that way, it is reducing membrane cleaning requirements (Jefferson et al., 1999). A submerged MBR made of polyethylene with pore size 0.4 μm for low strength bath grey water treatment showed an efficient effluent quality. The COD was reduced from 130–322 in the influent to 18 mg/l in the effluent. NH4–N concentration has decreased from 0.6–1.0 mg/l to less than 0.5 mg/l. BOD5 was reduced from 99–221 mg/l to less than 5 mg/l. Anionic surfactants (AS) were reduced from 3.5–8.9 mg/l to less than 0.5 mg/l. The effluent was colorless, odorless and free of SS and faecal coliform concentrations were below the determination threshold (Li et al., 2009).

The performance of a low strength GW treatment process was investigated using combined RBC, sand filtration and chlorination. The treatment started by a fine screen for the removal of gross solids and hairs larger than 1mm, then RBC step and followed by a sedimentation step in a sedimentation basin to separate sludge from the effluent. The TSS, turbidity, COD, BOD and faecal coli-form were reduced. Sand filtration step further reduced the TSS, turbidity, COD and BOD where the results were astonishing. The faecal coliform level increased after the sand filtration, demanding a disinfection step that actually was able to reduce it in the final effluent. Effluent from this pilot grey water treatment plant met the non-restricted non-potable water reuse standard proposed for the study (Li et al., 2009).

Constructed wetlands have been used successfully in the past for the treatment of wastewaters. They show examples of a combination of the physical, chemical, and biological processes to remove contaminants as shown in Figure 2.7 (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007). The constructed wetland has been considered as the most environmentally friendly and costs effective technology for grey water treatment. They showed good performance to an average BOD residual of 17 mg/l and the average residual concentration of 8 NTU for turbidity and 13 mg/l for suspended solids were reported (Li et al., 2009). In addition, reported cases showed accepted reduction in all of the TSS, BOD5, COD, TN, TP, anionic surfactants, boron and faecal coliform.

Greywater treatment is achieved by soil filtration in reed-bed systems reduces the organic load of the GW significantly, in addition to decreasing the concentrations of faecal bacteria. If appropriately designed, these systems would produce a clear and odorless effluent, which can be stored for several days without the need for disinfection. One disadvantage is the high evaporation rate from the reed beds, especially in warm climates and the high space requirement. Constructed wetlands tend to be simple, inexpensive and environmentally friendly. They can also provide food and habitat for wildlife and create pleasant landscapes (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007). However, they require a large space and, therefore, it is not suitable to be applied in the urban areas (Li et al., 2009).



*Source: Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007

Figure 2.7: Few biological treatments

A review of the biological treatments for GW reveals that aerobic biological processes are able to achieve excellent organic and turbidity removals. The poor removal efficiencies of both organic substances and surfactants make anaerobic processes unsuitable for grey water recycling, though biogas production is an advantage. The aerobic biological grey water treatment processes including constructed wetland can achieve satisfactory performances with regard to the removal of the biodegradable organic substances. After aerobic biological grey water treatment processes, most of the biodegradable organic substances are removed and as a result the re-growth of micro-organisms and odor problems are avoided (Li et al., 2009). This therefore, is making the treated grey water more stable for storage over longer periods.

### 2.7.4 Membrane systems

The membrane systems offer a permanent barrier to suspended particles greater than the size of membrane material. The pores can range from 0.5μm for microfiltration membranes down to molecular dimensions for reverse osmosis. The treated water is thus generally extremely low in turbidity below the limit of detection for coliforms. The energy required for membrane systems is substantially high and they are operated at pressures up to 2.0 bar(Al-Jayyousi,2003, Jefferson et al., 1999). However, it should be stressed that the organic strength and the turbidity in the treated GW may be extremely low. It might be strengthened using nano-filtration membranes as about 92–98% of anionic surfactant LAS (linear alkylbenzene sulfonates) and 88–92% of nonionic surfactant were rejected by the nano-filtration membranes (Li et al., 2009). The LAS concentrations in permeate were still higher than the predicted no-effect concentration and further treatments are required.

The economic viability of membrane systems is hindered by the fouling of the membrane surface by pollutant species which can cause flux declination by up to 90% after just 1 hour of operation. The increased hydraulic resistance of the membrane by the fouling is proportionally increasing the energy demanded for membrane permeation and/or decreasing the permeate flux. Fouling can be covered up by operating at a lower membrane flux, which will consequently increase the area requirements for the membrane and is substantially removed by cleaning. In all, this will increase the overall process cost, in addition, the cleaning process will also impart an undesirable chemical load on the waste stream (Jefferson et al., 1999). Another significant issue regarding the membranes systems lay in the GW residence time as a major cause for concern. Over long time, the GW can become anaerobic which results in the generation of organic components which are less readily rejected by the membrane (Al-Jayyousi, 2003).

Regarding the biological treatment, it is found that the deficiency of both macro-nutrients and nutrients in the grey water can limit the efficiency of treatment. The ratio of COD[1]: BOD5 in grey water of about 0.50 shows a good potential for biological treatment. However, the concentrations of nutrients do not reflect limitation for the growth of micro-organisms. Based on several studies, it is found that grey water that is high in S, Ca, Kand Al and the concentration levels of the trace nutrients are closed to the reported requirements (Li et al., 2009).

### 2.7.5 Bio-mechanical systems

The Advanced bio-mechanical treatment systems are considered the most advanced domestic GW systems that were developed first in Germany. Combining physical and biological treatment generally produces the highest quality water, but it also uses a significant amount of energy, is expensive to purchase and operate, and maintenance costs are uncertain. They are best installed during construction and are not suitable for retrofitting into existing buildings due to cost and other practical difficulties. Solid material is allowed to settle to the bottom of the tank and is removed automatically. The system encourages bacterial activity by bubbling oxygen through the water. The

[1]COD, chemical oxygen demand, BOD, biochemical oxygen demand which is a measure of the amount of organic material in the water, $BOD_5$ five-day biochemical oxygen demand

final stage of the system is UV disinfection to remove any remaining bacteria (Environment-Agency-Abu-Dhabi, 2011).

### 2.7.6 Integrated greywater/rainwater systems

Integrated systems use both treated greywater and harvested rainwater. These systems can be used where one or the other of the non-potable sources are insufficient to meet the end uses ((Environment-Agency,2011) as presented in Figure 2.8. An international scan shows that GW finds applications in many cases as presented in Table2.3.


*Source: modified by the author from (Kariuki et al., 2011)

Figure 2.8: A low cost GW treatment system

Table 2.3: Selected Study cases for GW reuses in several countries

*Source: adopted from (Cook et al., 2009)

| No | Name of the Case | Treatment Approach | Type of treatment, System | Served Size | Reused for |
|---|---|---|---|---|---|
| 1* | Residential (Leisure village) | Onsite treatment of wastewater | by immersed membrane bioreactor, UV and chlorination; | 46 houses | toilet flushing, garden irrigation and dedicated disposal areas |
| 2* | Residential | Centralized wastewater collection | by immersed membrane bioreactor, UV, chlorination and carbon filtration | 24 lots | toilet flushing and garden |
| 3* | Residential | | aerobic membrane bioreactor | 250 residences | toilet flushing, laundry, garden watering and car washing |
| 4* | Residential | | low infiltration gravity sewer treated for reuse using membrane filtration and disinfection | 50,000 lots | |
| 5* | Residential | | aerobic systems with nitrogen removal, followed by tertiary treatment using flocculation, clarification and sand filtration | 36,000 houses | toilet, garden and car wash |

| | | | | |
|---|---|---|---|---|
| | | then, recycled via dual pipe systems disinfected using UV+ chlorination | | |
| 6** | Oxley Gate | Ecoplay*a greywater management systems | 150 dwellings in Milton Keynes | toilet flushing |

* Australia-Queensland developments adopting the integrated urban water cycle management approach (Cook et al., 2009).

** The case To help the housing association meet carbon reduction targets and higher levels of Code for Sustainable Homes (CSH) (Environment-Agency-Abu-Dhabi, 2011).

*a Ecoplay system can hold up to 100 liters of water, which can provide approximately 15 toilet flushes.

## 2.8 Evaluation of the GW treatment Systems

There are six key factors considered in implementing GW treatment approaches as planning, demography, technology, economic, environmental and social. Planning considers urban area planning, geographical distribution and land uses, urban development plans, legislation and institutions, and the administrative and political reforms. Demographic issues consider size, population distribution, density, and growth rate. Technological issues consider each of sewer system existence and coverage, wastewater treatment existence and coverage, non-conventional technologies, technologies combination, water demand, waste water production and composition, efficiency, reliability, reclamation and reuse of wastewater, combination of centralized and decentralized systems and the level of compliance with quality standards(Bernal and Restrepo, 2012). Regarding technical issues, it is essential to have water transfer and distribution pipelines, since most of the users of the reclaimed water are in the city area (Wang et al., 2008).

Economic factors consider costs of the collecting and the conveying, treatment, construction, maintenance and operation, materials and environment. It is vital in this place to realize that, and regarding the centralized systems, that is most of the financial costs are related to the construction and maintenance of the sewage collection system. Conversely, most of the decentralization costs are related to the treatment unit. The environmental issues consider resources consumption, environmental protection and benefits. Finally, the social issues consider the acceptance, culture, health impact, environmental education and the social awareness (Bernal and Restrepo, 2012).

Water use patterns vary widely between households, and accordingly, assessment should consider the suitability in specific context. Some households may use a large amount of water for showering and bathing in the morning and evening but they spend the majority of the day at work where other toilet facilities are available creating much of the GW. Instead, occupants could have a low use of water for bathing and spend the majority of the day at home, therefore using a larger amount of water for flushing the toilet. This would create a higher demand for treated GW than the quantity available and would also lead to minimal water savings.

Moreover, GW treatment and reuses are assessed in terms of technical feasibility, public health, social acceptability and sustainability (Al-Jayyousi, 2003). The users of the treated GW may be initially happy with the systems, however, with time, they may identify problems such as odor, performance, noise and water poor quality. These problems were exacerbated by difficulties in gaining access to the systems in the flats for service and repair, and eventually led to their removal. The payback for high efficiency and complex systems was estimated at over 65 years which will significantly be longer than the life of the systems (Environment-Agency-Abu-Dhabi, 2011), the users and the buildings themselves.

Complexity of the technology applied is generally corresponding to the scale of the GW scheme. For instance, the cost implications may direct the designer to choose coarse filtration devices with downstream disinfection for a single-house treatment system, where the emphasis is on simple and reliable systems. However, the colleges and small offices can better utilize physical or simple biological systems as they have been shown to be far more economically viable than single-house systems taking into consideration the payback time of about 10 years (Al-Jayyousi, 2003).Components of the GW that are required to be removed in addition to the potential uses will affect the system that the designer will consider. For instance, physical processes were found to be not sufficient alone to guarantee an adequate reduction of the organics, nutrients and surfactants. The chemical processes can efficiently remove the suspended solids, organic materials and surfactants in the low strength grey water. The combination of aerobic biological process with physical filtration and disinfection is considered to be the most economical and feasible solution for grey water recycling. Therefore, the MBR appears to be a very attractive solution in collective urban residential buildings. Chemical solutions seem attractive for the single household low strength GW treatment system as the variability in strength and flow of the grey water did not affect their performance. However, they often fail to meet the turbidity value of less than 2 NTU till the present time (Li et al., 2009).

Organic materials in the GW require disinfection such as chlorine which has disinfectant byproducts such as chloramines and trihalomethanes. They have a lower disinfectant capability and adversely affect human health. Then, additional problems occur due to the presence of detergents that are known to produce an odor in water at concentrations above 3mg (Al-Jayyousi, 2003). This in turn lays extra load in defining the best way in treating water in order to reduce the contradictions in the performance. Biological processes are suggested to medium to high strength grey water treatment. However, poor removal of micro-organisms, suspended solids and turbidity were observed, which demands a final filtration and/or a disinfection step to meet the proposed urban reuse standard. The combination of aerobic biological processes with physical filtration and/or disinfection is considered to be the most economical and feasible solution for grey water recycling (Li et al., 2009).

Poor-treated water quality with membrane systems in addition to the difficulties in cleaning the membrane efficiently are significant problems. The residence time of the system has been identified as being a major cause for concern. Over extended time periods, the grey water can become anaerobic resulting in the generation of organic components which are difficult to be rejected by the membrane (Jefferson et al., 1999). The RBC-based system was found to be economically feasible in buildings up to seven storey's or 28 flats. The RBC step proved to be efficient in reducing BOD to below 5mg/l. The sequencing batch reactor (SBR) can operate for a high strength grey water treatment. It can result in increasing the sludge retention time to 378 days and the hydraulic retention time was reduced to 5.9 hours. The SBR can account for 90% COD and 74% TP, indicating that the transformation of particulate organic nitrogen to ammonia during the aerobic treatment was very limited. A percentage of 97% of anionic surfactants can be eliminated by the aerobic degradation (Li et al., 2009).

MBRs and BAFs processes have significant differences in removing turbidity and coli-form. Submerged MBR meets the strict water recycling standards 100% of the time, while BAF failed to meet water quality standards 40% of the time in terms of water quality determinants(Jefferson et al., 1999). BAFs combine depth filtration with a fixed film biological reactor. As such, they present no absolute barrier to suspended materials and thus do not substantially disinfect the water (Al-Jayyousi, 2003). Coli-form rejection is 100% efficient and much steadier than in the case of physical membrane systems as bioreactor digests protein. This facilitates the transport of microorganisms through the membrane. Flocculation is retaining micro-organisms in the flocculent material. Submerged MBR are expensive and exhibit a limited tolerance to shocks by bactericidal agents such as bleach (Jefferson et al., 1999). Therefore, dilution of chemical shock is sufficient to avoid medium-scale system failure. Nevertheless, the relative higher residual organic substances in the treated grey water by MBR filtration often promote the re-growth of the micro-organisms in the storage and transportation system. Furthermore, the membrane fouling and its consequences in term of operating and maintenance costs can restrict the widespread application of membrane technologies for grey water treatment (Li et al., 2009).

In general, the most efficient systems for the treatment of GW are biological systems in combination with physical treatment processes. These have proved to reduce the BOD and produce a better effluent quality than systems which merely apply physical processes (AL-Hamaiedeh and Bino, 2010). Moreover, the MBR is the only technology being able to achieve satisfactory removal efficiencies of organic substances, surfactants and microbial contaminations without a post filtration and disinfection step. The qualities of the MBR effluent meet the most stringent non-potable urban reuse standards. Due to the excellent and stable effluent quality, high organic loading rate, compact structure as well as low excess sludge production, the MBR appears to be an attractive technical solution for grey water recycling, particularly in collective urban residential buildings (Li et al., 2009).

## 2.9 Guidelines and Specifications of Reused Treated Grey Water

Stored GW have to incorporate some level of treatment as untreated GW deteriorates rapidly in storage because of it is often warm and rich in organic matter such as skin particles, hair, soap and detergents. The reuse of GW for irrigation in developing countries is gaining momentum, however, it is often used without any significant pre-treatment which is an unsafe practice that can damage soil and may pose a potential risk to human health. It is therefore important to treat and disinfect it in order to inactivate the pathogenic microorganisms (Kariuki et al., 2011). The characterization of grey water reveals that it should be treated to a higher standard before reusing to avoid the health risk and negative aesthetic and environmental effects. Often established by local authorities, national water reuse guidelines focus on healthy and environmental impacts. There is considerable variation among these guidelines regarding identifiable values and the limited parameters. The differences observed between the reuse criteria reflect differences in need, applications and social factors. Few reuse guidelines are particularly made for grey water recycling (Li et al., 2009). These guideline outlines the microbiological requirements which is differs according to local regulations. Germany as the first to regulate the reuses of the treated GW considered a very wide range of specifications to control health and environment. They include parameters like BOD7, oxygen concentration, total coliform, faecal coliform and pseudomonas aeruginosa. In addition, the guidelines consider pH, TSS, BOD5, turbidity, total coliform and fecal coliform and the limits for parameters such as ammonia, phosphors, nitrogen and chlorine residual. However, the Chinese guideline for treated GW reuse ask for additional parameters like TDS, TN, NH4–N, TP and detergent for wastewater recycling (Li et al., 2009).

Grey water is relatively low in suspended solids and turbidity indicating that a greater proportion of the contaminants are dissolved. Although the concentration of organics is similar to domestic wastewater, the chemical nature differs. The COD:BOD ratio may be as high as 4:1 which is greater than values reported for sewage. This is associated with a macro-nutrients deficit of nitrogen and phosphorus. COD:NH3:P of grey water has been measured at 1030:2.7:1 compared with 100:5:1 for domestic wastewater. The low values of biodegradable organic matter and the nutrient imbalance can limit the efficiency of biological treatment (Jefferson et al., 1999). Table 2.4 provides some recommended range of acceptable GW specifications.

Table 2.4: Hygiene requirements for the treated GW for use as a non-potable water

| Country | Total coliforms | E coli | Helminth eggs | Pseudomonas aeruginosa | faecal Streptococci | Candida albicans | Staphylococcus | Salmonella sp 0/ |
|---|---|---|---|---|---|---|---|---|
| Germany, EU *a | < 10 000 / 100 ml | < 1 000 / 100 ml | | < 100 / 100 ml | 0 / 0 1 ml | 0 / 0 1 ml | aureus 0/1 ml | 100 ml |
| | < 1000 ml$^{-1}$ *b | | | | | | | |
| WHO, 2006 *c Restricted Irrigation | | < $10^5$/100 ml | <1 /1 1 | | | | | |
| WHO, 2006 *c Un-Restricted Irrigation | | < $10^3$/100ml | <1 /1 1 | | | | | |

*a Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007
*b (Al-Jayyousi. 2003)
*c (Li et al., 2009)

Physical and chemical parameters of significance

| **Country** | **BOD** | **$BOD_7$** | **$O_2$ Saturation** | **UV-Transmission at 254nm (1 cm)** |
|---|---|---|---|---|
| **Germany, EU *a** | | < 5 mg/l | > 50% | > 60% as a minimum transmission for UV-disinfection |
| **Japan/T. Flush** | (<20 mg/l-$^{1}$) *b | | | |

This table is developed by the author based on the following references
*a Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007
*b (Al-Jayyousi, 2003)

A successful GW treatment and safe reuse depends on its immediate processing and reuse before it has reached the anaerobic state (Al-Jayyousi, 2003). Therefore, the national and international guidelines show the accepted specifications that could pave the road towards the safe reuse of the treated grey water. They describe the recycled GW physical, chemical and biological quality. Physical quality includes how clear the water is (turbidity), total suspended solids in the water and its temperature, while chemical quality shows the acidity or alkalinity of the water (pH), level of disinfection, the amount of dissolved oxygen and biochemical oxygen demand

(BOD). Biological quality relates to the presence of bacteria and viruses (Environment-Agency-Abu-Dhabi, 2011).

## 2.10 Grey Water Recycle and Reuse Risks and Challenges

Expansion of the urban areas usually involves the large-scale schemes in new or existing centralized sewage treatment plants. This negates any cost advantage for wastewater systems with more than around 1,000 connections. Theoretical relationship between effluent reuse system scale and pathogen risks has been examined. Waterborne disease is considered to be a significant factor when reusing effluent in urban areas and smaller systems were found to pose a lower risk of infection. Pathogen risks were then included within an economic analysis of system scale. With the inclusion of pathogen risks as a cost externality, taking a decentralized approach to urban water reuse, it would be economically advantageous in most cases. In an urban area where community exposure to the treated GW containing human pathogens, waterborne diseases are possible, particularly because of viruses, helminths, parasitic protozoa or bacteria (Fane et al.).

Regarding the policy level, both the government which promotes water use and the users who use the reclaimed water are interested in lowering the price for the treated water versus the tap water. In order to encourage this issue, a number of cities have lowered the selling price of the reclaimed water regardless how much is spent for its production. Governments however, subsidize the business in order to promote wastewater reuse. This may not be a sustainable way for wastewater reuse, therefore decentralized systems for wastewater treatment and reuse are drawing attention widely. These systems stress on-site wastewater treatment and reuse (Wang et al., 2008).

Decentralized approaches of GW treatment impact urban water cycle. They investigated priority substances (PSs) or 'Priority Hazardous Substances' (PHS) which are known to be present in GW under the European Water Framework Directive (WFD). The study shows the likely benefits/shortcomings of different treatments in terms of micro-pollutant perseverance and possible impacts on municipal wastewater flow. The results focus on cadmium (Cd), nickel (Ni), lead (Pb), benzene and 4-nonylphenol (4-NP). Cadmium, Ni and Pb are metal pollutants of high concern in the municipal wastewater treatment process, as their tendency to accumulate in sludge can counteract its beneficial reuse for nutrient recovery and soil conditioning (Revitt et al., 2011).

Poor performance for small-scale wastewater treatment in addition to the institutionalization of centralized approaches is crucial factors that support centralization (Fane et al.). One of the key issues in implementing decentralized systems in urban areas is focused on small-scale and on-site treatment of waste/GW. Framework for GW reuse is based on the closed-loop concept in order to manage and reuse GW in a decentralized manner within the household, neighborhood, and/or community (Al-Jayyousi, 2003). This gives few limitations for the large-scale for the treated grey water schemes.

Lack of appropriate water quality or guidelines has hampered appropriate grey water reuse (Li et al., 2009). One of the challenges that form a major difficulty in GW treatment is the large variation in its composition. For example, COD mean values varied from 40 to 371 mg/l between sites, with similar variations arising at an individual site which reflect great variation. This in turn attributes to changes in type and quantity of detergent products. GW quality then is subjected to significant chemical changes over a few hours (Jefferson et al., 1999). Research has shown that counts of total coliform and faecal coliforms increased from 100-105/100 ml to above 105/100 ml within 48 h in stored GW from various sources (Al-Jayyousi, 2003). This in fact turns the alarm on in order to focus research area for scientific breakthrough regarding the appropriate GW treatment that is relevant to its components.

Energy is also another challenge to explore regarding the GW treatment and energy requirements. Greenhouse gas emissions result from GW treatment and reuse systems. According to the wide range of variation in GW treatment systems, then energy requirements and carbon emissions will vary depending on system type, installation arrangements and level of the demand(Environment-Agency, 2011). Economies of scale are important issues that exist in both capital and operating costs of GW treatment. Diseconomies of scale are, yet, apparent in plumbing networks. This results because each of the number of connections, the distance of pipe required per connection and the need for larger pipes with greater volumes increase (Fane et al.).

Technical requirements of the treated GW revealed that they should not be a source of odors and nuisance to the user and it should be nearly free from coloration and suspended solids. No cross-connections should exist between the drinking water and service water (treated GW) networks. A proper and clear designation of the network pipes with different colors and labels protects against un-authorized use. Skilled knowledge is needed for the installation and maintenance of more sophisticated GW treatment systems in order to protect human health (Fachvereinigung Betriebs- Und Regenwassernutzung E.V. FBR, 2007).

## 2.11 Summary

The Chapter has mainly highlighted the potential savings that the government could achieve in the case of reusing the treated GW in the residential urban uses. The researcher therefore, preludes for the problem of water resources scarcity in the UAE which coincides with the overconsumption which is characterized in the new evolving towns such as Al Wagan as they are dominated local citizens. The scene is clearly illustrated by the fact the locals do not pay for water as the government subsidize water prices for them.

Several cases studies for grey water recycling and reuse have been done and reviewed either internationally, regionally or locally in order to scan the related literature. The main focus was on tracking the experiences in recycling the grey water of the residential use and the potential uses. These cases show irrigation and toilet flushing as the most common and accepted uses for the grey water. However, the researcher considers the treated water instead of the fresh water in the toilet flushing.

In the context of the Abu Dhabi, it has been found that the growing awareness of the water scarcity as reflected by the growing percentage of dependency of treated and desalinated water while decrease the reliance on the ground water. The local experiences in this topic were in public uses. Therefore, this research is targeting the residential uses and the potential savings in order to establish for the new set-up in water consumption in one neighborhood then to generalize. The next Chapters will highlight the systems of grey water recycling and treatment levels, and a demonstration of the context of the case study.

Grey water treatment and recycling can potentially save significant volumes of potable water and reduce pollution. The choice of the treatment approaches are determined essentially by the processes adopted for the design and implementation, the type of the applied treatment, the site conditions, maintenance and monitoring system. Micro-pollutants in GW significantly determine the efficiency of treatment in particular concerning pathogens, sludge separation and its effect on soil. The dominant removal processes for the pollutants mostly depend on the physical, chemical and biological properties of that pollutant. Some substances may be more readily biodegraded than others while other substances may be more subject to sorption or volatilization. Therefore, the success of the GW treatment system needs continuous tests in order to match the treatment requirements. Physical treatments alone do not guarantee an adequate reduction of the organics, nutrients and surfactants, while the chemical treatment provides higher efficiency in removing the suspended solids, organic materials and surfactants in the low strength grey water. However, anaerobic processes have poor efficiency in removing both organic substances and surfactants and they are not recommended even with the emissions of methane gases. The aerobic biological treatments such as RBC and SBR can be applied for medium and high strength grey water treatment. Combining the aerobic biological process with physical filtration and disinfection is recommended as being the most economical and feasible solution for GW treatment. MBR also provides efficiency for medium-high strength GW recycling as it proves particularly in collective urban residential buildings.

# CHAPTER 3: STUDY METHODOLOGY AND DATA COLLECTION

## 3.1 Introduction

This research methodology and comprised of the following logical stages as presented in the flowchart shown in Figure 3.1:

1. **Literature Review:** This covered the theoretical background for the GW as a new evolving discipline. This was done through a desk study that relied on several types of references such as books, journal papers and web sites. This derived data that supported the literature documented in the first two chapters. The literature review covered previous studies in urban settlements that have adopted the GW recycling and reuse where each case was analyzed in order to different GW systems, benefits and potential socio-economic, environmental, health and policy impacts. Important lessons gathered in each case study that would guide in the practical implementation of Al Wagan district GW recycling project has also been documented.

2. **Field Work and Interviews:** The second important stage involved primary data collection through interviews using questionnaires with managers of various pertinent government institutions. These included; Al-Ain Municipality, Abu Dhabi Water & Electricity Authority, Environment Agency Abu Dhabi (Refer to Appendix A), Al Ain Distribution Company and TRANSCO. The range of the collected data included; populations, water consumptions and productions, water treatment processes, energy consumptions and revenues, water sources and grey water estimates.

3. **Data Analysis:** This involved quantitative analysis of the collected data, presenting the justification for the need for grey water recycling in Abu Dhabi, project feasibility, grey water recycling options testing, project costing, decision making.

4. **Recommendations:** Based on the data analysis and optioneering stage, this stage of the study provided recommendation on what option of grey water would be adopted, limitations and challenges.

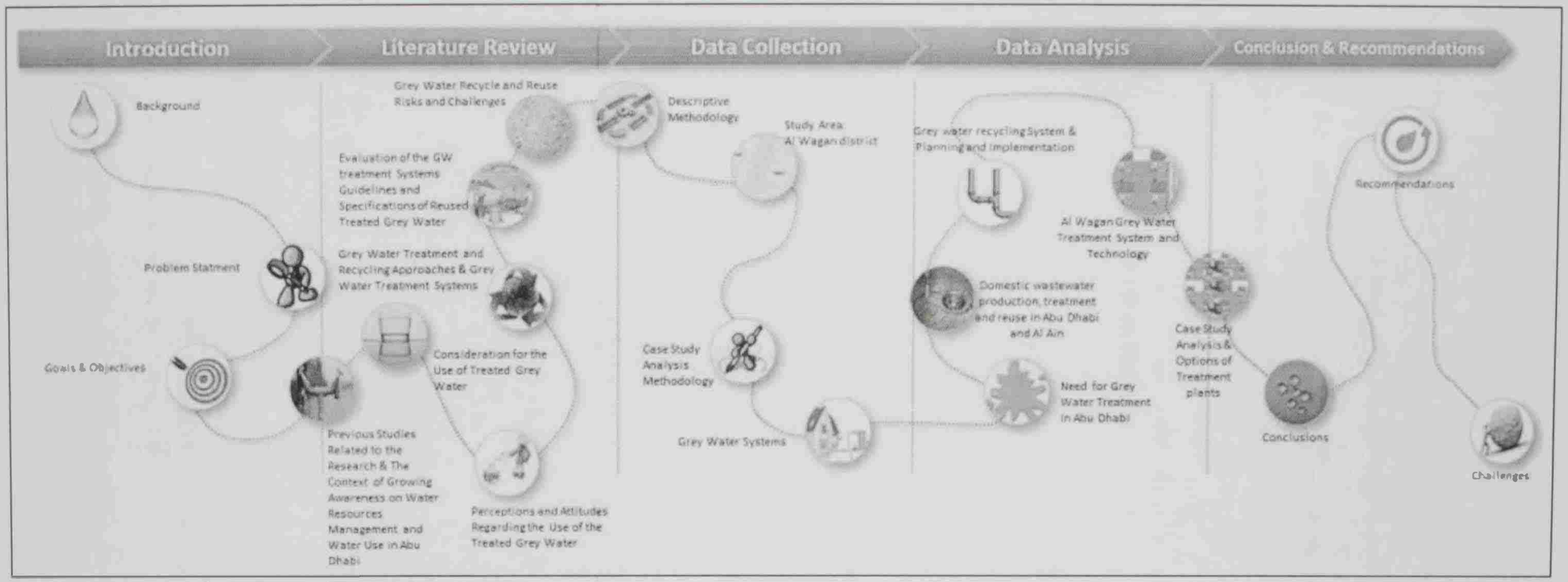
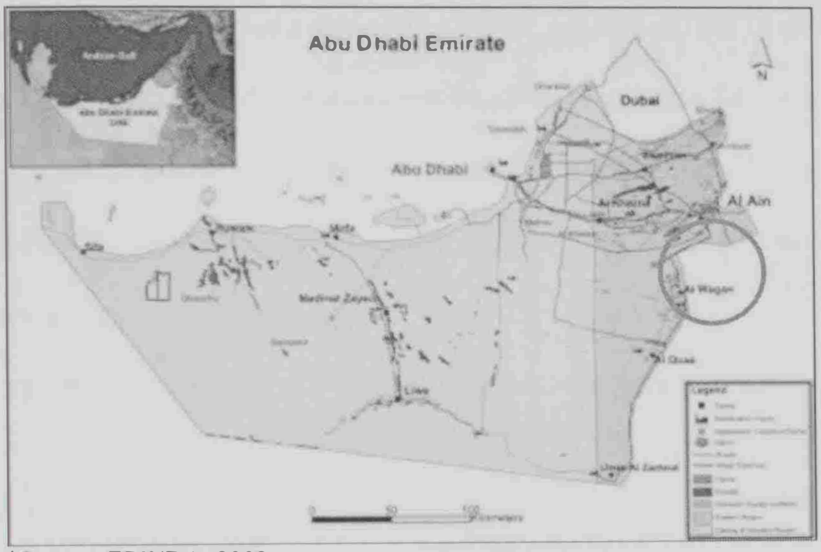



Figure 3.1: Methodology Flowchart/Roadmap

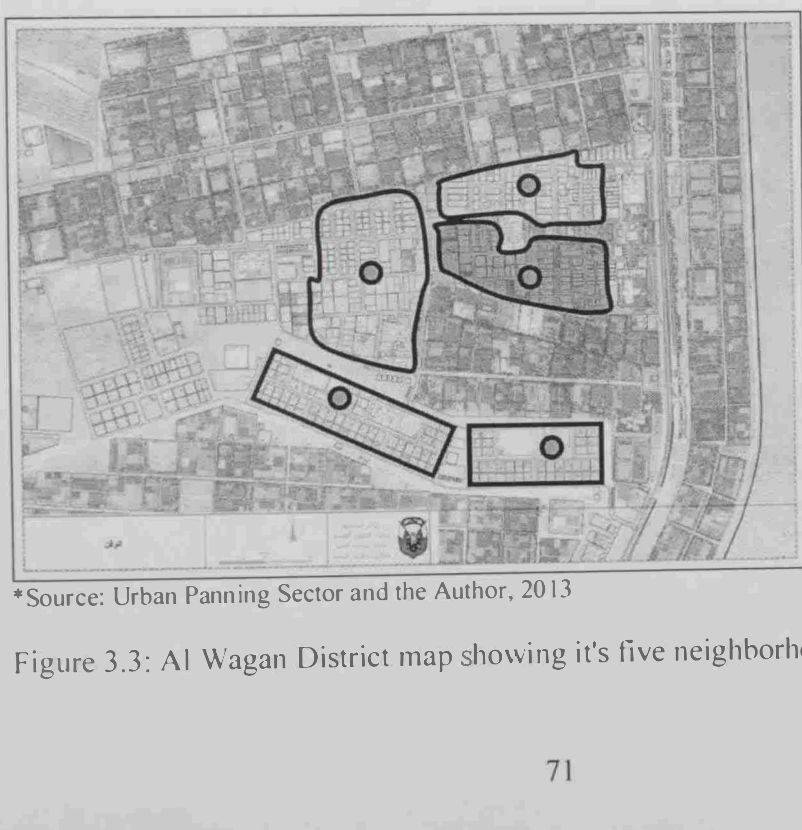
### 3.2 Study Area

As presented in Figure 3.2, Al Wagan is a new evolving district located in the South of Al Ain City. It has of a total of five neighborhoods where three of them are old and the other two are newly constructed neighborhoods. Locals own farms which are heavily water consumers are surrounded by these five neighborhoods' as illustrated in Figure 3.3.




*Source: ERWDA, 2002

Figure 3.2: Location of Al-Wagan City within the Emirate of Abu Dhabi

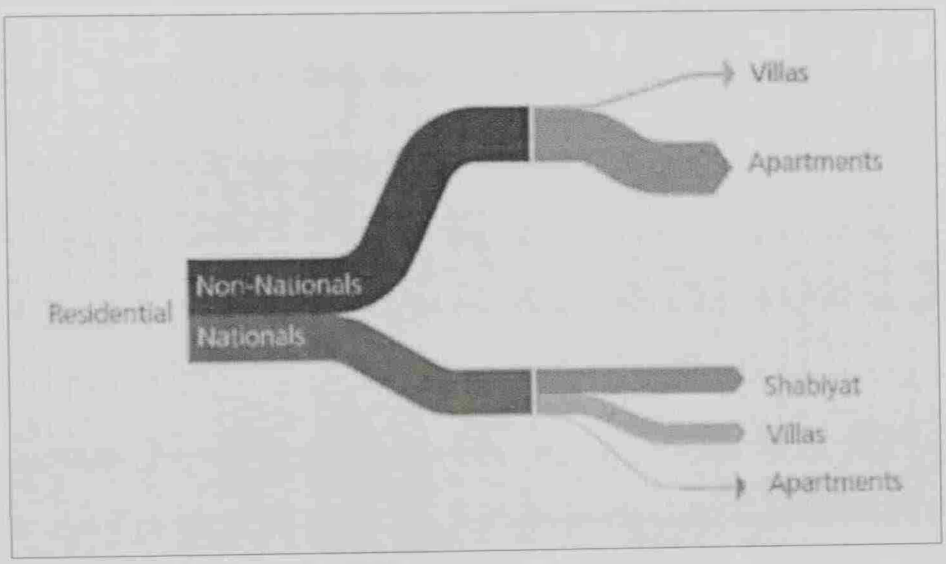


*Source: Urban Panning Sector and the Author, 2013

Figure 3.3: Al Wagan District map showing it's five neighborhoods

Al Wagan district is selected as a case study because it's a typical rural community, easy to obtain the required data since it's the Author town and it's isolated area to be considered as a typical case study for rural areas in UAE.

Demographically, the residential sector can be broken down into two main subgroups of residents; nationals (20% of total population), and non-nationals (80% of total population) as illustrated in Figure 3.4. It is evident on this schematic that even though nationals make-up only a small percent of the population, they consume almost equal amounts of water since nationals consume 74.2 $Mm^3$ per year while non-nationals consume 90.4 $Mm^3$ per year. Roughly 41.7 $Mm^3$ per year and 32.2 $Mm^3$ per year of national consumption can be attributed to high water use in shabiyat and villas, as the schematic graph shows next. These forms of residence offer great opportunities for conservation in the residential sector (Columbia-University, 2010).




*Source: Columbia-University, 2010

Figure 3.4: Residential water use schematic representation for nationals and non-nationals

# CHAPTER 4: Al Wagan District Case Study

## 4.1 Introduction

Grey water recycling and reuse has recently received great attention due to its potential as a substitute for fresh water needs. It also helps in reducing the need for desalinated water and the energy consumed in the desalination process. Al Wagan district receives 1,200 gallons of water through AADC which is tapped from Umm Al Nar, Al Taweelah and Al Fujairah while the daily discharge of grey water in Al Wagan is estimated to be about 195,611.16 gallons[1]. The purpose of the study is therefore to determine the feasibility and whether it is sustainable to treat this large amount of grey water as a potential source in Al Wagan. The outcome of the study is aimed at reducing the amount of water supplied to Al Wagan and the energy consumed in the water supply and treatment operations.

## 4.2 The Need for Grey Water Treatment in Abu Dhabi

The main sources of domestic water needs in Abu Dhabi as proportionately presented in Figure 4.1 comprise of ground water, desalinated and recycled treated waste water. While the use of the reclaimed (treated wastewater) is driven by both scarcity of water and environmental concerns, however the economic concerns become increasingly important. Reclaimed water has become an additional and supportive source of water in many parts of the world due to increasing water scarcity coupled with rapid population and economic growth. The most popular worldwide uses for the reclaimed water are toilet flushing, agricultural irrigation, groundwater recharge, car washing, urban lawn watering, road cleaning and recreational amenities among other. As presented in Figure 4.2, reclaimed water find use mainly in irrigating public gardens.

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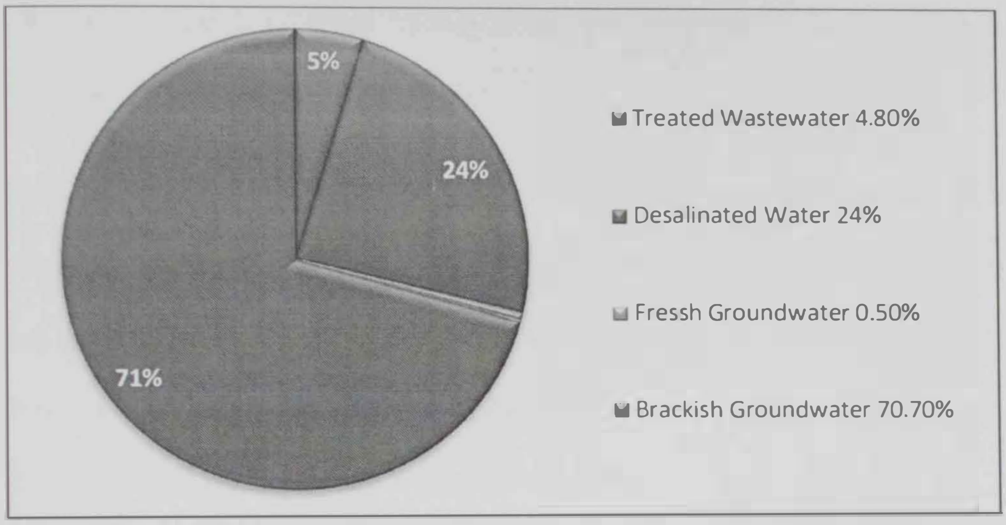
[1] It is calculated according to the total residential daily use in the district –based on the monthly bills in year 2012- considering grey water as 40% of the total use =489027.9*40%= gallons

The main reasons for this are related to the relatively low water quality requirements for this use, relative low cost of the infrastructure for the irrigation water supply and the increasing need for irrigation (Dawoud, 2009 ).




*Source: Dawoud, 2009

Figure 4.1: Abu Dhabi water resources by source

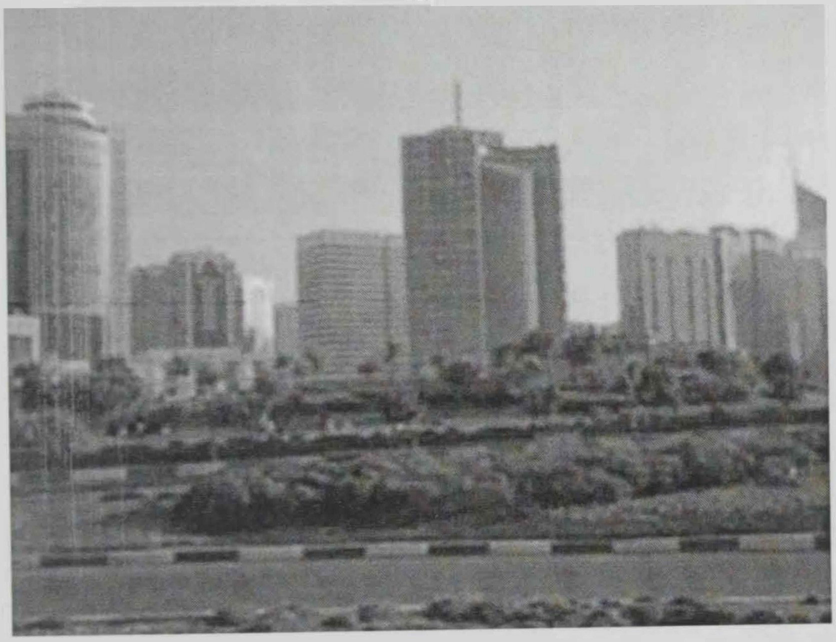


Figure 4.2: Use of treated waste water in irrigation, Abu Dhabi.

Over-reliance of desalinated water is costly and not sustainable and this therefore calls for the development of policies that match the supply and demand for water and also based on both quality and quantity principles. Desalinated water should be used for high-end use where quality is important. It is estimated that if the use of desalinated water was reduced by 50% within household water needs, then about 2 to 4 million tons of carbon emissions could be reduced (Environment-Agency-Abu-Dhabi, 2011). This has a strong potential in directing water and energy consumption towards sustainability.

Desalinated water represents the second highest resources that Abu Dhabi Emirate whose main water source is brackish ground water. As presented in Table 4.1, there has been an increase in the demand and supply of desalinated water between the years 2005-2011(SCAD, 2012). The Abu Dhabi Emirate consumed a total of 999.2 mm$^3$ in 2011 which accounts for 34.6% increase since 2005.

Table 4.1: Desalinated water supply by ADWEC and from Al Fujairah

*Source: SCAD, 2012

| Description | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|
| By ADWEC/Mm$^3$ | 636.9 | 670.5 | 719.4 | 784.5 | 845.4 | 834.5 | 854.6 |
| By Al Fujairah/Mm$^3$ | 105.2 | 131.7 | 133.9 | 118.6 | 115.9 | 128.3 | 144.6 |

High prices and energy cost for the desalinated water are threatening the continuation of using this resource and as a consequent it calls for an urgent need to treat and reuse the grey water. Meanwhile, more than 4% of the total needs of the Abu Dhabi water requirements are obtained from the 22 sewage treatments plants (Dawoud, 2009). It was also revealed through interviews with the professionals that water treatment is carried without the separation between the grey and black water.

Presently, the use of treated waste water is expected to be an important part of water resources in the near future. This can be used for landscape irrigation, the non-contact agricultural crops and the re-charge of the aquifers after performing the adequate treatment. Water conservation policy should therefore focus on the agricultural sector as the biggest water consumer in Abu Dhabi which can also be supplied by the reuse of the treated water resulting from treating the GW from residential sector(Dawoud, 2009).

Therefore, grey water treatment has high potential of saving much of governmental expenses of water supply. On the other hand it will decrease the amount of desalinated water for the domestic sector and agricultural uses as the Alain. Further, the reuse of the treated grey water is positively affecting the fuel consumption, economy and environment such as the emissions of $CO_2$ resulted in the desalination processes.

## 4.3 Stages of the institutional awareness in water treatment in Abu Dhabi Emirate

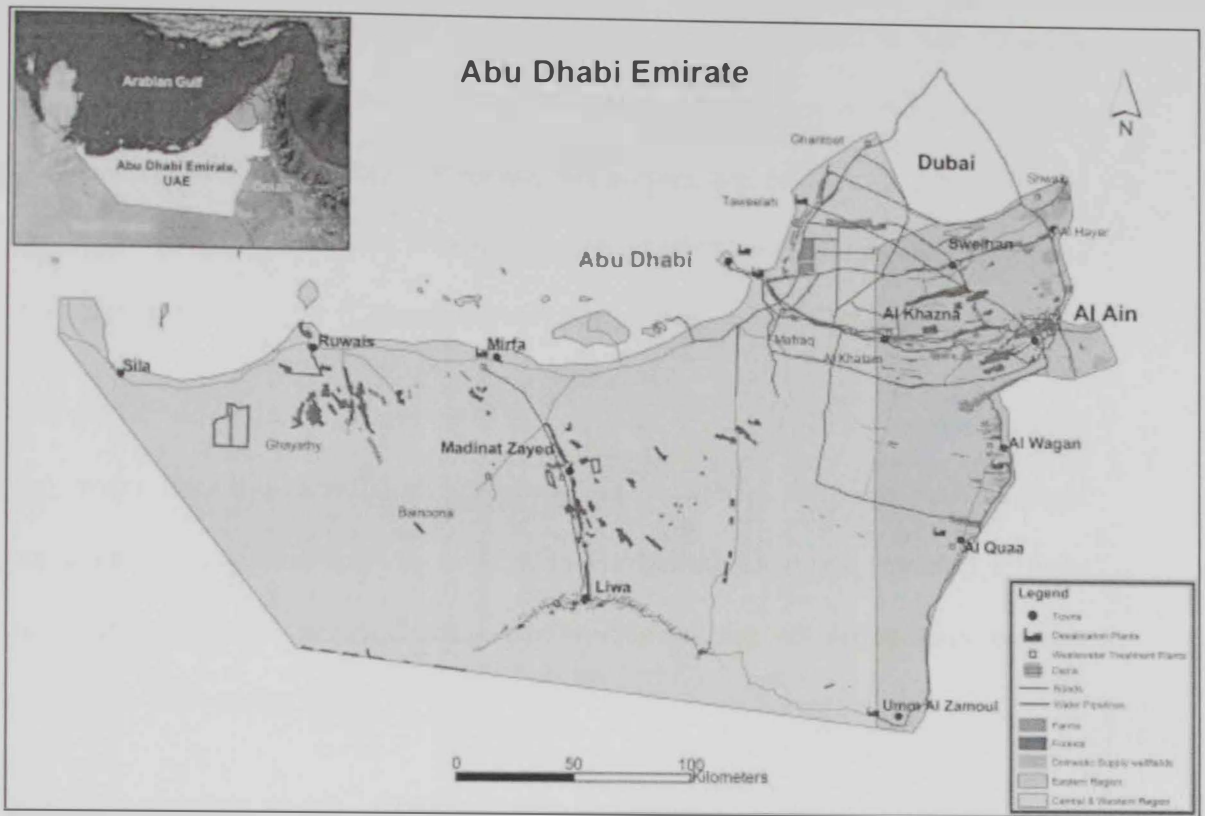
The growing attention of waste water treatment in Abu Dhabi has evolved through several stages. It started in 1975 where the Abu Dhabi Sewerage Projects Committee (SPC) was established in order to provide a modern, efficient and well-constructed sewerage system to collect, convey and treat the sewage.

Between the years 1977 and 1982, the waste water reclamation and reuse was recognized as a promising strategy to handle water scarcity and reduce the impacts on environment, however, the actual reused water was not exceeding the 56.3% in Abu Dhabi while the rest was disposed in the gulf. The accelerating development in Abu Dhabi resulted in an increase in demand for the sewage treatment plant. The current operating treatment plants are now overloaded which has led to the generation of a low quality treated effluent affecting both reuse potentials and the marine environment (Dawoud, 2009 ).

Three decades later, the Abu Dhabi Sewage Service Company (ADSSC) carried the management of the Sewage Treatment Plants (STPs). In 2005, the Regulation and Supervision Bureau (RSB) was given the responsibility to regulate the sewage service throughout the Emirate. The executive council formed a high committee in 2007 to strategically develop the reuse of the treated waste water and bio-solids in the public gardens. The committee included the interested institutions such as Abu Dhabi, Al Ain and Western Region Municipalities and ADSSC among others (Dawoud, 2009 ).

Al Ain consumed 28% and 60.7% of desalinated water for the domestic sector and agriculture respectively as the second consumer after Abu Dhabi which consumed 60.8% and 36.3% for the same sectors respectively in 2011 (SCAD, 2012). This emphasizes the need to substitute this resource with another one with lower prices, less environmental impacts and efficient.

Up to 2009, the treatment system in the Emirate of Abu Dhabi comprised of 28 sewage treatment plants STPs as presented in Figure 4.3. Western and Eastern regions equally produce about 150 $Mm^3/yr$ which represent 4.8% of the total demand. Zakher in Al Ain and Mafraq in Abu Dhabi are the main STPs producing 95% of the total treated effluent while other STPs are small since they cover the remote urban expansion. The treated effluent is mostly used to irrigate the parks, gardens and other recreational amenities (Dawoud, 2009 ).




*Source: Dawoud, 2009

Figure 4.3: Location of waste water treatment plants in Abu Dhabi Emirate

The main single distributor of water in the Emirate of Abu Dhabi is the Abu Dhabi Water and Electric Company (ADWEC) - a company that totally owned by the Abu Dhabi Water and Electricity Authority (ADWEA). ADWEC's With a capacity to produce 683 Million Gallons per day, its main role is to ensure that both water and electricity demands are met at a continuous basis (SCAD, 2012; ADWEC, 2012a).

## 4.4 Domestic wastewater production, treatment and reuse in Abu Dhabi and Al Ain

Domestic water demand includes the water needed for residential, commercial establishment, hospitals, hotels, offices and shops. This sector is the second highest water consumer after the agricultural sector. Domestic sector in Abu Dhabi Emirate consumed 23% of the total water consumption in 2005 where 98% of it from desalination and the remaining 2% is from groundwater well-fields (Dawoud, 2009 ).

More than a third of the treated sewage effluent (TSE) produced in Abu Dhabi is disposed of into the Arabian Gulf due to capacity limitations of the current TSE irrigation distribution network. However, this surplus can be used in more efficient way to be reused for industrial uses in power generation, electronics, cooling systems and construction industry (Columbia-University, 2010).

One strategy in sustaining water use is to consider the reuse of the recycled treated grey water resulting from domestic sector. As for hotels, there are three ways of implementing this; building a decentralized greywater systems, develop a linen exchange program, and facilitating the sharing of the employee best practice (Columbia-University, 2010).

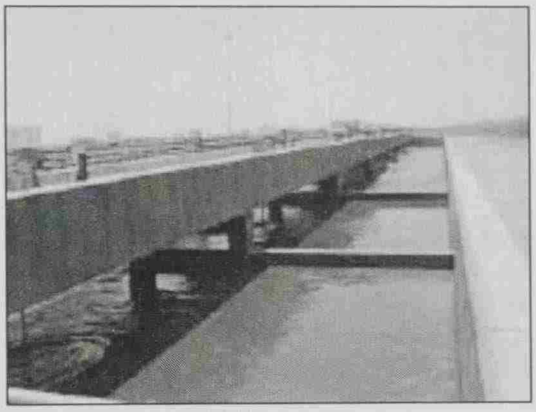
Water conservation strategy should consider its management so as to achieve efficient supply and demand systems. This relies on three main water management areas. The first involves a reduction in demand and increase efforts for water conservation. Secondly, considering alternative water resources to substitute or augment conventional resources, or to consider the brackish groundwater, as an alternative to meet some demand. Finally, move more potable water allocation to domestic/industrial developments as this will lead to an increased wastewater recycling system. This, of course differs from allocating more potable water for agriculture which does not allow for water recycling (Environment-Agency-Abu-Dhabi).

In this context, and according to ADWEA (Dawoud, 2009),current per capita consumption in UAE is 350 l/c/d. This large amount generates huge waste water that is distributed to the treatment plants which are generally close to the source. The first and main treatment plant to serve Abu Dhabi was constructed in Mafraq in 1975 which was prepared to serve total population of 665,000. This plant along with the Al Ain city plant is catering about 65% of the total Emirates population.

Al Mafraq plant's capacity reached 260,000m$^3$/d which is equivalent to 725,000 served persons. It uses the anaerobic digesters and the activated sludge method of treatment to the tertiary level where the final effluent is filtered through the sand medium to remove the fine solids. Chlorine is used to disinfect and kill micro-organisms. Al Mafraq intake sewage and the aeration for waste water are shown in Figures 4.4 and 4.5. There are 15 operating WWTP's in the Eastern Region. The largest plant is STP-M4 at Zakher- Al Ain, which accounts for 92% of the total production while the other 14 plants are very small that they serve small towns and villages (Dawoud, 2009).

*Source: Dawoud, 2009

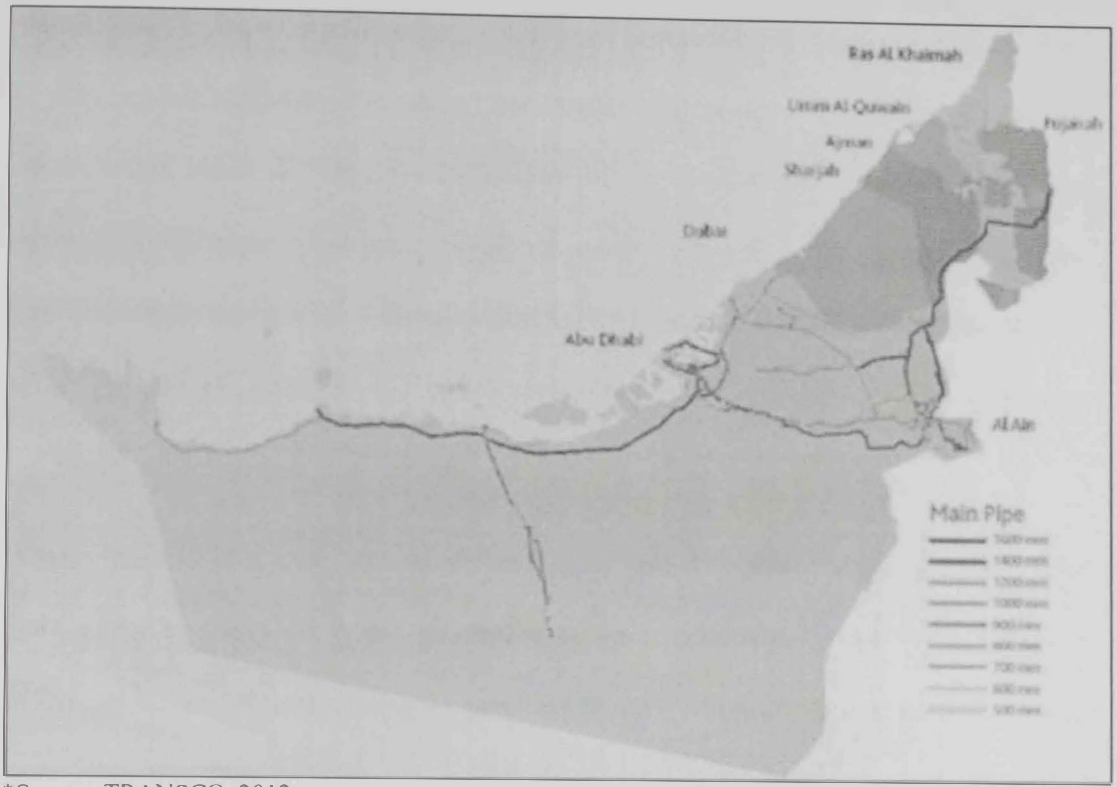
Figure 4.4: Intake sewage in Al Mafraq



*Source: Dawoud, 2009

Figure 4.5: Aeration for the waste water in Al Mafraq

Al Ain city water treatment system was developed in two phases; 1981 and in 1990-1995. Up to 250,000 people were served with a capacity of 27,000m$^3$/d that planned to be extended to 45,000m$^3$/d to be able to cater the population of Al Ain. This plant produces treated effluent to tertiary levels and the salinity levels between 1200 to 1490 mg/l TDS (Dawoud, 2009). This produces effluent of good quality that can match international specifications regarding the human use.




*Source: TRANSCO, 2012

Figure 4.6: Abu Dhabi - Al Ain water pipeline network by TRANSCO with the main pipes and the hierarchy in diameters of supply pipes.

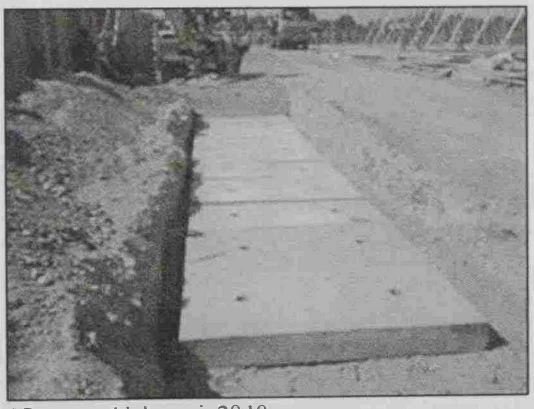
Abu Dhabi Transmission and Dispatch Company (TRANSCO) is the main body that is responsible for transmitting water and electricity in a reliable, safe and secure manner from the generation companies to the distribution companies in Abu Dhabi region and other emirates in UAE (Alshamsi, 2010).

The Company promoted its performance in both the quality of the provided service and the quantity of expenses. The annual capital for water decreased from 2,754.80 AED millions in 2009 to 1,539.60 AED millions in 2010 while the annual returns increased from 1,098.19 AED millions to 1,397.61 AED millions for the same period (TRANSCO, 2011). This in fact reflects the progress in both water provision and public awareness of the importance and value of water. The company carried several projects in order to increase water supply to Abu Dhabi, Al Sadiyat and Al Reem islands. The company also transfers water to Al Ain and other Southern regions. The Al Ain network receives the water from three main sources located at Taweelah, Fujairah, and Umm Al Nar through Shobaisi. Pumping stations are divided into two types – the first type is transmission pumping station which is used to transmit water from one pumping station to another; the other type is distribution pumping station which distributes water to the consumers through Al Ain Distribution Company (Alshamsi, 2010).

Water transmitted to Al Ain city arrives at Al Ain reception pumping station. The main parts of this station are chlorination room, pump receiving room and four reservoirs at the outside part. Al Ain reception pumping station receives water through carbon steel pipelines. The water is stored in four reservoirs with a capacity of 5 million gallons each. There are four groups of pumps transmitting water to four different distribution stations in Al Ain city. Each group contains four pumps that are operated depending on the demand for water. The stations where these pumps are transmitting water are Hilli, Maqam, Khabisi, and Sarouj. Figures 4.7 & 4.8.show both the four groups of pumps which are used at Al Ain reception pumping station and the pipes protection (Alshamsi, 2010).

*Source: Alshamsi, 2010

Figure 4.7: The four groups of pumps



*Source: Alshamsi, 2010

Figure 4.8: The pipes protection

Transmitted water by TRANSCO is generally pumped through pipes into pumping station. The main parts for the pumping station are: water pumps, control room, valves, water reservoirs, chlorination room, diesel generator, and surge vessels. Water pumps are used to increase the pressure of water in order to transmit it to far areas through pipelines. Valves are used to control the pressure and flow of water through pipelines. In addition, water reservoirs are required in order to store the water received from other pumping stations. Chlorination room is used to inject chloral gas into water in order to purify and clear the water from water germs and viruses. Diesel generator is used at emergency situation to power the pumps in case of electricity blackout situation at the pumping station. Surge vessel absorbs water surges that appear at the valves during opening and closing operations. It consists of a vertical tank which is filled to the half with water and the remaining half is filled with compressed air in order to absorb the water surges (Alshamsi, 2010).

In relationship to the connecting pipes, there are three types of pipes used to connect pumping stations. They are ductile iron pipes, carbon steel pipes, and Glass Reinforced Pipes (GRP) (Alshamsi, 2010). The GRP type does not need any protection since it is made of glass and works as insulation material between the water and ground. However, carbon steel and ductile iron types use cathode protection at which a conductor is connected from the outer side of the pipe to the ground in order to take any eddy currents that appear on the pipe surface due to water flow

Water operation and maintenance department in Al Ain is responsible of transferring potable water from Abu Dhabi and Fujairah to Alain region with high efficient quality. The water operation and maintenance department is managed by the Network Services Division. The department is divided in two zones: Zone 4 and Zone 5 where each zone is responsible for operating a number of pumping stations. Zone 4 consists of four pumping stations; Al Ain reception, Sweihan, Qidfa (Fujairah), and Ajban. Zone 5 contains 12 pumping stations which are Ramah, Al Saad, Al Natla, Jabal Hafeet, Maqam, Khabisi, Sarouj, Hilli, Power House, Zoo, Zakher, and Military. Al Ain reception pump station in turn is managed by the Network Services Directorate which is responsible for operating and controlling water from Al Taweelah and Alfujarh and distributed to various Al-Ain pump stations (Alshamsi, 2010).

As shown in Table 4.2, water consumption in the Al Ain City increased through the years 2008-2011 (AADC, 2012b). Al Ain consumes about third of the total consumption of the Abu Dhabi Emirate. Al Ain peak water supply by ADWEC in 2011 and 2012 were 180 and 199 Million Imperial Gallons (MIGD) out of the total of 655 MIGD and 714 MIGD respectively for the Abu Dhabi Emirate (ADWEC, 2012a). However, the annual quantity of water transmitted by TRANSCO was 207,519MIGD in 2010 and 216,026 MIGD in 2011 (TRANSCO, 2012).

Table 4.2: Water supply by Al Ain Distribution Company(AADC) to Al Ain 2008-2012

*Source: AADC, 2012b, 2013b

| Year | 2008 | 2009 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|
| Consumption ($m^3$/yr) | 186,914,181 | 160,372,475 | 194,449,372 | 183,455,506 | 283,468,050 |

AADC supply in 2012 reached 283,468,050 cu.m/yr (AADC, 2013b). However, the authorized consumption for the same year was 267,220,335 (TRANSCO, 2013) which shows the difference between supply and consumption resulting from either leakage or water losses due to reading errors in meters, piping or fittings. The table also shows the increase in water consumption between 2008-2012 which in a way justify the need for the treatment and reuse of grey water.

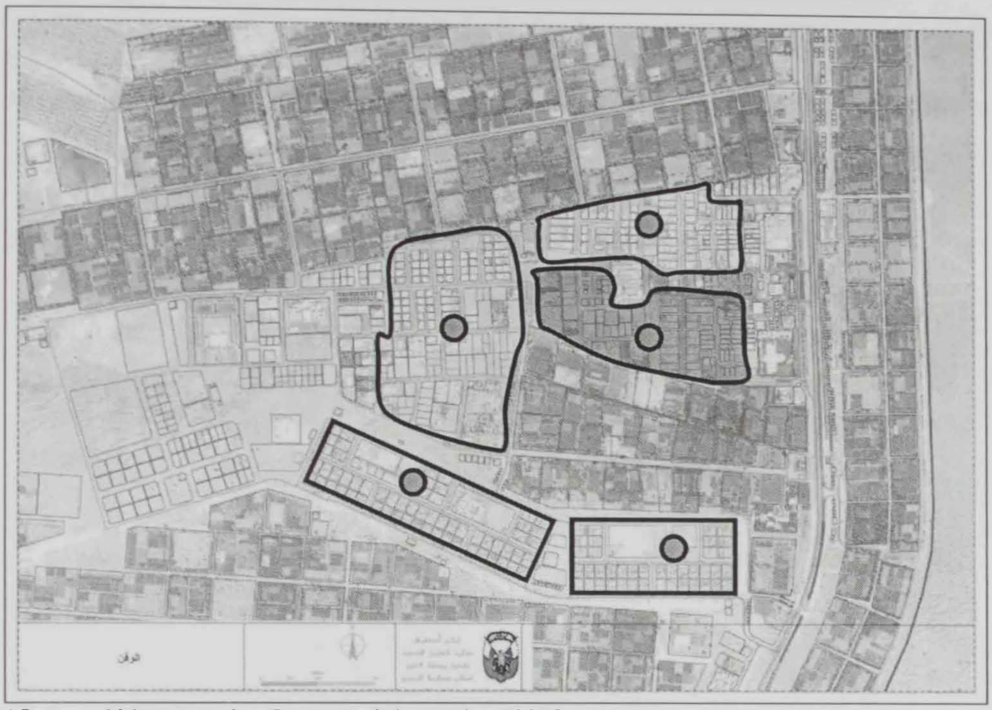
## 4.5 Water Supply and wastewater treatment in Al Wagan District in the Southern Region

Eastern Region in Abu Dhabi includes Al Ain city and satellite surrounding sectors. The Southern sector with a total area of 2674 km$^2$ contains five residential districts in addition to Um al zomool as a desert un-inhabited district. Figure 4.9 shows these districts and the area of each one. Al Wagan is the second largest district following Al Qua'a with an area of 240 km$^2$. Al Wagan population is 10,337 according to 2005 statistics (Al-Ain-Municipality, 2011), however, the mean residential population is 12,016 according to 2010 statistics (Southern sector population in Arabic, 2010).


*Source: Al-Ain-Municipality, 2011

Figure 4.9: Districts of the southern sectors

Al Wagan is a desert district located 87 km to the south of Al Ain city centre. This district has a total of 651 houses in five neighborhoods as shown in Figure 4.10. The majority of the houses are traditional houses (shabia) houses separated by few untapped residential lands as presented in Figure 4.11. Palm trees plantation are the dominant agricultural activity (Al-Ain-Municipality, 2011).



*Source: Urban Panning Sector and the Author, 2013

Figure 4.10: Al Wagan District map showing it's five neighborhoods


*Source: Al-Ain-Municipality, 2012

Figure 4.11: A plan for Al Wagan neighborhoods

There are growing needs for water supply and grey water recycle as well. According to the last statistics, Al Wagan receives about 1,200,000 g/d of water. The main branches of the water supply for all the southern sector districts are shown in Table 4.3. It shows the connection sizes, the daily demand and the supply period. The total number of connections available in the Southern Sector districts is estimated to be (2,083 house connections + 7 bulk connections) = 2,090.

Table 4.3: Water supply for all the southern sector districts

*Source: AADC, 2012a

| No . | Main Taps | Connection Details | | Current daily Demand in the node points/ Gallon | Current supply Period/ Hours daily | Supply Source |
|---|---|---|---|---|---|---|
| | | Connection Size / mm | Connected from line / mm | | | |
| 1 | Al Dhahera Shabia | 400/300 | 600 | 500,000 | 9 | By Gravity From Al Ain |
| 2 | Bu Kraya Shabia & Green Farm | 400 | | 350,000 | 6 | |
| 3 | Al Erad Shabia | 300 | | 120,000 | 6 | |
| 4 | Shaikh Tahnoon Palace | 150/100 | | 60,000 | 24 | |
| 5 | Al Wagan Filling St. Tab - 1 | 300/200/100 | | 350,000 | 12 | Al Wagan Pumping Station |
| 6 | Al Wagan Old Tab – 2 | 300 | | 1,100,000 | 6 | |
| 7 | Al Wagan Old Tab – 3 | 300/200 | | | | |
| 8 | Al Wagan Old Tab - 4 - (HDPE) | 200 | | | | |
| 9 | Al Wagan New Tab – 5 | 300 | | | | |
| 10 | Al Qua High Shabia - Tap 1 | 300 | | 2,200,000 | 6 | Seih Al Raheel Pumping Station |
| 11 | Al Qua High Shabia - Tap 2 | 200 | | | | |
| 12 | Al Qua High Shabia - Tap 3 | 200 | | | | |
| 14 | Al Qua Old Shabia Tap - 4.1 | 200 | 600/ 300 | | | |
| 15 | Al Qua Old Shabia Tap - 4.2 | 200 | | | | |
| 16 | Al Qua Teacher Accom. Tap - 4.3 | 200 | | | | |
| 17 | Al Qua Teacher Accom. Tap - 4.4 | 200 | | | | |
| 18 | Al Qua Filling St.(1) Tap - 4.5 | 100 | | | | |
| 19 | Al Qua Filling St & water st.(2) Tap - 4.6 | 150/100 | | | | |
| 20 | Al Qua Caravan Tap -4.7 | 200 | | | | |
| 21 | Al Qua Caravan Tap - 4.8 | 200 | | | | |
| Total Demand (Approximate) for Southern Region | | | | 4,680,000Gallons | | |

The table also shows that three of the five districts are served by gravity while the Al Wagan and Al Qua'a districts are served using the pumping station which requires extra equipments and expenses as well. The connections available in Al Wagan district and their diameters are shown in Table 4.4. Therefore, the total connections that serve Al Wagan District are 520 in all where the majority of them with 1 and ¾ inches.

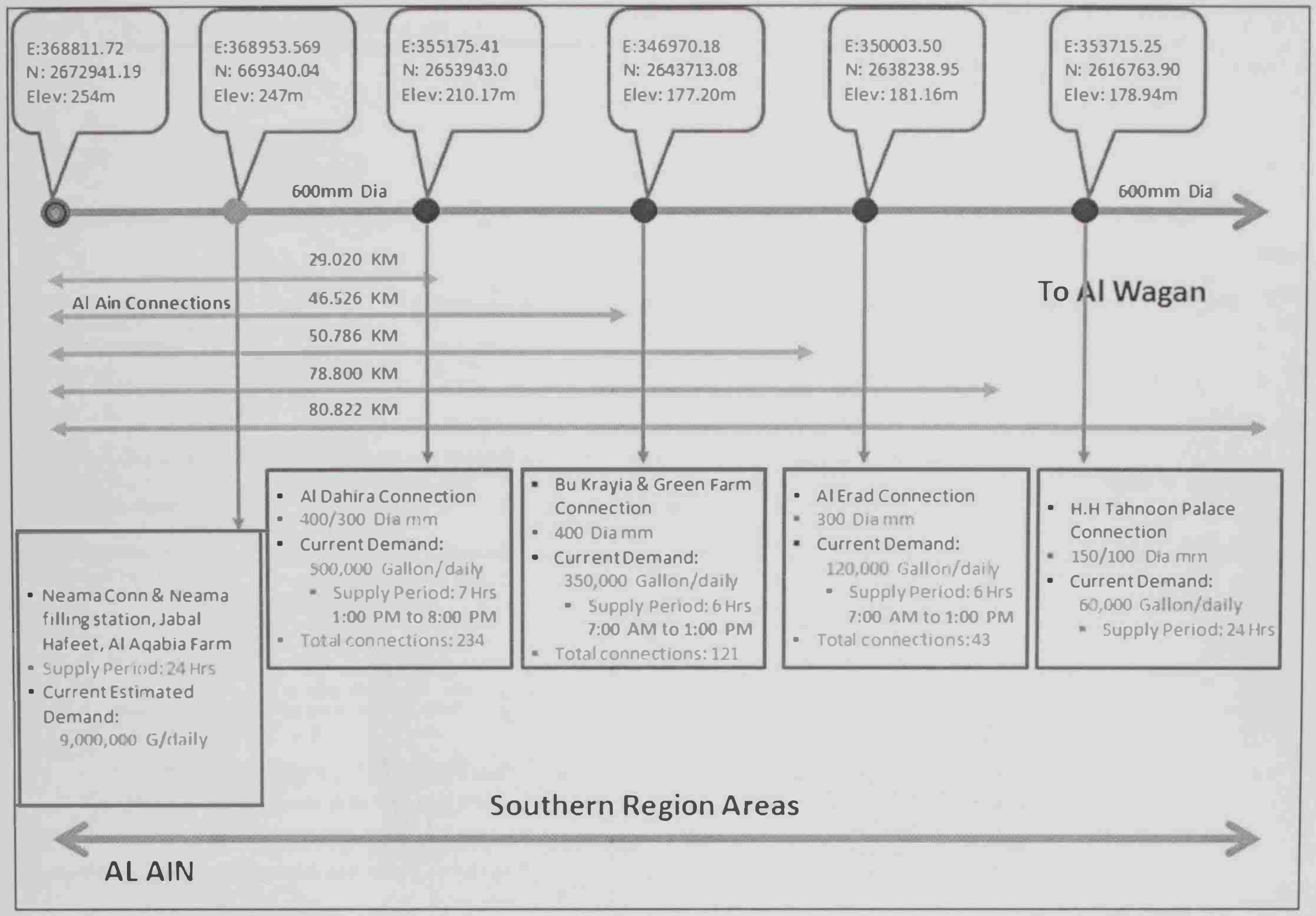
Table 4.4: Summary of all water connections available in Al Wagan District

*Source: AADC, 2013a

| Areas | DMA | "2 | "1½ | "1 | "3/4 | "1/2 | Total No. of Connections | Additional Connections Available More than 2" |
|---|---|---|---|---|---|---|---|---|
| Al Wagan Old | 1003R | 1 | 1 | 111 | 84 | 14 | 211 | |
| Al Wagan New | | 0 | 0 | 85 | 15 | 1 | 101 | |
| Al Wagan Villas* | | 10 | 17 | 12 | 1 | 0 | 40 | * One Connec. "6 ( Meter size for Tahnoon Palace 4") 850 C88 – 19000 |
| Al Wagan Facilities | | 18 | 13 | 72 | 31 | 34 | 168 | |

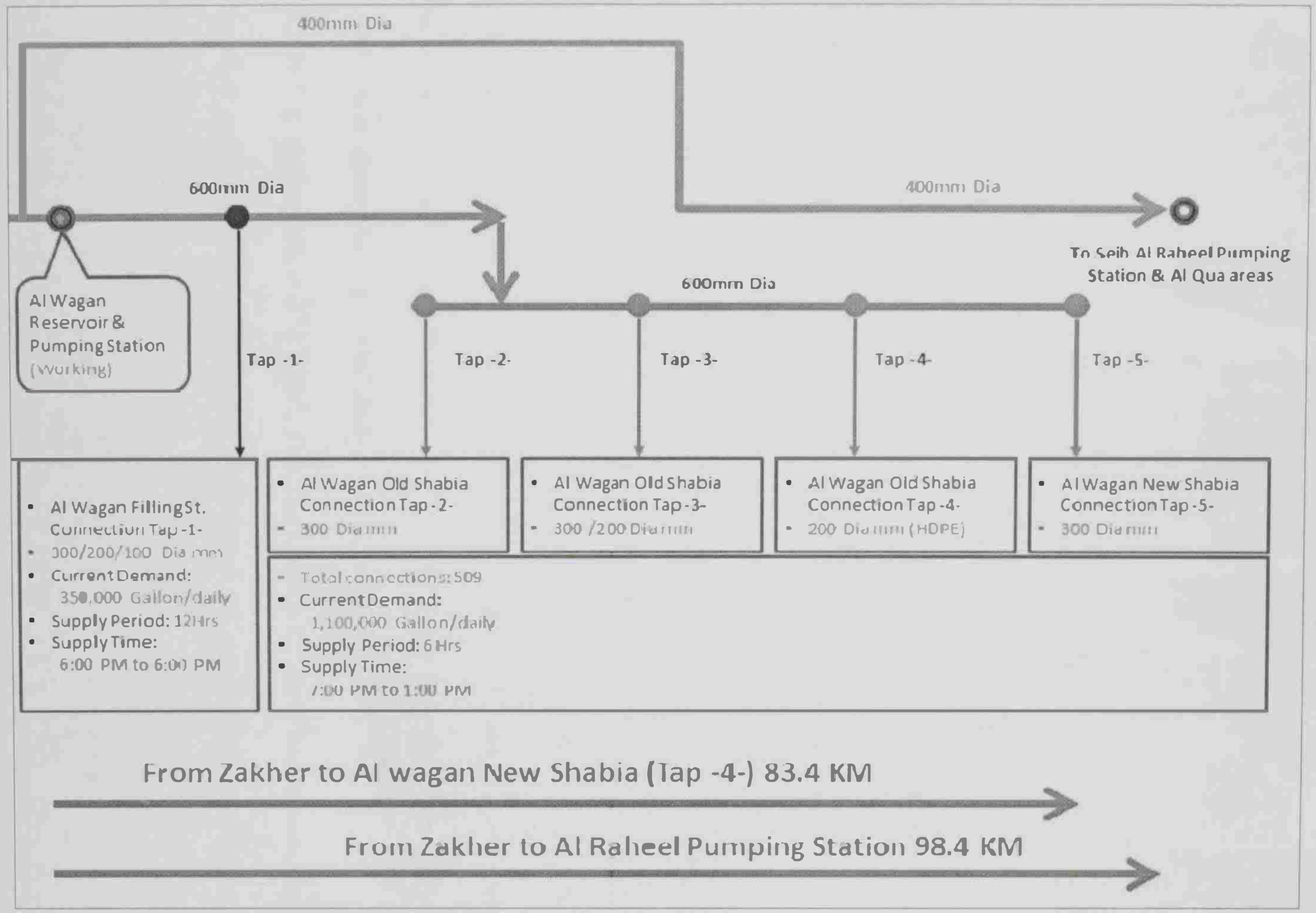
However, the treated waste water in Al Wagan WWTP – according to 2006 statistics - accounts for 0.365 $Mm^3/yr$ out of total 31.519 $Mm^3/yr$ of the treated waste water of the Eastern Region and out of the total production 149.89 $Mm^3/yr$ of treated water of the Abu Dhabi Emirate (Dawoud, 2009 ).

Figure 4.12 shows the scheme for the main pipe line areas from Al Ain Reception and filling station by gravity to southern districts. While Figure 4.13 shows scheme for the water supply from Zakher to Al Wagan new shabia using Al Wagan reservoir and pumping station.




*Source: AADC, 2012a

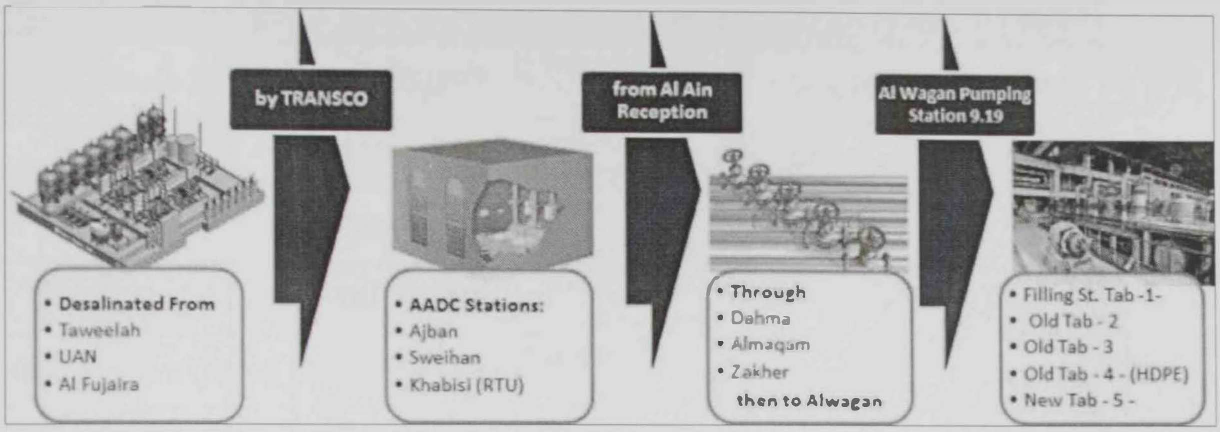
Figure 4.12: Main pipe line areas from Al Ain Reception and filling station by gravity to southern districts




*Source: AADC, 2012a

Figure 4.13: Water supply from Zakher to Al Wagan new shabia using Al Wagan reservoir and pumping station

From Al Ain reception, water is transmitted through Dahma, Almaqam, Zakher and then to Al Wagan where it is distributed using five main tabs that supply the five neighborhoods of Al Wagan as presented in Figure 4.14.




*Source: author

Figure 4.14: Water transmission to Al Wagan in the southern Sector

## 4.6 Case Study Analysis

Al-Wagan district receives 438,000,000 gallons of water on an annual basis for all purposes. A pilot study was done in order to obtain information on the correlation between water consumption and number of housing units within a selected neighborhood's. A survey population of fifty two (52) housing units was covered in the study, which is the number of housing in a neighborhood. The water consumption of a sample of 13 out of the total 52 housing units of Al Wagan local residents is shown in Table 4.5. A sample of Water Consumption bill is shown in Appendix B. Calculation shows that the total daily water consumption for each neighborhood is 97,814.6 g equivalent to 370.27m$^3$. Therefore, the total daily water consumption for the five neighborhoods comprising Al-Wagan is approximately 97,814.6 g*5= 489,027.9 gallons.

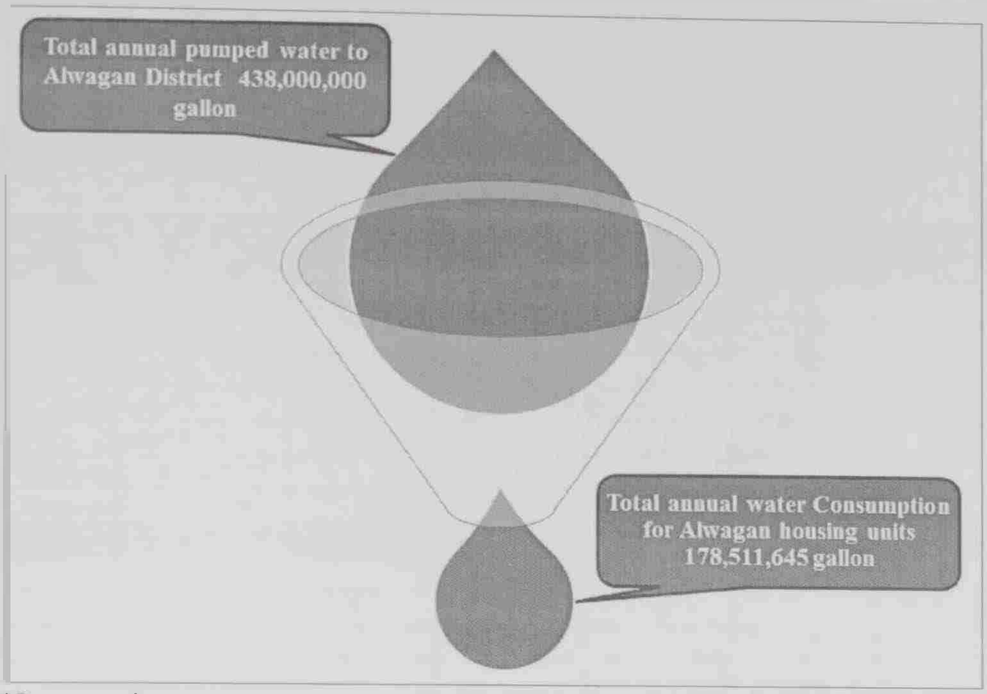
Table 4.5: Sample water consumption of housing units in neighborhood

*Source: AADC, 2012)*1[1]

| Owner Name | BADGE_NBR | SA_TYPE_DES | PREM_TYPE | Average annual water consumption g/yr |
|---|---|---|---|---|
| Salem Nassib Suhail | 06508602WI | Water Utility SA – Residential | Shaabia | 2,279.00 |
| Alkhaza Mohd Alqrain | 06508644WI | Water Utility SA – Residential | Shaabia | 933.00 |
| Mubarak Hamad Rumailah | 06508745WI | Water Utility SA – Residential | Shaabia | 3,739.00 |
| Alsuadi Hamad Hamroor | 06508747WI | Water Utility SA – Residential | Shaabia | 3,881.00 |
| Mohd Musalm Qanzol | 06508761WI | Water Utility SA – Residential | Shaabia | 6,422.00 |
| Mohd Hamad Rai-Alsheijah | 06508768WI | Water Utility SA – Residential | Shaabia | 3,536.00 |
| Madoob Mohd Yatba | 06508775WI | Water Utility SA – Residential | Shaabia | 237.00 |
| Madoob Mohd Yatba | 06041625WI | Water Utility SA – Residential | Shaabia | 405.00 |
| Hamad Mohd Matar | 06041933WI | Water Utility SA – Residential | Shaabia | 673.00 |
| Mubarak Helal Aljunaibi | 06041936WI | Water Utility SA – Residential | Shaabia | 2,849.00 |
| Qwaiah Mohd Alameri | 06035148WI | Water Utility SA – Residential | Shaabia | 1,912.00 |
| Baynah Salem Alameri | 06066879WI | Water Utility SA – Residential | Shaabia | 4,169.00 |
| Salem Mohd Yatba Alameri | 06038348WI | Water Utility SA – Residential | Shaabia | 1,816.00 |

Field work survey based on the monthly consumption bills shows that 178,511,645 gallons in one year are used for houses as presented in Figure 4.15. This amount represents 40.75 % of the total water supply for all uses in Al Wagan district.

[1] These statistics are extracted from Al Ain Distribution Company AADC




*Source: author

Figure 4.15: Total annual pumped water to Al Wagan district and consumed water amount in Al Wagan housing units, based on the water bills 2012.

The percentage of household water that is greywater varies regionally and between households, depending on the primary uses of water in a home and how efficiently water is used. It is generally between 50% and 80% (Allen et al., 2010), however, in this research the grey water is assumed about 40% which results from the hand basins, showers and ablution. This percent was assumed according to the water consumption in the middle east countries such as India, Oman, Syria and Iraq for similar purpose like kitchen ablution, shower and toilet flushing.

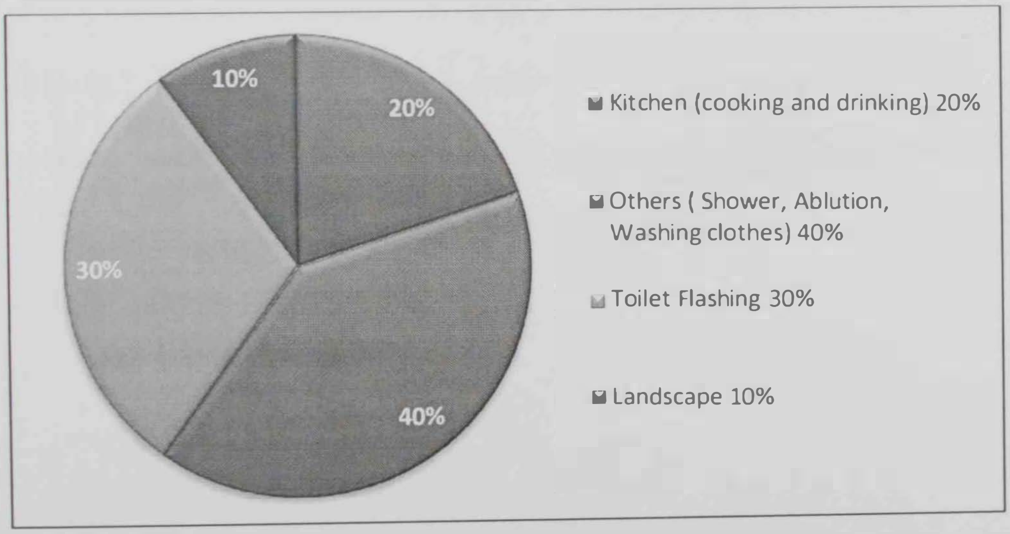
In this research, water consumption for the housing units from different countries that share similar water consumption habits, traditions and even regulations and systems such as India, UK and Canada were obtained for comparison purposes. A study conducted by Deepika Mandal, et al. (2011), found that total water requirement for kitchen is 18%. Further, Fidar et al. (2010) found that the toilet flushing is the highest activity that requires about 31% of the total water use in a house. Table 4.6 shows water requirement for different activities of household in various countries as per the aforementioned studies.

Table 4.6: Water requirement for different activities of household in various countries

| Country | | Washing Basins | Washing clothes | Washing House | Flushing Toilets | Kitchen | Bathing |
|---|---|---|---|---|---|---|---|
| England*1 | | 9 | 20 | | 31 | 15 | 15 |
| India*2 | | 10 | 20 | 3 | 16 | 18 | 18 |
| Oman*3 | | 7 | 8 | | | 34 | |
| Sana'a*3 | | 32 | 13 | | | 37 | |
| Syria*4 | | 12 | 8 | 10 | 36 | 12 | |
| Baghdad | Rusafa*5 | | 18 | | | 16 | 24 |
| Baghdad | Harkh*5 | | 16 | | | 16 | 27 |
| **Country** | | **Ablution** | **Drinking** | **Cooking** | **Shower** | **Cooling** | **Others** |
| England*1 | | | | | 5 | | 5 |
| India*2 | | 11 | 2 | 3 | | | |
| Oman*3 | | | | | 51 | | |
| Sana'a*3 | | | | | 18 | | |
| Syria*4 | | | | | 14 | | 10 |
| Baghdad | Rusafa*5 | | | | 31 | 11 | 24 |
| Baghdad | Rusafa*5 | | | | 30 | 11 | 27 |

*Water requirement for different activities of household in different countries (source: *1 Fidar (2010), 2* Mandal (2011), *3 Al Mughalles (2012), 4* Mourad (2011), *5 Abbood, (2012))

Based on the available data, it has been assumed that toilet flushing and kitchen activity in the Abu Dhabi Emirate house consumes about 30% and 20% from the total amount of used water respectively. The landscape required 10% of the used water and the remaining 40% of water would be used for different activities like shower, ablution and washing clothes as shown in Figure 4.16.




*Source: author

Figure 4.16: Water requirement for different activities of household in UAE

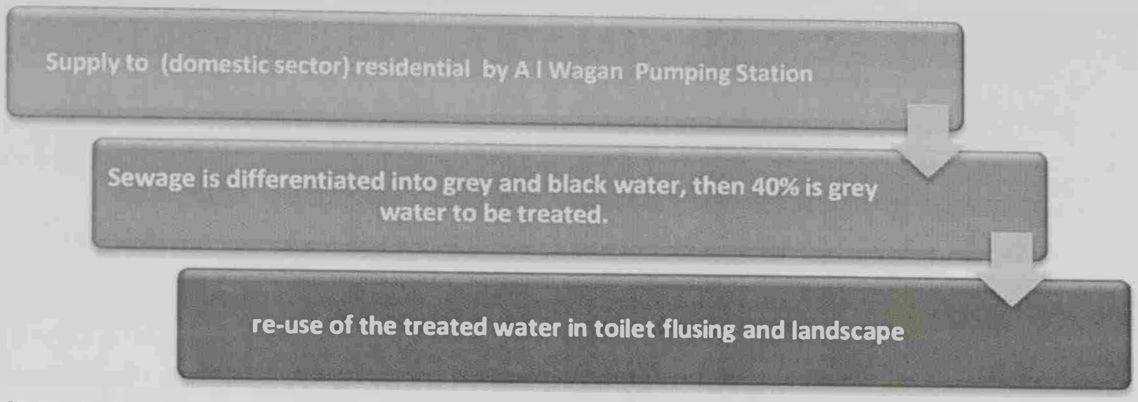
According to the water recycling industry, the systems varied according to different factors such as efficiency, capacity, type, cost and others. These factors affect the selected system within the neighborhood. So the total amount of greywater to be treated and reused in neighborhood is 48,907.3 g/d[1]. The total water consumption for a neighborhood (g/d) has been calculated using Equation (1). However, Equation (2) demonstrates the annual water consumption for all the five neighborhoods in Al Wagan.

Total daily water consumption for the selected neighborhood =
Total daily water consumption for a house gallon X number of housing units in the selected neighborhood .................. Equation (1)

Total annual water consumption for Alwagan housing units =
Total daily water consumption for the selected neighborhood gallon X number of neighborhoods X 365 days ......................Equation (2)

Where total annual water consumption for a housing unit (g)/day is the average of total water consumption of 52 housing unit/52 which is total number of housing units within selected neighborhood. Calculations show that the required treatment system should be capable of treating efficiently a minimum daily amount of grey water of 195,629.2 gallon/day in order to decrease the governmental supply from costly desalinated water and limiting the need for the energy consumed in water provision and supply. A schematic chart sums the process of water supply, treatment and reuse in the toilet flushing and landscaping.

[1] GW is considered 40% of the total daily residential water use of the whole district= 178,511,645/365* 0.4= 195,629.2 gallon/day




*Source: author

Figure 4.17: Proposed water cycle in Al Wagan district, author, 2013

## 4.7 Conclusions and Recommendations

There are many stakeholders involved in sustaining water use in Abu Dhabi Emirate and in Al Wagan in particular. These include among others Abu Dhabi Distribution Company, Abu Dhabi Sewage Services Company, Abu Dhabi Transmission and Despatch Company, Department of Municipal Affairs, Abu Dhabi Urban Planning Council, Environment Agency and the general public. It is therefore recommend that continued active involvement and participation of these stakeholders should be encouraged in order to get an integrated vision in sustaining water use within the Emirate.

A number of integrated efforts should consider pricing water consumption by the removal of water subsidies, regulating car washing and villa landscaping, and giving residents clear feedback on their level of water consumption in relationship to the neighboring neighborhoods. This might be of a powerful inducement in reducing water and electricity consumption.

As for Al Wagan case, thinking should be globally (and centralized regarding the whole country) and management should be locally (decentralized) in order to guarantee integrated solution. Therefore, a central body should be both responsible and able to carry out the regulatory and control functions of water resources management such as groundwater, desalinated and treated waste water in all water sectors (agriculture, domestic, industrial and environment). There is an opportunity of creating an integrated vision in order to implement effective re-organization of the water sector within an overall strategy. The planning should be centralized while the management should be decentralized.

Based on the privacy of Al Wagan, culture, customs and traditions, number of population, the applied system is expected to treat efficiently an amount of about 200,000 gallon per day in a de-centralized manner that sustain the water use in the district. This in turn could be promising for other districts as well in the future.

# CHAPTER 5: DISCUSSION

## 5.1 Introduction

The proposed grey water treatment system for Al Wagan district is a first of its kind in UAE and will serve five neighborhoods with more than 12,000 populations at present. After consultations with personnel of the companies in the field, there was a general consensus that the treatment unit provided in this study is available and capable of achieving a considerable saving in the annual governmental costs. If implemented, it will also give an impetus and inspiration towards integrated water management in Al Wagan District and UAE in general. Data collected from household annual water bills were analyzed and presented qualitatively and provided the basis for determining the most appropriate grey water

## 5.2 Water Consumption in Al Wagan District

In order to understand the annual water consumption of Al Wagan District, a pilot study was done to obtain information on household water consumption within a selected neighborhood. In total, fifty two water bills of the case study neighborhood households were collected in order to find the average annual water consumption per household whose summary is provided in Appendix C.

According to the obtained data, each neighborhood comprises of fifty two housing units which account for 40.75% of the total water supply to Al Wagan district with an average water consumption per household of 1,881.05 gallon/day which is equivalent to 7.12 $m^3$ daily. The selected case study neighborhood's water consumption for the 97,814.6 gallon/day which is 370.27 $m^3$/day. Based on the data provided by TRANSCO company, the total pumped water to Al Wagan District per day is equivalent to 1,200,000 gallons whereas the total daily residential water use in Al

Wagan district is 1,851.35 m$^3$ with about 40% of this amount is grey water = 740.54 m$^3$ which can be treated and reused. The water consumption in Al Wagan is illustrated in Figure 5.1.

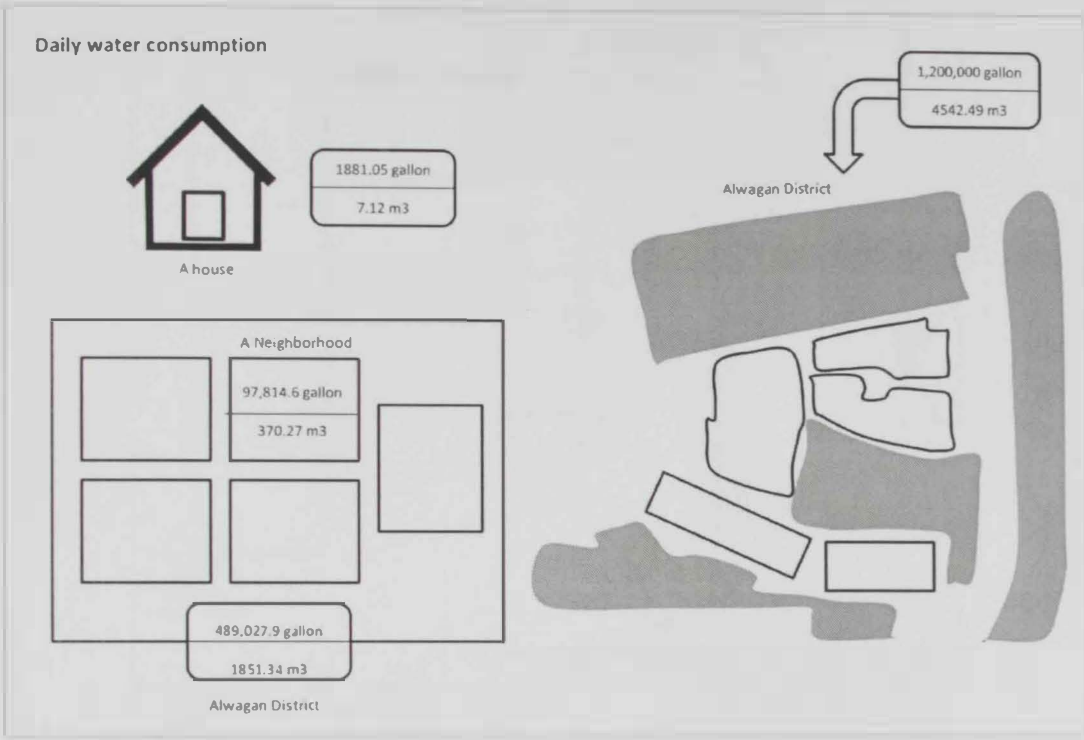



Figure 5.1: Daily water consumption in Al Wagan District (gallon and equivalent m$^3$)

## 5.3 Grey water recycling System

The proposed grey water recycling system in the selected neighborhood is expected to provide sufficient water for toilet flushing and landscaping use as provided in the schematic diagram in Figure 5.2. The grey water treatment process may take the discussed technologies provided in Chapter 2.

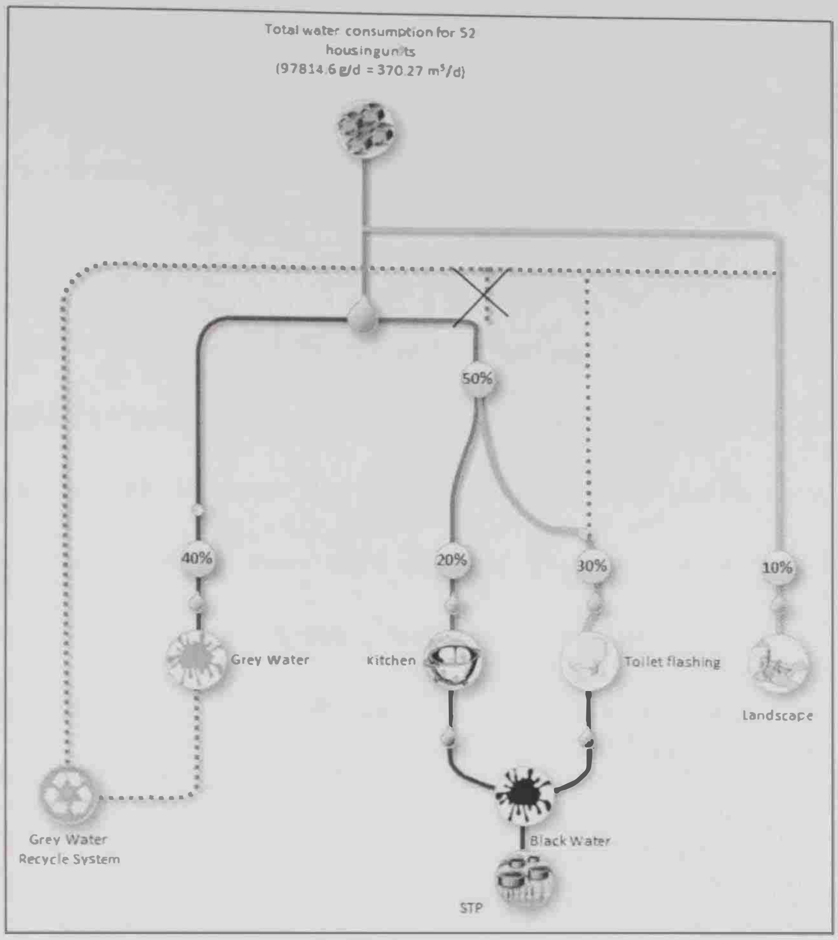



Figure 5.2: The proposed grey water recycling system

## 5.4 Planning and Implementing Grey Water Systems and Technologies

The determination of whether the grey water treatment system should be centralized or decentralized depends on a number of society related derivers such as the quality of life in urban and rural communities, population growth, resource constraints, increased demand, new ideas and design concepts, and innovations by entrepreneurs. The decentralized systems can be applied at different spatial scales; individual homes, clusters of homes, urban communities. Further, the decentralized systems have the potential of reducing the treatment costs in the long term. These systems can act either as separate facilities or in combination with a centralized system and can be managed as stand-alone systems which suites Al Wagan. Decentralization can also suit individual needs especially at locations with low density and scattered population such as peri-urban areas. Onsite scale is a type of decentralized approach in treating GW, which offer technologies and systems that provide water and wastewater services at the scale of an individual lot, cluster or neighborhood development scales.

Decentralization, as shown in Figure 5.3, considers the benefits of reducing the amount of waste at source and the option of recycling or reuse at the site. Further, decentralization collects the components of the system as minimal as possible and stress on the necessary treatment and disposal of wastewater. The fee collection costs can be reduced down to more than 60% of the total budget for wastewater management in a centralized system, particularly in small communities with low population densities such as Al Wagan district they are bridging the gap between onsite, centralized, and the semi-centralized (satellite) systems.

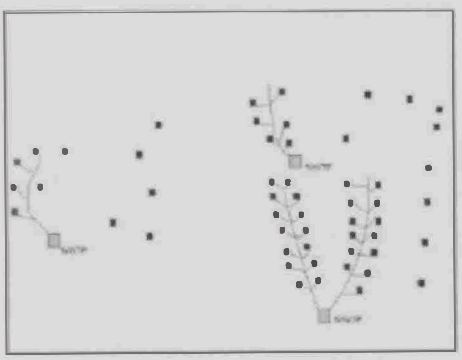


Figure 5.3: Decentralization system

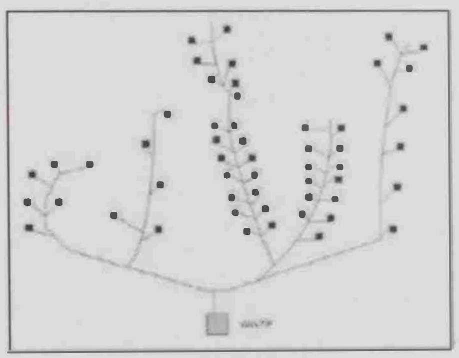


Figure 5.4: Centralized System

On the other hand, in a centralized system, as shown in Figure 5.4, the collection system needs large pipe diameters for long distances. For the operation and maintenance, it requires full time technical staff. The system produces many types of water (less uniformity) and the resulting risk is on large scale. There is a need for water transfer and distribution which minimizes social control. Expansion requires high costs with more complexity to implement and the potential to reuse is based on water concentration in one point.

To the contrary, the decentralized system offers small diameters and short distances through the collecting process. It needs small areas in many places and the operation and maintenance are less demanding and can be monitored remotely, this treatment system produces more uniform water and the risk is distributed. Water could be reused in the same area so there is no water transfer with more social control. The system can be expanded easily with low cost and less complexity to implementation, in a centralized treatment plants, disposal and reuse of the treated effluent, are usually many miles far from the point of origin. Regarding the Al Wagan district treatment unit, and according to the orientation and the combination of the five neighborhoods, it is expected to consider the centralized satellite in relation to the district and decentralized system in relation to the Eastern region.

However, in the centralized approach, the construction cost of transferring and distributing pipelines often becomes more expensive compared with the construction cost for the tertiary treatment facility and the operation cost in them. Regarding the Al Wagan case, the infrastructure of the grey water is not prepared, and thus should be provided upon the implementation of the treatment unit. In addition, the grey water collected from the hand basins, ablution and showers should be channeled into separate tank storage before directing towards the treatment unit.

Also to be assessed regarding the applied system are the infrastructure costs -repairs and expansion, all-encompassing grey infrastructure, alternatives to sprawl development and available technology. Grey water treatment system is evaluated according to hygienic safety, aesthetics, environmental tolerance, and technical and economic feasibility. However, the implemented treatment technology could be differentiated into primary, secondary and tertiary levels. The primary treatment performs by absorbing soap suds using a synthetic sponge and sedimentation settlement tank. The secondary treatment involves filtration of the treated water by gravel (10–60mm size) and sand. The tertiary treats effluent using aeration and chlorination before being pumped to an overhead tank for use in toilet flushing. For the case study, the primary level treatment level has been proposed for Al Wagan district.

The treatment technology (physical, biological, chemical or mixed and the complexity of the applied technology (low, complex)) are crucial and need to be established at an earlier stage in order to yield hygienically safe water for non-potable uses. The simple systems may route GW directly to applications such as toilet flushing and garden irrigation, while the complex ones incorporate varied levels of treatment such as sedimentation tanks, membranes, bioreactors, filters, pumps and disinfections units that allow storage for long times and wider range of uses.

As a concluding note, simple systems result in minimal treatments and storage while more complex systems treat GW to sufficient amounts to allow extended storage. Some simple systems have technical limitations while complex systems have other trade-offs such as energy use for high-tech options and space for intensive biological options. The most likely option to be applied in the Al Wagan district is the simple physical technology. Such systems are commercially available at reasonable price and they offer minimum payback periods.

## 5.5 Al Wagan Grey Water Treatment System and Technology

In this research, the selected grey water recycling system has the potential of reducing the supplied water by about 40% and 50% reduction in energy consumed. According to the grey water recycling systems industry described in Chapter 2, the systems are various and are controlled by factors such as efficiency, capacity, type, cost and others. These factors affect both to use centralized or decentralized system as well as the number of treatment units within the selected neighborhood.

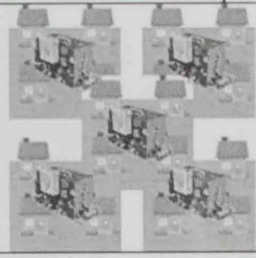
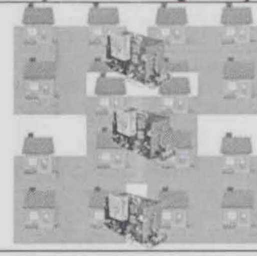
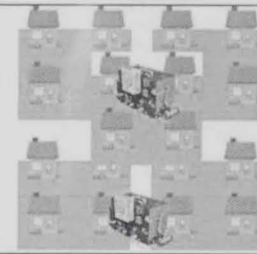
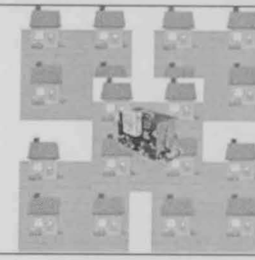
In order to start establishing a proper treatment system and technology in the residential neighborhoods in Al Wagan district, there are important key issues that should be considered. Planning considers studying the central planning for water resources and supply regarding the whole UAE country. Coming from Al Ain city, Al Wagan supply for water is distributed through five main valves to the five new and old neighborhoods. However, treating the sewage will take place next to the residential areas, starting from the individual houses into the treatment unit passing through the public lands. All of this should be within the legislative, institutional and the administrative and political framework. As a tool to facilitate the assessment process, the researcher created several alternatives illustrated by a simple scheme in Table 5.1 in order to select the most appropriate one to carry out the necessary studies and calculations.

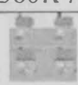
Demographics should also be considered to calculate the required capacity for the units for the potential future expansion within 10-15 years. Both technology and economic are impacting the system used and operating technology. It also influences the payback period and life time extension. The treatment unit should also fulfill the social and environmental needs for the UAE locals as the majority of the Al Wagan district regarding customs and traditions which both will affect the amount of used water, public acceptance of treatment technology and the potential future uses for the treated water. Actual implementation and operation for the treatment technology should also be considered.

## 5.6 Al Wagan residential Grey Water treatment and reuse

As the need to save and reduce the cost of treating fresh and desalinated water resources continue to rise especially for the housing sector, the researcher has relied on theoretical background and consultations with local technical firms in the field whether it is feasible to use the greywater treatment technology in Al Wagan five neighborhoods. The considered grey water is harnessed from the hand basins, showers and ablution and the treated grey water will be used for flushing toilets.

Table 5.1: Comparison between the four options for treatment plants using the proposed system

| | | | | |
|---|---|---|---|---|
| **Alternative Scheme** |  |  |  |  |
| **Capacity** | Each grey water treatment unit can serve only one neighborhood with 52 house | There are three treatment units; the author considered the physical location for the nearest two together and the individual unit for the fifth neighborhood alone | There are two treatment units; the first serves three neighborhoods while the second serves the other two neighborhoods | There is only one central treatment plant that serves the five neighborhoods in Al Wagan district |
| **Assessment** | • Inflow of 148 $m^3$/day per cluster unit. Connections should be in a central area with respect to levels away from residential areas.<br>• Unit can be expanded feasibly for an addition of 30-40 $m^3$/day for the additional houses with approximate cost of 110K AED.<br>• System efficiency is:(95-97)% | • Inflow of 148 $m^3$/day per cluster unit. And 296 $m^3$/day for the two common clusters unit. Connections should be in a central area with respect to levels away from residential areas.<br>• Unit can be expanded feasibly for an addition of 30-40 $m^3$/day for the additional houses with approximate cost of 110K AED.<br>• System efficiency is:(95-97)% | • Inflow of 444 $m^3$/day per three cluster unit. And 296$m^3$/day for the two common clusters unit. Connections should be in a central area with respect to levels away from residential areas.<br>• Unit can be expanded feasibly for an addition of 100 $m^3$/day for the additional houses with approximate cost of 200K AED.<br>• System efficiency is:(95-97)% | • Inflow of 740 $m^3$/day per all five cluster units. Connections should be in a central area with respect to levels away from residential areas.<br>• Unit can be expanded feasibly for an addition of 250 $m^3$/day for the additional houses with approximate cost of 580K AED.<br>• System efficiency is:(95-97)% |
| **Cost** | 380K AED | 720K AED | 900K AED | 1,700K AED |

 Grey Water Treatment Unit  Neighborhood

*Separate connection to be modified in each house connections individually so as to collect the grey water from showers, hand wash basin and the ablution only. Modification will include the preparation of separate tanks to collect the grey water and another one to collect the treated water in order to be used for flushing toilet and landscape.

## 5.7 Grey Water Treatment Technique

All grey water treatment technologies are based on a combination of chemical, physical and biological processes such as adsorption, coagulation, precipitation, filtration, aeration, biodegradation, and disinfection. Most of GW treatment technologies are preceded by a solid-liquid separation step and followed by a disinfection step as post treatment. To avoid the obstruction of the later treatment, the pre-treatments such as septic tank, filter bags, screen and filters are applied to reduce the amount of particles, oil and grease. The disinfection step is used to meet the microbiological requirements.

Consultations between the researcher, experts, technicians and managers in the company make the recommendations to use the fourth alternative, which uses a central unit that can treat the total amount of the grey water resulted in the district. The recommended plan for implementing the treatment unit is discussed in the following three sections.

**First: The proposed treatment technology has high potentials to fulfill the following advantages**

i. Minimize both the use of treated potable water for housing activities and the capacity of the sewage treatment plants.

ii. Appropriate use for the clean water resources.

iii. Minimize the use of chemicals and electrical energy.

iv. The treated water could be re-injected into the ground without causing pollution.

v. Treatment will minimize the required size of the greywater collecting reservoirs.

vi. The use of this treatment system in the high buildings proves efficiency. System fixation requires a minimum area with a yearly maintenance cost of about 2.5%-5% of the total cost of the project. System equipments can easily be fixed in the pumps room in the building. In addition, the system operates automatically, which reduces the need for permanent monitoring of the system. The system also ensures that no emission of any odors will cause inconvenience to the population.

vii. Finally, the system can help in substituting the cooling towers, irrigation and toilet flushing, which is expected to save the cost of water and energy as well.

**Second: The treatment unit is composed of the following parts**

i. Hair screening barrier which helps in protecting the filters and pumps by filtering the hair from the residential grey water.

ii. Injection pump that reduces the emission of undesired odor which accumulates from the grey water through first use, storage and operating.

iii. Sterile chlorine injection pump that kills the bacteria. It also prevents clogged filters by the killed bacteria through the layers of sand and gravel of the filters.

iv. Air bags which are responsible for pumping air consistently to ensure that the emission of odors and encourage getting rid of BOD and COD.

v. Grey water pumps that push the collected residential grey water from the collecting tanks to the tank of the treated water through the different parts of the treatment unit.

vi. A multi-layers sand filter, which filters the suspended solid particles before passing through the carbon filter in a fully automation mode.

vii. A carbon filter, which carries out the carbonation process which is subsequent to the multi-layers filter. It carries the filtration of the organic substances due to the wide surface area of carbon.

viii. Washing filters' pumps that continuously clean the filters.

ix. Final chlorination phase which sterilizes the resulted treated grey water preparing it for the reuse process.

**Third: Feasibility study for the project**

The economic evaluation of the proposed treatment technology should be carried out in order to determine the difference between the cost of the traditional routine of water supply by the UAE to Al Wagan district and the cost of the new routine of water supply which is used for flushing toilets and landscape irrigation utilities. Assessment will consider the following alternative.

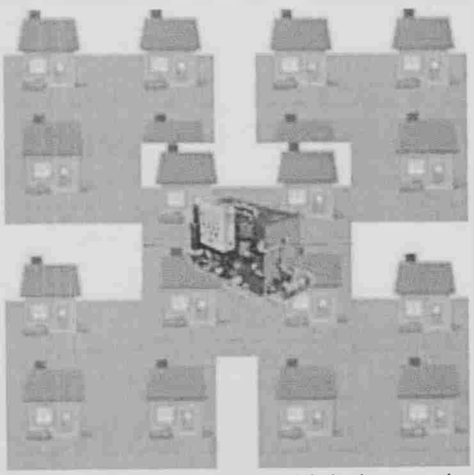


Figure 5.5: System which has only one central treatment plant that serves the five neighborhoods in Al Wagan district

The true cost of electricity and water in Abu Dhabi should consider the price market which could be changed up and down. According to information obtained from Economic & Energy Affairs, the cost of water depending on the time of year and the fuel mix during the year. During 2012 for example, true cost of power in Abu Dhabi was 29.6 fils, however the marginal cost of power ran by both ADWEA and the RSB is 53 fils per kwh.

Based on the alternatives developed by the author and the consultation with the technical department of a local company, the fourth alternative was recommended. It relies on the use of one central treatment unit that can serve the five neighborhoods and can produce an amount of 740.46 $m^3$ grey water. Connections should be in a central area with respect to levels away from residential areas. The unit will cost 1,700,000 AED and can be expanded for an addition of 250 $m^3$/day for the additional houses at an approximate cost of 580,000 AED. System efficiency is 95-97%. However, its feasibility considers the following Figure 5.6.

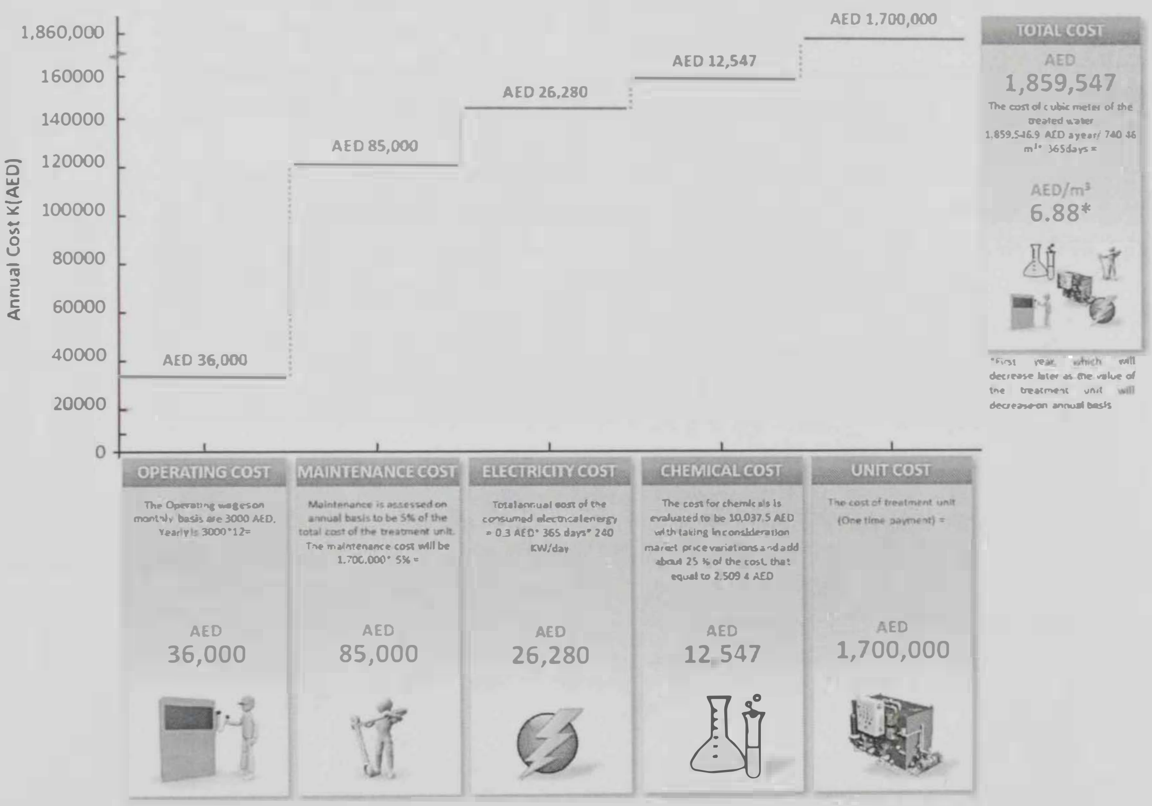



Figure 5.6: Grey water recycling system cost (Unit, Operation & Maintenance)

The figure calculation details are as follows:

- The cost of treatment unit = **1,700,000 AED**.
- Operating wages on monthly basis are 3000 AED, 3000*12= **36000AED/year**.
- Maintenance is assessed on annual basis to be 5% of the total cost of the treatment unit. The cost of the central unit that will treat the grey water for the five neighborhood will be 1,700,000 AED. So the maintenance cost will be 1,700,000* 5% = **85,000 AED**.
- Electricity cost is calculated based on the consumption of 10 KWH for the treatment unit, therefore, the consumed electrical energy is 24 h*10 KWH = 240 KW/day. The cost of each one consumed kilo watt is 0.3 AED/KW. Total annual cost of the consumed electrical energy = 0.3 AED* 365 days* 240 KW/day = **26,280 AED/year.**
- The cost of chemicals (chlorine and a deodorant) is calculated based on the use of 10 liters/day of chlorine which cost 2 AED/liter and 0.5 liters/ day of deodorant which cost 15 AED/liter. The cost for chemicals is evaluated to be (10*2 + 0.5*15)AED * 365 days = 10,037.5 AED. It is recommended to consider market price variations and add about 25 % of the cost (2,509.4 AED) to **be 12,546.9 AED/ year in all.**
- The total cost of operating the treatment unit on an annual basis will be the sum of the five aforementioned entities. Total cost = treatment unit price + Operating + Maintenance + Electricity + Chemicals = 1,700,000 + 36000 + 85,000 + 26,280 + 12,546.9 = **1,859,546.9 AED/year**.
- Accordingly, the cost of cubic meter of the treated water = 1,859,546.9 AED a year/ 740.46 $m^3$* 365 days = **6.88 AED/ $m^3$**, for the first year, which will decrease later as the value of the treatment unit will decrease on annual basis.

The following calculations are to compare both current system cost and grey water recycle system cost:

- The cost of **6.88 AED/ $m^3$** for the treated water compared with the cost of **10 AED / $m^3$** will result in the following savings in the country supply and cost.
- Saving will consider the difference between the cost of country daily supply for 1200000 gallon a day * 40.75% for the residential use /264.17= 1,849.7 $m^3$ a day with a cost of 1,849.7 $m^3$ water supply * 10 AED/ $m^3$ = 18,497 AED a day, the yearly cost will be 18,497 AED * 365 = **6,751,405 AED**.
- This amount will be reduced by about 38-40 % according to the accurate amount of the resulting treated grey water.

- ❒ 18,497 AED a day * 40 % reduction by the reused treated grey water = **7,398.8 AED**

- ❒ Then the cost for water supply by the country will drop to this amount 18,497 – 7,398.8 =**11,098.2 AED a day**

- ❒ 11,098.2 * 365 days = **4,050, 843 AED a year**

- ❒ So, the difference will be 6,751,405-4,050, 843= **2,700,562 AED**

Both systems can be compared for 10 years operation as shown in Figure 5.7.

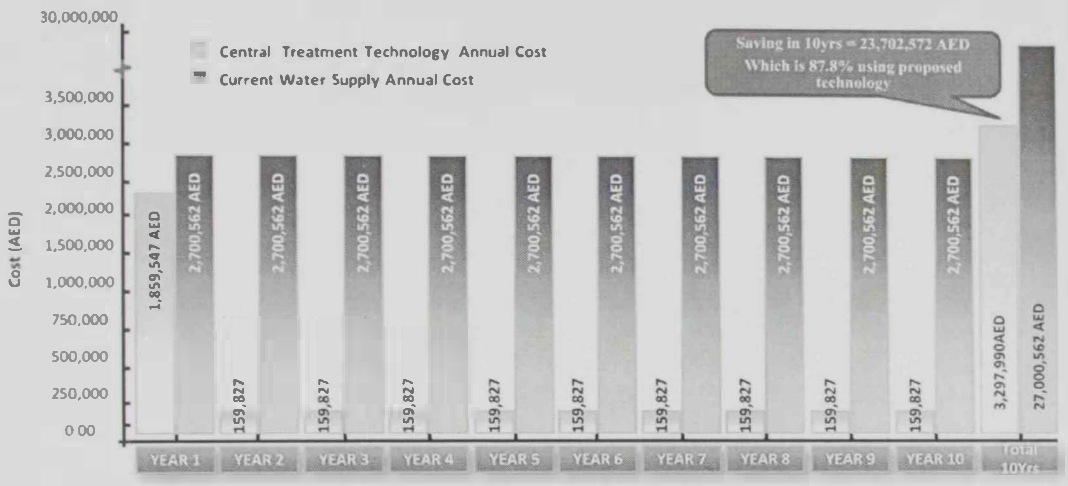



Figure 5.7: Cost of using current system vs grey water recycling system for 10 years

It's clear that grey water recycling system is more efficient in cost saving in the future. Cost saving reach to 87.8% comparing to using current system.

### 5.8 Summary of Result

The above computations illustrate that based on water supply, and residential use in particular; it has revealed the importance of hiring the grey water treatment technologies in order to sustain water resources and decreasing the cost of water supply for the UAE country. It also demonstrates the potential of GW treatment technology being fixed in the houses of the five neighborhoods with slight modifications in sewage system fittings. It will be decentralized in relationship to the UAE and Eastern region while it will be centralized regarding the district itself. The proposed treatment unit could have the capacity to treat more than 740 $m^3$ grey water with the capacity for future expansion for a third of this amount.

Feasibility study of the proposed system and technology –physical treatment- showed a saving of 2,700,562 AED which is a promising step that can influence the adoption of this technology and others in other districts within the Emirates and the Gulf region as well. This saving will allow the government to direct and spend more expenses in other issues while sustaining a very precious resource.

# CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

## 6.1 Conclusions

Water resources management has become one of the most discussed both at a global level and in the United Arab Emirates in particular. Water scarcity, increasing demand, cost of distribution and sustainability present real and serious challenges that call for actions to save water supply and consumption both not only locally but also globally. Ground water and desalination are the two major resources in UAE where the first faces depletion while the second is associated with both huge capital/operational costs and negative environmental impacts.

While water scarcity has become a common agenda in the region, this study focuses on grey water in order to draw the attentions of practitioners towards the treatment and reuse of this valuable source of water that is often ignored. The study, has elaborated key issues that surround grey water use UAE, Abu Dhabi Emirate, Al Ain and Al Wagan district. The UAE government has adopted two strategies aimed at increasing public awareness on water scarcity and conservation within the Emirate. These comprise of the sensitization through mass media water conservation campaign and influential public figures to publicize the message of sustainable use of both water and energy. These are aimed at making people aware of the potential future shortages and an understanding that their lifestyle contributes to this shortage and therefore calls for behavior change towards water conservation.

One of the potential roadmap to addressing water problems within UAE is to create a price for water as an effective policy that has been applied in OECD countries which involves switching from fixed charges for public water services to volumetric charging This implies that the much people use water, the more they pay. This therefore calls -for an urgent need to conduct a comprehensive study which will propose all schemes that may help the Emirate's residents to value and appreciate the value of water.

Efficiency of water management is also lacking as more than a third of the treated sewage effluent produced in Abu Dhabi is disposed into the Arabian Gulf without utilization which is leading to loosing water and as well energy. This is due to capacity limitations of the existing TSE irrigation distribution network. This TSE surplus can be put to productive use and reused for many industrial uses, such as for power generation, electronics, cooling systems, and construction industries (Columbia-University, 2010).

Further, the implementation of grey water treatment plants should consider the existing infrastructure. In many utility systems around the world and in UAE, grey water is combined with black water in a single domestic wastewater stream. In order to minimize water wastage, the reuse of grey water requires the separating grey water from sewage water, which is not standard plumbing practice in many countries, and therefore requires plumbing retrofits. The difficulty and expense of this retrofit varies widely, and depends on the building and complexity of the system. A permit is necessary for any grey water system to be installed so that grey water can be that collect and stored for outdoor, subsurface irrigation.

## 6.2 Recommendations

Sustainability forms the basis on how Abu Dhabi should develop; where present growth should not sacrifice the ability of future generations. In fact, sustainable growth can help the Emirate keep a lasting place among world economic leaders. As for water resources and provision for the water, desalination plants have proliferated throughout the UAE, viewed as simple solutions to overcoming freshwater scarcity, however, this is often associated with high capital costs and environmental impacts and does not address over-consumption of water in the country.

Solutions of focusing on reducing water demand targeting the four most water-intensive sectors: agricultural, residential, public, and tourism therefore become essential. However, the other technological solutions such as desalination and grey water treatment are other alternatives that must be considered in order to support the sustainability efforts for water supply. Strategies that aim at mitigating the drivers of over-consumption as the main reason for the high water need in the country should be proposed. These include the need for:

- a convincing institutional framework for water management across all Abu Dhabi's government agencies,
- a coordinated data flow, management and communication system for water supply and consumption,
- family unit-level water monitoring and metering within the water distribution network,
- a mix of strategies designed to change the social, environmental, and economic value of water within the Emirate.

However, within the framework of the aforementioned generalized recommendations, this study came with these outcomes for conserving water in Al Wagan district as a step to be replicable in other districts all over the Emirate. As potential uses of treated grey water have not established, the study looked into the need for setting up a system that can treat grey water resulting from the hand basins, showers and ablution in order to be used for flushing toilets and landscape irrigation. The literature review has provided a range of treatment systems that are applied in treating the grey water.

Further, sewage comprises of grey and black waters, whose treatment represents a real loss for a considerable resources (water and energy) simultaneously which is consumed for the treatment of the whole amount of sewage instead of treating the grey water only.

The recycling of the grey water technologies are recommended to be fixed in a centralized or decentralized manner. Decentralized systems can be more efficient in UAE, eastern region and in Al Ain as most of the settlements are spread with several satellite districts such as Al Wagan in the Southern Sector. However, the recommended system for treating the grey water in Al Wagan district has the capacity to recycle more than 740 $m^3$ capable in extending for about the third of this amount gaining a decrease in the country expenses for water supply to Al Wagan residential sector alone for more than 2,700, 000 AED. The step is strongly promising and carrying the potentials to reflect this into other regions and other industrial and commercial uses.

The government should consider investing in grey water as an additional source especially when planning for the positive realization of the Expo 2020. The government should also work towards creating awareness on sustainable use of water and energy. In energy conservation, for example, promoting awareness so that people believe in a possible shortage of energy in the future and an understanding that their lifestyle is contributing to the shortage has led to substantial conservation results. As seen with energy use, basic awareness is fundamental when attempting to shift the behavior of people toward conservation. There are two outlining strategies for increasing public awareness on water scarcity and conservation within the Emirate. The first is to launch a mass media water conservation campaign while the second is to use influential public figures to publicize the message of water conservation (Columbia-University, 2010).

Regarding to the potential horizons for the solutions of water problems within the UAE is to create a price for water as an effective policy. This has been applied in the countries of Organization for Economic Co-operation and Development (OECD) which encourages water conservation by switching from fixed charges for public water services to volumetric charging. The policy reveals success, as it means, the more you use the more you pay. Volumetric charging decreases block tariffs, which reduces the practice of providing discounts to high-volume users. This is applied in several countries such as Hungary, Poland, and the Czech Republic which are using volumetric pricing. Therefore, at the policy-maker level in Abu Dhabi, there is an urgent need to conduct a thorough study of all potential schemes that may help the Emirate's residents to appreciate the value of water (Columbia-University, 2010).

From another perspective, water management is limited in efficiency till the mean time. More than a third of the treated sewage effluent (TSE), (51 Mcm/yr), produced in Abu Dhabi is disposed of into the Arabian Gulf without utilization. This is due to capacity limitations of the existing TSE irrigation distribution network. This TSE surplus can be put to productive use and reused for many industrial uses, including within the power generation, electronics, cooling systems, and construction industries (Columbia-University, 2010).

## 6.3 Challenges

In spite of the promising future for implementation of this industry, however there are still several challenges that need careful attention and intervention. Grey water technologies, uses, and policies vary widely around the world. However, real experiences worldwide prove that grey water reuse presents a variety of challenges. For Abu Dhabi, the most important confrontation that grey water reuse industry faces is the low value given to water either at economic, environmental and social level. Over-consumption of water presents the greatest pressure on Abu Dhabi's water resources, and is a direct result of water's low value. The prevailing political, economic and social structures that have created Abu Dhabi's explosive short-term growth have played an important role in perpetuating a model of un-sustainability. In addition, there are numerous challenges that should be addressed in order to sustain a tangible improvement in this industry and to widen the potential uses for the treated grey water.

- **First** challenge is related to investigating the public health considerations in regards to the presence and/or the concentration of the contaminants. It might also contain some pathogens as those found on the skin. The grey water can be of specifications that are similar to water for drinking, bathing, irrigation standards; it must therefore be subjected to satisfactory level of the safety by treating before reusing it and by eliminating the physical contact of people. Choosing the proper system of treatment should consider the individual basis in relationship to the quality of the raw grey water and the quality of resulted treated grey water according to the potential uses. If it is to be used for irrigation, an underground irrigation system may be considered in order to prevent the physical contact with people. In addition, the quality of the resulting treated grey water relies on the used system, storage and the end use.

- **Second**, the public perception for the reuse of the treated grey water presents another significant challenge in the region. People main concerns regarding the reuse of the treated grey water are that its unhealthy and unsafe, cannot be used for certain activities. This forms a significant barrier to the acceptance of the grey water reuse solutions. Factors that determine the level of public acceptance are health risk, cost, operation regime and environmental awareness. Other obstacles regarding the public acceptance are related to the lack of compatibility with the Islamic beliefs. Therefore, decision makers could adopt few strategies that can improve people perceptions and awareness with regard to the reuse of the treated grey water. These strategies include public education campaigns, media sensitization and community engagement.

- The **Third** challenge is the amount of grey water as a percentage of total water use. This could be increased and decreased based on the attitudes and awareness for the users. In both cases there are potential scenarios in treating the resulting water and uplifting its quality in order to be reused.

- **Fourth** challenge in reusing the treated grey water is the energy consumption needs while treating grey water. This challenge should call for an essential infrastructure change, where the sewage utilities should be separated in order to pave way towards the treatment of the water according to the composition of this water and to the future uses, instead of being treated collectively and disposed in the ocean.

- The use of the treated grey water in agricultural activities represents the **Fifth** challenge. This needs to consider the analysis of both the components of the resulted treated water and the potential agricultural activities in order to maintain WHO specifications that might impact people's health. This should also be investigated in the light of people behaviors, customs and traditions in preparing food using the agricultural products which are irrigated by the resulted treated grey water.

- Financing the grey water treatment projects is the **Sixth** challenge to be considered. It might hinder cost benefit considerations, where the cost may be high compared to the water prices. Meanwhile, the main issue in this regard is that the water is inappropriately priced in many parts of the world and in the UAE in particular, which results in little incentives to water conservation. The grey water treatment then could be assigned as an adaptation strategy for water scarcity, insecurity and climate change.

However, as the worldwide growing interest in water resources and water treatment and recycling, it is a pressing challenge to develop a consistent industry standard and support the research issues that make the main focus on the general health and the environment as well. This should be relevant and calls for the establishment of specialized institutions that carry the role of organizing and managing grey water subject with all relevant organizations within the country and worldwide.

## 6.4 Future Opportunities

- More research can be carried out by updating the Engineering and financial calculation for the new accruement.

- The percentage of grey water assumed in this study, that is 40%, can be calibrated by studying other communities to figure out correlated percentages.

- The study of grey water system can be expanded to cover different land uses such as high-rise buildings, low-rise residential buildings and mixed-residential and commercial buildings.

- Further studies can be carried to evaluate the energy saved for pumping water from declination plants and water pumped to STPs.

- The deployment of Gray water treatment system shall be studied and evaluated after implementation.

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# APPENDICES

# Appendix A: Data Collection Letter

UAEU College of Engineering

جامعة الإمارات العربية المتحدة
United Arab Emirates University

Arch/30/Second semester/2012-2013
March 25, 2013

سعادة المهندس محمد سالم بن عمير الشامسي　　　المحترم
مديـــر عـــام شركـــة العيـــن للتوزيـــع

السلام عليكم ورحمة الله،

أرجو أن أفيد سعادتكم علماً بأن المهندسة الدهيم نصيب العامري، ذات الرقم الجامعي 200104994 هي طالبة في مرحلة الماجستير في قسم الهندسة المعمارية بكلية الهندسة، جامعة الإمارات، وتعمل على مشروع بحثي ذي علاقة بدراستها حول استخدامات المياه، وجعلت منطقة الوقن هدفاً لدراستها، وهي تحتاج إلى بعض البيانات عن تاريخ منطقة الوقن في المياه وعن استخدامات المياه فيها، فأرجو التكرم بالموافقة والإيعاز لمن يلزم لتزويدها بهذه المعلومات لأهميتها في موضوع دراستها.

وانني إذ أشكر سعادتكم على التعاون وتسهيل مهمة الطالبة في بحثها لأتمنى لكم كل النجاح ولشركة العين للتوزيع كل التقدم والازدهار.

وتفضلوا بقبول الاحترام.

أ.د. خيرة أنيسا ثابت

رئيس قسم الهندسة المعمارية

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## Appendix C: Sample of Water Consumption Bill

Oracle TM إطار العمل لـ

Page 2 of 2

معرف العداد ! Water - Non-Moving Parts - Cubic Meters - 40mm / 06510244W / 06510244 - نشط - تم التثبيت

معلومات السجل M3، تنسيق 7.0، 1.000000 معرف السجل 5774790969

الترشيح حسب القراءات القابلة للفوترة فقط

| تاريخ/وقت القراءة | الفرق بين القراءتين | الرسالة | قراءة السجل | نوع القراءة | الاستخدام على الفاتورة | تجاوز حد القرا |
|---|---|---|---|---|---|---|
| 01:04PM 18-09-2011 | 255.000000 | الاستخدام: 255، غير مرتفع/منخفض | 9200.000000 | منتظمة | ✓ | |
| 11:59PM 11-08-2011 | 219.000000 | الاستخدام: 219، الاستخدام الصالح: 153 - 307، القراءات الصالحة: 8879 - 9033 | 8945.000000 | تقدير النظام | ✓ | |
| 12:29PM 13-07-2011 | 482.000000 | الاستخدام: 482، غير مرتفع/منخفض | 8726.000000 | منتظمة | ✓ | |
| 01:16PM 15-05-2011 | 744.000000 | الاستخدام: 744، غير مرتفع/منخفض | 8244.000000 | منتظمة | ✓ | |
| 03:03PM 16-02-2011 | 168.000000 | الاستخدام: 168، غير مرتفع/منخفض | 7500.000000 | منتظمة | ✓ | |
| 11:59PM 11-01-2011 | 232.000000 | الاستخدام: 232، الاستخدام الصالح: 163 - 325، القراءات الصالحة: 7263 - 7425 | 7332.000000 | تقدير النظام | ✓ | |
| 07:22AM 14-12-2010 | 274.000000 | الاستخدام: 274، غير مرتفع/منخفض | 7100.000000 | منتظمة | ✓ | |
| 11:59PM 11-11-2010 | 226.000000 | الاستخدام: 226، الاستخدام الصالح: 158 - 317، القراءات الصالحة: 6758 - 6917 | 6826.000000 | تقدير النظام | ✓ | |
| 09:47AM 17-10-2010 | 500.000000 | الاستخدام: 500، غير مرتفع/منخفض | 6600.000000 | منتظمة | ✓ | |
| 01:21PM 16-08-2010 | 241.000000 | الاستخدام: 241، غير مرتفع/منخفض | 6100.000000 | منتظمة | ✓ | |
| 11:59PM 11-07-2010 | 78.000000 | الاستخدام: 78، الاستخدام الصالح: 55 - 110، القراءات الصالحة: 5836 - 5891 | 5859.000000 | تقدير النظام | ✓ | |
| 01:21PM 14-06-2010 | 209.000000 | الاستخدام: 209، غير مرتفع/منخفض | 5781.000000 | منتظمة | ✓ | |
| 11:59PM 11-05-2010 | 133.000000 | الاستخدام: 133، الاستخدام الصالح: 93 - 187، القراءات الصالحة: 5532 - 5626 | 5572.000000 | تقدير النظام | ✓ | |
| 12:15PM 14-04-2010 | 197.000000 | الاستخدام: 197، غير مرتفع/منخفض | 5439.000000 | منتظمة | ✓ | |
| 12:37PM 14-03-2010 | 148.000000 | الاستخدام: 148، غير مرتفع/منخفض | 5242.000000 | منتظمة | ✓ | |
| 07:41AM 17-02-2010 | 211.000000 | الاستخدام: 211، غير مرتفع/منخفض | 5094.000000 | منتظمة | ✓ | |
| 11:59PM 11-01-2010 | 195.000000 | الاستخدام: 195، الاستخدام الصالح: 136 - 273، القراءات الصالحة: 4824 - 4961 | 4883.000000 | تقدير النظام | ✓ | |
| 11:27AM 14-12-2009 | 134.000000 | الاستخدام: 134، غير مرتفع/منخفض | 4688.000000 | منتظمة | ✓ | |

## Appendix B: Water Consumption for 52 Residential Plots

| Number | SA_TYPE_DES | PREM_TYPE | SUM(CONSUMPTION) | BADGE_NBR |
|---|---|---|---|---|
| 1 | Water Utility SA - Residential | Shaabia | 158.00 | 06035148 |
| | Water Utility SA - Residential | Shaabia | 246.00 | 06035148 |
| | Water Utility SA - Residential | Shaabia | 497.00 | 06035148 |
| | Water Utility SA - Residential | Shaabia | 112.00 | 06035148 |
| | Water Utility SA - Residential | Shaabia | 196.00 | 06035148 |
| | Water Utility SA - Residential | Shaabia | 398.00 | 06035148 |
| | Water Utility SA - Residential | Shaabia | 305.00 | 06035148 |
| 2 | Water Utility SA - Residential | Shaabia | 427.00 | 06066879 |
| | Water Utility SA - Residential | Shaabia | 377.00 | 06066879 |
| | Water Utility SA - Residential | Shaabia | 648.00 | 06066879 |
| | Water Utility SA - Residential | Shaabia | 728.00 | 06066879 |
| | Water Utility SA - Residential | Shaabia | 604.00 | 06066879 |
| | Water Utility SA - Residential | Shaabia | 721.00 | 06066879 |
| | Water Utility SA - Residential | Shaabia | 361.00 | 06066879 |
| | Water Utility SA - Residential | Shaabia | 303.00 | 06066879 |
| 3 | Water Utility SA - Residential | Shaabia | 132.00 | 06038348W |
| | Water Utility SA - Residential | Shaabia | 75.00 | 06038348W |
| | Water Utility SA - Residential | Shaabia | 336.00 | 06038348W |
| | Water Utility SA - Residential | Shaabia | 125.00 | 06038348W |
| | Water Utility SA - Residential | Shaabia | 218.00 | 06038348W |
| | Water Utility SA - Residential | Shaabia | 308.00 | 06038348W |
| | Water Utility SA - Residential | Shaabia | 322.00 | 06038348W |
| | Water Utility SA - Residential | Shaabia | 300.00 | 06038348W |
| 4 | Water Utility SA - Residential | Shaabia | 229.00 | 06039093W |
| | Water Utility SA - Residential | Shaabia | 568.00 | 06039093W |
| | Water Utility SA - Residential | Shaabia | 157.00 | 06039093W |
| | Water Utility SA - Residential | Shaabia | 296.00 | 06039093W |
| | Water Utility SA - Residential | Shaabia | 353.00 | 06039093W |
| | Water Utility SA - Residential | Shaabia | 621.00 | 06039093W |
| | Water Utility SA - Residential | Shaabia | 569.00 | 06039093W |
| | Water Utility SA - Residential | Shaabia | 191.00 | 06039093W |
| 5 | Water Utility SA - Residential | Shaabia | 329.00 | 06039482W |
| | Water Utility SA - Residential | Shaabia | 39.00 | 06039482W |
| | Water Utility SA - Residential | Shaabia | 438.00 | 06039482W |
| | Water Utility SA - Residential | Shaabia | 857.00 | 06039482W |
| | Water Utility SA - Residential | Shaabia | 855.00 | 06039482W |
| | Water Utility SA - Residential | Shaabia | 414.00 | 06039482W |
| | Water Utility SA - Residential | Shaabia | 839.00 | 06039482W |
| | Water Utility SA - Residential | Shaabia | 700.00 | 06039482W |
| | Water Utility SA - Residential | Shaabia | 450.00 | 06039482W |
| 6 | Water Utility SA - Residential | Shaabia | 128.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 66.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 55.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 65.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 124.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 51.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 107.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 23.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 69.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 19.00 | 06041527W |
| | Water Utility SA - Residential | Shaabia | 138.00 | 06041527W |
| 7 | Water Utility SA - Residential | Shaabia | 346.00 | 06041559W |
| | Water Utility SA - Residential | Shaabia | 325.00 | 06041559W |
| | Water Utility SA - Residential | Shaabia | 177.00 | 06041559W |
| | Water Utility SA - Residential | Shaabia | 243.00 | 06041559W |
| | Water Utility SA - Residential | Shaabia | 102.00 | 06041559W |
| | Water Utility SA - Residential | Shaabia | 149.00 | 06041559W |
| | Water Utility SA - Residential | Shaabia | 102.00 | 06041559W |

| Number | SA_TYPE_DES | PREM_TYPE | SUM(CONSUMPTION) | BADGE_NBR |
|---|---|---|---|---|
| | Water Utility SA - Residential | Shaabia | 286.00 | 06041559W |
| 8 | Water Utility SA - Residential | Shaabia | 312.00 | 06041577W |
| | Water Utility SA - Residential | Shaabia | 322.00 | 06041577W |
| | Water Utility SA - Residential | Shaabia | 111.00 | 06041577W |
| | Water Utility SA - Residential | Shaabia | 155.00 | 06041577W |
| | Water Utility SA - Residential | Shaabia | 126.00 | 06041577W |
| | Water Utility SA - Residential | Shaabia | 411.00 | 06041577W |
| | Water Utility SA - Residential | Shaabia | 316.00 | 06041577W |
| | Water Utility SA - Residential | Shaabia | 133.00 | 06041577W |
| 9 | Water Utility SA - Residential | Shaabia | 375.00 | 06041591W |
| | Water Utility SA - Residential | Shaabia | 914.00 | 06041591W |
| | Water Utility SA - Residential | Shaabia | 319.00 | 06041591W |
| | Water Utility SA - Residential | Shaabia | 161.00 | 06041591W |
| | Water Utility SA - Residential | Shaabia | 399.00 | 06041591W |
| | Water Utility SA - Residential | Shaabia | 192.00 | 06041591W |
| 10 | Water Utility SA - Residential | Shaabia | 47.00 | 06041625W |
| | Water Utility SA - Residential | Shaabia | 0.00 | 06041625W |
| | Water Utility SA - Residential | Shaabia | 98.00 | 06041625W |
| | Water Utility SA - Residential | Shaabia | 97.00 | 06041625W |
| | Water Utility SA - Residential | Shaabia | 22.00 | 06041625W |
| | Water Utility SA - Residential | Shaabia | 70.00 | 06041625W |
| | Water Utility SA - Residential | Shaabia | 39.00 | 06041625W |
| | Water Utility SA - Residential | Shaabia | 32.00 | 06041625W |
| 11 | Water Utility SA - Residential | Shaabia | 152.00 | 06041933W |
| | Water Utility SA - Residential | Shaabia | 56.00 | 06041933W |
| | Water Utility SA - Residential | Shaabia | 219.00 | 06041933W |
| | Water Utility SA - Residential | Shaabia | 85.00 | 06041933W |
| | Water Utility SA - Residential | Shaabia | 0.00 | 06041933W |
| | Water Utility SA - Residential | Shaabia | 113.00 | 06041933W |
| | Water Utility SA - Residential | Shaabia | 48.00 | 06041933W |
| 12 | Water Utility SA - Residential | Shaabia | 227.00 | 06041936W |
| | Water Utility SA - Residential | Shaabia | 224.00 | 06041936W |
| | Water Utility SA - Residential | Shaabia | 0.00 | 06041936W |
| | Water Utility SA - Residential | Shaabia | 2,191.00 | 06041936W |
| | Water Utility SA - Residential | Shaabia | 207.00 | 06041936W |
| 13 | Water Utility SA - Residential | Shaabia | 82.00 | 06041985W |
| | Water Utility SA - Residential | Shaabia | 124.00 | 06041985W |
| | Water Utility SA - Residential | Shaabia | 150.00 | 06041985W |
| | Water Utility SA - Residential | Shaabia | 164.00 | 06041985W |
| | Water Utility SA - Residential | Shaabia | 73.00 | 06041985W |
| | Water Utility SA - Residential | Shaabia | 60.00 | 06041985W |
| | Water Utility SA - Residential | Shaabia | 233.00 | 06041985W |
| | Water Utility SA - Residential | Shaabia | 79.00 | 06041985W |
| 14 | Water Utility SA - Residential | Shaabia | 1,267.00 | 06042217W |
| | Water Utility SA - Residential | Shaabia | 798.00 | 06042217W |
| | Water Utility SA - Residential | Shaabia | 421.00 | 06042217W |
| | Water Utility SA - Residential | Shaabia | 700.00 | 06042217W |
| | Water Utility SA - Residential | Shaabia | 802.00 | 06042217W |
| | Water Utility SA - Residential | Shaabia | 772.00 | 06042217W |
| 15 | Water Utility SA - Residential | Shaabia | 14.00 | 06042821W |
| | Water Utility SA - Residential | Shaabia | 46.00 | 06042821W |
| | Water Utility SA - Residential | Shaabia | 120.00 | 06042821W |
| | Water Utility SA - Residential | Shaabia | 6.00 | 06042821W |
| | Water Utility SA - Residential | Shaabia | 60.00 | 06042821W |
| | Water Utility SA - Residential | Shaabia | 47.00 | 06042821W |
| | Water Utility SA - Residential | Shaabia | 106.00 | 06042821W |
| | Water Utility SA - Residential | Shaabia | 53.00 | 06042821W |
| | Water Utility SA - Residential | Shaabia | 91.00 | 06042821W |
| 16 | Water Utility SA - Residential | Shaabia | 177.00 | 06045637W |
| | Water Utility SA - Residential | Shaabia | 303.00 | 06045637W |
| | Water Utility SA - Residential | Shaabia | 120.00 | 06045637W |

| Number | SA_TYPE_DES | PREM_TYPE | SUM(CONSUMPTION) | BADGE_NBR |
|---|---|---|---|---|
| | Water Utility SA - Residential | Shaabia | 127.00 | 06045637W |
| | Water Utility SA - Residential | Shaabia | 587.00 | 06045637W |
| | Water Utility SA - Residential | Shaabia | 120.00 | 06045637W |
| | Water Utility SA - Residential | Shaabia | 422.00 | 06045637W |
| | Water Utility SA - Residential | Shaabia | 389.00 | 06045637W |
| 17 | Water Utility SA - Residential | Shaabia | 489.00 | 06045644W |
| | Water Utility SA - Residential | Shaabia | 234.00 | 06045644W |
| | Water Utility SA - Residential | Shaabia | 191.00 | 06045644W |
| | Water Utility SA - Residential | Shaabia | 324.00 | 06045644W |
| | Water Utility SA - Residential | Shaabia | 424.00 | 06045644W |
| | Water Utility SA - Residential | Shaabia | 385.00 | 06045644W |
| | Water Utility SA - Residential | Shaabia | 400.00 | 06045644W |
| | Water Utility SA - Residential | Shaabia | 147.00 | 06045644W |
| 18 | Water Utility SA - Residential | Shaabia | 114.00 | 06045715W |
| | Water Utility SA - Residential | Shaabia | 188.00 | 06045715W |
| | Water Utility SA - Residential | Shaabia | 242.00 | 06045715W |
| | Water Utility SA - Residential | Shaabia | 153.00 | 06045715W |
| | Water Utility SA - Residential | Shaabia | 99.00 | 06045715W |
| | Water Utility SA - Residential | Shaabia | 199.00 | 06045715W |
| | Water Utility SA - Residential | Shaabia | 231.00 | 06045715W |
| | Water Utility SA - Residential | Shaabia | 92.00 | 06045715W |
| 19 | Water Utility SA - Residential | Shaabia | 201.00 | 06045761W |
| | Water Utility SA - Residential | Shaabia | 139.00 | 06045761W |
| | Water Utility SA - Residential | Shaabia | 92.00 | 06045761W |
| | Water Utility SA - Residential | Shaabia | 229.00 | 06045761W |
| | Water Utility SA - Residential | Shaabia | 146.00 | 06045761W |
| | Water Utility SA - Residential | Shaabia | 123.00 | 06045761W |
| | Water Utility SA - Residential | Shaabia | 184.00 | 06045761W |
| | Water Utility SA - Residential | Shaabia | 105.00 | 06045761W |
| 20 | Water Utility SA - Residential | Shaabia | 144.00 | 06046103W |
| | Water Utility SA - Residential | Shaabia | 76.00 | 06046103W |
| | Water Utility SA - Residential | Shaabia | 72.00 | 06046103W |
| | Water Utility SA - Residential | Shaabia | 54.00 | 06046103W |
| | Water Utility SA - Residential | Shaabia | 88.00 | 06046103W |
| | Water Utility SA - Residential | Shaabia | 77.00 | 06046103W |
| | Water Utility SA - Residential | Shaabia | 160.00 | 06046103W |
| | Water Utility SA - Residential | Shaabia | 87.00 | 06046103W |
| | Water Utility SA - Residential | Shaabia | 34.00 | 06046103W |
| 21 | Water Utility SA - Residential | Shaabia | 575.00 | 06046280W |
| | Water Utility SA - Residential | Shaabia | 554.00 | 06046280W |
| | Water Utility SA - Residential | Shaabia | 1,274.00 | 06046280W |
| 22 | Water Utility SA - Residential | Shaabia | 135.00 | 06046293W |
| | Water Utility SA - Residential | Shaabia | 74.00 | 06046293W |
| | Water Utility SA - Residential | Shaabia | 84.00 | 06046293W |
| | Water Utility SA - Residential | Shaabia | 46.00 | 06046293W |
| | Water Utility SA - Residential | Shaabia | 110.00 | 06046293W |
| | Water Utility SA - Residential | Shaabia | 224.00 | 06046293W |
| | Water Utility SA - Residential | Shaabia | 102.00 | 06046293W |
| | Water Utility SA - Residential | Shaabia | 19.00 | 06046293W |
| 23 | Water Utility SA - Residential | Shaabia | 397.00 | 06046382W |
| | Water Utility SA - Residential | Shaabia | 161.00 | 06046382W |
| | Water Utility SA - Residential | Shaabia | 175.00 | 06046382W |
| | Water Utility SA - Residential | Shaabia | 389.00 | 06046382W |
| | Water Utility SA - Residential | Shaabia | 288.00 | 06046382W |
| | Water Utility SA - Residential | Shaabia | 281.00 | 06046382W |
| | Water Utility SA - Residential | Shaabia | 210.00 | 06046382W |
| | Water Utility SA - Residential | Shaabia | 221.00 | 06046382W |
| 24 | Water Utility SA - Residential | Shaabia | 691.00 | 06046598W |
| | Water Utility SA - Residential | Shaabia | 700.00 | 06046598W |
| | Water Utility SA - Residential | Shaabia | 453.00 | 06046598W |
| | Water Utility SA - Residential | Shaabia | 355.00 | 06046598W |

| Number | SA_TYPE_DES | PREM_TYPE | SUM(CONSUMPTION) | BADGE_NBR |
|---|---|---|---|---|
| | Water Utility SA - Residential | Shaabia | 388.00 | 06046598W |
| | Water Utility SA - Residential | Shaabia | 377.00 | 06046598W |
| | Water Utility SA - Residential | Shaabia | 600.00 | 06046598W |
| | Water Utility SA - Residential | Shaabia | 680.00 | 06046598W |
| 25 | Water Utility SA - Residential | Shaabia | 338.00 | 06046635W |
| | Water Utility SA - Residential | Shaabia | 368.00 | 06046635W |
| | Water Utility SA - Residential | Shaabia | 157.00 | 06046635W |
| | Water Utility SA - Residential | Shaabia | 177.00 | 06046635W |
| | Water Utility SA - Residential | Shaabia | 147.00 | 06046635W |
| | Water Utility SA - Residential | Shaabia | 362.00 | 06046635W |
| | Water Utility SA - Residential | Shaabia | 31.00 | 06046635W |
| | Water Utility SA - Residential | Shaabia | 269.00 | 06046635W |
| | Water Utility SA - Residential | Shaabia | 162.00 | 06046635W |
| 26 | Water Utility SA - Residential | Shaabia | 451.00 | 06046662W |
| | Water Utility SA - Residential | Shaabia | 230.00 | 06046662W |
| | Water Utility SA - Residential | Shaabia | 392.00 | 06046662W |
| | Water Utility SA - Residential | Shaabia | 159.00 | 06046662W |
| | Water Utility SA - Residential | Shaabia | 449.00 | 06046662W |
| | Water Utility SA - Residential | Shaabia | 204.00 | 06046662W |
| | Water Utility SA - Residential | Shaabia | 143.00 | 06046662W |
| | Water Utility SA - Residential | Shaabia | 600.00 | 06046662W |
| | Water Utility SA - Residential | Shaabia | 600.00 | 06046862W |
| | Water Utility SA - Residential | Shaabia | 273.00 | 06046862W |
| | Water Utility SA - Residential | Shaabia | 317.00 | 06046862W |
| | Water Utility SA - Residential | Shaabia | 249.00 | 06046862W |
| | Water Utility SA - Residential | Shaabia | 327.00 | 06046862W |
| | Water Utility SA - Residential | Shaabia | 594.00 | 06046862W |
| | Water Utility SA - Residential | Shaabia | 626.00 | 06046862W |
| | Water Utility SA - Residential | Shaabia | 600.00 | 06046862W |
| 27 | Water Utility SA - Residential | Shaabia | 297.00 | 06047277W |
| | Water Utility SA - Residential | Shaabia | 198.00 | 06047277W |
| | Water Utility SA - Residential | Shaabia | 481.00 | 06047277W |
| | Water Utility SA - Residential | Shaabia | 172.00 | 06047277W |
| | Water Utility SA - Residential | Shaabia | 428.00 | 06047277W |
| | Water Utility SA - Residential | Shaabia | 473.00 | 06047277W |
| | Water Utility SA - Residential | Shaabia | 101.00 | 06047277W |
| | Water Utility SA - Residential | Shaabia | 101.00 | 06047277W |
| 28 | Water Utility SA - Residential | Shaabia | 7.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 107.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 0.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 62.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 369.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 58.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 363.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 92.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 53.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 211.00 | 06047372W |
| | Water Utility SA - Residential | Shaabia | 142.00 | 06047372W |
| 29 | Water Utility SA - Residential | Shaabia | 98.00 | 06047426W |
| | Water Utility SA - Residential | Shaabia | 181.00 | 06047426W |
| | Water Utility SA - Residential | Shaabia | 195.00 | 06047426W |
| | Water Utility SA - Residential | Shaabia | 194.00 | 06047426W |
| | Water Utility SA - Residential | Shaabia | 134.00 | 06047426W |
| | Water Utility SA - Residential | Shaabia | 147.00 | 06047426W |
| | Water Utility SA - Residential | Shaabia | 91.00 | 06047426W |
| 30 | Water Utility SA - Residential | Shaabia | 29.00 | 06047469W |
| | Water Utility SA - Residential | Shaabia | 26.00 | 06047469W |
| | Water Utility SA - Residential | Shaabia | 26.00 | 06047469W |
| | Water Utility SA - Residential | Shaabia | 211.00 | 06047469W |
| | Water Utility SA - Residential | Shaabia | 46.00 | 06047469W |
| | Water Utility SA - Residential | Shaabia | 76.00 | 06047469W |

| Number | SA_TYPE_DES | PREM_TYPE | SUM(CONSUMPTION) | BADGE_NBR |
|---|---|---|---|---|
| | Water Utility SA - Residential | Shaabia | 204.00 | 06047469W |
| | Water Utility SA - Residential | Shaabia | 32.00 | 06047469W |
| 31 | Water Utility SA - Residential | Shaabia | 114.00 | 06058105W |
| | Water Utility SA - Residential | Shaabia | 151.00 | 06058105W |
| | Water Utility SA - Residential | Shaabia | 74.00 | 06058105W |
| | Water Utility SA - Residential | Shaabia | 113.00 | 06058105W |
| | Water Utility SA - Residential | Shaabia | 99.00 | 06058105W |
| | Water Utility SA - Residential | Shaabia | 77.00 | 06058105W |
| | Water Utility SA - Residential | Shaabia | 49.00 | 06058105W |
| | Water Utility SA - Residential | Shaabia | 135.00 | 06058105W |
| | Water Utility SA - Residential | Shaabia | 24.00 | 06058105W |
| 32 | Water Utility SA - Residential | Shaabia | 396.00 | 06058119W |
| | Water Utility SA - Residential | Shaabia | 338.00 | 06058119W |
| | Water Utility SA - Residential | Shaabia | 644.00 | 06058119W |
| | Water Utility SA - Residential | Shaabia | 342.00 | 06058119W |
| 33 | Water Utility SA - Residential | Shaabia | 871.00 | 06506808W |
| | Water Utility SA - Residential | Shaabia | 585.00 | 06506808W |
| | Water Utility SA - Residential | Shaabia | 206.00 | 06506808W |
| | Water Utility SA - Residential | Shaabia | 195.00 | 06506808W |
| | Water Utility SA - Residential | Shaabia | 331.00 | 06506808W |
| | Water Utility SA - Residential | Shaabia | 54.00 | 06506808W |
| | Water Utility SA - Residential | Shaabia | 1,200.00 | 06506808W |
| | Water Utility SA - Residential | Shaabia | 270.00 | 06506808W |
| | Water Utility SA - Residential | Shaabia | 1,000.00 | 06506808W |
| 34 | Water Utility SA - Residential | Shaabia | 5.00 | 06508345W |
| | Water Utility SA - Residential | Shaabia | 4.00 | 06508345W |
| | Water Utility SA - Residential | Shaabia | 3.00 | 06508345W |
| | Water Utility SA - Residential | Shaabia | 5.00 | 06508345W |
| | Water Utility SA - Residential | Shaabia | 7.00 | 06508345W |
| | Water Utility SA - Residential | Shaabia | 2.00 | 06508345W |
| | Water Utility SA - Residential | Shaabia | 5.00 | 06508345W |
| | Water Utility SA - Residential | Shaabia | 14.00 | 06508345W |
| 35 | Water Utility SA - Residential | Shaabia | 1,033.00 | 06508590W |
| | Water Utility SA - Residential | Shaabia | 1,121.00 | 06508590W |
| | Water Utility SA - Residential | Shaabia | 1,000.00 | 06508590W |
| | Water Utility SA - Residential | Shaabia | 1,079.00 | 06508590W |
| | Water Utility SA - Residential | Shaabia | 468.00 | 06508590W |
| | Water Utility SA - Residential | Shaabia | 1,217.00 | 06508590W |
| 36 | Water Utility SA - Residential | Shaabia | 216.00 | 06508602W |
| | Water Utility SA - Residential | Shaabia | 243.00 | 06508602W |
| | Water Utility SA - Residential | Shaabia | 337.00 | 06508602W |
| | Water Utility SA - Residential | Shaabia | 169.00 | 06508602W |
| | Water Utility SA - Residential | Shaabia | 214.00 | 06508602W |
| | Water Utility SA - Residential | Shaabia | 332.00 | 06508602W |
| | Water Utility SA - Residential | Shaabia | 424.00 | 06508602W |
| | Water Utility SA - Residential | Shaabia | 344.00 | 06508602W |
| 37 | Water Utility SA - Residential | Shaabia | 261.00 | 06508644W |
| | Water Utility SA - Residential | Shaabia | 72.00 | 06508644W |
| | Water Utility SA - Residential | Shaabia | 121.00 | 06508644W |
| | Water Utility SA - Residential | Shaabia | 176.00 | 06508644W |
| | Water Utility SA - Residential | Shaabia | 89.00 | 06508644W |
| | Water Utility SA - Residential | Shaabia | 49.00 | 06508644W |
| | Water Utility SA - Residential | Shaabia | 77.00 | 06508644W |
| | Water Utility SA - Residential | Shaabia | 88.00 | 06508644W |
| 38 | Water Utility SA - Residential | Shaabia | 797.00 | 06508745W |
| | Water Utility SA - Residential | Shaabia | 316.00 | 06508745W |
| | Water Utility SA - Residential | Shaabia | 313.00 | 06508745W |
| | Water Utility SA - Residential | Shaabia | 660.00 | 06508745W |
| | Water Utility SA - Residential | Shaabia | 500.00 | 06508745W |
| | Water Utility SA - Residential | Shaabia | 531.00 | 06508745W |
| | Water Utility SA - Residential | Shaabia | 622.00 | 06508745W |

| Number | SA_TYPE_DES | PREM_TYPE | SUM(CONSUMPTION) | BADGE_NBR |
|---|---|---|---|---|
| 39 | Water Utility SA - Residential | Shaabia | 247.00 | 06508747W |
| | Water Utility SA - Residential | Shaabia | 774.00 | 06508747W |
| | Water Utility SA - Residential | Shaabia | 224.00 | 06508747W |
| | Water Utility SA - Residential | Shaabia | 600.00 | 06508747W |
| | Water Utility SA - Residential | Shaabia | 254.00 | 06508747W |
| | Water Utility SA - Residential | Shaabia | 626.00 | 06508747W |
| | Water Utility SA - Residential | Shaabia | 329.00 | 06508747W |
| | Water Utility SA - Residential | Shaabia | 827.00 | 06508747W |
| 40 | Water Utility SA - Residential | Shaabia | 1,100.00 | 06508761W |
| | Water Utility SA - Residential | Shaabia | 525.00 | 06508761W |
| | Water Utility SA - Residential | Shaabia | 1,096.00 | 06508761W |
| | Water Utility SA - Residential | Shaabia | 445.00 | 06508761W |
| | Water Utility SA - Residential | Shaabia | 356.00 | 06508761W |
| | Water Utility SA - Residential | Shaabia | 1,100.00 | 06508761W |
| | Water Utility SA - Residential | Shaabia | 626.00 | 06508761W |
| | Water Utility SA - Residential | Shaabia | 1,174.00 | 06508761W |
| 41 | Water Utility SA - Residential | Shaabia | 530.00 | 06508768W |
| | Water Utility SA - Residential | Shaabia | 688.00 | 06508768W |
| | Water Utility SA - Residential | Shaabia | 167.00 | 06508768W |
| | Water Utility SA - Residential | Shaabia | 600.00 | 06508768W |
| | Water Utility SA - Residential | Shaabia | 652.00 | 06508768W |
| | Water Utility SA - Residential | Shaabia | 285.00 | 06508768W |
| | Water Utility SA - Residential | Shaabia | 259.00 | 06508768W |
| | Water Utility SA - Residential | Shaabia | 355.00 | 06508768W |
| 42 | Water Utility SA - Residential | Shaabia | 11.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 16.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 46.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 5.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 25.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 19.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 42.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 15.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 20.00 | 06508775W |
| | Water Utility SA - Residential | Shaabia | 38.00 | 06508775W |
| 43 | Water Utility SA - Residential | Shaabia | 1,483.00 | 06508779W |
| | Water Utility SA - Residential | Shaabia | 1,300.00 | 06508779W |
| | Water Utility SA - Residential | Shaabia | 690.00 | 06508779W |
| | Water Utility SA - Residential | Shaabia | 684.00 | 06508779W |
| | Water Utility SA - Residential | Shaabia | 1,033.00 | 06508779W |
| | Water Utility SA - Residential | Shaabia | 799.00 | 06508779W |
| | Water Utility SA - Residential | Shaabia | 661.00 | 06508779W |
| | Water Utility SA - Residential | Shaabia | 1,478.00 | 06508779W |
| 44 | Water Utility SA - Residential | Shaabia | 6.00 | 06509955W |
| | Water Utility SA - Residential | Shaabia | 5.00 | 06509955W |
| | Water Utility SA - Residential | Shaabia | 10.00 | 06509955W |
| | Water Utility SA - Residential | Shaabia | 9.00 | 06509955W |
| | Water Utility SA - Residential | Shaabia | 24.00 | 06509955W |
| | Water Utility SA - Residential | Shaabia | 8.00 | 06509955W |
| | Water Utility SA - Residential | Shaabia | 11.00 | 06509955W |
| | Water Utility SA - Residential | Shaabia | 5.00 | 06509955W |
| 45 | Water Utility SA - Residential | Shaabia | 7.00 | 06510625W |
| | Water Utility SA - Residential | Shaabia | 9.00 | 06510625W |
| | Water Utility SA - Residential | Shaabia | 24.00 | 06510625W |
| | Water Utility SA - Residential | Shaabia | 9.00 | 06510625W |
| | Water Utility SA - Residential | Shaabia | 29.00 | 06510625W |
| | Water Utility SA - Residential | Shaabia | 8.00 | 06510625W |
| | Water Utility SA - Residential | Shaabia | 10.00 | 06510625W |
| | Water Utility SA - Residential | Shaabia | 5.00 | 06510625W |
| 46 | Water Utility SA - Residential | Shaabia | 692.00 | 06510642W |
| | Water Utility SA - Residential | Shaabia | 384.00 | 06510642W |
| | Water Utility SA - Residential | Shaabia | 992.00 | 06510642W |

| Number | SA_TYPE_DES | PREM_TYPE | SUM(CONSUMPTION) | BADGE_NBR |
|---|---|---|---|---|
| | Water Utility SA - Residential | Shaabia | 360.00 | 06510642W |
| | Water Utility SA - Residential | Shaabia | 718.00 | 06510642W |
| | Water Utility SA - Residential | Shaabia | 347.00 | 06510642W |
| | Water Utility SA - Residential | Shaabia | 295.00 | 06510642W |
| | Water Utility SA - Residential | Shaabia | 721.00 | 06510642W |
| 47 | Water Utility SA - Residential | Shaabia | 318.00 | 06511269W |
| | Water Utility SA - Residential | Shaabia | 333.00 | 06511269W |
| | Water Utility SA - Residential | Shaabia | 645.00 | 06511269W |
| | Water Utility SA - Residential | Shaabia | 756.00 | 06511269W |
| | Water Utility SA - Residential | Shaabia | 0.00 | 06511269W |
| | Water Utility SA - Residential | Shaabia | 306.00 | 06511269W |
| | Water Utility SA - Residential | Shaabia | 922.00 | 06511269W |
| | Water Utility SA - Residential | Shaabia | 296.00 | 06511269W |
| | Water Utility SA - Residential | Shaabia | 600.00 | 06511269W |
| 48 | Water Utility SA - Residential | Shaabia | 7.00 | 06512466W |
| | Water Utility SA - Residential | Shaabia | 18.00 | 06512466W |
| | Water Utility SA - Residential | Shaabia | 2.00 | 06512466W |
| | Water Utility SA - Residential | Shaabia | 10.00 | 06512466W |
| | Water Utility SA - Residential | Shaabia | 12.00 | 06512466W |
| | Water Utility SA - Residential | Shaabia | 18.00 | 06512466W |
| | Water Utility SA - Residential | Shaabia | 10.00 | 06512466W |
| | Water Utility SA - Residential | Shaabia | 16.00 | 06512466W |
| 49 | Water Utility SA - Residential | Shaabia | 1,405.00 | 06513116W |
| | Water Utility SA - Residential | Shaabia | 1,046.00 | 06513116W |
| | Water Utility SA - Residential | Shaabia | 599.00 | 06513116W |
| | Water Utility SA - Residential | Shaabia | 533.00 | 06513116W |
| | Water Utility SA - Residential | Shaabia | 536.00 | 06513116W |
| | Water Utility SA - Residential | Shaabia | 1,345.00 | 06513116W |
| | Water Utility SA - Residential | Shaabia | 1,193.00 | 06513116W |
| | Water Utility SA - Residential | Shaabia | 751.00 | 06513116W |
| 50 | Water Utility SA - Residential | Shaabia | 9.00 | 06513133W |
| | Water Utility SA - Residential | Shaabia | 16.00 | 06513133W |
| | Water Utility SA - Residential | Shaabia | 23.00 | 06513133W |
| | Water Utility SA - Residential | Shaabia | 21.00 | 06513133W |
| | Water Utility SA - Residential | Shaabia | 9.00 | 06513133W |
| | Water Utility SA - Residential | Shaabia | 24.00 | 06513133W |
| | Water Utility SA - Residential | Shaabia | 12.00 | 06513133W |
| | Water Utility SA - Residential | Shaabia | 23.00 | 06513133W |
| 51 | Water Utility SA - Residential | Shaabia | 652.00 | 06513145W |
| | Water Utility SA - Residential | Shaabia | 600.00 | 06513145W |
| | Water Utility SA - Residential | Shaabia | 242.00 | 06513145W |
| | Water Utility SA - Residential | Shaabia | 271.00 | 06513145W |
| | Water Utility SA - Residential | Shaabia | 628.00 | 06513145W |
| | Water Utility SA - Residential | Shaabia | 700.00 | 06513145W |
| | Water Utility SA - Residential | Shaabia | 289.00 | 06513145W |
| | Water Utility SA - Residential | Shaabia | 317.00 | 06513145W |
| 52 | Water Utility SA - Residential | Shaabia | 676.00 | 06518128W |
| | Water Utility SA - Residential | Shaabia | 1,236.00 | 06518128W |
| | Water Utility SA - Residential | Shaabia | 682.00 | 06518128W |
| | Water Utility SA - Residential | Shaabia | 1,450.00 | 06518128W |
| | Water Utility SA - Residential | Shaabia | 1,160.00 | 06518128W |
| | Water Utility SA - Residential | Shaabia | 762.00 | 06518128W |
| | Water Utility SA - Residential | Shaabia | 1,546.00 | 06518128W |
| | Water Utility SA - Residential | Shaabia | 870.00 | 06518128W |

بحث بعنوان:

# معالجة المياه الرمادية في المباني الخضراء: فوائد معالجة المياه الرمادية وإعادة استخدامها في حي الوقن السكني في مدينة العين

إعداد: الدهيم نصيب سهيل يطبع العامري

إشراف: د.راشد خليفة الشعالي

يمثل نقص المياه مشكلة عالمية تتطلب حلولاً و سياسات أكثر حكمة وأكثر استدامة لإدارة الموارد المتوفرة منها. و لهذا فإن التوجه نحو معالجة و إعادة استخدام المياه الرمادية بدأت تنتشر على نطاق واسع و أصبحت تهيمن على مبادئ و سياسات إدارة المياه من أجل الاستعاضة عن النقص المحتمل.

و لقد شهد استخدام المياه في العقود الثلاثة الماضية في الإمارات زيادة كبيرة و ضغطا على مصادر المياه الجوفية و المياه المحلاة . وهذا ما دعا بصناع القرار الى استحداث جهود جادة ومتنوعة و حثيثة في نفس الوقت من أجل تحسين التزويد بالمياه والعمل على إعادة استخدام المياه الرمادية و معالجتها و إعادة استخدامها.

وفي هذا السياق، فإن الباحثة اعتمدت منهجية البحث الكمية و الوصفية. الباحثة سلطت الضوء على الخلفية النظرية الوصفية على مصادر المياه في إمارة أبو ظبي- دولة الإمارات العربية المتحدة، و منطقة الوقن على وجه التحديد. بينت هذه الخلفية النظرية نظم معالجة المياه الرمادية المركزية و اللامركزية و المختلطة، كما بينت التقنيات التي تتم بها عمليات المعالجة تلك. المنهجية الكمية اتبعت في دراسة الحالة في منطقة الوقن في المنطقة الشرقية.

لقد كشفت الدراسة الحاجة المتزايدة باستمرار للإمداد بالمياه من شركة ترانسكو للقطاع السكني بصفة خاصة - عدا عن الاستخدامات الأخرى- ، ففي عام 2012 قامت الشركة بتزويد منطقة الوجن ب 1200000 جالون لكامل الحي. يستهلك الاستخدام السكني منها ما يمثل 40.75%، و ينتج ما مقداره 40% من المياه الرمادية الناتجة عن الوضوء ، وأحواض غسيل الأيدي و الأدشاش، مما أعطى إمكانيات ضخمة نحو إعادة تدوير و إعادة استخدام المياه الرمادية المعالجة.

تم اقتراح استخدام النظام اللامركزي و المعالجة الطبيعية التي تعتمد على فصل الأجسام العالقة في المياه الرمادية و من ثم تعقيمها باعتماد خبرة شركة محلية. لقد أظهرت الباحثة من خلال الدراسة أمكانية أن توفر هذه المعالجة على الحكومة أكثر من مليوني درهم سنوياً بحيث يمكن تخصيصها لأنشطة تنموية أخرى في منطقة الوجن. و على هذا الأساس فإن هذا البحث يعطي ثقلاً كبيرا و يفتح أفاقاً واسعة للدراسات الأخرى ذات الصلة و الشبيهة في مناطق أخرى من أجل المحافظة على الموارد المائية و استدامتها في دولة الإمارات العربية المتحدة ودول الخليج.

UAEU College of Engineering

جامعة الإمارات العربية المتحدة
United Arab Emirates University

جامعة الامارات العربية المتحدة

كلية الهندسة

قسم الهندسة المعمارية

# معالجة المياه الرمادية في المباني الخضراء: فوائد معالجة المياه الرمادية وإعادة استخدامها في حي الوقن السكني في مدينة العين

الدهيم نصيب سهيل يطبع العامري

رسالة مقدمة لاستكمال متطلبات الحصول على درجة الماجستير في الهندسة المعمارية

قسم الهندسة المعمارية

باشراف: د. راشد خليفة الشعالي

يوليو 2014

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