UNIVERSITY OF BIRMINGHAM

Development of an Environmental Health Risk and Socio-Economic Perception Framework to Critically Assess the Management of TWW Reuse Practice and Options in Kuwait

By

Sadeq H. GH. H. Muqeem

B.Sc. in Environmental Health, Eastern Kentucky University (EKU), USA

M.Sc. in Environmental Management, Arabian Gulf University (AGU), Bahrain

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Abstract

This thesis introduces a new methodological approach to provide a framework for environmental health and socioeconomic perception that critically assesses the management of treated wastewater (TWW) reuse practice and options. The methodology combines Multi-Criteria decision Making (MCDM) and Rapid Impact Assessment Matrix (RIAM). The approach uses expert opinion to assess TWW reuse options and converts the qualitative subjective evaluation of experts into quantitative objective and numeric output. The methodology includes the use of a Driver Force, Pressure, State, Impact and Response (DPSIR) framework to analyse the current situation in a specific case study (Kuwait). The research identified the best available TWW reuse options for Kuwait and determined the essential environmental health and socioeconomic criteria affected by the practice of selected TWW reuse options. The latter include recreational and agricultural irrigation, firefighting and industrial and ruses, oil depressurization and groundwater recharge. Options where the public had direct contact with TWW, such as showering, cooking and drinking were rejected. Environmental health criteria were found to be the most significant criteria associated with TWW reuse practice and options, but given current heavy subsidies of wastewater treatment, distribution and transportation, the economic burden was also significant. Further research in this area is recommended to enable a reduction of pressures on freshwater resources through TWW reuse practice and this should be included within a wider context of integrated water management (IWM).

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Chapter 1

Introduction

1.1 Preface and Rationale

Improving water consumption and management has become one of the critical issues globally. The 4th edition of the World Water Development Report (WWDR) suggested that all associated water sectors (stakeholders) should be involved, and participate in water management (UNESCO, 2012).The report also suggested that lack of interaction and isolation between decision makers (water managers) has increased the challenges of water resource management and hence the risk to other sectors and consumers. Among many studies, EL-Ashry et al. (2010), Choukr-ALLAH (2010), Yi (2011) Barbagallo et al. (2012) and (Jhansi et al. (2013) highlighted that many countries are confronted with situations of water stress with respect to conventional freshwater supplies which requires new solutions such as water desalination. In a number of cases individual countries have to expand existing water sources and identify more sustainable alternatives. One of these alternatives is the reuse of treated wastewater (TWW) and for many countries, TWW reuse practice has become a vital process in water resource management for both environmental and economic reasons.

As highlighted by Asano (2001) and Zhang (2006), TWW reuse has a long history of practice (since the 19th Century) especially for agricultural and recreational irrigation as well as for industrial purposes. In most cases, the agricultural sector accounts for up to 70% of freshwater use compared to municipal and industrial sectors (UNESCO, 2012). Sustainable agricultural water management, therefore, plays an important role in minimizing the stress on freshwater. In this regard, Barbagallo et al. (2012) pointed out that as a major TWW reuse option; agricultural (or recreational) irrigation should be integrated within water resources management. Accordingly, as part of an integrated water management strategy, the potential risk and benefits of TWW reuse together with building the capacity of practitioners and planners, and developing appropriate policy frameworks to protect human health and the environment, have to be recognized and considered.

Perceptions of the risks and benefits of TWW reuse practice usually differ between stakeholders. Public perceptions regarding this issue differ significantly from that of private stakeholders. A number of studies including Robinson et al. (2005) Dreizin (2007), Abu-Madi et al. (2008), Dolnicar and Schafer (2009), AL-Humoud and Madzikanda (2010), and Baawain et al (2012) recognized that public perceptions toward TWW reuse are influenced by individual values, beliefs, and personal or previous experiences and the reasons for rejecting TWW are mostly associated with health, social and cultural risks. Therefore, the public need to trust the management process and decision makers must be confident of TWW quality to ensure that the public are willing to use (reuse) such water. In contrast, government and private stakeholders (e.g. agricultural companies and farmers) will need to consider economic pressure (feasibly and investment in commercial agriculture, fisheries, and tourists services etc.) as highlighted by Pelesikoti (2003).

Environmental issues are usually associated with several economic, social and cultural and political aspects. For the reason empowered decision makers must consider each aspect of an environmental issue separately and disregard general predicted and uncertain risks. The decision making process must consider all these criteria (aspects) when confronted with a complex or difficult situation. Provision of expert opinion and judgment before taking action will support the decision making process as recommended by many previous studies regarding TWW reuse practice and options (Radcliffe, 2006; Hajeeh, 2010; Slotterback et al, 2010; Al-humoud, and Madzikanda, 2010; Akpor and Muchie, 2011; Baawain et al, 2012).

Reliability and safety of TWW reuse as well as public policy and perception will change with advanced WWT systems and good TWW quality. Asano (2006) concluded that TWW reuse practice and options (as an alternative water supply) should be expanded as an essential element in sustainable water resources management. In addition, Hamoda (2013), highlighted that regulatory TWW quality limits can determine TWW reuse applications. Accordingly, as WWT level increases, more TWW reuse options can be practiced (with more environmental health safety and less risks). Moreover, Ordonez et al. (2011) recognized that advanced WWT meets most discharge criteria and is often suitable for direct reuse.

Risk communication involves and integrates information from stakeholders, risk assessors and managers which actively informs and updates other processes. Risk management and communications should be based on the outcomes of a full risk assessment. Accordingly, Chen et al. (2013b) suggested that cost and social analysis are required so that policies can be established to reduce risks to human health and the environment in a sustainable way. Risk analysis = risk assessment + risk management + risk communication (Australian Government, 2005; Australian Government, 2008). Risk analysis is an integrated framework for TWW reuse (Ganoulis, 2012) including risk assessment (which considering the physical system, loads, uncertainties, risk quantification), and risk management (addresses alternative risks, costs, social and health aspects).

Although the above studies consider public participation to be an effective process within the wider decision making process, public opinion (as highlighted by some experts and decision makers) might be neglected in situations when the decision is critical. It is usually hard for the public to reflect an objective reaction when investigating a complex environmental issue that involves several criteria (e.g. environmental health, socio-economic, political, cultural and psychological criteria). Such criteria include many factors involving risks and influencing perceptions. Therefore, government has to regulate the decision making process towards what is considered best for all stakeholders, making trade-offs to achieve environmental equity within such situation. Thus expert judgment involving all stakeholders is important to handle such issues for successful integrated risk assessment for the management of TWW reuse practice.

Hence, complex projects comprising environmental issues with multi-interacted impacts can be difficult to assess and evaluate. Environmental assessment of alternatives is complex and difficult to quantify for further evaluation for an ultimate decision making process. Frequently, there is a lack of quantifiable information available to perform an assessment analysis (Alessandri et al, 2004). Therefore, Barjoveanu et al. (2010) recommends developing appropriate indicators and weighting scales. This can be effective for a reliable environmental health risk or environmental impact assessment (EIA) as discussed by Forsyth et al. (2010) and Slotterback et al. (2010). In such cases, quantitative research approaches suggest that the application of more qualitative processes such as strategic proactive planning can be effective in environmental decision making.

This thesis adopts a MCDA methodology to take into account different but significant criteria which are influenced and affected by TWW reuse practice and options. The development of this decision making system is intended to lead to an effective diagnostic resolution which can improve TWW reuse management. The methodology involves developing a decision making approach that can be applied by any local authority responsible for TWW and reuse management. Further the thesis assesses selected TWW reuse options by a second EIA tool using expert opinion and judgement called Rapid Impact Assessment Matrices (RIAM). Finally, RIAM is used to compare and test its results against the first method (MCDM) to provide more confident decision making.

As highlighted by Forsyth et al. (2010) and Slotterback et al. (2010), environmental health impact assessment (EHIA) can provide a ‘smart’ approach for planning which addresses critical aspects of human health and the environment. Specific elements of EHIA (Forsyth et al, 2010) include Screening (filtering out projects that do not need health impact assessment), Scoping (determining what should be assessed and how) and Rapid Assessment (either fully open or with invited participants who read background materials in advance and provide expert judgments). Rapid Assessment can involve more people in the health impact assessment process as required to aid long-term monitoring.

Thus the design for Rapid Assessment is a critical part of public or environmental health assessment and can be achieved through an EHIA. The tool is unusual because it specifically focuses on health issues related to urban and comprehensive planning and post research suggests that EHIA is a growing field that comes in a number of forms (Forsyth, 2007; Forsyth et al, 2010; Slotterback et al, 2010) including, audits, coping tools, screening tools or preliminary checklists.

A number of studies (Pastakia, 1998a; Pastakia, 1998b; DHI, 2009a; DHI, 2009b; Yousefi et al, 2009) considered RIAM as an innovative and progressive EIA tool that can be constructed by experts' opinions and perceptions; surveying the opinions of experts within designed matrices that are divided into four groups: Biological-Ecological, Physical-Chemical, Social-Cultural, and Economical-Operational, which might be directly or indirectly, affected by the project during its different phases. The RIAM tool overcomes the problems in recording subjective judgments by defining the criteria and scales against which these judgments are to be made (converting subjective qualitative opinions and judgments to objective quantitative results).

1.2 <u>Research Gap, Aim and Objectives</u>

The research presented in this thesis addresses environmental health impact and socio-economic (risks and benefits) perceptions of TWW reuse practice and options. It concerns countries that challenge water scarce, freshwater stress and have the opportunity to reuse TWW as an alternative water resource for different purposes. Gaps in assessing TWW reuse practice and options towards an integrated water management (providing effective and efficient assessment that support decision making) persist with inadequate research. This research emphasizes the potential risks that the reuse of TWW might cause (environmental health and socio-economic impacts in the future) for the management of TWW to proactively plan for TWW reuse strategies.

The novelty of this research is that it is directed toward developing an integrated framework of TWW reuse assessment to support decision makers and assists in TWW management. To justify and fulfill the above gap, this thesis aims to create an optimized assessment framework for the management of TWW reuse practice. It also targets the potential and or future risk associated with this environmental issue. The aim of this research will be accomplished by addressing the following objectives:

1. Literature review of resent researches and studies associated with TWW reuse practice and options assessment and management.
2. Investigate and document the current TWW reuse practice for the case study (Kuwait).
3. Analyze the available and applicable TWW reuse options with respect to critical criteria of any case study.
4. Develop a suitable assessment of available TWW reuse options (as a baseline study for strategic planning and management of TWW reuse practice).
5. Predict potential environmental health and socio-economic risks that may be caused by practicing any TWW reuse applicable option.

Given the research aim and objectives, the thesis addresses the following questions:

1. What are the major problems of TWW resource and reuse?
2. What are the main TWW reuse options? Which options are applicable?
3. How can TWW reuse practice be assessed conclusively and managed (with all components, factors and criteria) in an integrated model?

1.3 <u>Study Justification</u>

TWW options must be adequately and efficiently assessed before reuse. Water management authorities have to plan to strategically consider TWW reuse practice as an alternative water resource. To approve TWW as an alternative water resource, TWW reuse practice and options must be assessed efficiently. Future studies then can be confident in relying on their results for proactive actions to address TWW reuse practice and options to include TWW when seeking to manage national water in an integrated manner. Unlike previous research in this field, the current study covers most aspects and factors associated with TWW reuse practice as demonstrated in Figure 1-1. An integrated research approach is adopted to involve most TWW reuse practice and options aspects rather than assessing each aspect separately. This research combines all factors and components associated with TWW reuse practice and provide an effective decision making of available options by efficient expert perceptions in an integrated assessment model.

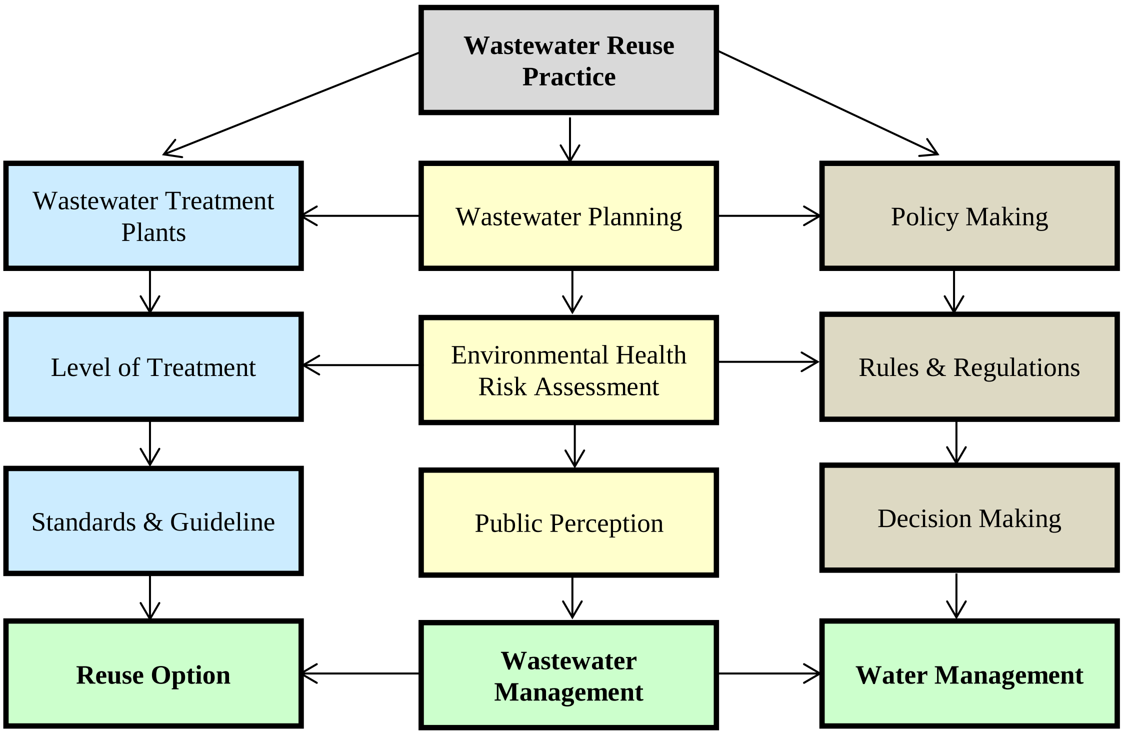

Figure 1 - 1: The interrelationship and Directions of TWW Reuse Practice

A variety of factors affect TWW reuse practice. Policy making, rules and regulation, financial affordability, water resources planning and management, and environmental health risk assessment all influence TWW reuse practice options. Each TWW reuse option requires certain regulations and specific guidelines. The level of treatment depends on the type of practice. Public perception is also an essential aspect for TWW reuse planning and management. Therefore, effective and integrated assessment of environmental health risks and socio-economic perceptions prior to such practice is essential.

It is important when dealing with environmental health impacts to use combined or mixed methodologies, selecting suitable methods to overcome data quality limitations (Walker et al, 1999; Forsyth et al, 2010; Randall and Jowett, 2010, UNEP / UN-HABITAT, 2011). Respectively, such an approach efficiently assesses the situation (and perceptions) and improves public health awareness of TWW reuse practice. However, the level of knowledge of participants is also important. Expert judgement and opinion is preferred rather than socio-cultural attitudes and beliefs only. Consequently, policies, rules and regulations and thus decision making will be performed more effectively.

The approach in this thesis can be applied in any case study and the outcome will play an important role in assisting associated authorities and directing public participation. It is suggested that the study results will assist and support policy and decision making, rules and regulation setting and strategic planning and management. It will also guide and assist stakeholders and the public toward more effective perception for performing proactive action toward TWW reuse practice and options.

At present, there has been no efficient or proper application in relation to TWW reuse practice that takes into consideration the combination of environmental health, economic, social, institutional and technical aspects. It has also been found that there has been no clear strategic planning for TWW reuse practice and applications in Kuwait (as discussed below). This current research addresses the following original aspects:

1. Stakeholder perceptions and opinions (government decision makers, empowered researchers and specialists, private stakeholders and public representatives) on TWW reuse practice and options.
2. Selection of best available TWW reuse options and assessment of these options for further management and planning using effective methods and tools to cover all aspects that have not been adequately addressed previously.
3. Analysis of critical criteria and factors of importance that will be affected by practicing each selected applicable TWW reuse option to ensure efficient assessment and management of water resources.

Thus this research delivers baseline information for further TWW reuse management and planning that can reduce pressure on freshwater utilization. It is justified in order to fill the gaps of TWW reuse for being practiced as an alternative water resource.

Kuwait (the case study) has limited freshwater resources and must utilize every available alternative water resource. This research assesses and contributes sustainable management of this alternative water source in Kuwait. Finally, the result of this research will support decision makers in any case study to consider these findings into the national water strategies. Using Kuwait as a case study provides an excellent example for other countries with similar water resources and environmental conditions. Moreover, this research approach can be conducted for any case study (even with different conditions) once it is simulated and reformed as necessary.

1.4 Research Case Study Justification

As a highly water stressed country, Kuwait relies extensively upon desalinated water and groundwater abstraction to satisfy water demand. Brackish groundwater and treated wastewater (TWW) are used to a limited extent for agricultural and industrial purposes. Currently, the overall water consumption reached 1,202 x 10^6 m^3 (EPA, 2012), and about half of the national water supply is provided by desalinated water. Domestic and agriculture sectors account for the majority of Kuwait's total water demand, with only a small quantity used by industry. On a per capita basis, Kuwait has one of the highest water usage rates in the world (AL-Humoud and Madzikanda, 2010; Kuwait EPA, 2012). Thus for Kuwait, TWW at least for irrigation (both recreational and agricultural) and industrial (industrial processes and fire-fighting) purposes could be a vital source of water (to supplement water from other sources) and should not be wasted. TWW reuse can potentially contribute to environmental conservation and reduce fresh water demand.

Currently Kuwait is developing one of the largest advanced wastewater treatment plant (WWTP) with Reverse Osmosis (R.O.) technology. Such technology is usually used for water desalination. Utilization of such costly advanced WWT technology and lack of TWW reuse practice management justify the necessity for assessing TWW reuse practice in Kuwait as the case study country for such research approach. Nevertheless, those reasons include the following characteristics:

1. Kuwait is characterized by an arid, desert environment with no surface water. Its freshwater resources include only limited quantities of groundwater.
2. Kuwait mainly relies on non-conventional water resources which are desalinated and TWW and consequently the country suffers from recurrent water scarcity.
3. Mean rainfall in Kuwait is around 100 mm per year. With limited annual groundwater recharge, freshwater resources are deteriorating in quantity and quality.
4. In Kuwait, water management problems include an absence of development plans, weak tariff system, high water subsides and high leakage in the water supply systems, as well as economic growth (increasing water demand) and a lack of awareness of the value of water that result in a high water per capita consumption that exceeds 500 liters per day.
5. Kuwait manages water through fragmented water institutions. There is a lack of coordination between the appropriate authorities and government departments (several governmental authorities oversee water resources development and management).
6. The water demand (consumption) in Kuwait is managed unsustainably (water policy is insufficient and there is a lack of enforcement of water legislation.

Hence, Kuwait suffers from an unsustainable development and management of water and TWW resources. In addition, the current gap between the available water resources and water demand is anticipated to increase in future thus further increasing the stress on freshwater resources. Therefore, TWW reuse is considered to be a potentially important alternative water resource for the country.

Thus, this thesis discusses the major elements of TWW reuse practice. It identifies the best options for the case study country and assesses the environmental health risks and socio-economic perceptions of TWW reuse practice and options. The research recommends that proactive actions should be adopted to select the best TWW options, planning, and management.

1.5 Research Approach Strategy, Design and Organization

As mentioned above, Kuwait was selected for the case study where this approach of TWW reuse practice and options assessment is conducted. The research draws heavily on data provided by the government and private sectors in Kuwait: it investigates a complex problem, controls and minimizes potential risk in the society. While contacting government and private sector representatives is not a problem, the data collected can sometimes be inadequate, confidential and subject to uncertainty. Thus the research focuses on collecting qualified data and responses from interviews and designed short survey questionnaires elicited from experts (for expert judgement) and stakeholders (for their perceptions).

The research strategy adopts a combined qualitative and quantitative approach. It employs expert opinions, judgements and perceptions within short survey questionnaires, assessment checklists, field-work observations and interviews. The design of this research follows a certain pattern (through the research process) leading to the acquired results for future practical actions. Analysis of the current situation explores areas where further results of decision making and assessment can be employed.

The research involves selected stakeholders and decision makers as well as personnel and workforce (within TWW reuse practice) for expert judgments. The main methods of data collection include designed interview checklist, survey questionnaires (to be used for expert judgment results) consisting of specified and categorized number of questions. Additional assessment elements are also obtained through prepared EIA checklist and matrices. The mixed qualitative and quantitative research method for such research study provides an objective description of the data (using quantified numbers that represents the qualitative opinions) enable statistical analyses to analyse obtained data. The research steps and structure are as follows:

1. Literature review (Chapter 2) includes related official documents, reports and publications. This chapter reviews current understanding of TWW reuse practice and options, different perceptions of TWW and tools and methods for TWW reuse practice assessment and management. It also aids in providing the wider context to the research approach (area) and topic.

2. The current situation (of the case study) is analysed in Chapter 4 using an integrated environmental assessment framework called DPSIR (Driving Forces, Pressures, State, Impacts and responses). Major problems of TWW reuse and critical relevant factors to the issue (such as population growth rate, lifestyle and attitudes, water policies, and institutional capabilities) that both directly and or indirectly influences TWW reuse practice planning and management are described and analysed.

3. Interviews and short survey questionnaires were conducted as follows:

    a. Experts and specialists, public representatives, stakeholders and other TWW reuse beneficiaries' environmental health risk and socio-economic perception to select TWW best applicable / acceptable reuse options.
    b. Decision makers' participants for TWW reuse criteria weighing and TWW reuse best applicable options.
    c. Researchers and specialists for Component of TWW reuse practice and assessment for each TWW reuse option utilizing RIAM.

4. Conducting Multi-Criteria Decision Making (MCDM) (Chapter 5). Options of environmental health considerations and highest weight in the decision-making process are followed by testing and assessment based on certain criteria within the previously gathered data and utilized EIA tool (RIAM).

5. Applying the Rapid Impact Assessment Matrix (RIAM) to assess each TWW reuse option, and test and compare with the results of MCDM (Chapter 6).

Finally, the results (Chapter 7) of the research investigation are followed by a discussion considering the study limitations, recommendations and implications for future research studies (Chapter 8). Figure 1 - 2 summarizes the thesis design and structure.

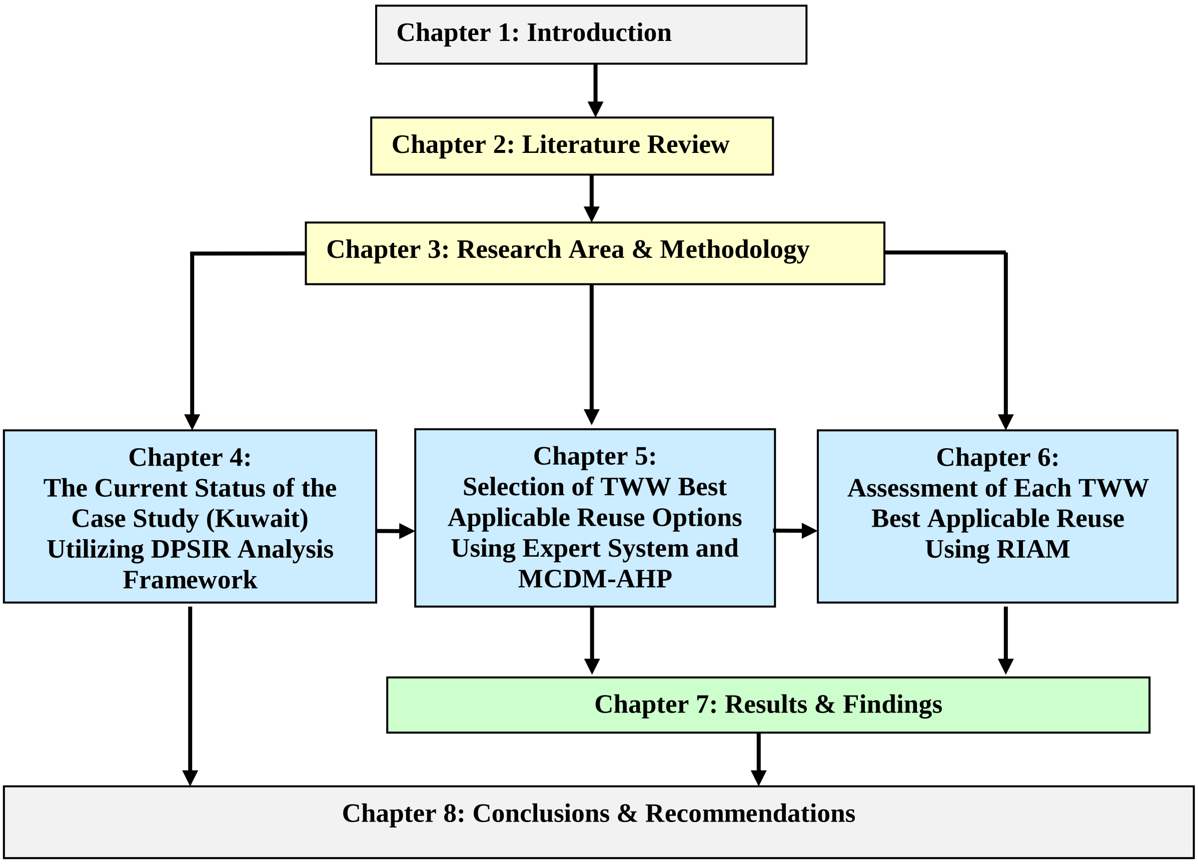

Figure 1 - 2: Summary of Thesis Design and Structure

Chapter 2

Literature Review

This chapter reviews recent research on treated wastewater (TWW) reuse practice and options. The chapter outlines the conceptual background to this area of research including different applications of TWW, and methods to assess and manage advanced TWW reuse practice. The chapter first explores levels of treatment and guidelines before discussing TWW reuse categories and applications. The chapter identifies previous studies, methods and tools that have been used for TWW reuse practice assessment and management, and outlines the scope of study. Finally, a summary of recent literature is provided to identify the key research gaps addressed by this thesis and justify the approach adopted.

2.1 Background

Water scarcity and the associated shortage of water resources for human consumption and services is one of the most pressing urban problems globally. It has been widely recognized that many environmental health problems (including depletion of surface and groundwater resources, water quality degradation, increased water salinity and emerging pollutants) are directly associated with conditions of water scarcity, excessive water consumption, and improper water resources management (WHO and UNICEF, 2000; Chen et al, 2013a). To overcome such problems, it is essential to proactively plan and manage water resources, identify alternative water sources and improve the efficiency of water consumption. As pressures on freshwater resources increase, the challenge of meeting water demand is becoming more difficult. Amongst many other research studies, UNEP (2005) and Allen et al. (2010) suggest that the efficiency of water consumption and the development of alternative water resources has become such a critical issue that water resources must be supplemented where possible by alternative water sources. One of the main alternatives capable of reducing pressure on freshwater resources is TWW reuse which has become an important component of water resource management for both environmental and economic reasons.

Grey or untreated water is a mixture of wastewater from households, offices and industrial effluent (Smith and Scott, 2005; Allen et al, 2010). It is a less polluted course of wastewater generated (about 40%) from households' washbasins, baths and showers (Memon et al, 2007). Wastewater discharged through kitchen sinks, WCs and washing machines (with the exception of rinse water) is normally excluded from the definition of greywater. Such recycled or reclaimed water can be utilized for different direct or indirect purposes when treated to standards that allow safe reuse (Haering et al, 2009). Important chemical or physical characteristics of TWW (among many other researches) are listed by Smith and Scott (2005), Dreizin (2007), Haering et al. (2009), Chen et al. (2013b) and Hamoda (2013), and include suspended sediment concentration, and levels of ammonia, nitrate and phosphate. Heavy metals and organic chemicals are associated with household sewage. Pathogenic microorganisms (which pose a biological risk) include bacteria, viruses, protozoans and parasitic worms.

According to the "Dublin Principles and Bonn Recommendation for Action", Esposito et al. (2005) and Criddle et al. (2010) suggest that wastewater is a valuable, socio-economic resource, which should be sustainably handled and equitably distributed. In this respect, recent research recommends that TWW reuse should be included as a part of an integrated water management strategy (Barbagallo et al, 2012). This builds upon early suggestions that strategic water reuse shall be developed in conjunction with public perception (Hochstart, 2006). Hastuti et al. (2011) concluded that domestic TWW reuse is a good non potable water resource with potential applications for urban housing. These studies (referenced here) are amongst many that recommend utilizing TWW for agricultural and recreational irrigation to reduce pressure on freshwater consumption.

Following what was generally unplanned and inefficient wastewater reuse practice in the 19th Century (principally in Europe and North America), wastewater treatments became widely practiced through the 20th Century and included a variety of reuse options depending on the resources available and local needs (Asano, 2001; Zhang, 2006). For example, TWW reuse practice has been used in industrial applications and recreational irrigation (e.g. green spaces, golf courses and sport areas) which were technically easy to manage and control. Agriculture is one of the most important applications of TWW reuse, and this is currently projected to increase especially in developing countries (UNEP, 2005). Merzthal and Bustamante (2008) suggested that a national legal and institutional framework has to be created to encourage productive utilization of TWW for agriculture and green areas. Barbagallo et al. (2012) pointed out that the agricultural irrigation is the major TWW reuse option in any integrated water resources management. Therefore, such practices should be integrated within the national water management policies as it represents a good alternative water resource.

Recent developments in TWW reuse practices have been reviewed by Chen et al. (2013a) and Hamoda (2013), and include the potential that with recent more advanced wastewater treatment plants (WWTP's) utilizing ultrafiltration (UF), reverse osmosis (RO) and microfiltration (MF) processes, it is possible to remove most Total Suspended Solids

(TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and microbial pollutants. This makes TWW suitable for more reuse options. At present, several countries including Australia, China, Singapore, the United States, Canada, Middle East and Kuwait, have utilized these technologies and have adopted TWW reuse practices for a variety of options (Ordonez et al, 2011; Chen et al, 2013a; Hamoda, 2013).

Commonly, TWW quality depends on the level of treatment. TWW then is used for each reuse option accordingly (each reuse option must be within the safe limits for both human health and the environment). Water quality is based on the WWTP design and how the wastewater is operated. The risk of any failure in this case is defined as the impact of water quality due improperly TWW and standard obstacles (Astaraie-Imani et al, 2012). Therefore, to reduce water quality risk failure, operational control and an optimized design are required to reduce such risk (e.g. of dissolved oxygen and ammonia concentrations).

2.2 TWW Reuse Categories and Applications

TWW reuse is an evolving practice worldwide which has become a ‘smart’ option for reducing stress on freshwater and increasing available water resources. TWW reuse can be practiced for applications including agricultural irrigation, aquaculture, landscape irrigation, urban and industrial uses, recreational and environmental uses, and groundwater recharge (Asano et al., 2006; Scheierling et al, 2010). UNEP (2005), Chen et al. (2013a) and Hamoda (2013) amongst others have highlighted that depending on the wastewater treatment level (proper and advanced wastewater treatment, which complies with water standards and guidelines), TWW can be reused for different purposes as illustrated in Figure 2 - 1.

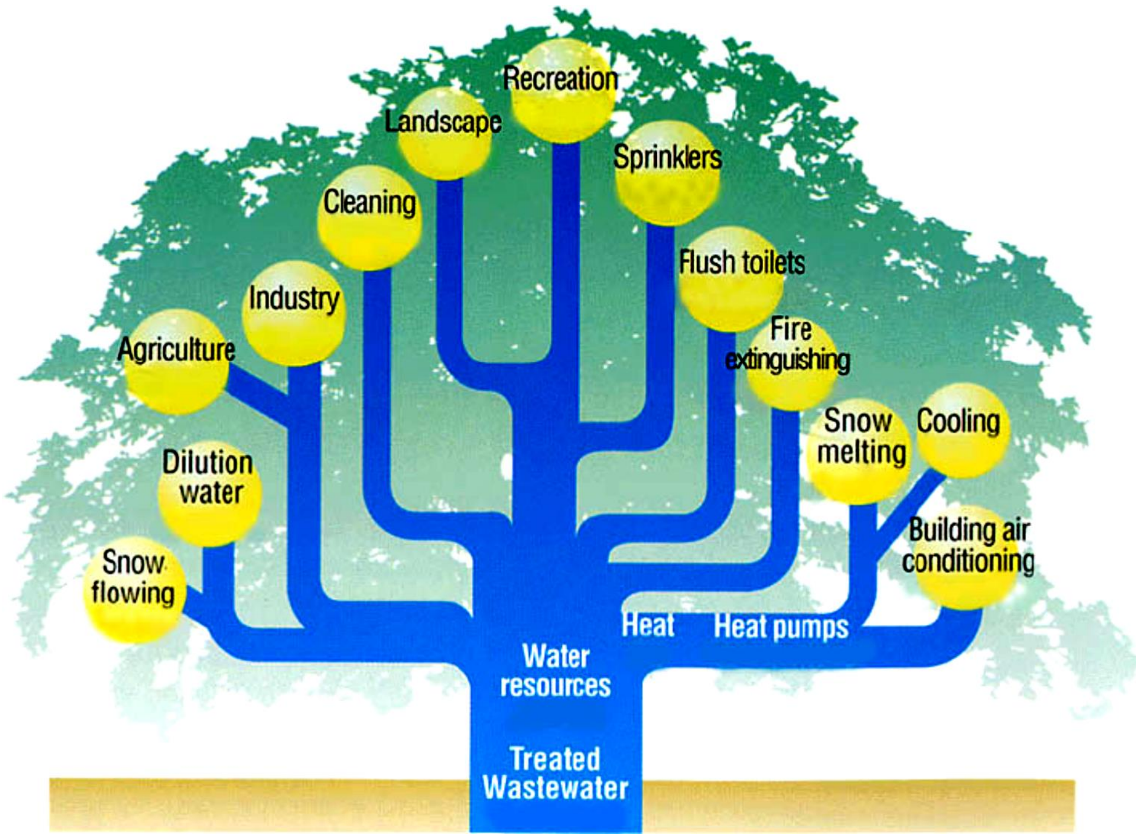

Figure 2 - 1: Tree of Water Resources Recycling (UNEP, 2005 Based on Ministry of Land, Infrastructure and Transport of Japan (MLIT), 2001)

By satisfying some of the water demand by TWW reuse, it may be possible to reduce the need for additional infrastructure with financial, technological and environmental implications. Reuse practices can include replacing potable water with non-potable waters applications including toilet flushing and landscaping (Allen et al, 2010). Houses usually have one set of pipes of water and another for water removal (this system uses highly treated water for all applications including potable drinking water). Even though implementing additional infrastructure within household properties for such applications has a high initial economic burden (financial and technological cost), this can be reduced over the short or long-term depending upon the TWW reuse option.

Studies of water and TWW assessment and management (e.g. Robinson et al., 2005; Dreizin, 2007; Abu-Madi et al., 2008; Merzthal and Bustamante, 2008; AL-Humoud and Madzikanda, 2010; AL-Anzi et al., 2011) recognized that despite widespread urban water shortages and conditions of water scarcity, many countries still make only limited use of TWW and only a minimal part of their total water resource demand is satisfied by TWW. As suggested earlier, the agricultural sector (principally irrigation) is one of the most important areas of TWW reuse and TWW is mostly used for agricultural (e.g. crops, palms, and other agricultural products) and recreational activities (e.g. green areas, sports fields, and public parks).

Firefighting, industrial processes, groundwater recharging, and oil field depressurization are also areas where wastewater (especially advanced TWW) is currently reused (Chen et al, 2013a). However within the domestic sector, the use of TWW for purposes such as car washing, toilet flushing, and showering, has been minimal. This reflects uncertainties over the implications for human health as well as psychological, religious and precautionary reasons. For these reasons, utilizing treated wastewater as potable water even after application of highly effective treatment technologies such Reverse Osmosis (RO), is still not recommended.

In contrast, Jamwal and Mittal (2010) point out that TWW is suitable for many applications and has been recognized as an alternative water resource which must be effectively evaluated and reused to reduce stress on freshwater resources. Hespanhol (1997) classified TWW reuse into four main categories: (1) Agriculture and aquaculture (most widely used for low quality water); (2) Urban (mainly utilized for non-potable purposes including recreational irrigation, fire protection and toilet flushing); (3) Industry, which does not require water of potable quality (e.g. for industrial cooling and boiler water, and other industrial processes); (4) Recreation and landscape enhancement**,** ranging from small recreational landscaped areas to fully water-based recreational sites for swimming, boating and fishing and artificial wetlands.

Hazra et al. (2011) suggested that constructed artificial wetlands are a good example of a successful TWW reuse practice with two main systems (types): (1) free water surface (water flows above the ground and plants are rooted in the sediment layer at the base of water column) and (2) subsurface flow (water flows through a porous surface such as stony, sandy or mixed permeable media in which the plants are rooted). This TWW reuse option provides a method of sewage treatment in which organic pollutants degrade to non-toxic substances without additional use of chemicals (Hazra et al, 2011). They can be adopted and managed easily by local authorities.

Asano et al. (2006), on the other hand, identified seven categories of water reuse applications as listed in Table 2 – 1 which summarizes most TWW reuse options. Most wastewater reuse projects are for non-potable applications such as agricultural and landscape irrigation and industrial uses. Importantly, Asano et al. (2006) suggested that there is no framework to compare reuse practices and options. Moreover, the interests of future generations are not considered in water management and planning.

Table 2 – 1: Water Reuse Categories and Applications (from Asano et al, 2006)

Category	Typical Application
Agricultural Irrigation	Crop Irrigation and Commercial Nurseries
Landscape Irrigation	Parks, School Yards, Freeway Medians, Golf Courses, Cemeteries, Greenbelts and Residential
Industrial Recycling and Reuse	Cooling Water, Boiler Feed, Process Water and Heavy Construction
Groundwater Recharge	Groundwater (GW) Replenishment, Salt Water Intrusion Control, and Subsidence Control
Recreational / Environmental Uses	Lakes and ponds, Marsh enhancement, Stream-flow Augmentation, Fisheries and Snowmaking
Non-potable Urban Uses	Fire protection, Air Conditioning and Toilet flushing
Potable Uses	Blending in Water Supply Reservoirs, Blending in GW and Direct pipe to pipe Water Supply

Hence, new and effective methods and tools are required to assess the various aspects of water sustainability to ensure sustainable water resources use. Merzthal and Bustamante (2008) suggested a national legal and institutional framework should be created to encourage integrated wastewater treatment and TWW reuse. Some TWW reuse practices and guidelines worldwide are provided (within Tables and Figures) in Appendix (1).

2.3 Levels of Treatment and Guidelines Vs Reuse Options

To a large degree, TWW reuse options depend upon the degree or level of treatment (Hamoda, 2013). This is the most essential element of TWW reuse practice and is generally referred to as wastewater treatment (WWT) (Hearing et al, 2009). WWT includes purification and disinfection of wastewater prior to reuse to avoid (or minimize) any expected human or environmental health risks. Within an Environmental (Health) Impact

Assessment (EIA) or (EIHA), monitoring (regular sampling and monitoring TWW effluents) is essential (O'Flynn, 2010). Barbagallo et al. (2012) suggested that once water has been treated prior to any reuse practice, wastewater must be monitored effectively, especially for irrigating crops. This monitoring must cover wetlands, sub-surface water systems, irrigation time periods as well as rainfall amounts (Hamoda, 2013). Thus, TWW characteristics for each option must remain within the safe limits for human health and the environment.

2.3.1 Levels of Treatment

Understanding the concepts and levels of water treatment is essential for WWTP engineers and for TWW reuse management personnel and individuals assessing TWW reuse options. Municipal wastewater passes through several levels of treatment; primary, secondary, and tertiary levels of treatment. In addition, some WWTPs provide quaternary treatment of tertiary TWW using membrane processes (e.g. ultrafiltration and reverse osmosis) to deliver enhanced TWW which is suitable for more reuse options (Hamoda, 2013). Figure 2 - 2 illustrates the first three wastewater levels of wastewater treatment (WWT) process (CSS, 2011).

The primary treatment level uses screens and settling tanks to remove the majority of the solid waste which can then be disposed of, for example by landfill. Water is then passed through settling tanks (or clarifiers) for several hours to allowing the sludge to settle and a surface scum to form.

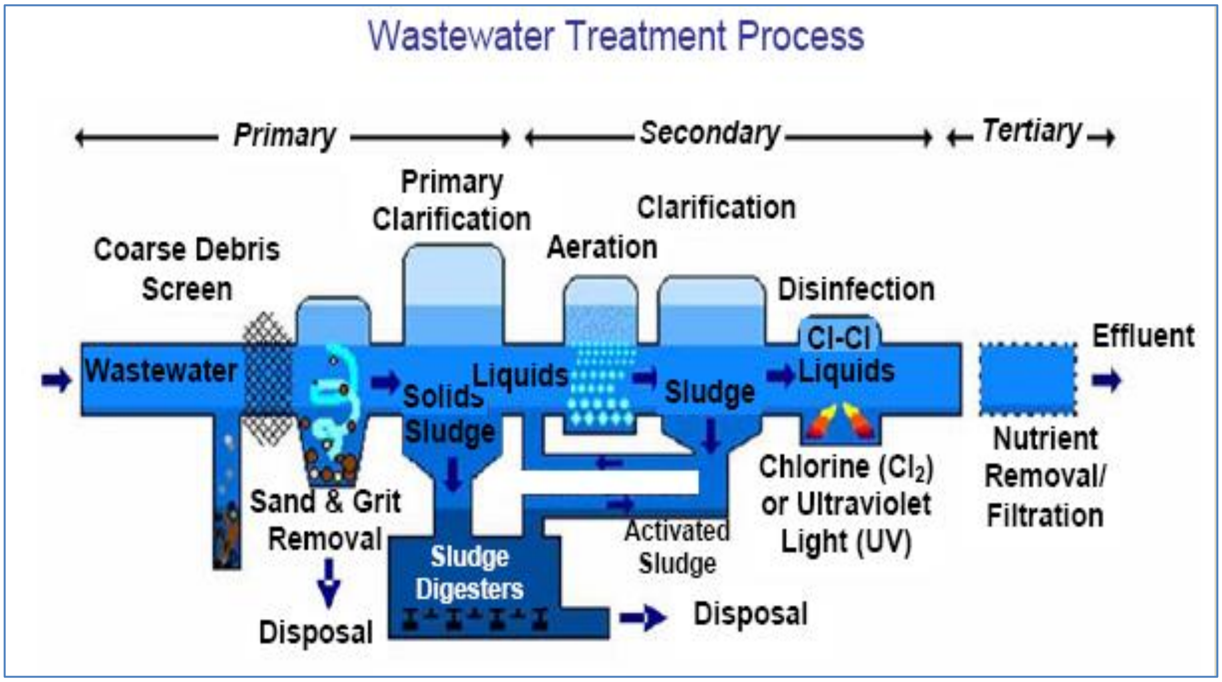

Figure 2 - 2: Diagram of Wastewater Treatment Process (from CSS, 2011)

The scum is then skimmed off, the sludge is removed from the bottom, and the partially treated wastewater proceeds to the secondary treatment level. A well-designed and operated primary treatment process should remove up to 70% of suspended sediment and 40% of the Biological Oxygen Demand (BOD) (90% of suspended solids, and up to 50% of coliforms) (M/J Industrial Solutions, 2003; Hamoda, 2013).

The Secondary treatment level uses bacteria to digest remaining pollutants. This is achieved by mixing wastewater with bacteria and oxygen. The latter helps the bacteria to digest the pollutants faster. The water then proceeds to settling tanks where the remaining sludge settles leaving the water mostly free of pollutants. Generally, secondary treatment removes up to 85% of BOD and suspended sediments, and 90 to 99% of coliform bacteria (M/J Industrial Solutions, 2003; Hamoda, 2013).

As an advanced level of treatment, Tertiary treatment removes colour and odour as well as dissolved materials such as metals, organic chemicals, phosphorus and nitrogen (M/J Industrial Solutions, 2003; Hamoda, 2013). As mentioned above, quaternary treatment of the tertiary TWW using membrane processes (e.g. ultrafiltration and reverse osmosis) can produce better quality TWW for certain reuse options.

To achieve urban wastewater reuse quality standards, Hastuti et al. (2001) suggested that regulation of treatment types must be carefully determined for individual reuse purposes**.** Hamoda (2013) also highlighted that with increasing treatment level, accepted levels of human exposure would increase. Figure 2 – 3 summarizes the suitable level of treatment for some TWW reuse options.

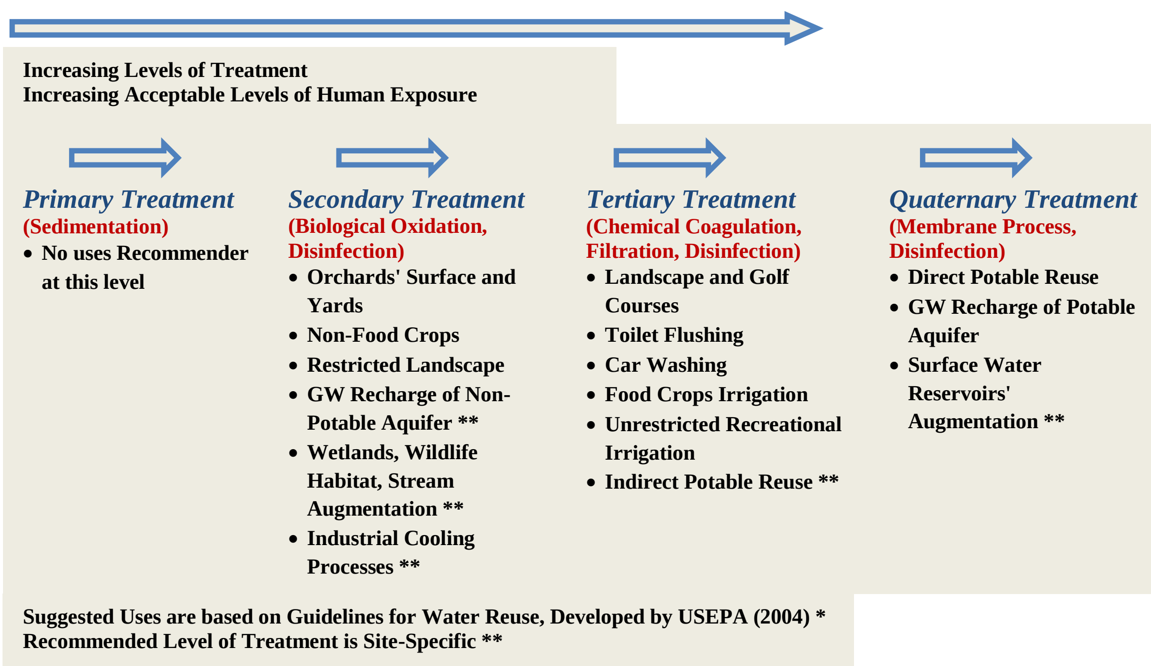

Figure 2 -3: Wastewater Treatment Levels Vs Reuse Options (from Hamoda, 2013)

2.3.2 <u>TWW Reuse Standards and Guidelines</u>

To consider TWW as a critical water resource, it is essential that there is effective assessment of the effluent quality from WWTPs and guidelines for its use for different activities. In 2006, the WHO set new standards and guidelines for TWW reuse practice to include most environmental health targets associated with reuse options, particularly agricultural irrigation (Scheierling et al, 2010). In this regard, Asano et al. (2006) recognized that water quality is an important factor of the potential applications and treatment requirements for water reuse. This enables wastewater reuse option to be distinguished and accepted by the public. To understand the relationship between water qualities and reuse levels, a conceptual representation of water quality changes through municipal applications is presented in Figure 2 – 4.

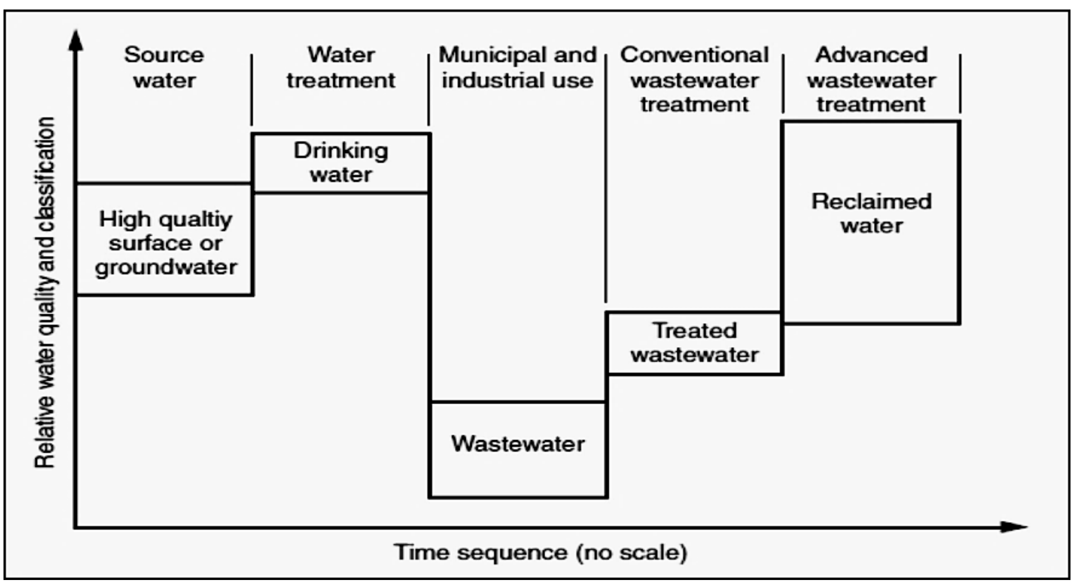

Figure 2 – 4: Water quality changes during municipal water uses in a time sequence and the concept of water reclamation and reuse (from Asano et al, 2006)

The level of treatment and technological efficiency determine TWW quality. For example, conventional secondary TWW does not meet the microbiological quality requirements for agricultural use unless it is supplemented by tertiary treatment (Peasey et al., 2000). Wastewater treatment has to achieve standards and guidelines set by regulatory agencies to protect human health and the environment (including aquatic ecosystems when TWW is discharged into a water body) and preserving the beneficial uses of receiving the TWW **(**Asano et al, 2006). For example, McKenzie (2005) and Haering at al. (2009) indicated that TWW reuse guidelines for agricultural irrigation in Mediterranean countries should either comply with World Health Organization (WHO) rules or rules modified from the United States Environmental Protection Agency (USEPA). As highlighted by Massouda et al. (2003), relatively few countries have developed their own guidelines.

Holt et al. (2006) indicated that water quality deteriorates when it is used or reused and that irrespective of how clean discharged water may be will require further treatment for its next reuse practice. Dreizin (2007) indicated that WWTPs can reduce concentrations of pathogenic microorganisms, but they cannot eliminate them completely. This problem can be solved by desalination of TWW (advanced WWT utilizing membrane process), but this is expensive and is usually not required if the water is to be used for agricultural purposes. Accordingly (as highlighted by Holt et al. (2006) amongst others), urban reused water is suitable for various uses including toilet flushing, public open space irrigation and private garden irrigation (recreational irrigation), cold washing machine taps, and environmental flows and water bodies (artificial wetlands).

2.4 <u>Environmental Health Risk Perception of TWW Reuse Practice and Options</u>

Environmental health risks associated with untreated or improperly treated WW can be derived from a variety of sources including industrial, agricultural, and sanitary wastewater discharges. Public health risk management plan should be established to minimize risk (Christchurch City Council, 2005; O'Flynn, 2010). The Environmental Health Quarterly Report reviewed by Graham (2000), recognized the relationship between wastewater (contaminated water) quality and human health including gastrointestinal, respiratory, eye, ear, and skin infections. Ingestion appears to be the most common mean of exposure to waterborne diseases. Besides microbial contamination, the physical and chemical characteristics of TWW such as pH, dissolved oxygen (DO), oxygen demand (chemical and biological), suspended and dissolved sediment concentrations, nitrogen (nitrite, nitrate and ammonia), phosphate, and metal concentrations must be continuously monitored (Umuhoza et al, 2010; Akpor and Muchie, 2011).

Human health and the environment will be affected by the complex relationship between water, agriculture and food quality (UNEP / UN-HABITAT, 2011; FAO / UNW-DPC / UNU-INWEH, 2011). As discussed by Lili et al. (2011), such water-related pollutants filtered through soil can accumulate due to long-term irrigation causing significant groundwater degradation. Water security issue would require water resources diversifying (distinguishing between water resources) in order to maintain water distribution in case of any breakdown or serious contamination (Cobos, 2015). Thus risk assessment is critical when reusing TWW in agriculture especially for soil and groundwater. The most common toxic impact resulting from TWW reuse for agricultural purpose is due to the accumulation of elements such as boron, chloride, sodium, as well as some heavy metals (Lili et al, 2011). Soil contamination may in turn affect crop growth and quality (which consequently affects human health through ingestion). Moreover, pathogenic microorganisms in TWW can transfer through the air to the human respiratory system during irrigation (Lili et al, 2011; Ganoulis, 2012).

Hence, agricultural TWW reuse requires that appropriate water quality guidelines are produced and each crop should have its own irrigation quality permit. High quality standards must be enforced for irrigation to prevent potential environmental health risks (Dreizin, 2007). There are several significant issues and challenges in reclaimed water reuse as pointed out by Choukr-ALLAH (2010) and Lili et al. (2011) including: (1) insufficient knowledge of water resources and incomplete regulations and policies supporting TWW reuse; (2) pricing structure for marketing TWW; (3) lack of public awareness and acceptance; (4) insufficient financial support; and (5) lack of systemic risk management.

All stakeholders should contribute in water resources management process as highlighted by UNESCO (2005), and this participation should address all associated issues for an effective proactive planning and or management. Before assessing or managing TWW reuse practice and considering the potential for TWW as an alternative source of freshwater, it is necessary to distinguish between direct and indirect uses of TWW (Ganoulis, 2012). Direct reuse is when TWW is reused immediately after treatment (as for industrial TWW reuse in industrial processes), whereas indirect reuse is when TWW is first discharged to the environment (groundwater or river) before water is abstracted for use (Ganoulis, 2012).

Winpenny et al. (2010) suggested that water resources planning and management should be based on the quantity, quality and affordability (costs-benefits assessment of available applicable options). In developing an integrated water reuse strategy and predicting the future role and potential of water reuse, Hochstrat et al. (2008) suggested that the status of reuse activities and general water management data must be taken as a starting point. Risk management evaluates which of those risks identified in the risk assessment process require management and detailed plans or actions to control these risks. Risk communication involves an interactive dialogue between stakeholders and risk assessors and managers which actively informs other processes. Risk analysis = risk assessment + risk management + risk communication (Australian Government, 2005; Australian Government, 2008). Hence, risk communication is a dynamic process of interaction between the public and government (Ackley, 2008).

As suggested by California EPA (2000), health risk assessments can contribute to risk management by evaluating the best available alternatives (one of the most difficult questions of risk management is: how much risk is acceptable?). It is usually not possible to completely avoid risk or remove impact of any pollutant once it has been released into the environment. Even with the recent modern treatment technologies used in WWT, it is still difficult to overcome all potential risks to human and environment health. Incomplete and uncertain data and scientific knowledge make conclusions and decisions more complex (UNESCO, 2005). In addition to lack of knowledge of how much risk is accepted, there are still some unknown or known harmful contents of TWW which are not monitored.

As previously mentioned, advanced WWT technologies can provide more efficient TWW that may be more acceptable as a controlled water resource. To reduce risk to what is deemed a safe level (to protect human health and the environment), assessment and management scenarios can involve and represent ranges of treatment from low level to advanced most expensive treatments such as desalination using Reverse Osmosis (RO) technology (Salgota et al, 2006). Ortiz e al. (2007) suggested that modern WWT systems can provide purified water for certain reuse purposes that could play a significant role in water resources management in water scarce areas. In this area (reusing advanced TWW for different proposes), Du et al. (2014) suggested that different combinations of decision variables can help decision makers to identify the best solutions under the different environmental, economic, and technological concerns alongside considering trade-offs between economic benefits and environmental-capacity destruction.

2.5 Public Perception Vs Expert Judgement towards TWW Reuse Practice

As discussed by Klinke and Renn (2004), the uncertainties and complexities associated with TWW quality and reuse guidelines for different purposes complicates the assessment and decision making process (when seeking public perception, specialists' opinion and expert judgement) in water assessment, management and future researches. Future studies need to depend on reliable perception and results regarding TWW reuse practice for certain options. Invisibility of risk (when risk is uncertain or unpredictable) usually further complicates the assessment and decision making. The EIA process needs signs and indicators for the risk to be trusted, effectively monitored and controlled; otherwise, the "Precautionary Principle" must be used unless an efficient objective evaluation and assessment of the situation is provided (to avoid or mitigate the potential harm before there is scientific proof) (Klinke and Renn, 2004; Schafera and Bederb, 2006; UNDESA, 2012).

TWW reuse practices have been characterized by two conflicting perspectives; first TWW presents an invaluable water source which could play a critical role in water resources management; and second as a probable source of environmental health risk. The perception of risk reflects individual values, beliefs, and experiences as indicated by previous studies (by Robison et al., 2005; Abu-Madi et al., 2008; AL-Humoud and Madzikanda, 2010; and others). Social scientists have identified factors that affect perceptions of risk such as uncertainty, voluntary (exposure can be controlled) and equitability (risk distribution) (Klinke and Renn, 2004; Zhang, 2004; UNESCO, 2005). There are measurable differences in how technical experts and citizen stakeholders define and assess risk. Citizen knowledge and technical expertise are both relevant to assessing risk (Beecher et al, 2005) and thus ideally all stakeholders should be involved in risk assessment and management.

The inter-relationship of water risks to business, government and society groups are different (perceptions toward water risks differ amongst these stakeholders) (UNESCO, 2012). They weigh associated criteria (e.g. environmental, health, economic and social factors) differently based on their beliefs, knowledges and experiences as mentioned above. Hence, these perceptions are important and must be considered for an effective decision making process. For example, society is more concerned about risks to human health without considering benefits, whereas the government or private stakeholders seeks feasibility, cost-effectiveness and further economic benefits. This should not isolate a community from the decision-making process but should enable the public to contribute to an environmental problems’ resolution (Pelesikoti, 2003). The relationships between water risks among business, government and society are illustrated in Figure 2 – 5.

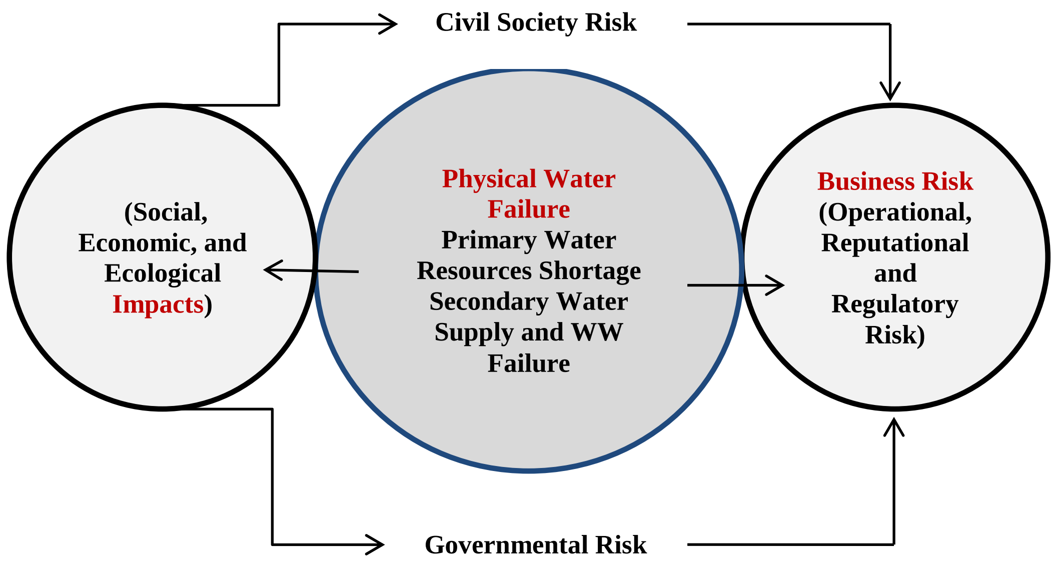

Figure 2-5: Inter-Relationship of water risks among business, government and society (from UNESCO, 2012)

Risk communication (Australian Government, 2005; Australian Government, 2008) amongst others was developed to address the gap between experts and the public in knowledge of technical topics. There are three ways for risk communication (Beecher et al, 2005): (1) Two-way communications (dialogue), (2) Addressing public useful knowledge and concerns, and (3) Transmitting information and levels of trustworthiness, fairness, and respect within the public. Different objectives can consider public perception and participation including TWW reusing economics, water conservation, TWW reuses options, and ownership and operation of small TWW projects. Thus public participation in the decision making process can improve TWW reuse practice planning and management. In China, for example, it is recognized that water resources management (WRM) needs to consider the relationship between government (with macro-regulation) and market regulation to achieve sustainable development and ensure water resources conservation and equity (Qiting et al, 2013).

The community must actively participate and should play an essential role in water resources management as highlighted by Sojamo (2015). All stakeholders must cooperate in water management and governance processes to ensure water sustainability and equity. Public perception of TWW options can be reflected and reviewed within survey methods such as interviews, checklists and questionnaires. However, such perceptions mostly reflect their health belief and behavior and may lead to subjective (insufficient) results (Robinson et al, 2005). In this regard, Ackley (2008) highlighted that in addition to inadequate or subjective perception, public acceptance of risk might be influenced by economic benefits regardless to any environmental health control.

In response to this, it has been suggested that experienced public representatives (trusted credible non-governmental originations (NGOs) such as civil society groups) can provide more objective and reliable public based-perception of the risk (Ackley, 2008). Dolnieara and Saunders (2006) stated that adoption of public participation, and considering public responses towards TWW reuse and obtaining efficient (more accurate) perception of TWW reuse (rather than hypothetical evaluations by respondents) will contribute to effective TWW planning and management. To build and maintain public confidence in water resource management and water reuse decision making, five critical themes can be used: (1) managing information for all stakeholders; (2) maintaining individual motivation and demonstrating organizational commitment; (3) promoting communication and public dialog; (4) ensuring a fair and sound decision making process and outcome; and (5) building and maintaining trust (Hartley, 2006).

Regarding the rural water management in China, Yu et al. (2015) suggested that successful integrated water management can be achieved by “appropriate policy encouragement, effective technology and information support, continuous capacity building activities and broad international collaboration" including: (1) institutional reform so that different stakeholders can work together and ensure concrete effort to promote water management, (2) revision of the current water management regulations seeking changes for more water management improvement, (3) adoption of efficient economic tools, (4) technology improvement and (5) capacity-building to improve overall public awareness.

Hence, public intention in trusting scientists and health professionals is to gain necessary information on environmental health and technical aspects of the issues. Although they behave and act with more trust to their own personal impressions trying to form their own judgments, they still need to follow and depend on experts' advices. Hartley (2006) recognized that the public usually prefer that water is reused for reasons such as water conservation, environmental health protection, and for cost-effective and water resource management. Therefore, there is an argument to develop a strategy of public support and participation in decision making within TWW reuse practice. This strategy should include market analysis, grouping individuals and assessing their behavior (Hartley, 2006; Dolnieara and Saunders, 2006). Thus, the more diverse the backgrounds of experts and professionals (from both government and non-government organizations (NGOs), as well as other environmental and academic institutions), the more successful decision making and the more concrete results in assessment and management (Rey et al.2014).

Regulating public participation and perception in this case is essential to developing an integrated EIA. Previous literature regarding public perceptions toward TWW Reuse and options (Table 2A; Appendix 2) recommended expert system and professional involvement to assist public perceptions and support in sufficient decision making.

2.6 Method and Tools of Assessing Environmental Health Impacts

The published literature on Environmental Health Impact Assessment (EHIA) has mostly focused on specific technical participatory approaches; however, environmental health professionals need to develop more powerful methods to support planning and decision making (Forsyth et al, 2010). As previously mentioned, risk analysis is the sum of risk assessment, risk management and risk communication. Risk communication is a dynamic process of interaction between the public and government (Ackley, 2008). Hence, risk management and communication should be based on results from risk assessment as well as cost and social analysis so that policies toward risk reduction on human health and the environment can be established (Chen et al, 2013). Health impact assessment is considered an attractive methodology to integrate health issues into planning process; it is the combination of methods and tools by which an environmental issue or project can be evaluated for its potential effects on the public health and environment (Forsyth et al, 2010). Table 3A (Appendix 3) provides a comparison of planning analysis tools and health impact assessment.

There has been no clear assessment of TWW within water resource in the water management literature. Wastewater or TWW has been mostly presented as an available water source (portion) within the national water balance. Previous studies of wastewater and TWW reuse follow a particular approach using typical (common) methods and tools of assessment and management. Moreover, the assessment and management of wastewater and TWW reuse practice and options mostly reflect the researchers' and specialists' academic field or study area. The following examples summarize the dimensions of the research areas of previous studies (Table 4A; Appendix 4):

1. Engineering and technical type of studies directed toward WWTPs systems and networks to provide more TWW with better quality reflect.
2. Chemists or biologists (microbiologists) utilize experimental and scientific approaches that involve laboratories and measuring instruments that deal with specific water types (wastewater or TWW) contamination and assessing the chemical, physical and biological water quality by comparing them with the standards required for different purposes.
3. Social research directed toward the public issues, public policy making, public participation and perceptions. Such studies include the use of checklists, questionnaires and interviews to achieve qualitative or quantitative results.
4. Research by environmentalists (within any of the latter mentioned fields) includes for example LCA, EIA, MCDA, and HIA tools and methods to support in decision making process by conducting an assessment of a particular subject or TWW reuse option (e.g. TWW reuse in agriculture, artificial wetlands or groundwater recharge).

Thus to address the persistent gap in this area, an integrated assessment using a combination of methods and tools is needed to conclusively assess TWW reuse and options. A research approach adopting a case study reflecting a country with water scarcity and freshwater stress (such as Kuwait that has the opportunity for practicing TWW reuse within several available reuse options) can contribute in resolving this issue.

Therefore, as suggested above, a number of systematic and dynamic EIA methods and tools can be utilized (within an integrated framework) to assess of the management of TWW reuse practice (with diverse information from scientists, experts and local people, and by incorporating the subjective preferences of stakeholders into the analysis) as follows:

Life Cycle Assessment (LCA), or system analysis usually, includes multiple indicators (Balkema et al, 2002). LCA is a commonly used environmental impact assessment (EIA) tool for environmental issues and used to track impacts (and causes of impacts) through the entire lifespan of any product (from cradle to grave). LCA can also be used to quantify and assess the environmental impacts of activities or operations that directly or indirectly affect natural resources and have positive or negative environmental consequences (Memon et al, 2007). Few LCA studies have emphasized water as a product or as a result of a production process which has environmental impacts (Al-Salem and Lettieri, 2009; Barjoveanu et al, 2010). TWW reuse involves many human health and environmental impacts. Although LCA can be used for any (only one) TWW reuse option as a water product, it is too difficult and complicated to be used in the current research that deals with several TWW reuse options.

Hussain et al. (2001) suggested that the challenges and limitations of TWW assessment and management approaches include: i. problems with assessing a number of impacts of TWW, ii. the long term cause and effect relationship (i.e. correlation) between the impact and TWW risk, iii. valuing impacts and iv. complexity and uncertainty. Klinke and Renn (2004) pointed out that risk management faces three main challenges; complexity, uncertainty, and ambiguity. Zhang (2004) discussed the uncertainties associated with water demand and water quality. Uncertainty in risk management reduces confidence in the results especially with a lack of knowledge regarding cause and effect. Severity of risk based on uncertain parameters, compels management to adopt the precautionary principle approach (The Rio Declaration on Environment and Development, 1992; Klinke and Renn, 2004; Zhang, 2004).

It is usually difficult to identify and quantify specific interrelationships between a multitude of risk sources and their impacts (Klinke and Renn, 2004). There are no straight-forward definitions of indirect and cumulative impacts and impact interactions and they are all interacted (Walker et al, 1999). Therefore, clear definitions have to be developed first prior to any approach formation. Interacted factors as well as all affected criteria have to be comprehensively defined to cover all aspects of the issue. Therefore, EIA methods and tools to convert expert judgement (the qualitative evaluation of experts) to scaled and weighed criteria and impacts (quantitative results).

To resolve the above issue (interaction between risk variables and difficulty to assess and manage the risk), EIA is a growing field that comes in a number of forms, including audits, scoping tools, screening tools, preliminary checklists, and other assessment toolkits (Forsyth, 2008; DHI, 2009a and DHI, 2009b; Forsyth et al, 2010; Slotterback et al, 2010). As a significant tool in projects developed by DHI (2009a), the EIA report provides a descriptive baseline of the area and the project giving an assessment of the conditions within all phases. Developers can then respond proactively to address predicted impacts, reduce or eliminate them by changing procedures, design or other factors to mitigate the impacts (DHI, 2009a).

The aim of the EIA is to provide management with a clear evaluation of any environmental consequences to enable decision-making within any environmental activity (Forsyth et al, 2010; Randall and Jowett, 2010). For any EIA, suitable applicable methods and approaches should be selected to assess different types of impacts. Indirect and cumulative impacts of certain projects (as a source of risk) as well as impact interactions should be considered as part of an integrated EIA. It is also considered an effective practice contributing to decision making (Walker et al, 1999; Forsyth et al, 2010; Randall and Jowett, 2010) and environmental indicators can play critical role in helping countries with knowledgeable decision making (United Nations, 2007).

As pointed out by the European Environment Agency (EEA), DPSIR offers a basis for analyzing inter-related factors that impact the environment. This approach aims to provide information on all the different elements in the DPSIR chain to demonstrate their interrelationships and estimate the effectiveness of responses. It is considered to be a logical and good way to structure information to visualize the links between the causes of environmental problems, their effects on the state of the environment, and relevant societal responses (Gabrielsen and Bosch, 2003; Kristensen, 2004).

Hence, the management of TWW reuse (as a critical environmental activity) should involve a mixture of creative approaches that engage the public and private sector at local and national scales using different techniques during the assessment process (UNEP / UN-HABITAT, 2011). The method selected should be compatible with available data, time and resources. The nature of the impact, and the availability and quality of data and resources as well as the time available are all critical aspects within selecting suitable methods (Walker et al, 1999; Forsyth et al, 2010; Randall and Jowett, 2010).

EIA tools can be reformed and adapted to include targeted EIA components to reorganize and reform the research approach as explored by Randall and Jowett (2010).

Several methods (including expert opinion, questionnaires, checklists, spatial analysis, networks, matrices, and modeling) can be used and combined during the EIA. Walker et al. (1999) divided these methods into two main types of technique; scoping and impact identification techniques (which identify how and where an indirect or cumulative impact or impact interaction would occur) and evaluation techniques (which quantify and predict the magnitude and significance of impacts based on their context and intensity). Other studies (HDI, 2009; Forsyth et al, 2010; Randall and Jowett, 2010; Slotterback et al, 2010) in this field (EIA or EHIA) reorganized that these methods and tools are effective when utilized within specific environmental issues. Figure 2-10 illustrates the relationship between used techniques and suitable assessment methods and tools.

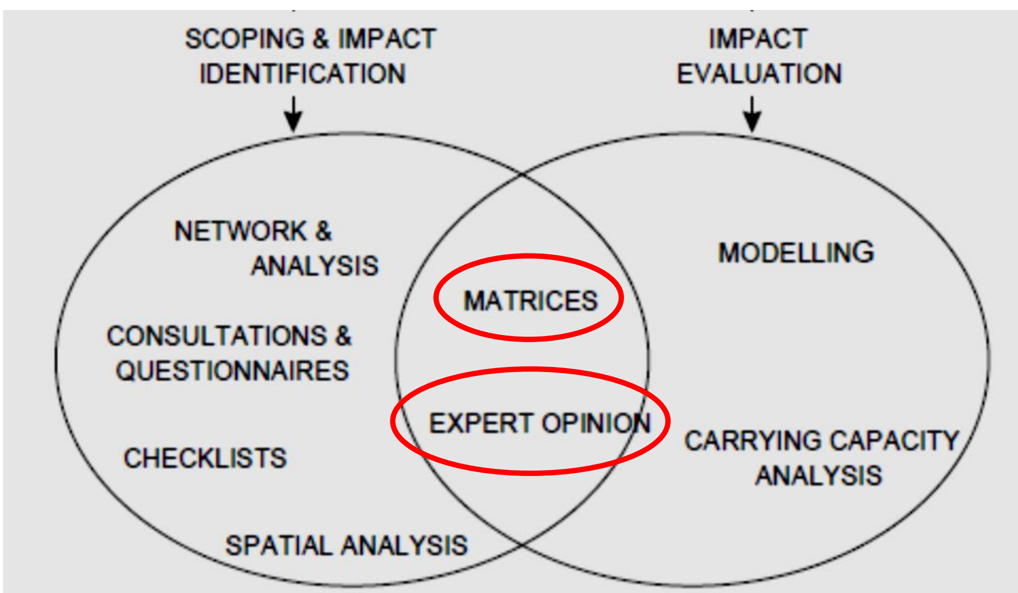

Figure 2 – 6: Impact Identification and Evaluation Techniques, and Assessment Methods and Tools (Walker et al, 1999)

2.7 <u>Summary of Literature Review, Research Gap and Study Scope</u>

There have been no clear results from previous studies regarding environmental health risk and socio-economic assessment of TWW reuse practice that effectively support in decision making (Robison et al., 2005; Dreizin, 2007; Abu-Madi et al., 2008; AL-Humoud and Madzikanda, 2010; AL-Anzi et al., 2011; and others). For example, socio-economic aspects of TWW reuse practice, understanding individual attitudes and behaviours, knowledge, data and information on TWW quality, practice, options, and possible environmental health risks are all essential in considering this issue. Integrated Water Resources Management (IWRM) or water sustainability requires attention to all water bodies (e.g. surface water such as lakes and rivers, groundwater and wetlands). It requires strategic water planning and conservation. In addition, applications of water alternatives can be practiced to conserve and protect available water resources (Salinas, 2015).

The, integration of these factors with an Integrated Environmental Assessment (IEA) approach is necessary for the success of this field of study (Randall and Jowett, 2010); EIA is considered a suitable tool for decision-making, predicting and planning proactively for reducing the adverse environmental impacts. This current study seeks to assess and reform qualitative data to quantitative data to achieve objective (unbiased) results. Babbitt et al. (2015) highlighted that qualitative data can give essential knowledge and reliable reasons to explain such quantitative data results. Qualitative interviews of stakeholders can play a successful role in water resources management. Directly questioning experienced stakeholders (experts) regarding the components of water resource management can be as valuable and beneficial as data obtained from field observations, laboratory experiments, and extensive literature reviews (Babbitt et al, 2015).

When dealing with public resources and values within the risk management process, reliable judgements are needed to assist and guide decision makers. Decision support assessment tools and methods are considered effective approaches when dealing with uncertainty, complexity or issues involving a variety of stakeholders (Ellis et al, 2011). McDaniels et al. (1999), Klinke and Renn (2004) and Alessandri (2004) suggest that environmental risk management decisions concerning TWW reuse practice involve complexity, uncertainty and confusing value trade-offs. The nature of risk and uncertainties cannot be addressed without expert system in the field (directors, executives, managers and other experienced decision makers) in the decision making process (Alessandri, 2004). Therefore, a systematic decision making process is needed that involve experts and specialists to deliver the best results with the least risk.

Maintaining public confidence in the quality of the water provided, regardless of its source, is the key to successful planning of both TWW reuse and wider water resources management (Dolnieara and Saunders, 2006). Studies of public participation regarding TWW reuse practice and options (Abu-Madi et al., 2008; Robison et al., 2005; AL-Humoud and Madzikanda, 2010; Dreizin, 2007; AL-Anzi et al., 2011; and others) therefore, recommend further (future) qualitative research drawing upon expert judgments and opinion. Public perceptions and willingness to adopt TWW reuse practices have to be effectively and efficiently assessed. In other words, TWW quality, estimated TWW quantities and beneficial parties must be determined prior to depending on TWW for any reuse option (or considering an alternative). Accordingly, future studies and scenarios can confidently rely on predicted results of alternative water resource for strategic plans and management.

Multi-criteria analysis within using tools and methodologies including matrices has been widely suggested to be used within environmental issues involving multi factors. It enables obtained information (both quantitative and qualitative) to be used in a reliable way to increase decision making efficiency by facilitating stakeholder participation in the decision-making process (Ellis et al, 2011). The systematic structure of Multi-Criteria Decision Making (MCDM) emphasizes impacts arising from any environmental practice or project. MCDM has considerable potential in supporting the different phases of EIA, including the scoping phase and identifying the most important issues.

To achieve equally distributed benefits between stakeholders benefitting from TWW, a basic model of management and assessment (for environmental mitigation and rehabilitation) alongside proactive regulation must be conducted to avoid future environmental impacts. This conceptual approach was recommended by the United Nation's World Water Assessment Program (The UN WWAP, 2012) for both water and wastewater management schemes. Thus MCDM, alongside other assessment tools, can assure TWW beneficiaries have equitable access to TWW benefits, providing healthy reuse practice that minimize environmental risk and uncertainty. There are different methods for MCDM and weighting process as described by Linkov and Steevens (2008). Linkov and Steevens (2008) compare several advanced MCDA methods: Multi-Attribute Utility Theory (MAUT), AHP, and Out-ranking as listed in Table 2 - 2.

Table 2 - 2: Comparison of Critical Elements, Strengths and Weaknesses of Several Advanced MCDA Methods: MAUT, AHP, and Outranking.

Method	Important Elements	Strengths	Weaknesses
MAUT	1. Expression of overall performance of an alternative in a single, nonmonetary number representing the utility of that alternative. 2. Criteria weights often obtained by directly surveying stakeholders.	1. Easier to compare alternatives whose overall scores are expressed as single numbers. 2. Choice of an alternative can be transparent if highest scoring alternative is chosen. 3. Theoretically sound based on utilitarian philosophy. 4. Many people prefer to express net utility in non-monetary terms.	1. Maximization of utility may not be important to decision makers. 2. Criteria weights obtained through less rigorous stakeholder surveys may not accurately reflect stakeholders' true preferences. 3. Rigorous stakeholder preference elicitations are expensive.
AHP	1. Criteria weights and scores are based on pairwise comparisons of criteria and alternatives, respectively.	1. Surveying pairwise comparisons is easy to implement.	1. The weights obtained from pairwise comparison are strongly criticized for not reflecting people's true preferences. 2. Mathematical procedures can yield illogical results. For example, rankings developed through AHP are sometimes not transitive.
Outranking	1. One option outranks another if : a. It outperforms the other on enough criteria of sufficient importance (as reflected by the sum of criteria weights). b. It is not outperformed by the other in the sense of recording a significantly inferior performance on any one criterion. 2. Allows options to be classified as incomparable.	1. Does not require the reduction of all criteria to a single unit. 2. Explicit consideration of possibility that very poor performance on a single criterion may eliminate an alternative from consideration, even if that criterion's performance is compensated for by very good performance on other criteria.	1. Does not always take into account whether over performance on one criterion can make up for under performance on another 2. The algorithms used in outranking are often relatively complex and not well understood by decision makers.

Source: Linkov and Steevens, 2008

Hence, this research seeks to develop an integrated approach to Environmental Health Risk and Socio-Economic Perception Assessment for the Management of TWW reuse practice and options to fulfil the current research gaps in this area. As recommended by previous research, this study utilizes experts' and professionals' involvement (opinion and judgement) to achieve the best assessment that effectively support within the decision making process. The research also complements existing methods and tools by establishing a new creative approach as explored in chapter 3. As summarized in Figure 2 - 6, EIA matrices and expert opinion are considered for both scoping and impact identification, and impact evaluation techniques (Walker et al, 1999). Such methods and tools are combined to duplicate the assessment and management process to provide better results with less uncertainty and complexity.

In regard of the difficulties associated with identifying and quantifying interrelationships between multitude of sources of risk and their impacts (as previously discussed by Klinke and Renn, 2004), risk management faces three main challenges; complexity, uncertainty, and ambiguity. Zhang (2004) highlighted that uncertainty in risk management reduces confidence in the results especially with respect to the lack of knowledge regarding causes and effects. There is a growing need for developing EIA practices to influence decision making concerning environmental issues (Mustajoki, et al, 2013; Pope et al, 2013). Such assessments are most likely to influence decision making when they are perceived to be credible (expertise), relevant (address key problems) and legitimate (assessment perceived as fair) (Cash et al., 2003; Cash et al., 2006).

As highlighted earlier in Section 2.6, matrices tools and methodologies have been widely used with environmental issues involving multi factors to reform quantitative and qualitative data for decision making efficiency and effectiveness (Ellis et al, 2011). The Rapid Impact Assessment Matrices (RIAM) approach, in contrast, is a useful tool to improve planning decisions (DHI, 2009a). RIAM converts qualitative data (descriptive data based on subjective opinions and judgments) to quantitative data (measurable data based on numerical objective records) that can then be subsequently reassessed (Pastakia, 1998b). Subjective judgments in these environmental evaluations have to be quantified and presented in such a way that they lead to clear and more reasonable (objective opinions) results with little criticism (DHI, 2009a; DHI, 2009b). Hence, converting qualitative opinions into quantitative results should provide a more reliable evaluation of tested situation.

The rapid environmental assessment tool is used based on models widely used to address and assess environmental health impacts (Forsyth, 2008; Forsyth et al. 2010; Slotterback et al, 2010). Amongst other environmental assessment tools, expert opinion and judgement (perception) within MCDM and RIAM includes both scoping and impact identification techniques (which identify how and where an indirect or cumulative impact or impact interaction might occur) and evaluation techniques (which quantify and predict the magnitude and significance of impacts based on their context and intensity) discussed in Section 2.5 (Figure 2-10). In this research, RIAM was used to identify impacts associated with TWW reuse practice and options, assess the selected options and it represents a method to test (double check) the MCDM as mentioned in Chapter 3 (Section 3.4; Figure 3-1).

In essence, RIAM allows data from different components to be analyzed and compared against common important criteria within a common matrix. RIAM also provides an assessment of the major impacts after the surveying process (interviews, SSQs, and checklists). The impacts of certain activities are evaluated against the environmental components. Using defined criteria, a score for each component provides a measure of the impact expected from the component (DHI, 2009a; DHI, 2009b).

The research approach in developing an efficient EIA method that appropriately and effectively deals with TWW reuse practice (combining DPSIR, MCDM and RIAM using expert perception and judgement) strengthens the result and reduces the uncertainties associated with subjective opinions. As mentioned above, subjective qualitative opinions in RIAM can be converted to objective quantitative results. RIAM is used to both assess (evaluate) selected applicable TWW reuse options and can test MCDM by comparing compatible criteria and similar components between the two methods (MCDM and RIAM). The findings of all the methods used leads to reliable and trust worthy evaluation and assessment of issues associated with the management of TWW reuse practice and options.

Thus the context of this research study, as recommended by Randall and Jowett (2010), is to develop an EIA within an environmental framework approach which is considered an initial assessment and trade-off problem / stakeholder analysis for a proactive planning. It also provides linkages between interacted impacts prior, during and after any environmental activity.

Chapter 3

Research Area and Methodology

This chapter describes the research approach and the case study. First, the chapter provides an overview of the research area and methodology, and highlights the main phases of the research. The chapter then justifies the selection of the research case study and outlines the research methods and tools utilized in each phase of the research. Tools and methods addressing the research questions (designed to achieve the research aim) will be summarized accordingly. Finally, an overview of the research context is provided to summarize the research approach (general concept, brief background and phases of utilized methods and tools are outlined in this chapter and will be explored in detailed further in the following chapters).

In undertaking an integrated study of environmental health risk and socio-economic perception associated with the assessment and management of treated wastewater (TWW) reuse practice and options, this study aims to identify the social, economic, biological, environmental, and psychological components of TWW reuse practice. The research approach is developed here to provide an effective assessment tool to enable efficient decision making regarding TWW reuse practice and options. The chapter highlights the theoretical elements of the research as well as the practical processes and procedures required to achieve the aim and objectives (how the factors affecting TWW reuse practice and options and the potential environmental health impacts which might occur from improper reuse of TWW can be assessed). It also list sources of data and information associated with such practice (for environmental health and socio-economic perception) as well as the participating experts' fields and backgrounds.

3.1 <u>Research Approach Application</u>

Accordingly, empowered and expert participants representing different stakeholders (including government decision makers, scientists and specialists, experts from private sectors and experienced personnel from associated authorities) were considered within an integrated assessment approach to solicit their best judgement supporting decision making on both TWW reuse practice and options. The research focuses on Kuwait for applying this approach, nevertheless, the study innovation and results have wider applicability once simulated and could be manipulated to other case studies.

The research strategy approved by the expert participant adopts combined qualitative and quantitative approach. It employs experts' opinions and judgment utilizing specified short survey questionnaires (SSQs), assessment checklists and field-work observations and interviews. The research involves selected stakeholders and decision makers as well as personnel and workforce (within TWW reuse practice) who provide their expert judgments. Experienced public representatives also participated to reflect public perception and its importance in the decision making process. The main methods of data collection include a purposively designed interview checklist (for information and data collection) and survey questionnaires (used to collate expert judgment) comprising a specified number of categorized questions.

3.2 <u>Methods and Tools - Application and Innovation</u>

To attain the research approach objectives, the defined research questions outlined in Section 1.2 are addressed through a combination of research design and an appropriate research methodology. First, a Driving Forces, Pressure, State of Environment, Impact, and

Response (DPSIR) Framework is utilized to analyze the current situation (State) as demonstrated in Figure 3-1. This consolidates associated issues in an integrated framework providing effective analysis and producing a clear summary of current environmental conditions. The results and findings of this analysis (DPSIR) will be utilized for further assessment, decision and conclusion (assisting MCDA and RIAM results within the final assessment and decision regarding TWW reuse practice and options).

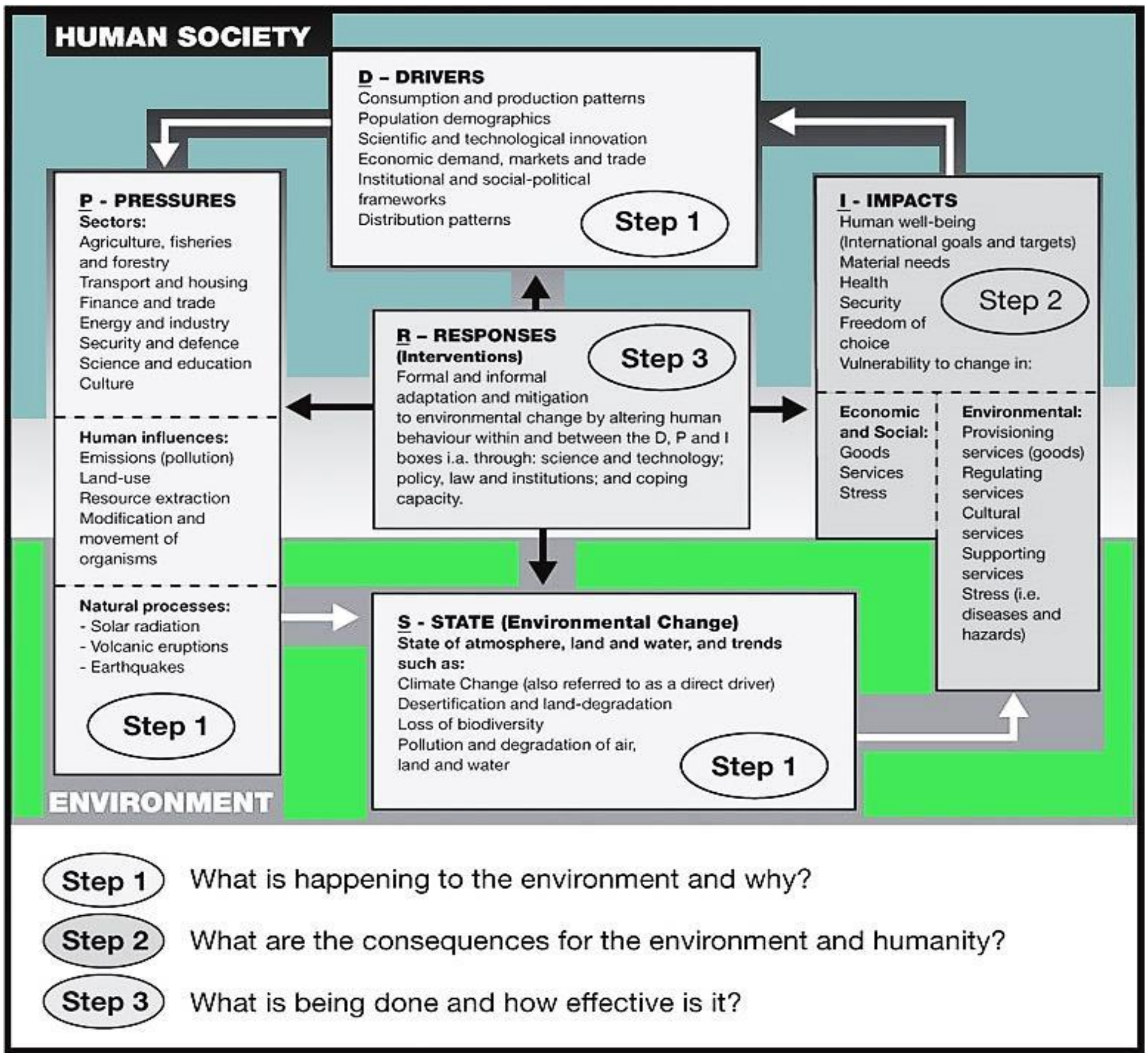

Figure 3 - 1: DPSIR Framework

As described by Gabrielsen and Bosch (2003) and Kristensen (2004), according to the DPSIR framework, there is an environmental chain of interlinkage. The framework starts with driving forces (D) (e.g. institutional and socio-economic factors) that indirectly affect the state of the environment such as population growth, industrial developments, transportation and awareness. Then (D) through pressures (P) relates to direct effects on the state of the environment (S) such as pollution and degradation caused by unsustainable practices to the state of the environment (physical, chemical and biological) that presents the main aspect of the framework (which is associated with the research approach such as the quality of air, water, and soil) causing Impacts (I) on ecosystems, human health and the environment. Finally the latter elements of the framework (D, P, S and I) lead to necessary responses (e.g. various policy measures such as regulations, information and taxes designed). Responses are to mitigate not only the impacts but also submitted to and work with the other DPSIR elements (D, P, S and I) as can be indicated from the arrows in the DPSIR process presented above in Figure 3-1.

As noted previously, risk management deals with both public resources and public values. Reliable judgments should be made to assist and guide decision making. Risk management with respect to TWW reuse practice is complex given the technical uncertainties and confusing value tradeoffs (McDaniels et al, 1999; Klinke and Renn, 2004; Alessandri et al, 2004). Therefore, the judgments of specialists in various fields (e.g. physical, biological, chemical, and social sciences) and stakeholders (government, researchers, private sectors and public representatives) should be taken into account so as to obtain reliable outcome. In such systematic method, perceptions of experts and specialists should reflect the best combination of least risk and efficient decisions.

Thus the second phase of the research process involves a multi-criteria decision analysis (MCDA) or a multi-criteria decision making (MCDM) method that helps decision makers facing a complex problem with multiple conflicting and subjective criteria. An Analytical Hierarchy Process (AHP) of MCDM is usually based on four steps: problem demonstration, weights valuation, weights collection and sensitivity analysis. The AHP provides decision makers with a better focus on specific criteria and sub-criteria based on their weights and ranks of selected choices or options (Ishizaka and Labib, 2009). MCDA for MCDM provides an interactive integrated assessment framework that identifies the key trade-offs of the available options (alternatives) as highlighted by Mustajoki et al. (2013). Yang and Shi (2002) represented the AHP process of MCDM in a simplified diagram within descending steps as shown in Figure 3 - 2.

Figure 3 - 2: AHP Process of Evaluating Long-Term Strategy Performance (Yang and Shi, 2002)

The third phase of the research involves the assessment and management of TWW reuse practice and selected best options for Kuwait. After selecting the best available TWW reuse options and Criteria Weighing of MCDM, selected options will be assessed and tested using an Environmental Impact Assessment (EIA) tool called Rapid Impact Assessment Matrices (RIAM). In RIAM, decision making provides an integrated investigation through an EIA matrix which includes various critical elements grouped into four categories of environmental components (physical and chemical, biological and ecological, sociological and cultural, and economic and operational).

Hence, the results of the MCDM are tested and compared with the RIAM results to provide more confident decision making, analysis and conclusions.

3.3 Research Questions Vs Tools and Methodology

To achieve the aims and objectives of the research, the following specific research questions will be addressed:

The first research question, regarding the major problems of TWW resource and reuse, will be addressed through a combination of literature review, comprehensive data collection, and field work (interviews and observations). The current status of the TWW resource in Kuwait will be examined, emphasizing the major problems of TWW reuse practice and highlighting the main issues regarding TWW both historically and in the future. As mentioned above, the DPSIR framework method will be used to consolidate and analyse collected data and information. Sources and types of data as well as procedural process are as follows:

To identify the major problems associated with the TWW resource in Kuwait, experts and decision makers in associated authorities, institutions, and wastewater treatment plants (WWTP's) and individual stakeholders were interviewed. Data sources and information regarding TWW resource and reuse in Kuwait are listed in Table 3-1. The major questions associated with this objective include:

1. Wastewater level of treatment and TWW quality.
2. Ratio of generated wastewater to freshwater consumption and ratio of produced TWW to generated wastewater (wastewater treatment efficiency).
3. Ratio of TWW utilization (reuse practice) to discharged quantity.
4. Public participation as well as data and information transparency.

Table 3-1: Sources of Data and Information Regarding TWW Resource

Source	Data and Type of Information
Ministry of Public Work (MPW)	Sanitary Engineering (WWTP's), TWW Network and Data Monitoring Centre (DMC)
Wastewater Treatment Plants (WWTP's)	TWW Capacities, Standards and Guidelines, TWW Quantities, Control & Monitoring
Ministry of Electricity and Water (MEW)	Desalinated (Fresh) Water Quantities, Water Per Capita Consumption & by Sectors (Domestic, Agricultural, and Industrial)
Kuwait EPA	WWTP's EIA Reports, TWW Rules and Regulations, Standards & Guidelines
Public Authority of Agriculture Affairs and Fish Resources	TWW Networks, TWW Quantities for Agricultural Sector and Farmers
Kuwait Institute for Scientific Researches (KISR)	Water Data & Information, Literature Reviews and Previous Studies
Kuwait University	Literature Reviews and Previous Studies

TWW reuse options and guidelines depend on TWW quality. TWW quality, on the other hand, depends on the treatment method and treatment level. To assess TWW quality, WWTP's were investigated to identify the methods used and observe the monitoring and control of TWW processes. Kuwait TWW standards and guidelines were reviewed to check compliance with international environmental organizations including WHO, UNEP, and USEPA. Further, TWW laboratory tests were compared with Kuwait standards and guidelines to check the treatment process efficiency and the quality of generated TWW.

Water, wastewater and TWW data and trends were collected from appropriate ministries and authorities. The ratio of generated wastewater to freshwater consumption and the ratio of produced TWW to wastewater indicate the wastewater treatment efficiency. In addition, both the quality and quantity of discharged wastewater to the sea can reflect the environmental status and impact on the marine environment. Moreover, the ratio of TWW utilization to discharged quantity indicates the current TWW reuse practice efficiency. Public participation and data transparency were discussed with decision makers to determine negative and positive aspects of this issue on TWW reuse practice (planning and management).

The second research question regarding the major TWW reuse options and options that are applicable for Kuwait, is addressed in two ways: through a literature review and expert system (expert judgement). Through a comprehensive literature review of previous research studies and scientific papers, TWW reuse practice and options worldwide are summarized. The major available TWW reuse options for Kuwait are then determined through expert system. A short interview with survey questionnaire was used to obtain expert judgment compromising a specified and categorized number of questions. Experts and specialists from different institutions associated with water and TWW resources management were interviewed regarding TWW reuse practice and options in Kuwait as listed in Table 3 - 2.

The major questions within the survey questionnaire and interview discussion at this stage include:

1. The degree of knowledge regarding TWW reuse practice and options (e.g. level of treatment, standards and guidelines, environmental health risk, available and applicable TWW reuse options, etc.).
2. Selection of TWW reuses options based on multi-criteria (such as environmental health, economic, social, political, and strategic criteria).
3. Reasons for selecting certain or each option based on the submitted criteria.

Table 3 - 2: Specialists and Experts Participants (EP) Group for TWW Reuse Practice and Options Assessment and Management

Institution	Specialists and Experts
Ministry of Public Work (MPW)	TWW Management Professionals and Decision Makers, Sanitary Engineers and Technicians
Wastewater Treatment Plants (WWTP's)	Engineers and Technicians
Ministry of Electricity and Water (MEW)	Water Management Professionals
Kuwait EPA	WWTP's EIA Exerts , Researchers and Reporters, TWW Rules and Regulations, Standards and Guidelines Submitters and Developers
Public Authority of Agriculture Affairs and Fish Resources	TWW Management Professionals, Water Irrigation Managers
Kuwait Institute for Scientific Researches (KISR)	Water Management Experts, Water Studies and Projects Researchers
Kuwait University	Water Studies and Projects Researchers
Ministry of Public Health	Water Related Diseases Specialists and Physicians
Other Stakeholders and Public Representatives	Industrial, Commercial, Firefighting, Parliament Members and Farmers

By evaluating the best available alternatives, assessment of the environmental health risks and socio-economic perceptions can contribute to effective management. Efficient assessment of TWW reuse practice and options can direct the decision making towards the best options with less environmental health risk as possible. When planning the process, economic calculations, and social investigations should be assessed to achieve TWW reuse best practice. Within assessment and management, scenarios could involve a range of treatment levels from a low level to advanced and most expensive treatments such as desalination and using reverse osmosis (R.O.) technology.

The third research question regarding how TWW reuse practice can be conclusively assessed and managed (with all components, factors and criteria) in an integrated model, is achieved in several steps. First, the best available (applicable) TWW reuse options are determined based on expert system. The best applicable and most accepted TWW reuse options are then adopted for further assessment and management processes within an effective decision making (DM) process and environmental impact assessment (EIA). These are the Multi-Criteria Decision Making - Analytical Hierarchy Process ((MCDM - AHP) and the Rapid Impact Assessment Matrix (RIAM) respectively. As a result, the environmental health risks and socio-economic perceptions of TWW reuse practice and options assessment and management are considered.

The results of the MCDM-AHP (options that consider environmental health considerations and which are given highest weight in the decision-making process) are followed by testing and assessment of their effectiveness based on criteria within the previously gathered data and the EIA tool (RIAM). Associated environmental health risks as well as socio-economic challenges are tested and assessed for their effectiveness within each of the accepted (best) TWW reuse option. Control and mitigation measures can then be recommended. Figure 3 – 2 summarizes the theoretical concept of the research approach as well as the empirical process and procedures (steps and phases for achieving the third research question); practical / applied research approach (how TWW reuse practice can be conclusively assessed and managed with all components, factors and criteria in an integrated framework).

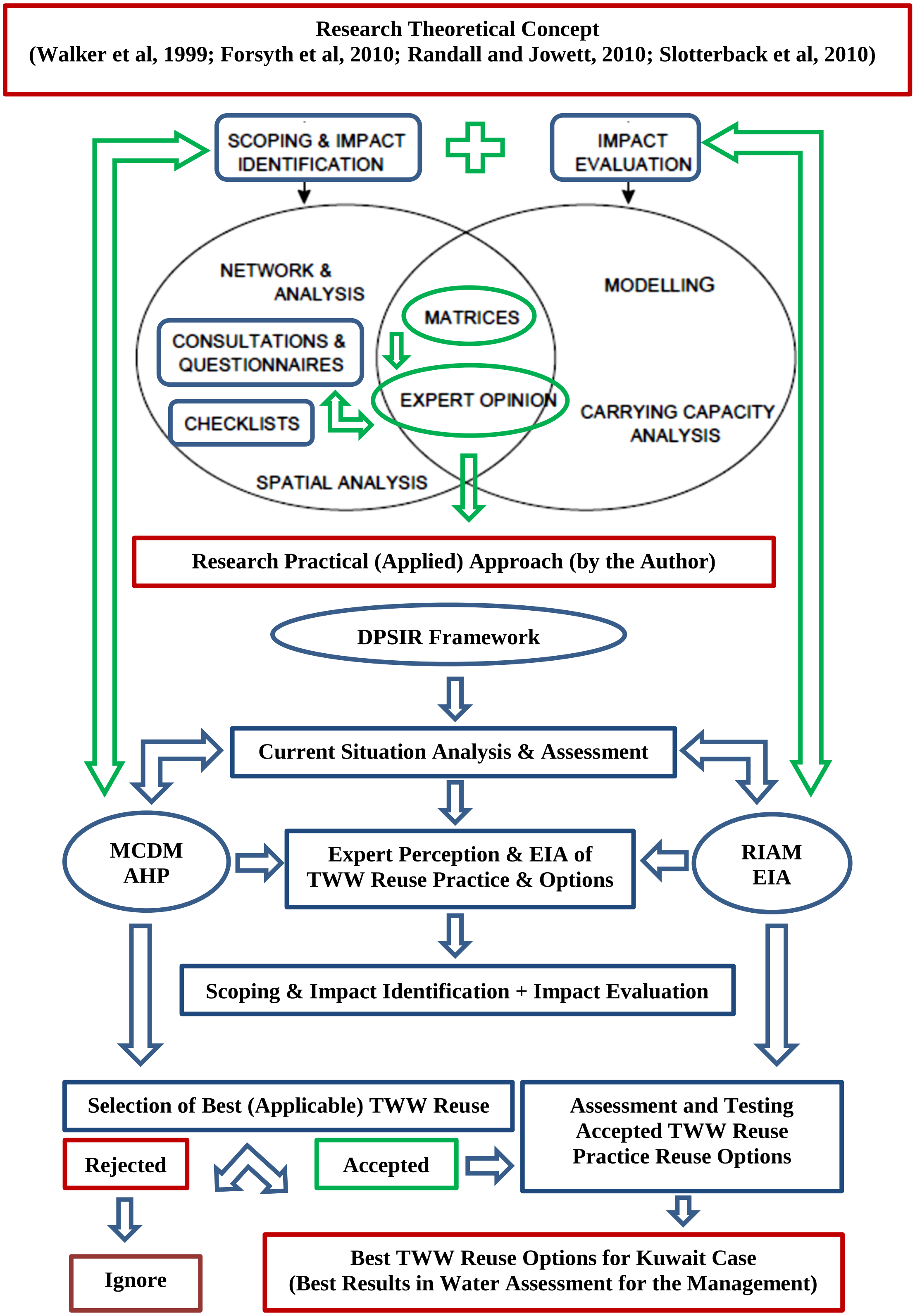

Figure 3 – 3: Theoretical Concept Vs Imperial (Practical) Research Approach

3.4 <u>Research Mehodology Application Phases</u>

The following sections will explore and clarify phases of the research approach:

3.4.1 Selection of TWW Best Available (Applicable) Reuse Options

To investigate TWW reuse environmental health risk and socio-economic perceptions of expert judgement and perception, a short survey questionnaire (SSQ) survey was used to determine the degree of knowledge of individuals, and their perceptions on human and environmental health risks, and socio-economic impacts. Then, based on their degree of knowledge regarding TWW reuse practice and options, participants selected the best applicable TWW reuse options listed within a designed Table in the SSQ (and whether each option is applicable or not).

Their acceptance and perceptions toward such reuse options (whether they agree or disagree with reuse such options) were also considered. The best applicable and most accepted TWW reuse options were then selected for further assessment within an effective decision making (DM) and environmental impact assessment (EIA) tools, which are the Multi-Criteria Decision Making - Analytical Hierarchy Process ((MCDM-AHP) and the Rapid Impact Assessment Matrix (RIAM) respectively.

3.4.2 MCDM and Assessment of the Best Applicable Option Using RIAM

The analytical hierarchy process (AHP) was used to determine the best available TWW reuse options that ensure water sustainability and minimize economic burdens (of water supply) and environmental impacts. The designed SSQ and interviews (for expert judgment) asked specialists and experts to rank TWW reuse options based on multi-criteria. With Multi Criteria Decision Making - Analytical Hierarchy Process (MCDM-AHP) methodology, management alternatives (TWW reuse practice and options) were identified. Further, TWW reuse options were assessed by RIAM for proactive actions within strategic planning.

As previously mentioned (in section 3.2), RIAM offers full transparency of the decisions made in an EIA and provides an integrated investigation within a matrix designed to include various critical elements grouped into four environmental categories; (1) Physical and Chemical, (2) Biological and Ecological issue, (3) Sociological and Cultural, (4) Economic and Operational. These environmental components could be, directly or indirectly, affected by the project or environmental issue that will be assessed during the different phases.

3.4.3 DPSIR Retracing, Combining MCDM and RIAM for the Development of the Framework to Critically Assess the Management of TWW Reuse Practice and options

By analysing the current status (the state of environment) using DPSIR and combining MCDM and RIAM, it is possible to first, assess TWW reuse practice and options (TWW reuse options selection and DM) and second, assess selected TWW reuse options utilizing RIAM, and identify data quality limitations associated with each tool. Thus, by developing an Environmental Health Risk and Socio-Economic Impacts expert perception of the combined methods, TWW reuse practice and options will be conclusively assessed. As a result, complexity and uncertainty issues will be minimized.

Chapter 4

Analysis of Kuwait Current Status Using DPSIR Methodology

This section describes the main issues related to water management in Kuwait outlining treated wastewater (TWW) reuse practice in the country. It emphasizes TWW reuse practice as a critical response to water stress in areas where TWW reuse options are practiced. The chapter first summarizes available water resources and current water uses. Second, it describes water uses by sectors (domestic, agricultural and industrial). Water policies and available strategic plans are documented focusing on TWW reuse. The chapter outlines national rules and regulations regarding TWW technology and standards and summarizes guidelines for TWW reuse. On the basis of the information, the Driving Forces, Pressures, State of the Environment, Impacts and Responses (DPSIR) Framework is utilized to analyze the current status of TWW reuse practice performance. As a result of the DPSIR analysis, the impacts of improper TWW management and reuse practice in Kuwait are highlighted.

4.1 Water Resources in Kuwait

Kuwait is 17, 818 km^2 in area and located to the north-west of the Arabian Gulf. It is bordered to the north and north-west by Iraq and in the south-west and west by Saudi Arabia. The population is currently exceeds 3.5 million which is distributed into six districts; Al-Farwaniyah, Hawalli, Al-Ahmadi, Kuwait City (The Capital or Al-Asimah), AL-Jahra and Mubarak AL-Kabir. Most of the population is concentrated within less than 25% of the total area around Kuwait Bay as designated in Figure 4 -1.

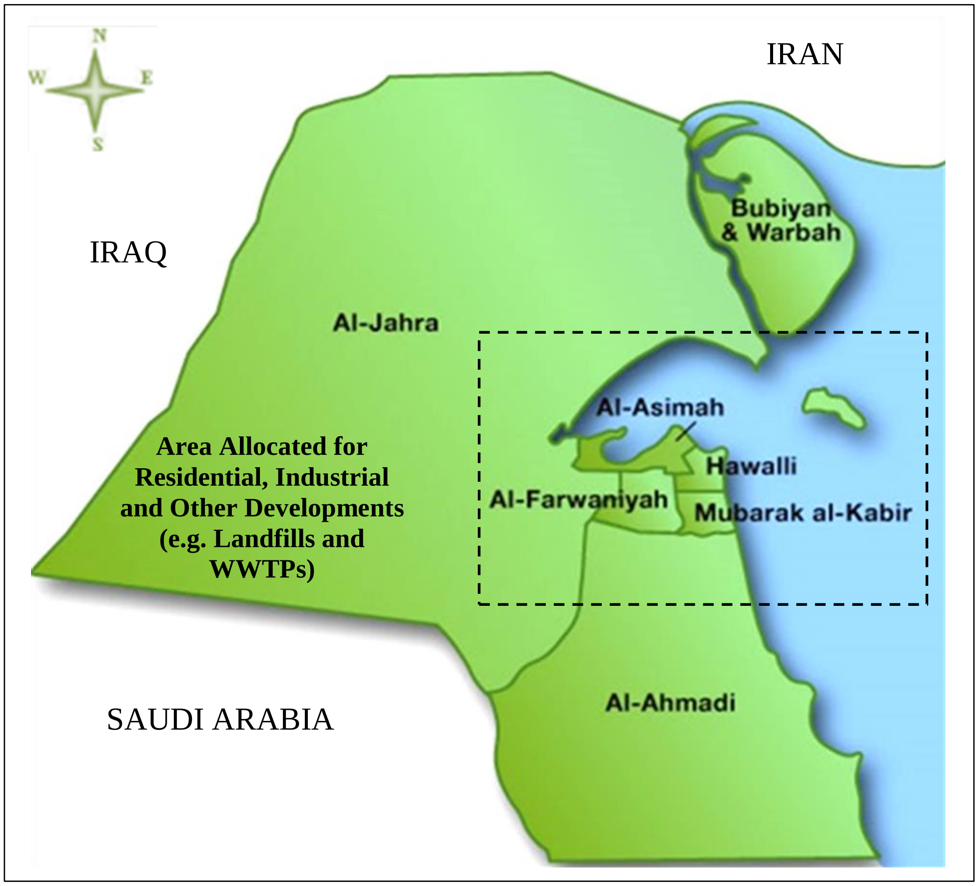

Figure 4 - 1: Governorates Map of Kuwait

Kuwait has an arid climate with very hot summers; summer temperatures in Kuwait range from 38 to 46 °C and exceed 50 °C in July (Al-Humoud and Al-Ghusain, 2003). Given an extremely arid climate and limited freshwater resources (with mean annual rainfall of 116 mm, high mean annual potential evapotranspiration rates of 3000 mm), Kuwait suffers from limited freshwater availability and experiences serious water stress (Eidan, 2008). Monthly mean temperatures as well as mean total precipitation are listed in Table 4-1 while Figure 4-2 shows the mean annual rainfall in Kuwait from 1958 to 2004.

Table 4-1: Monthly Mean Temperature & Total Precipitation

Month	Mean Temperature °C		Mean Total Precipitation (mm)
	Daily Minimum	Daily Maximum	
Jan	7.2	18.0	25.5
Feb	9.1	20.7	15.5
Mar	13.2	25.6	13.3
Apr	18.4	31.5	14.8
May	24.1	38.5	3.8
Jun	27.5	43.5	0.0
Jul	29.3	43.6	0.0
Aug	28.5	44.6	0.0
Sep	24.6	42.0	0.0
Oct	19.7	35.3	3.3
Nov	13.8	26.6	13.8
Dec	8.6	19.8	17.3

Source: World Meteorological Organization

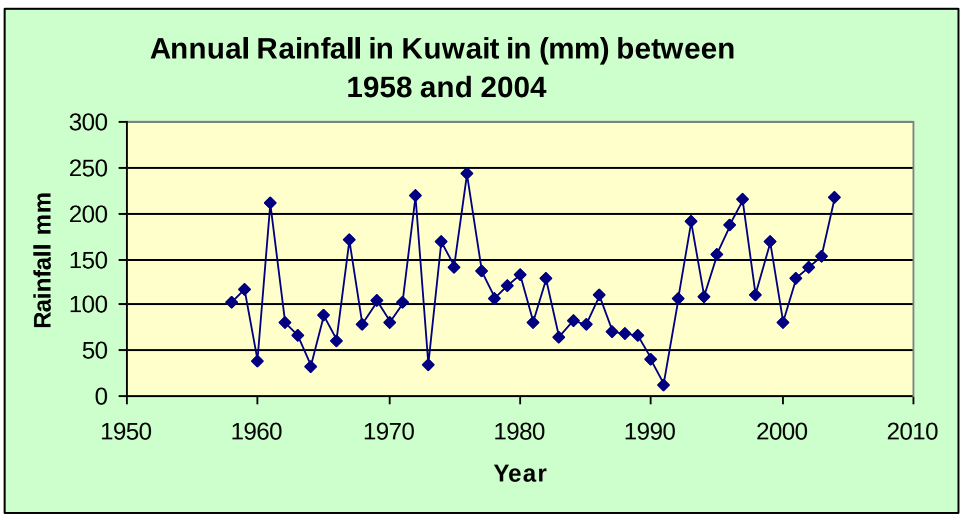

Figure 4 - 2: Annual Mean of Rainfall in Kuwait between 1958 and 2004 (Kuwait International Airport, 2006)

Mean annual rainfall in Kuwait is very low and irregular (the few years with high annual rainfall totals are unevenly distributed over the period). Therefore, rainfall in Kuwait is not considered a reliable water resource. Hence, its natural water resources are limited to the abstraction of brackish groundwater that flows from Saudi Arabia which is mostly utilized for agricultural purposes to ensure food security as discussed below. Kuwait is classified as a country of absolute water scarcity with per capita water availability of < 500 m^3/year (Eidan, 2008; Alshammari, 2014). In this context, water resource management represents a critical planning challenge given the need to maintain water status and ensure sustainable management of the resource in Kuwait. Given the combination of climate, current consumption pattern and water stress, it is expected that balancing water demand will become more problematic in future. Hence, it is essential that Kuwait develops viable plans to increase the use of water from other sources including TWW.

Currently, Kuwait depends on three main water sources; desalinated water (DW), groundwater (GW) and treated wastewater (TWW). Desalinated and GW (both fresh and small quantity of low salinity brackish water) are used as potable sources of water. TWW and low salinity (brackish) water are also used as non-potable sources of water. The percentage of each water resource from the total quantity of water used in 2011 as estimated by the Department of Water Resources, Ministry of Electricity and Water (MEW) in Kuwait (1157 million m^3 / Year) are 54% (DW), 37% (GW) and only 9% (TWW) respectively (Alshammari, 2014).

4.1.1 **<u>Groundwater (GW)</u>**

Fresh groundwater was discovered in limited quantities in Northern groundwater wells; Raudatain and Umm Al-Aish (stopped in 1991). Pumping operations commenced in 1962, when the estimated volume of the GW body was 182 x 10^6 m^3. The main source of fresh-GW is Raudatain which comprises 14 abstraction wells (with rates of abstraction of 4546 – 9092 m^3/day) with salinity ranging from 600 to 1000 mg/l. (Ministry of Electricity and Water). In general, brackish water in Kuwait is currently abstracted for purposes including livestock consumption, construction and it is also mixed with distilled water for potable uses (Al-Humoud and Al-Ghusain, 2003; Eidan, 2008; Alshammari, 2014).

Given the extremely low mean annual rainfall, groundwater constitutes the main conventional water source in Kuwait. As mentioned earlier in this section, GW in Kuwait can be separated into two types on the basis of salinity; fresh groundwater (salinity of 1000 mg/l) which is mostly found in Northern Kuwait in low quantities and low salinity groundwater (salinity of 3000 mg/l). The latter is the dominant type of groundwater.

Low salinity ground-waters are found in the South and the South-west of Kuwait. Figure 4 - 3 illustrates the location of the main wells for abstracting of brackish and fresh groundwater (GW). Brackish and fresh groundwater abstraction trends from 1995 to 2011 are summarized in Figure 4 - 4.

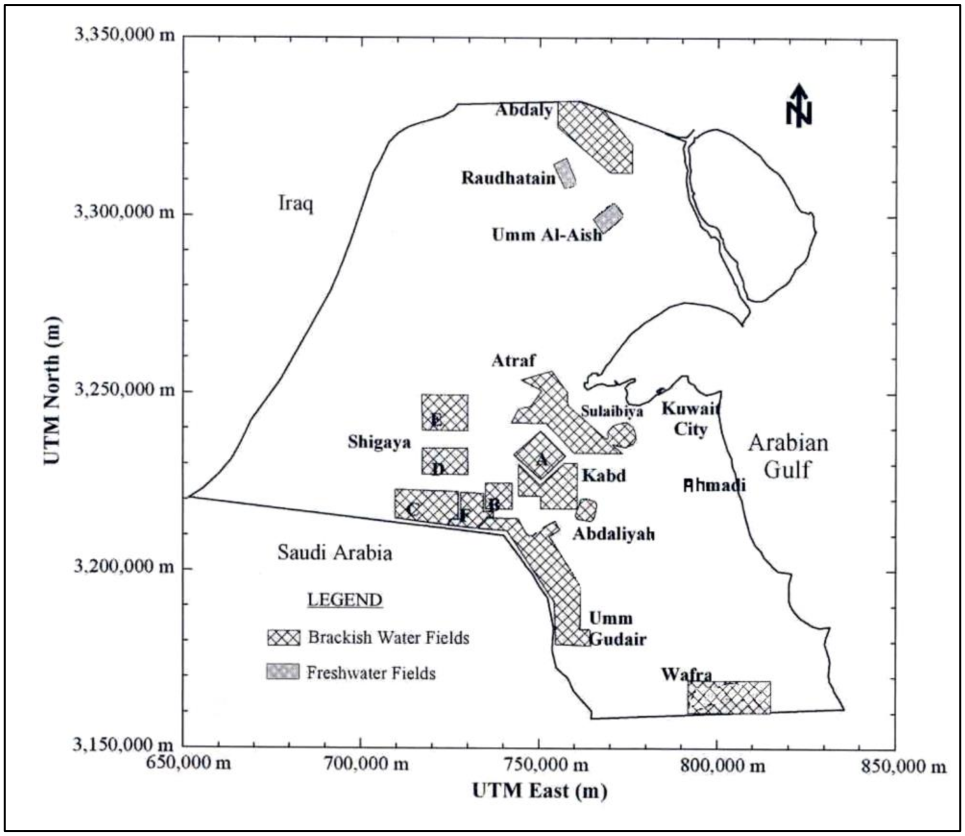

Figure 4 - 3: Groundwater Fields' Locations in Kuwait (Choukr-ALLAH, 2000 by Eidan, 2008)

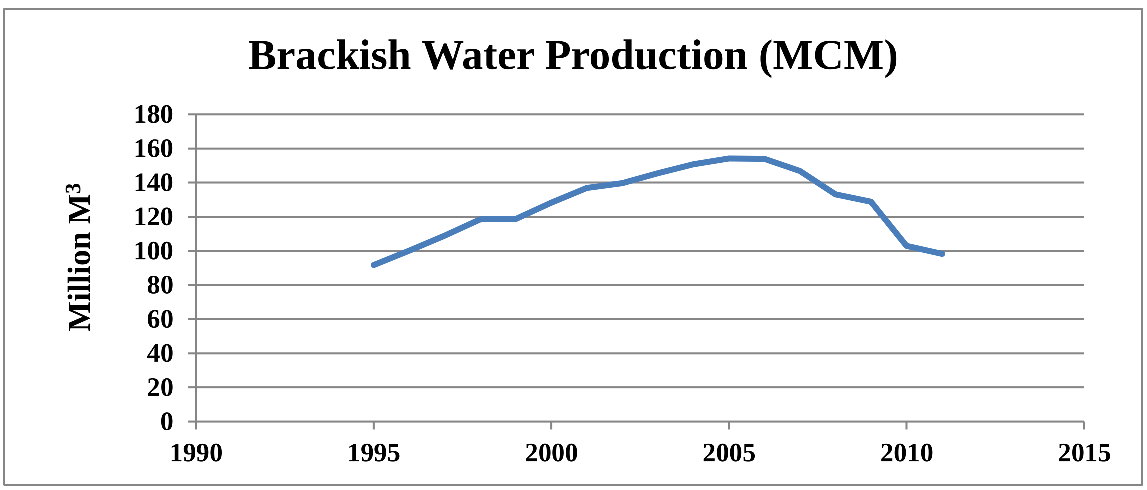

Figure 4 - 4: Trend in Groundwater Abstraction in10^6 m in Kuwait (Ministry of Electricity and Water, 2012)

4.1.2 Desalinated Water (DW)

Kuwait started to produce fresh water by desalination in 1951, since when, desalination has become the country’s main source of freshwater. The major water desalination plants in Kuwait are situated along the Gulf coastline from North (Sabbiya Desalination Plant) to South (S. Zour Desalination Plant). Water desalination is an expensive and resource intensive practice. In 2003, Al-Eisa et al. (2011) estimated that 10% of Kuwait's oil production was consumed by the cogeneration power desalination plants (comprising 6 desalination plants with all operating units listed in Table 4 -2). Figure 4 -5 summarizes trends in desalinated water production from 1995 to 2011.

Table 4 - 2: Water Desalination Plants in Kuwait

Desalination Plant	Year	Desalination Units	Capacity of Unit in m^3/day	Production Capacity in m^3/day
Suwaikh	1953	10	18,180	181,800
	1988	Three Not in Use		127,290
N. Shuaiba	1965	7	9,090	445,500
	1988	Three Not in Use		
	1992	**Not in Use**		
S. Shuaiba	1971	6	18,180	136,380
E. Doha	1978	7	27,270	190,930
W. Doha	1983	3	27,270	438,240
		13		
S. Zour	1988	5	27,270	218,210
	1989	3		
Sabbiya	2006	4	54,550	454,600
	2007	4		

Source: Ministry of Electricity and Water (2009)

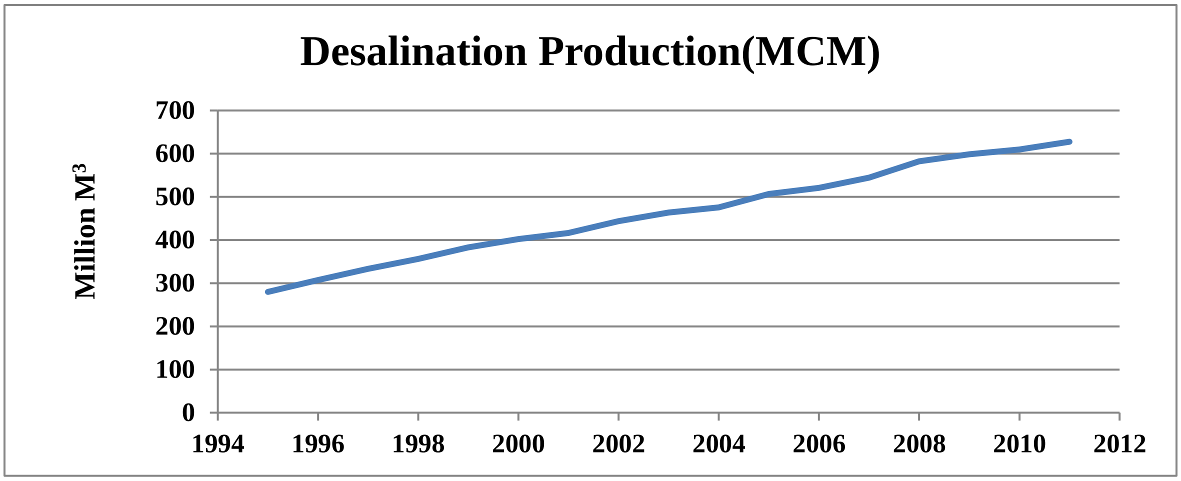

Figure 4 - 5: Trend in Desalinated Water Production in 10^6 m in Kuwait (Ministry of Electricity and Water, 2012)

Since the 1990s, the number of water desalination plants has increased in Kuwait for a number of reasons including (Al-Ghanim, 1994):

1. Limited rainfall (116 mm / year).
2. High (and increasing) demand for freshwater because of population growth.
3. Limited fresh water resources.
4. Availability of the energy required (Oil Production) for desalinated power plants.
5. Location on the Arabian Gulf (water source) and long experience within such technology.

Desalination plants discharge significant volumes of wastewater (produced during desalination) which is responsible for critical environmental impacts on the Kuwaiti coast including water quality problems, especially in Kuwait Bay. According to Al-Eisa et al. (2011), desalination plants discharges constitute a 'multi-component type of waste', and have multiple impacts on marine environment. High quantities of highly saline and high temperature cooling sea-waters are mixed and then discharged to the sea, thus raising seawater temperatures.

Discharge waters also contain chemical residuals including chlorine, antifoaming agents and heavy metals. Moreover, the desalination plants consume fossil fuels and emit gasses including Carbon Dioxide (CO_2), Nitrogen Oxides (NOx), and Sulphur Oxides (SOx) (Darwish et al, 2009). The atmospheric pollution associated with desalination power plants can also contribute to acidic rain near individual plants (Al-Eisa et al, 2011).

4.1.3 <u>Treated Wastewater (TWW)</u>

Currently, Kuwait is estimated to generate around 687,000 m^3 of wastewater daily. Wastewater in Kuwait is treated by four wastewater treatments plants (WWTPs): Jahra, Rigga, Um Al-Haiman and Sulaibiya. About 48% of this total (340 m^3 / day) of wastewater is treated by advanced technology Ultra Filtration (UF) and Reverse Osmosis (RO) membrane filtration at Sulaibiya WWTP which is one of the world's largest membrane-based water reclamation facilities. The remaining 52% (347 m^3 / day) TWW is treated by tertiary level treatment (rapid sand filtration and chlorination) at the other three WWTPs; Jahra, Rigga and Um Al-Haiman (MPW, 2012; Al-Anzi et al, 2011).

Table 4 – **3** lists the four current WWTPs in Kuwait and their designed and extended capacity and the quantities of wastewater each receives and treats while their locations are shown in Figure 4 - **6**. Treated wastewater (TWW) in Kuwait is transported from the wastewater treatment plants (WWTPs) for subsequent reuse either through the distribution network or road transport (tanker truck). There are two distribution networks for TWW in Kuwait; the first network is the responsibility of the Ministry of Public Works (MPW) and the second is used for irrigation proposes (agriculture and recreational) by the Public Authority for Agricultural Affairs and Fish Resources (PAAF). Both the MPW and PAAF

distribution networks rely upon a combination of pumping stations, gravity, and pressure systems.

Table 4 - 3: Main Wastewater Treatment Plants (WWTPs) in Kuwait

WWTP	Year	Designed Capacity (m^3/day)	Extended Capacity (m^3/day)	Received WW (m^3/day)	Treated WW (m^3/day)
Jahra (Tertiary)	1981	65,000	-	133,000	130,000
Rigga (Tertiary)	1982	85,000	180,000	200,000	196,000
Um Al-Haiman (Tertiary)	2001	27,000	-	22,000	21,560
Sulaibiya (Advanced-RO)	2005	425,000	600,000	440,000	320,000

Source: MPW (2012) and Al-Eisa et al. (2011)

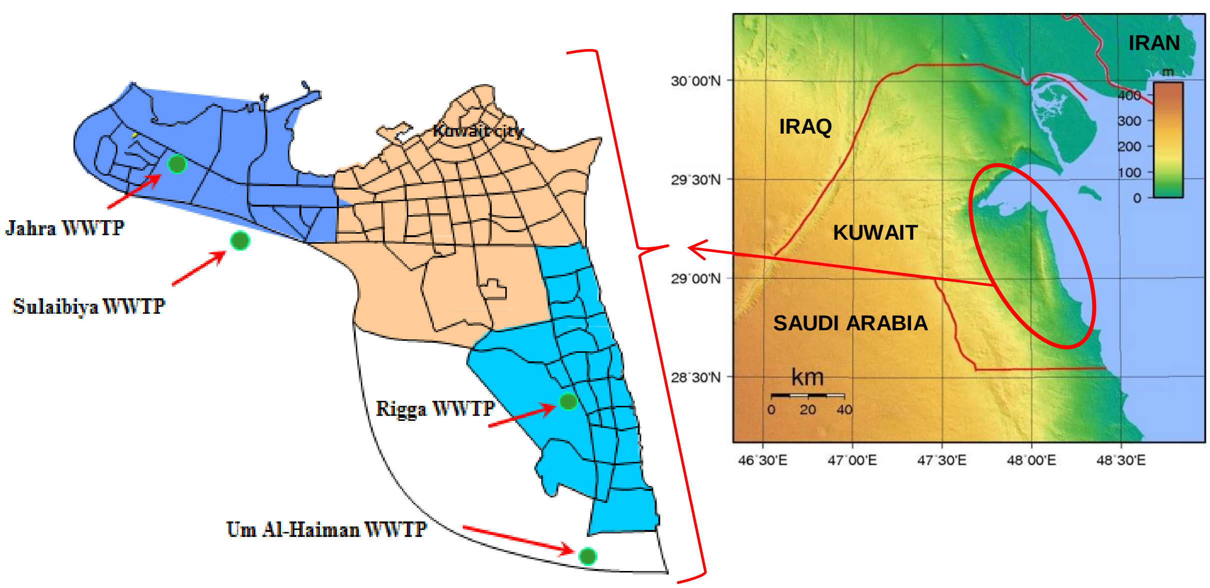

Figure 4 - 6: Location of Wastewater Treatment Plants (WWTPs) in Kuwait (MPW, 2012)

The MPW distribution network links Jahra, Rigga and Sulaibiya WWTP's to water storage reservoirs at the Data Monitoring Centre (DMC) in Sulaibiya (4 storage tanks x 85,000 m^3; two for tertiary TWW and two for RO TWW). From DMC, TWW is transported to agricultural areas around Sulaibiya, Abdaly in the North and Wafra in the South. However, the PAAF distribution network transfers TWW from Rigga WWTP to landscaping (LA) and greenery (G), projects A, B1, B2 and B3 as illustrated in Figure 4 - 7. Other smaller farming and agricultural areas receive TWW from Jahra, Umm-Al-Haiman and Rigga WWTP's (MPW, 2012, Al-Anzi et al, 2011).

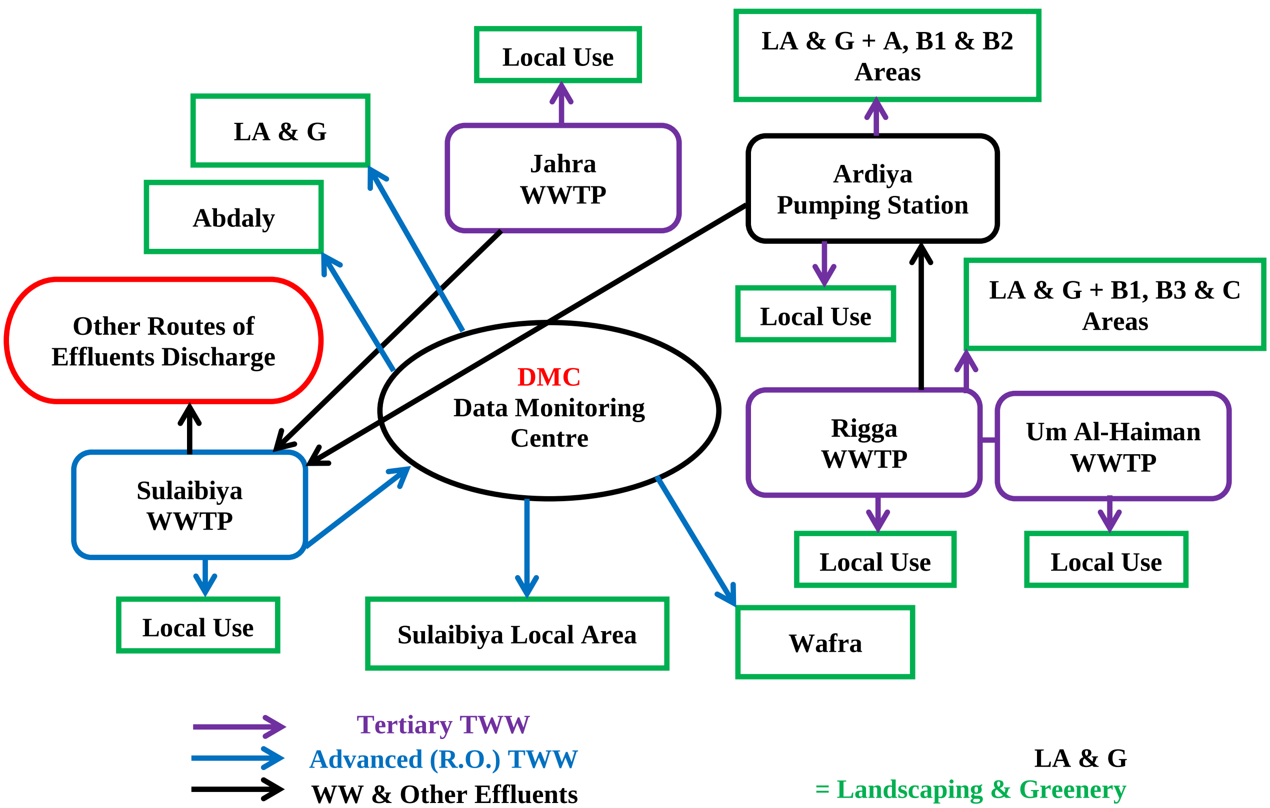

Figure 4 - 7: Distribution System for TWW Reuse Practice in Kuwait (Al-Anzi et al, 2011; Shahalam, 2008; MPW, 2012)

4.2 Water Consumption Sectors in Kuwait

There are three major sectors that consume water in Kuwait. According to Al-Awar (2005), the two largest sectors are: the domestic sector with a mean annual consumption of 461 million m^3 (50%) and the agricultural sector with a mean consumption of 430 million m^3 (47%). The industrial sector is the smallest water sector consuming only 27 million m^3 (3%). The mean consumption of these three sectors (domestic, agricultural, and industrial) has increased (over a period of 5 years) to 617 million m^3 (53%), 517 million m^3 (45%) and 22 million m^3 (2%) respectively (Al-Ruwaih et al, 2012).

4.2.1 Domestic Sector

According to the Ministry of Water and Electricity (Eidan, 2008; Alshammari, 2014), the domestic sector includes individual households, commercial activities and governmental sub-sectors, who receive water from two separate distribution networks. The first is a fresh-water network distributing desalinated water mixed with 10% of groundwater for potable / drinking waters. The second distributes non-potable water (low saline brackish groundwater), which is mainly used for irrigation. The domestic sector consumes up to 90% of desalinated fresh water in Kuwait.

In comparison with some developed countries, or other countries within the region or with a similar climate, Kuwait has one of the highest rates of daily per capita freshwater consumption as summarized in Figure 4-8 (AL-Humoud and Madzikanda, 2010). For a water scarce country like Kuwait, these water consumption patterns are likely have a critical impact on water resources in the future.

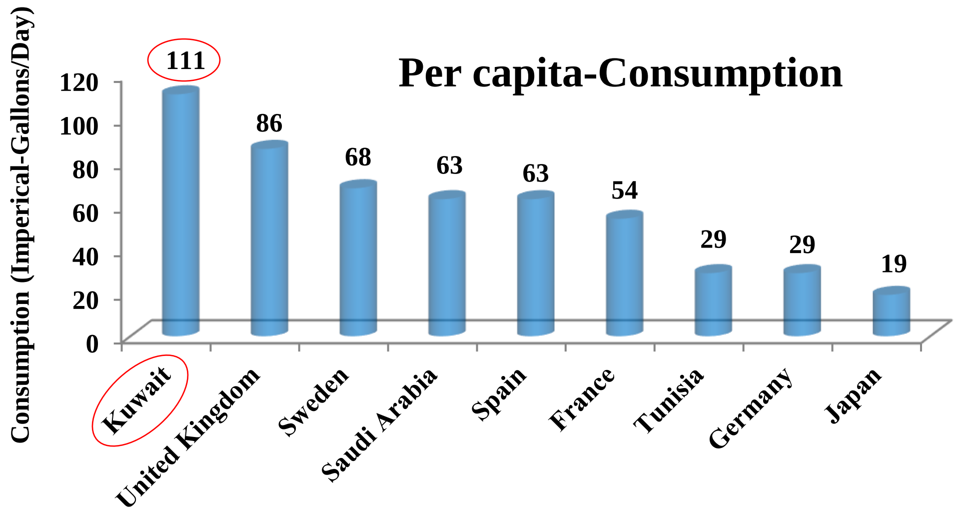

Figure 4-8: Daily Per Capita Freshwater Consumption in Kuwait Compared to Selected Countries (AL-Humoud and Madzikanda, 2010)

4.2.2 Agricultural Sector

The agricultural sector is the second largest water consuming sector. Eidan (2008) highlighted that in the 1990's, agricultural water consumption was 10% less than in 2005 (the percentage of agricultural water consumption of total consumption has increased from 33% in 1992 to 43% in 2005). Agriculture in Kuwait depends mainly on groundwater abstraction (mostly low salinity groundwater). In 2005, groundwater abstraction for agriculture is estimated to have been around 330 million m^3 (i.e. providing 75% of the total water required for agriculture). The remaining water used in agriculture include TWW (18% = 73 million m^3) and small quantities of desalinated water (7% = 27 million m^3) (Al-Awar, 2005 Eidan, 2008). A trend of agricultural water consumption from 2005 to 2011 in Kuwait (according to Al-Ruwaih et al, 2012) is shown in Figure 4-9.

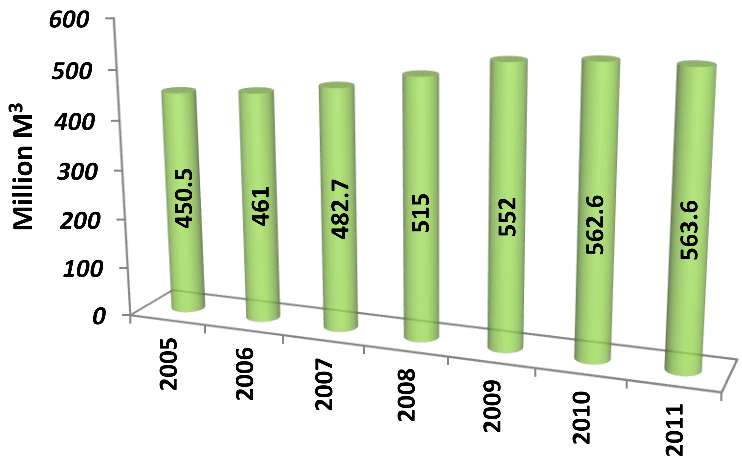

Figure 4-9: Agricultural Water Consumption (from2005 to 2011) in Kuwait (Al-Ruwaih et al, 2012)

4.2.3 Industrial Sector

Industry uses two types of water. It mainly uses desalinated water and small quantities of low salinity groundwater. Industrial water consumption has increased from 2.5 million m^3 in the 1980's to 27 million m^3 in 2005 as indicated earlier. Industry is the smallest (lowest) water consuming sector (representing 3% of total water consumption). However, with the current industrial expansion and development of mega projects in Kuwait (development projects such as new household areas, schools, malls and entertainment cities, roads and bridges, etc.), water demand by this sector is expected to increase. The trend in industrial water consumption from 2005 to 2011 in Kuwait **(**from Al-Ruwaih et al, 2012) is shown in Figure 4-10.

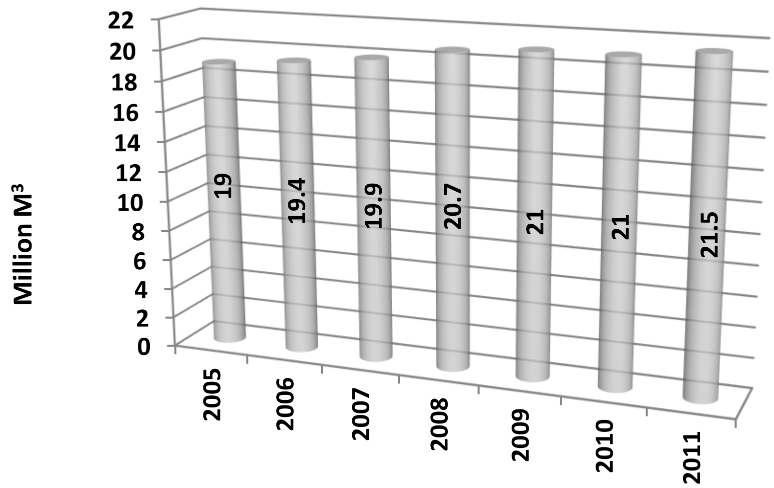

Figure 4-10: Industrial Water Consumption (from 2005 to 2011) in Kuwait (Al-Ruwaih et al, 2012)

4.3 Water and Treated Wastewater (TWW) Management in Kuwait

Water resource management is a critical planning challenge for Kuwait. With an extremely arid climate, current pattern of consumption, water stress, it is expected that balancing water demand will become more challenging in future. Hence it is essential that Kuwait plans to make full use of all available water resources including treated wastewater. There is no supreme authority or council for water management in Kuwait. Water resources are managed by several (different) ministries and authorities. For example, the Ministry of Electricity and Water (MEW) manages the desalination power plants and GW (fresh and brackish water), however, WWTPs and TWW are managed by the Ministry of Public Work (MPW). The institutional framework for water resources & TWW management in Kuwait is summarized in Figure 4 – 11, illustrating the role of the private sector Kuwait's EPA.

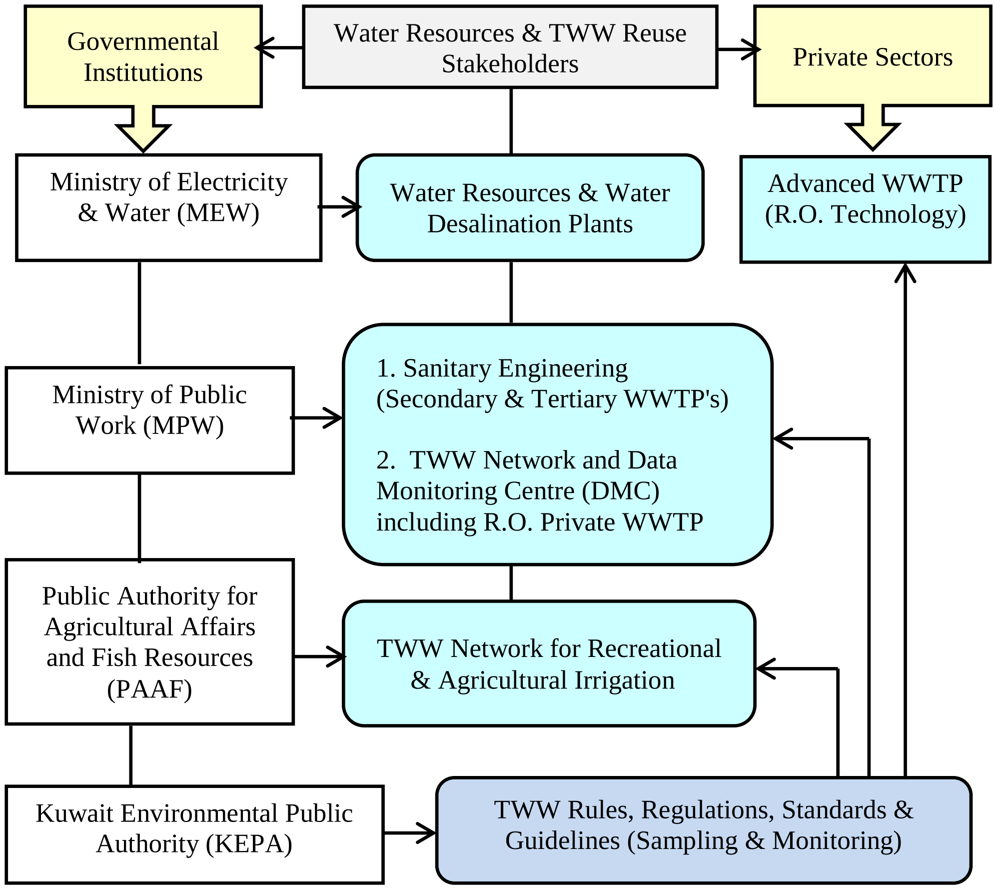

Figure 4 - 11: Institutional Framework of Water Resources & TWW Management in Kuwait

(1) Ministry of Electricity and Water (MEW)

The Water Resources Department is one of the main agencies of the Ministry of Electricity and Water (MEW) which oversees fresh water supply and management. Freshwater is provided by the water desalination plants situated along the gulf coastline. Groundwater (GW) resources (GW wells' drilling and utilization) are also managed by the MEW. The MEW is also responsible for constructing freshwater pipelines and transport and distributing water to households.

(2) Ministry of Public Works (MPW)

The Ministry of Public Works (MPW) oversees wastewater treatment and management in Kuwait. Both government and private wastewater treatment plants (WWTPs) are supervised by the MPW. The MPW Departments of Sanitary Engineering and Environmental Affairs are responsible for TWW reuse practice and management. The Data Monitoring Center (DMC) monitors TWW data monitoring, including the distribution network.

(3) Public Authority for Agricultural Affairs and Fishery Resources (PAAF)

The Public Authority for Agricultural Affairs and Fishery Resources (PAAF) has its own water distribution network (for water from GW abstraction and TWW) which is used only for agriculture, and irrigating recreational areas.

(4) Kuwait Environmental Public Authority (Kuwait EPA)

The Kuwaiti Environmental Public Authority (Kuwait EPA) monitors pollution (atmospheric, aquatic and terrestrial) through different departments and environmental laboratories (by continuous sampling and routine monitoring). With respect to water assessment and management, TWW rules, regulations, standards and guidelines set by individual agencies (e.g. MEW, MPW and PAAF) are supervised by the Kuwait EPA which checks for compliance either by continuous or periodic monitoring. Other institutions, such as the Ministry of Health and Kuwait Municipality undertake routine water and TWW examination.

4.4 <u>Water Policies, Available Strategic Plans for Water & TWW Reuse in Kuwait</u>

As mentioned above, Kuwait has the highest rates of water consumption in the world with a daily use of around 500 liters per capita which is more than double the mean international rate. Kuwait's strategic water planning mainly focuses on social elements of water use and neglects economic aspects. Water management and planning in Kuwait mostly focuses on ensuring the security of water supply for all water consuming sectors. At present, water policies in Kuwait encourage water demand by subsidizing the costs of providing water for all users regardless of their ability to pay. These policies contribute to unsustainable patterns of water consumption. Construction of more desalination plants to meet rising public demand does not mean that rising rates of water consumption will not present a serious risk to future water availability.

Recently, Kuwait has started to consider the potential for TWW to provide an additional water resource. TWW has been considered an alternative water source in the Gulf Cooperation Council (GCC) countries since the early 1970s. The design of wastewater treatment technologies and WWTPs sought to satisfy Kuwait's policy to protect the marine gulf environment in the mid-1970s. Kuwait became a pioneer amongst the GCC countries in the field of wastewater treatment. As mentioned earlier, the first WWTP in Kuwait was established in 1971: the Ardiya plant northwest of Kuwait city. By 2001, four WWTPs had been constructed in Kuwait that treated wastewater up to a tertiary treatment level except Sulaibiya (the advanced-R.O. treatment plant) which treats wastewater in the quaternary method; the first of its kind in the GCC.

In 2005, Sulaibiya WWTP, one of the largest advanced R.O. WWTP commenced operations. The Sulaibiya WWTP is currently the world's largest with a designed capacity of 425,000 m^3/day, which can potentially be increased to 600,000 m^3/day. The plant uses advanced WWT technology (including the quaternary and R.O. methods) to produce TWW that exceeds current standards set by the World Health Organization (WHO). The TWW quality is considered safe, with respect to environmental health for use for agricultural, industrial, commercial and domestic purposes (for both potable and non-potable uses including bathing and drinking uses) (Al-Anzi et al, 2011; MPW, 2012).

Unfortunately, the technological and operational feasibility of this alternative water resource use is not clear given its inefficiency. Water resources alternatives using new sustainable technologies including effective utilization of TWW and groundwater recharging using R.O) require effective planning (and assessment and feasibility studies). Kuwait started this project (the advanced WWTP) to provide fresh water without clear strategic planning. This water was intended to provide households with an alternative non-potable water uses (e.g. car washing, back and front yards irrigation) as well as other options to replace and reduce pressure on freshwater utilization.

4.5 Rules, Regulations, Standards and Guidelines of TWW Reuse and Options

As highlighted earlier by MPW (2012) and Al-Anzi et al. (2011), around 48% of Kuwait's wastewater is treated to an advanced level using Ultra Filtration (UF) and Reverse Osmosis (R.O.) membrane filtration at Sulaibiya WWTP. The remaining 52% of wastewater is treated to a tertiary level (rapid sand filtration and chlorination) by the three remaining WWTPs listed in Table 4 - 3. Conventional activated sludge is also processed at these WWTPs. Table 4 - 4 summarizes the treatment systems used in the four main WWTPs in Kuwait.

Table 4 - 4: Treatment Systems Used in Kuwait's Main WWTPs

WWTP	Secondary Treatment	Tertiary Treatment	Advanced Treatment
Jahra	6 Conventional Activated-Sludge Systems in Extended Aeration	Sand Filtration + Chlorination	--
Rigga	12 Conventional Activated-Sludge Systems in Extended Aeration	Sand Filtration + Chlorination	--
Um Al-Haiman	4 Oxidation Ditch Systems	Sand filtration + UV + Chlorination	--
Sulaibiya	9 BNR Activated-Sludge Systems	--	Disc Filtration + UF + RO + Chlorination

Source: Al-Anzi et al, 2011

The characteristics of TWW (wastewater treated effluents) used for irrigation in agriculture and landscaping are summarized in Table 4 - 5. As pointed out by MPW, the quality of effluent discharge compares (satisfactorily) with international standards (e.g. WHO, UNEP, USEPA). Such TWW standard limits and guidelines currently fall under the jurisdiction of Kuwaiti EPA and are supervised and monitored by MPW.

Table 4 - 5: Standard Limits and Characteristics of TWW Used for Agricultural and Recreational Irrigation Compared to Drinking Water in Kuwait

Parameter	UNIT	INFLOW	TERTIARY	R.O	Parameters of irrigation water	MEW Parameters of Drinking water
PH	—	6.5- 8	6.5- 7.5	6-8	6.5 – 8	6.8 – 7.5
Conductivity	µs/cm	1200- 3000	1100- 2200		1500	515
T.S.S.	mg/L	100- 500	< 10	< 1	15	_
V.S.S.	mg/L	70- 350	< 7.0	< 1	_	_
C.O.D.	mg/L	250- 750	< 40		100	_
$B.O.D_5$	mg/L	100- 400	< 10	< 1	20	_
Grease & Oil	mg/L	10- 50	NIL	< 0.05	5	_
T.D.S.	mg/L	700- 1800	800- 1500	< 100	_	400
Chloride	mg/L	200- 400	200- 400		_	103
Ammonia	mg/L	15- 50	1- 5	< 1	15	_
Nitrite	mg/L	0.04- 0.7	0.1- 1.5	< 1	_	_
Total Count	colony/100mL	2.40E+09	1E+03	NIL	_	NIL
T.Coli	colony/100mL	3.20E+08	400	NIL	400	NIL
F.Coli	colony/100mL	4.10E+07	0 - 10	NIL	20	NIL
Salmonella	colony/100mL	4.50E+06	NIL	NIL	_	NIL
Streptococci	colony/100mL	1.40E+07	NIL	NIL	_	NIL
Fungi	colony/100mL	2.10E+05	2- 100	NIL	_	NIL

Source: Kuwait EPA; MPW, 2012

4.6 DPSIR Analysis

As discussed in chapter 3 (section 3.2), DPSIR provides an integrated analysis of environmental problems and challenges, and assists in organizing data and selecting indicators. It highlights how research on specific environmental issues might be implemented and provides the basis for analyzing inter-related factors that impact the environment. DPSIR provides a detailed information on the current situation (state of environment), identifies interrelationships and determines the effectiveness of responses (Gabrielsen and Bosch, 2003; UNU / IAS, 2003; UNEP, 2005; Geo Resource Book, 2006).

To undertake an integrated analytical framework of wastewater reuse practice, the first step is to gather comprehensive data regarding wastewater reuse issue. Raschid-Sally et al. (2001) suggests that information should be gathered from experts within most related fields such as health, environment, water resources management, irrigation, agriculture, soil sciences, water quality, etc. For environmental issues, Hochstrat et al. (2008) highlighted that water management data and the status of current TWW reuse practice must be taken as a starting point. Findings must then be directed toward the best practices of wastewater reuse as well as protecting human health and the environment.

Accordingly, from the current investigation and data on TWW management and reuse practice in Kuwait, a general framework listing the DPSIR components are presented in Figure 4 – 12.

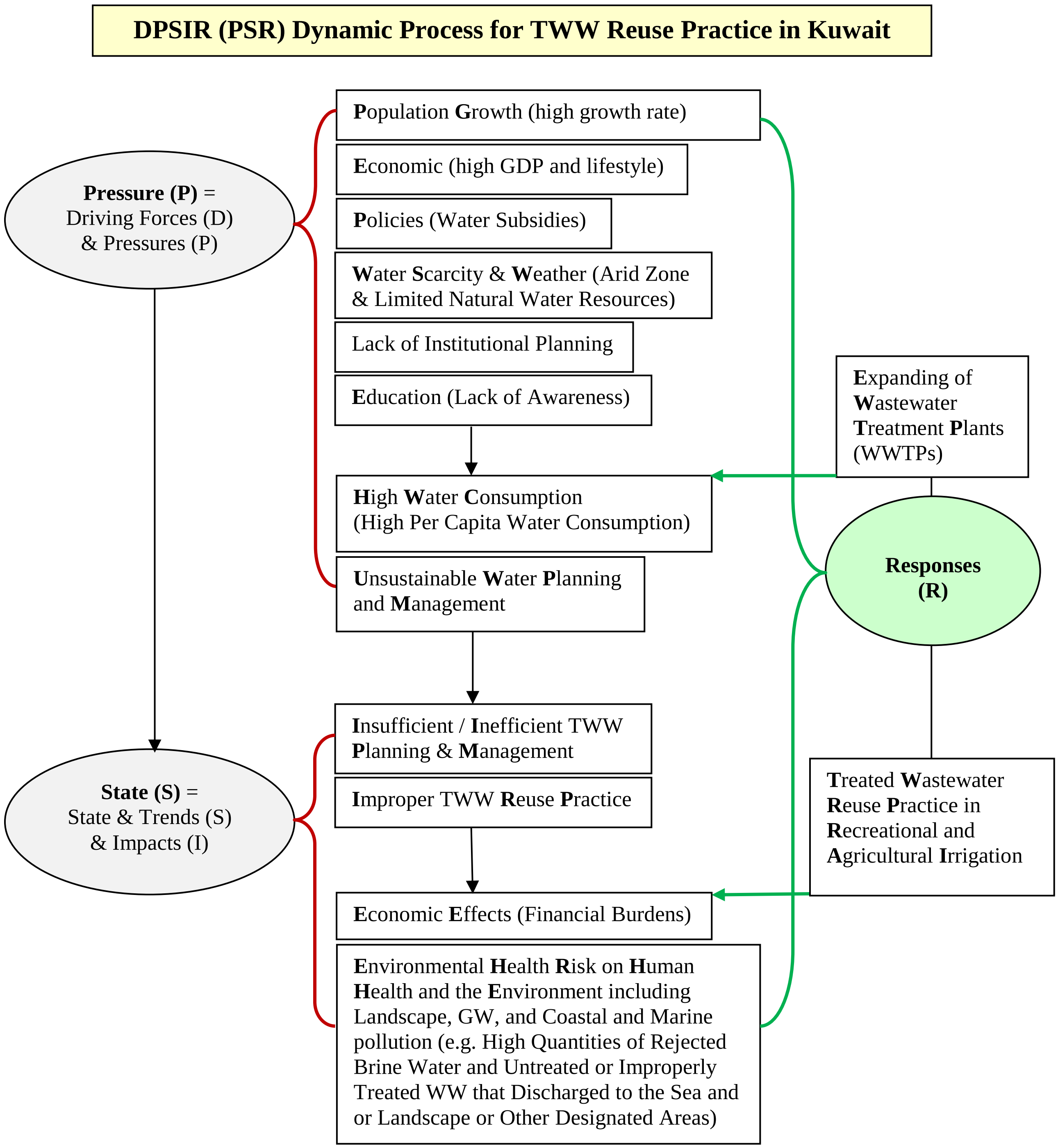

Figure 4 - 12: DPSIR (PSR) Framework of TWW Reuse Practice in Kuwait

4.6.1 Driving Forces

As mentioned earlier in Section 4.1, Kuwait is classified as one of the most water scarce countries in the world with water per capita of less than 500 m^3/year. The climate is characterized by high temperatures (with high evapotranspiration rates that can reach 3000 mm/year) and very low rainfall averages as presented in Figure 4 -13 (DGCA, 2014).

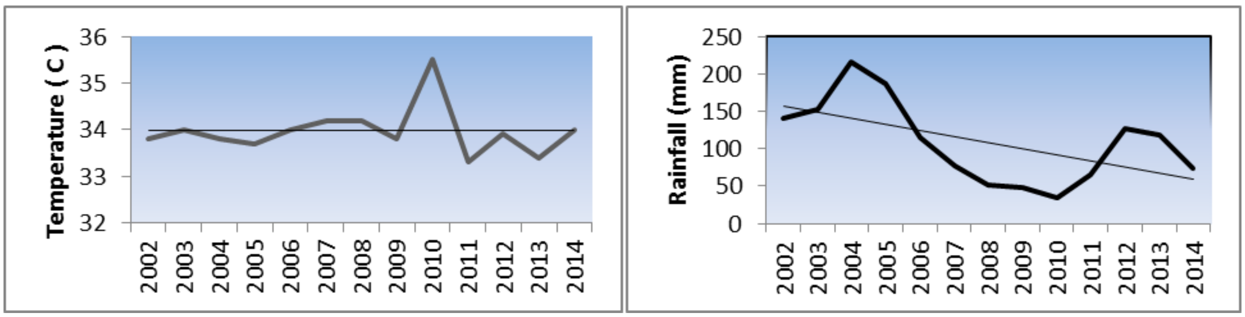

Figure 4 -13: Levels of Temperature and Rainfall Averages in Kuwait (between 2002 and 2014)

With a continuous increase in the annual mean temperature, the temperature increase in the next 20 years in Kuwait could reach 1.6°C (Kuwait EPA, 2012). Higher temperatures are one of the main driving forces behind unsustainably high water consumption patterns alongside other drivers such as lifestyle and governmental policies. Climate and population are considered global challenges within water sector in the 21st century; temperature projections for the UK future climate (until 2080), for example, predict significant rises of average summer temperatures (3 - 4°C), winters will become wetter, summers drier and there will be more frequent, extreme weather events (Butler et al, 2014).

Kuwait's water policies require reformation to address the problems associated with meeting water demand by increasing water supply whilst avoiding undue economic hardship. Increases in the capacity of water desalination plants and in rates of groundwater abstraction to meet water demands affect both the economy and availability of 'natural' water resources potentially leading to a future water crisis. There is a lack of effective and well-organized structural water tariffs. Freshwater costs are the same for all beneficiaries (all water consumers pay the same tariff regardless of how many properties they own or how much water they consume). Moreover, TWW is highly subsidized and distributed free of charge. The current price of tertiary TWW is 100 Fills (0.33 US Dollar) / 1000 IG (4.6 m^3) whilst the cost to government is 550 Fills (1.8 US Dollar). In contrast, advanced (R.O.) TWW price is 200 Fills (0.66 US Dollar) / 1000 IG (4.6 m^3) whilst the cost is 2.8 US Dollars.

In addition, there are no programs of water resources allocation nor to raise public awareness. No improvements are envisaged in water auditing nor in groundwater protection. At the same time as the rapid increase in population (Figure 4 – 14), urbanization, and changes in lifestyle (high GDP as provided in Figure 4 – 15) in Kuwait, there has been a proportional increase in water consumption. Within the last fifteen years, the average rate of increase of Kuwaiti citizens has been 2.98% and the average total population growth rate has been 4.43%, which is very high compared to world growth rates (Ministry of Planning, 2015).

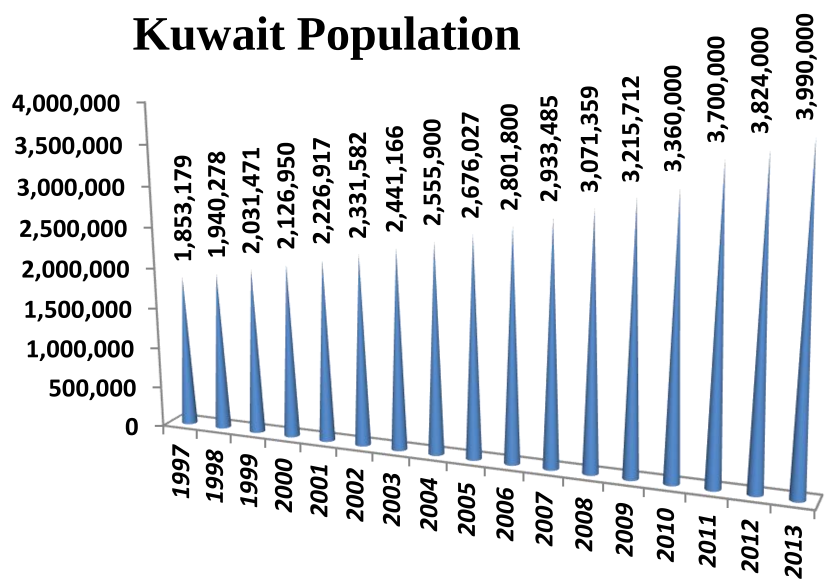

Figure 4 – 14: Population Growth in Kuwait between1996 and 2014 (Ministry of Planning, 2014)

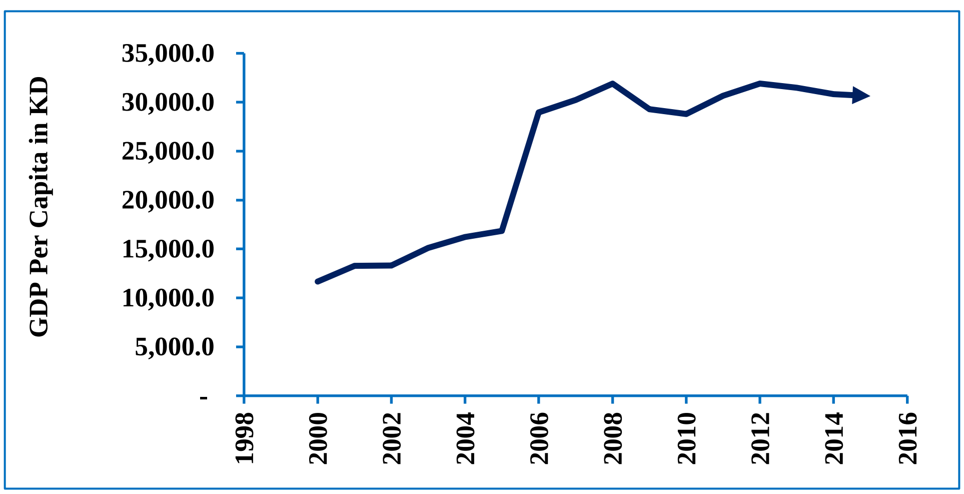

Figure 4 – 15: Trend in GDP in Kuwait (Ministry of Planning, 2014)

4.6.2 Pressures

The current institutional framework of water management and planning causes significant problems. The main natural water resource in Kuwait is groundwater. Given the above trends, including the rapid increase in population and high GDP in Kuwait, there has been a proportional increase in water consumption as demonstrated in Figure 4 - 16. In order to meet the demand for freshwater, seawater desalination has become the main alternative freshwater resource. High rates of water consumption have caused stress on available freshwater and threatened groundwater resources with excessive withdrawal rates. With such high population and economic growth, high per capita water consumption, and government policies (e.g. water tariffs and subsidies), it will be difficult for Kuwait to satisfy future anticipated freshwater demand.

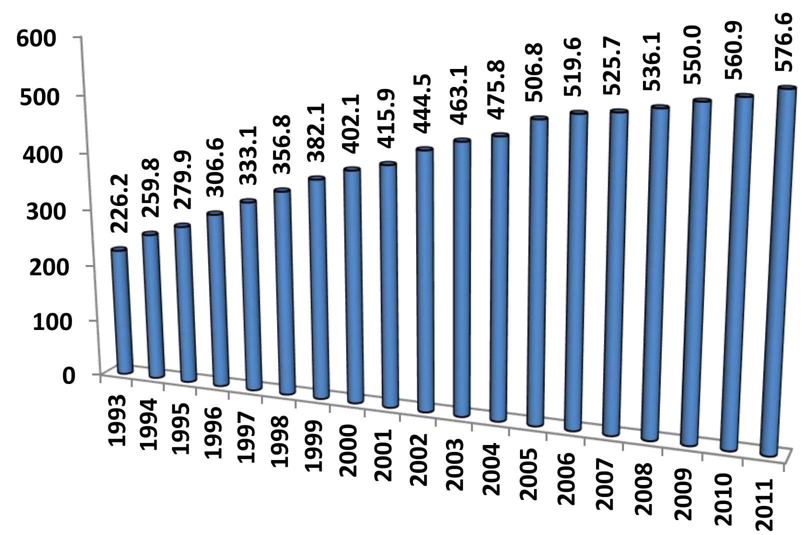

Figure 4 -16: Water Consumption in million m^3 in Kuwait from 1993 to 2011 (Ministry of Electricity and Water, 2012)

4.6.3 State of Environment

The quantity of wastewater produced increases in proportion to freshwater consumption resulting in greater loads on wastewater treatment plants (WWTPs). The Kuwaiti government is seeking to increase freshwater availability by developing WWTPs with more production capacity. Other logistic requirements, both technological and operational (e.g. energy use, production, purifying, pumping processes, conveying and distribution of water and TWW) also present challenges for planning and management. Due to insufficient and ineffective planning and management, there are significant challenges in reducing the stress on freshwater and GW reserves and rates of GW abstractions for agricultural purposes has recently increased. Thus to meet freshwater demand and treating wastewater, Kuwait has focused on establishment and expansion of desalination plants as well WWTPs.

According to Al-Anzi et al. (2012), large quantities of TWW and untreated WW are currently discharged into the sea. TWW reused for agriculture and recreational irrigation, and quantities discharged to the sea (2010 and predicted to 2020 by Al-Anzi et al. 2012) are represented in Figure 4 - 17. One positive action is that currently the discharge of WW or TWW to the sea has fallen, as a result of TWW reuse practices in agriculture and recreational irrigation (as shown in Figure 4 -12). However, it is still an ongoing challenge due to the current inefficient management of TWW and improper TWW reuse practices.

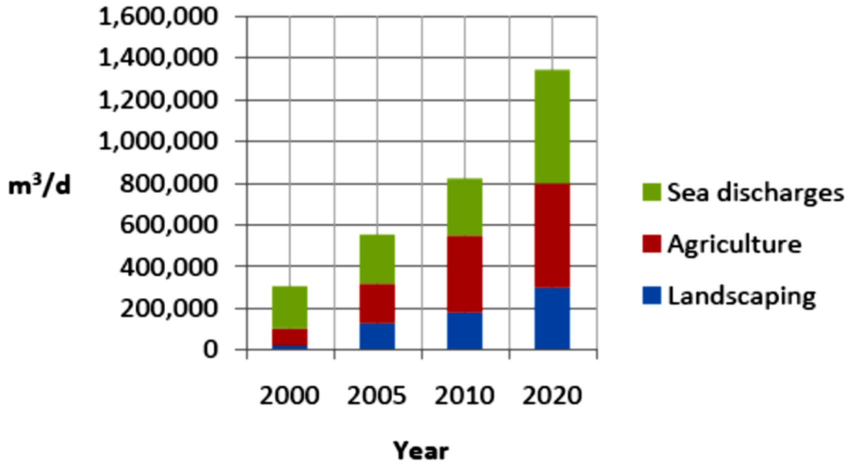

Figure 4 - 17: TWW reused in agriculture, landscaping or discharged to the sea in Kuwait (Al-Anzi et al, 2012)

Until 2010 (when TWW increased proportionally with freshwater production and consumption), TWW quantities discharged to the sea fell from 65% in 2000 to about 30% in 2010. However, as shown in Figure 4 -18, these quantities are expected to decline in future due to insufficient TWW storage capacity and the lack of TWW reuse practice planning and management.

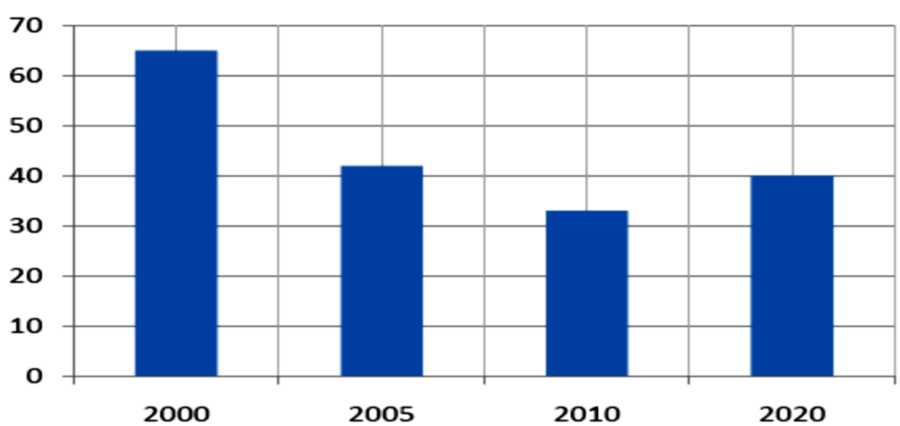

Figure 4 -18: Percent of TWW Discharged into the Sea in Kuwait (Al-Anzi et al, 2012)

4.6.4 Environmental Impacts

At the desalination power plants, a Multi Stage Flash Evaporating system (MSF) is used to produce desalinated freshwater and electricity. Reverse Osmosis (R.O.) is also used in several desalination plants to reduce operational costs and energy use but not in high quantities. Such plants use a combination of natural gas, heavy fuel oil, crude oil and gas oil, depending on boiler design to cover freshwater demand in Kuwait. Environmental impacts and socio-economic burdens will be increased accordingly.

To supply and distribute freshwater and electricity, there will be environmental impacts arising from atmospheric pollution (e.g. carbon dioxide CO_2, nitrogen oxides NO_X, and sulfur dioxides SO_X emissions) which will be continuously emitted. Power production is based on the use of natural gas with crude oil, residual oil, and diesel accounting for 75% of total emissions from all energy production and consumption activities in Kuwait. Furthermore, the water-energy nexus is expected to become a significant issue in future due to high temperatures in Kuwait. This can cause increased stress on available freshwater resources at a time when water demand is increasing in Kuwait. High mean temperatures significantly influence water consumption during summer (Kuwait EPA, 2012).

Another environmental health and socio-economic type of impact is associated with the continuous discharge of treated or untreated WW into the sea. As highlighted by Al-Anzi et al. (2012) such negative action causes serious environmental health impacts due to oxygen depletion, high biological oxygen demand (BOD), eutrophication (due to high concentration of N and P), pathogenic microorganisms, heavy metals and other organic compounds polluting the marine environment. Figure 4 – 19 summarizes TWW qualities that are discharged from WWTPs in Kuwait in 2005.

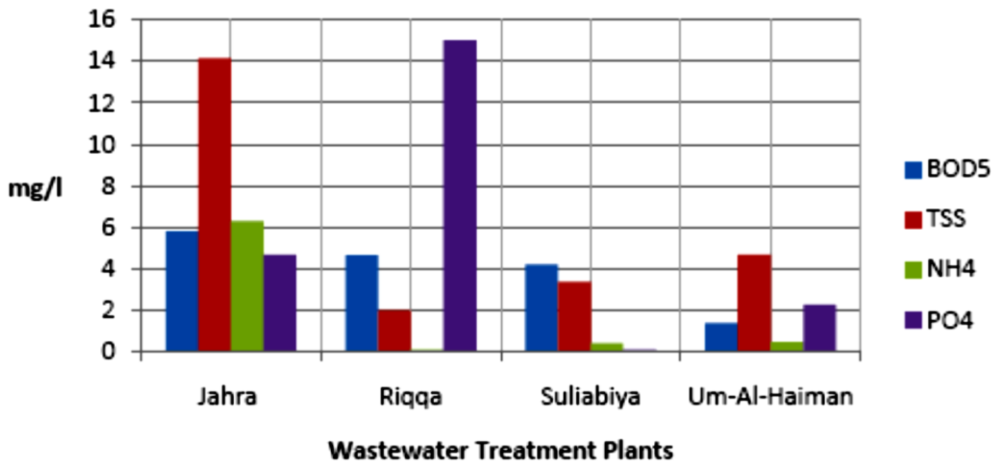

Figure 4 -19: TWW Qualities of Tertiary and Advanced WWTPs in Kuwait (Al-Anzi et al, 2012)

4.6.5 Responses

The interrelationships between water, food and energy offer possibilities for new directions in water resource management in future (Muller, 2015). Food security is considered one of Kuwait's most serious challenges given a high reliance on imported food. As previously mentioned, the agricultural sector is dependent on groundwater (75%), with small quantities of treated wastewater (18%) and freshwater (7%). Therefore, to reduce the pressure on both freshwater and groundwater, Kuwait has started to utilize TWW for agricultural irrigation (tertiary TWW since 1980 and quaternary TWW since 2005). As a result, quantities of groundwater abstraction used for agricultural irrigation started to fall from 2005 as evident earlier in this chapter (Section 4.1; Figure 4 – 4).

4.7 Summary of DPSIR Analysis

A DPSIR framework analysis of Kuwait indicates that Responses are directed toward the Pressure of high water consumption rates by expanding WWTPs. Another Response to Impacts on marine environment is to reduce the quantities of improperly treated or untreated wastewater discharge to the sea (by reusing TWW in agriculture and recreational irrigation). The dynamic process of DPSIR method is to respond to all components of the framework (the Driving Forces, Pressures, States, and Impacts) as explored in Figure 3-1 (Chapter 3). Therefore, TWW reuse practices within all available options must be sufficiently assessed to manage TWW. Accordingly, this alternative (TWW reuse) water resource can be included within the national water strategic planning and management. Figure 4 – 20 summarizes the DPSIR analysis for the TWW reuse practice in Kuwait.

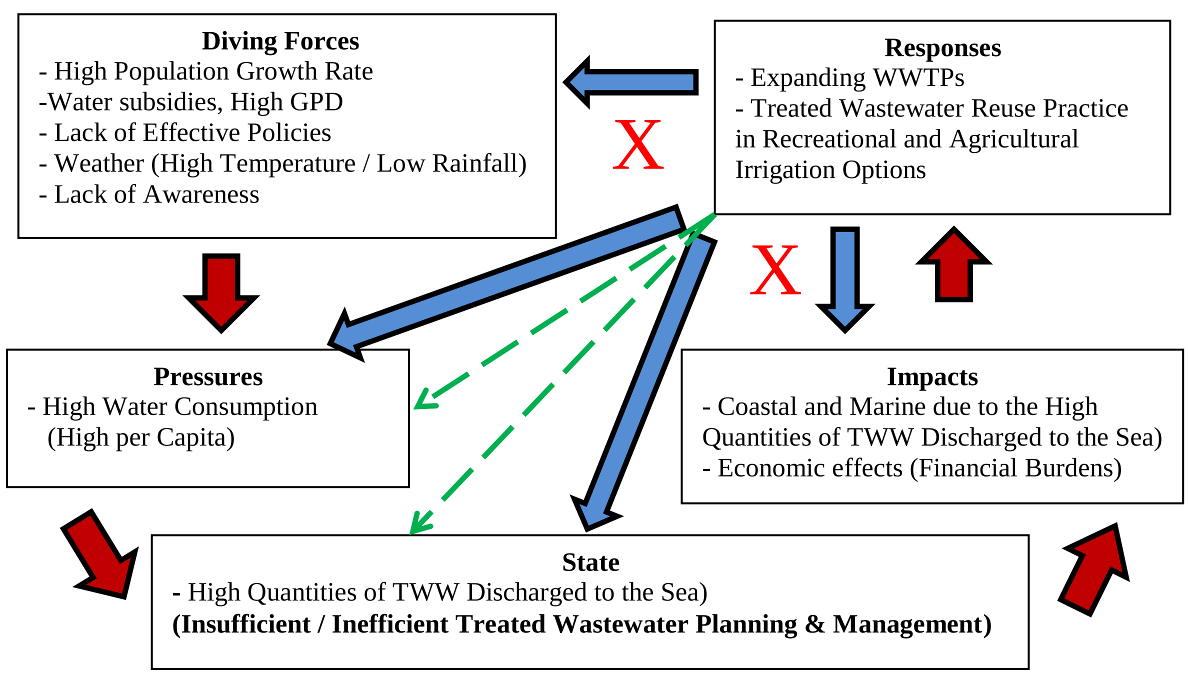

Figure 4 -20: Summary of DPSIR Analysis for the TWW Reuse Practice in Kuwait

Chapter 5

Multi-Criteria Decision Making (MCDM)

This chapter describes the first phase of the research (first method): a Multi-Criteria Decision Making (MCDM) investigation conducted on the case study (Kuwait). First, a pilot study was conducted interviewing and surveying the first group of expert and experienced participants to select the best available treated wastewater (TWW) reuse options for Kuwait and weighing the criteria used. Before starting MCDM, a short survey questionnaire (SSQ) was designed to evaluate the expert participants' judgements of TWW reuse options. On the basis of the SSQ result, the Analytical Hierarchy Process (AHP) was structured to include the best available (applicable) TWW reuse options as well as the affected criteria weightings required. Finally, Criteria (and sub-criteria) weightings were analysed for further assessment and decision making.

5.1 A Pilot Study of MCDM (Kuwait Case Study)

The method of MCDM starts by generating priorities before organizing the assessment elements for decision into steps (Saaty, 2008). After defining and specifying the problem (the environmental issue), the multi-criteria hierarchy is structured into three levels; the goal at the top, the criteria in the middle, and the alternatives at the lowest level. The process of weighing the priorities, rating or ranking the criteria can then be designed within a suitable survey for further analysis and evaluation. The method of pairwise comparison between the criteria used by Saaty (2008) was avoided for the complexity (difficulty) and weakness reasons as outlined in Table 2 -2 (Chapter 2, Section 2.7). This study stimulates and manipulates multi-criteria methods (as required) to achieve more reliable results.

To identify the critical issues and factors influencing TWW reuse practice and options, six criteria were preliminarily evaluated within a decision making process (within a pilot study) to identify the most applicable TWW reuse options. The criteria were selected to suit the situation of Kuwait. For both assessment and decision making of TWW reuse practice and options, environmental health risk and socio-economic perceptions of four types of expert participants (EP) were comprehensively surveyed:

1. **Decision Makers:** including specialists, researchers working in water or wastewater reuse planning and management and individuals involved in the decision making process. Most decision makers were from the Ministry of Electricity and Water (MEW) (including desalination power plants), the Ministry of Public Work (MPW) (government and private WWTP's and DMC), the Public Authority for Agriculture and Fishery (PAAF) and Kuwait EPA.

2. **Specialists and Researchers:** experts from MEW, MPW, PAAF and Kuwait EPA alongside Kuwait University and the Kuwait Institute for Scientific Researches (KISR).

3. **Other Stakeholders with Field Experience:** from private wastewater treatment plants (WWPTs) such as the advance R.O. treatment technology plant, industry, firefighting, farmers and other beneficiaries where TWW can potentially be reused.

4. **Experienced Public Representatives (PR):** experienced individuals invited for their expert opinion (e.g. researchers and employee or households who are knowledgeable and interested in the field).

The six preliminarily suggested criteria for the pilot study are as follows:

1. Environmental Health Criteria: including those environmental impacts (e.g. chemical, physical, and biological) that are predicted to occur from the practice of the reuse options which might cause a direct or indirect effect on human health, the environment (e.g. air and marine pollution, and land degradation), ecosystem and ecosystem services.

2. Economic-Financial Criteria: all economic criteria, financial support and logistics associated with the reuse options including initial and incremental costs, affordability and the ability to fund such options.

3. Technological-Operational Criteria: the technology required to operate and process the reuse options (e.g. WWTPs, pumping stations, monitoring and sampling techniques, and laboratories) including their availability, flexibility, reliability, and implementation.

4. Institutional-Legislative Criteria: the availability of institutions and well-trained workforce as well as the legislative requirements for TWW reuse practice (e.g. policies, legislations, standards and guidelines) that are reliable, with respect to international and national regulations.

5. Political Criteria: political risk and potential future crises predicted from practicing the TWW reuse options, and further political considerations including socio-political satisfaction or potential conflicts regarding practicing such reuse options (political stability).

6. Social Criteria: the effects of TWW reuse options on the community and social groups including public satisfaction (acceptance) and well-being (safe precautionary measures) for any educational, attitudinal, belief or religious reason.

The Analytical Hierarchy Process (AHP) is structured to include these criteria alongside the objective and alternatives (options) to start the first phase of the study (the pilot study) as illustrated in Figure 5 – 1.

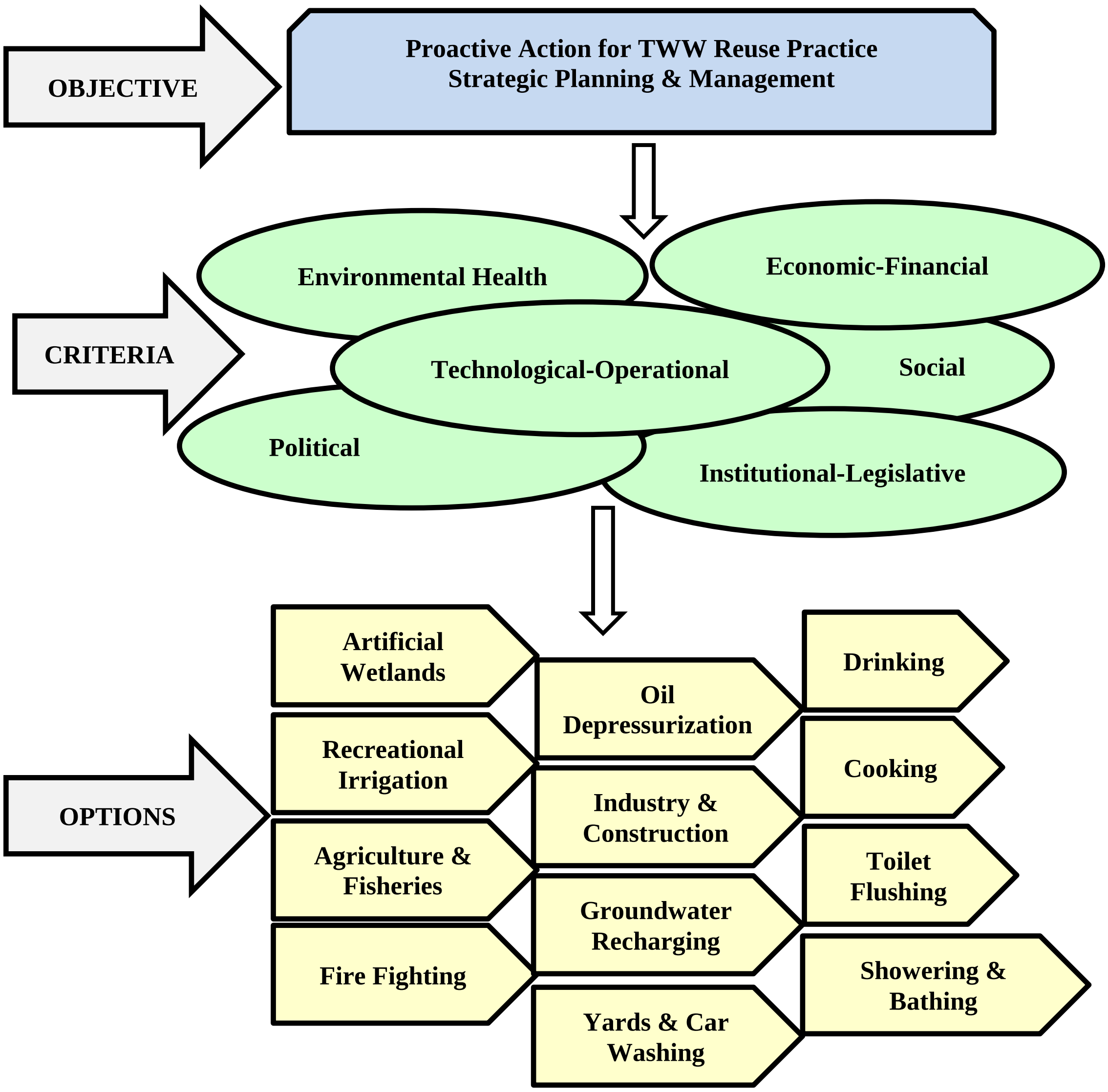

Figure 5 - 1: Diagram of Analytical Hierarchy Process (AHP) – Pilot Study

5.1.1 First Phase of the Pilot Study (Selection of TWW Reuse Options)

Interviews and a short survey questionnaire (SSQ) outlined in Appendix 5 (5A) were conducted with 50 participants (expert participants within different fields and backgrounds); comprising 14 expert decision makers and specialists and researchers (from both government and private sectors), 17 from the private sector and other stakeholders, and 19 from public as public representatives (PR). The SSQ was divided into two main tables; the first sought to determine the knowledge perception of participants regarding wastewater treatment and TWW Reuse Practice and options while the second represented their perception of reuse options (participants' selection of best applicable TWW reuse options).

The applicable, accepted or positive responses depend upon the extent of an individual's knowledge regarding TWW reuse practice and options. As mentioned above, some participants were from empowered government decision makers (DM). They were required to select options at this stage and were asked to weight criteria and scale the degree of effect for MCDA alongside other experts in the field and experienced public representatives (PR). Table 5-1 summarizes the results of a first phase survey of the participants regarding selection of TWW reuse options.

The interviewed participants' responses to the SSQ were positive. Some changes within the short survey questionnaire (SSQ) were suggested as summarized in Appendix 5 (5B). The result of each type of paticipants (showing some trade-off issues amongst all benefited stakeholders) in separate Figures is provided in Appendix 6 (6A, 6B and 6C) and the results from all participants regarding the 12 TWW reuse options are illustrated in Figure 5 - 2.

Table 5 - 1: Perception of TWW Reuse Options amongst Stakeholder for Kuwait

Group		Applicability or Acceptance	(1) Artificial Wetlands	(2) Recreational Irrigation	(3) Agriculture & Fisheries	(4) Industry & Construction	(5) Fire Fighting	(6) Oil Depressurization	(7) Ground Water Recharging	(8) Yards & Car Washing	(9) Toilet Flushing	(10) Showering & Bathing	(11) Cooking	(12) Drinking
Expert		**A or 1**	**13**	**13**	**14**	**14**	**13**	**14**	**12**	**10**	**11**	**0**	**0**	**0**
		N/A or 2	**1**	**1**	**0**	**0**	**1**	**0**	**2**	**4**	**3**	**14**	**14**	**14**
Other Stakeholders		**A or 1**	**14**	**16**	**12**	**15**	**15**	**15**	**4**	**15**	**11**	**3**	**0**	**0**
		N/A or 2	**3**	**1**	**5**	**2**	**2**	**2**	**13**	**2**	**6**	**14**	**17**	**17**
Public Representatives PR		**A or 1**	**18**	**19**	**17**	**18**	**19**	**18**	**10**	**15**	**16**	**4**	**1**	**1**
		N/A or 2	**1**	**0**	**2**	**1**	**0**	**1**	**9**	**4**	**3**	**15**	**18**	**18**
Total		**-**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**

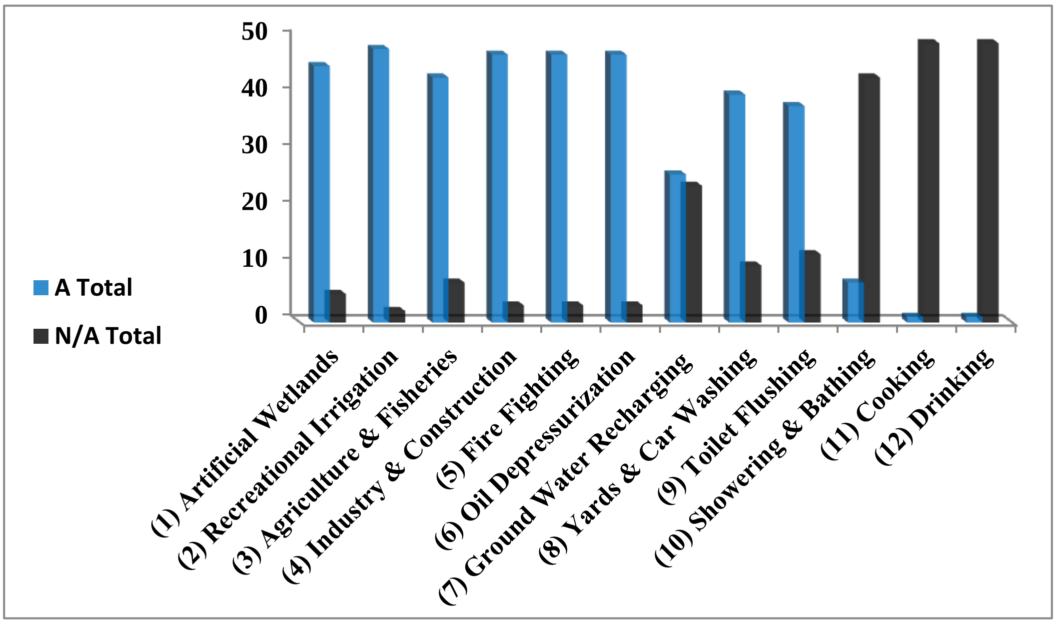

Figure 5 - 2: Perceptions of Participants Regarding TWW Reuse Options

In general, expert judgment and perceptions regarding the most applicable TWW reuse options were positive regarding the first 6 options (“artificial wetlands”, “recreational irrigation”, “agricultural irrigation”, “industrial and constructional processes”, “firefighting” and “oil-depressurization”). However, TWW reuse for option 7 (“groundwater recharge”) was found to be controversial (i.e. debatable). The result was almost equal between those who supported the option and those who were against it. TWW reuse options 8 and 9 (“yards, and car washing” and “toilet flushing”) showed a small number of rejections, 10, 11, and 12 (“showering and bathing”, “cooking” and “drinking”) were mostly rejected for environmental health risks and social reasons (e.g. religion, attitudes and personal beliefs).

For more effective analysis of perceptions, and to assist in the next phase of the survey for weighing criteria, the reasons for applicability (applicable A or not applicable N/A) or acceptance (agree 1 or disagree 2) were categorized into the four suggested criteria to be weighed for each reuse option within the next phase. The four submitted criteria affected by TWW reuse options (reasons for accepting and rejecting any option) that can then be used within the multi-criteria decision making (MCDM) process were:

1. **Environmental Health Criteria (C1):** covering positive environmental benefits (such as minimizing pollution, contributing to environmental mitigation, water management and water conservation) or negative impacts including the environmental health risks, pollution or deterioration potentially affecting human health and the environment.

2. **Economic Criteria (C2):** covering the positive economic feasibility, investments and other economic beneficiaries, or the negative effect of economic or financial costs.

3. **Technological – Operational Criteria (C3):** covering the availability of technology, infrastructure and logistics, flexibility in operational processes and workforce technological and operational development, or negatively associated with building infrastructure, implementation and operational challenges.

4. **Social Criteria (C4):** covering both positive and negative results of socio-cultural and psychological reasons including religion, beliefs and attitudes.

In general, most reasons for TWW reuse options to be applicable or acceptable, were associated with Environmental Health Criteria (C1), particularly marine pollution and Economic Criteria (C2), mainly reducing the economic burden (e.g. by reusing TWW rather than discharging TWW to the sea). Most reasons for rejecting TWW reuse options were associated with Environmental Health Criteria (C1), especially reusing TWW as potable water with direct contact to the public (being a possible human health risk), and Social Criteria (C4), which mainly were for religious or psychological reasons. The diagram in Figure 5-3 summarizes the reasons for TWW Reuse Options' acceptance, whereas the diagram in Figure 5-4 summarizes the reasons for TWW Reuse Options' rejection.

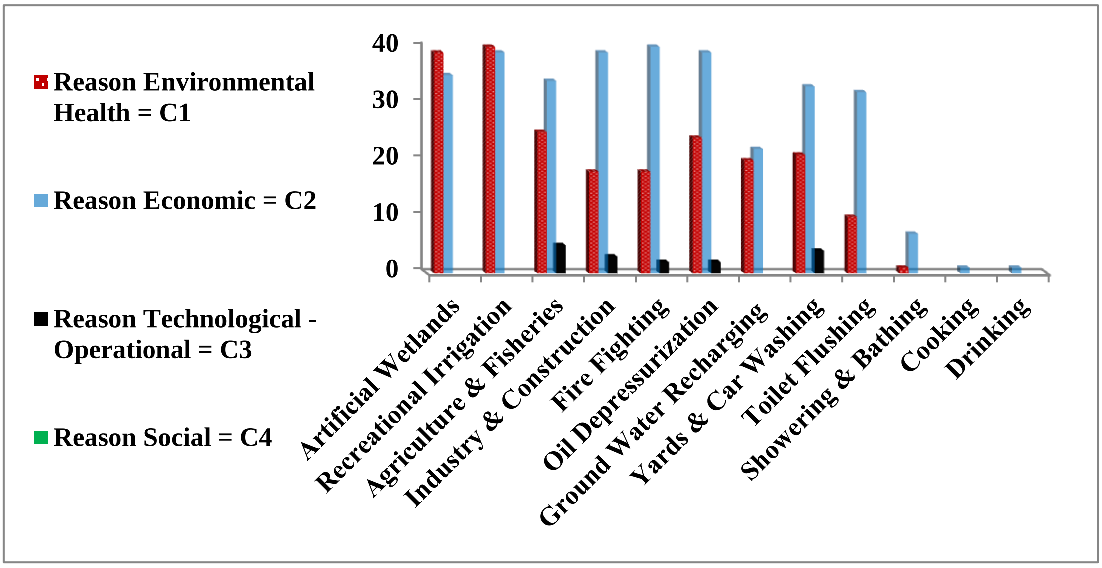

Figure 5 - 3: Reasons for Accepting TWW Reuse Options in Kuwait

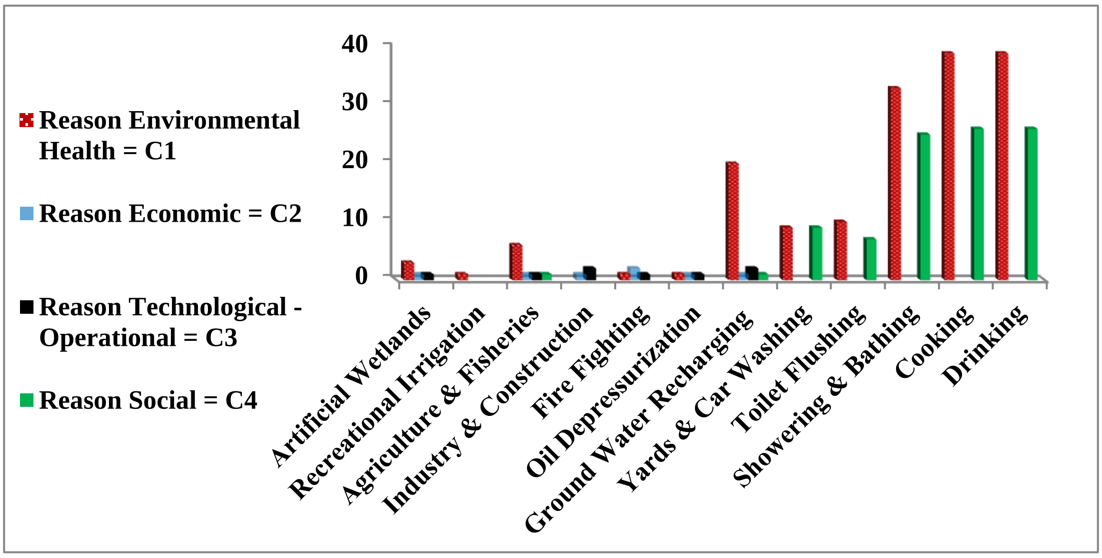

Figure 5 - 4: Reasons for Rejecting TWW Reuse Options in Kuwait

For criteria weightings at this stage (within the pilot study), 14 participants from the total of 50, who were mostly empowered experts, including government (G) and non-government (NG) decision makers, scientists and specialists in the field alongside other experienced stakeholders were selected as tabulated in Appendix (7).

5.1.2 Second Phase of the Pilot Study (Criteria Weightings)

Criteria weighing and numeric scaling of criteria for MCDM-AHP alongside further opinions on selecting TWW reuse options were obtained from the participants. Preliminary environmental components of the Rapid Impact Assessment Matrices (RIAM) for further assessment were also discussed with most participants surveyed in this phase and those who will be surveyed further within the main study investigation of this research approach which involves expert opinion and judgement (as listed in Appendix 8).

The participants' reactions to the SSQ were positive and included critical remarks and instructions (obtained from the survey and interviews). Changes within the short survey questionnaire (SSQ) that had been previously suggested were appreciated by the participants. The result of the criteria weighing by the 14 out of 50 expert participants (EP) within the pilot study is represented in Figure 5 - 5.

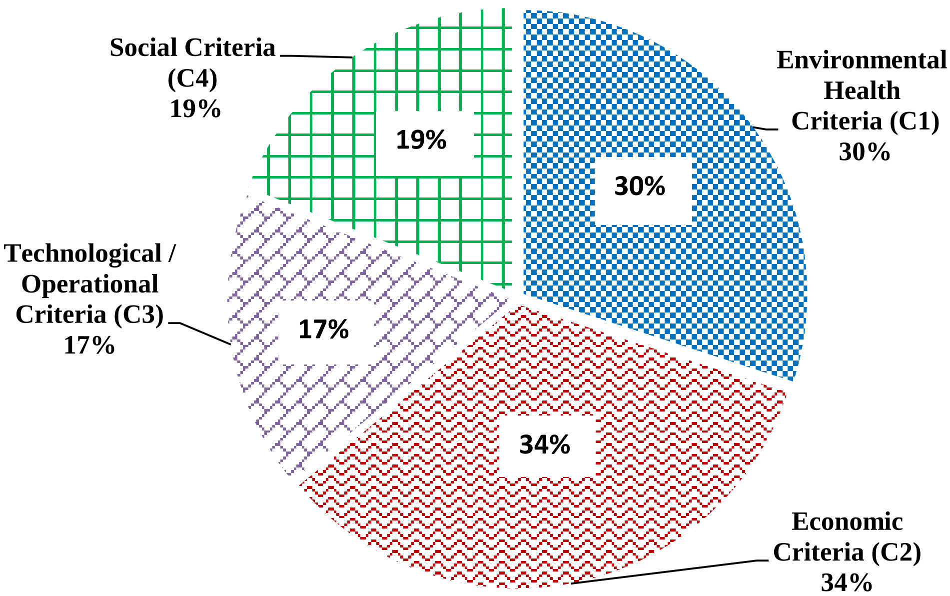

Figure 5 - 5: Total Criteria Weightings of Participants

5.2 <u>MCDM of TWW Reuse Options for Kuwait</u>

Interviews alongside the reformed SSQ were conducted on 40 participants from different backgrounds and fields of expertise to examine both the assessment and decision making process associated with TWW reuse practice and options (environmental health risk and socio-economic perception). The participants were from four different categories (summarized in section 5.1) in an attempt to identify the most applicable TWW reuse options for Kuwait. All expert participants (EP) within this study are tabulated (including their positions, job titles and shared information during the research study) in Appendix (8).

5.2.1 Evaluation of the Expert Participants (EP) Groups

In order to obtain reliable and confident results, the first part of the SSQ determined the degree of knowledge perception of the expert participants. The participants' knowledges within the fields of the study were determined prior to their participation in decision making and assessing TWW reuse options. As seen from Table 5 - 2, the participants were examined for their knowledge of reuse practice including treatment & guidelines, environmental health risk, risk transmission, and environmental impacts (as proposed and tested by the expert scientists and specialists particularly in EIA field). A scale of five was used (from none to excellent knowledge was divided into three classified degrees of knowledge; none – basic (weak), good (medium), and very good – excellent (strong).

Table 5 - 2: Knowledge Perception

Knowledge towards Certain Aspects	(1) None	(2) Basic	(3) Good	(4) Very Good	(5) Excellent
Treatment					
Guidelines					
Health Risk					
Environmental Impacts					
Risk Transmission					
Reuse Practice					

As shown in Figure 5 - 6, government experts and decision makers, specialists and researchers were more aware of TWW treatment and guidelines than the other participants. Most government decision making participants (70%) had very good knowledge of treatment and guidelines and the remaining 30% of participants had a good knowledge. This was anticipated given that they work in water or WWT management. Moreover, since the private sector has to comply with TWW treatment and guidelines, these participants should have a good knowledge of the field.

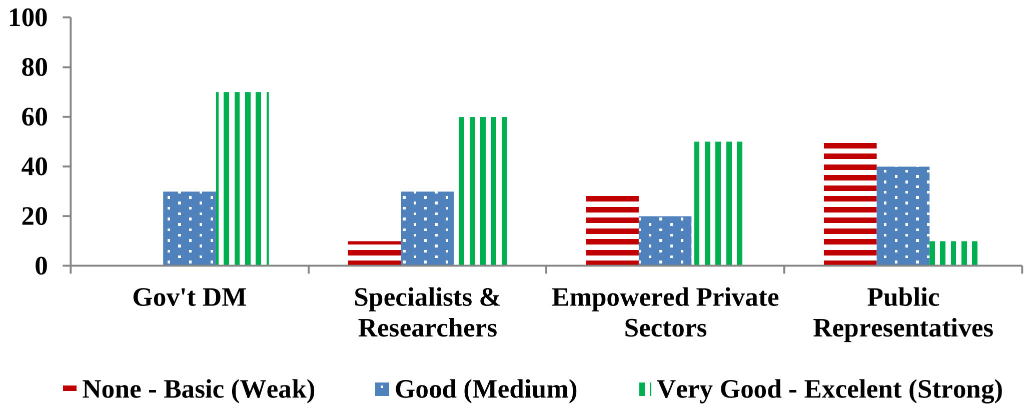

Figure 5 - 6: Degree of Knowledge of Participants on Treatment & Guidelines

Half of the private stakeholder participants (50%) and researchers (60%) had a very good knowledge of treatment and guidelines. This result was not expected; they should have had better knowledge than the researcher since they are working in the field and most specialize in WWT. In contrast, public representatives (PRs) had the least knowledge of this area. Of the PRs, only 10% had a very good knowledge and most (90%) were weak with none to basic knowledge regarding treatment & guidelines of TWW. This was anticipated as the PRs were not likely to be knowledgeable unless they worked within the field of WWT.

In terms of TWW reuse practice as demonstrated in Figure 5-7, most government DM had a high knowledge (90%) and only 10% had a good knowledge in TWW reuse practice. 70% of empowered private sectors showed substantial knowledge of reuse practice (20% of them had a good knowledge and 10% with feeble knowledge). Thus, the private sector needs more workshops or lectures to improve their knowledge within this field. Expert specialist and researchers presented a notable result regarding their knowledge in TWW reuse practice (60% of the participants had a very good to excellent knowledge and 40% had a good knowledge). Most of the PRs, however, (70%) indicated an average good knowledge.

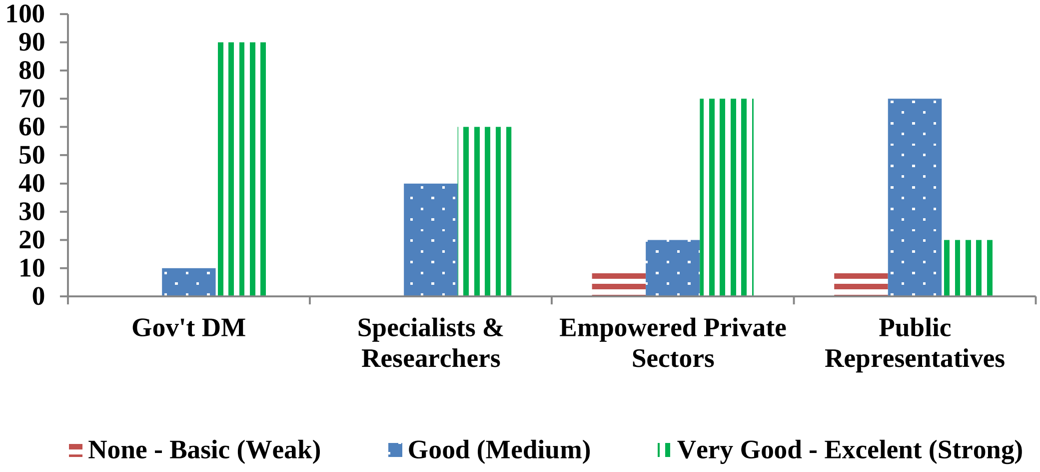

Figure 5 - 7: Degree of Knowledge of Participants on TWW Reuse Practice

As usual, government DM had a strong degree of knowledge amongst the other participants: 80% had a very good to excellent knowledge on environmental health risk aspects. The remaining 20% also showed a good knowledge regarding environmental health risks and risk transmission associated with TWW reuse practice and options as represented in Figure 5 - 8.

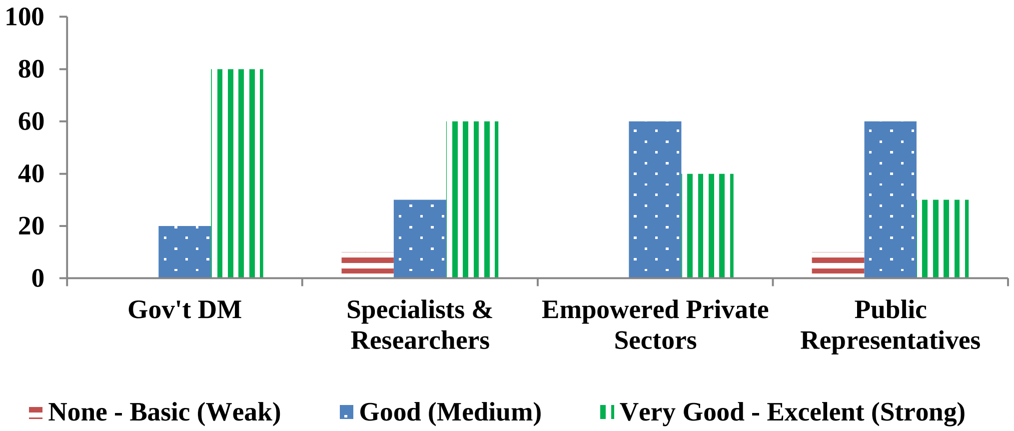

Figure 5-8: Degree of Knowledge of Participants on Environmental Health Risk

More than half of the specialists and researchers (60%) had a very good to excellent knowledge of the environmental health risks associated with TWW reuse practice. Most of the remaining participants had a good knowledge and only 10% had a weak knowledge. In contrast, all empowered private sectors' participants were knowledgeable in this field: 40% with a very good to excellent and 60% with a good knowledge. Expert specialists and researchers also had substantial knowledge: 60% had a very good to excellent knowledge, 30% had a good knowledge and only 10% had none to basic knowledge. Public Representatives (PRs) average knowledge were more than good regarding environmental health risks associated with TWW reuse: 60% had a good knowledge and 30% had an excellent knowledge.

Ultimately, results of expert participant's (EP) evaluation on knowledge perception (regarding TWW reuse practice and options) were considered to be dependable, supportable and trustworthy for this study.

5.2.2 Selection of Best Applicable TWW Reuse Options

The second part of the SSQ considered assessment of TWW reuse practice and selection of TWW reuse options for further decision making using a MCDM method. From a variety of TWW reuse options, 12 reuse options were selected by the EP as applicable reuse practice for the case study giving the reasons for accepting and rejecting different options (suggested by expert scientists and specialists as well as other experienced participants) shown in Table 5 - 3.

Table 5 - 3: Reuse Practice & Options Perception

TWW Reuse Practice (Option)	Expert Judgment	Reason			
	Applicability (A or N/A) Acceptance (Agree=1 or Disagree= 2)	C1 (Human H)	C2 (Environmental)	C3 (Social)	C4 (Economic)
		Public H. H. Risk Diseases Outbreaks	Water Conservation Marine Pollution Ecosystem Services Land Degradation.	Accept. Psycho. Attitude Religion	Technology Operation Feasibility Investment
(1) Artificial Wetlands					
(2) Recreational Irrigation					
(3) Agriculture & Fisheries					
(4) Industry & Construction					
(5) Fire Fighting					
(6) Oil Depressurization					
(7) Groundwater Recharging					
(8) Yards & Car Washing					
(9) Toilet Flushing					
(10) Showering & Bathing					
(11) Cooking					
(12) Drinking					

The results suggested that some TWW reuse options were not feasible in Kuwait and those were rejected by the surveyed participants. The rejected options included reuse of TWW for drinking, cooking, showering and bathing, toilet flushing, and car washing. The main reasons for such options being rejected, or being non-applicable, were mainly associated with human health (risk transmission and water-borne diseases) and psych-social issues such as religion, beliefs and attitudes.

As indicated in Figure 5-9, the remaining six applicable TWW reuse options for Kuwait were Artificial Wetlands, Recreational Irrigation, Agricultural Irrigation, Industrial Processes including reuse in construction and firefighting, Oil Depressurization and Groundwater Recharge (GWR). Such Reuse options were mostly characterized by indirect contact with the public (less contribution to public health problems). The reasons for accepting those reuse options include water conservation, protecting marine and land environment from excessive TWW discharges and being an economic investment.

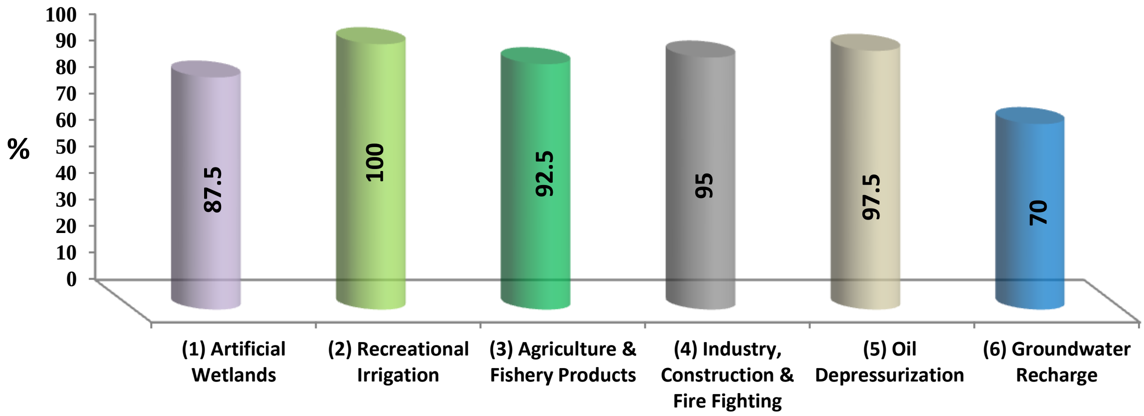

Figure 5-9: Percentage of Total TWW Reuse Options Selected by the EP

The perceptions of the EPs regarding TWW reuse in the first five reuse options (Artificial Wetlands, Recreational and Agricultural Irrigation, Industrial Processes and Oil Depressurization) were positive. Recreational Irrigation (RI) was entirely accepted (100%) as it has been practiced for a long time globally and in Kuwait. Oil Depressurization (OD) (97.5%) was accepted as there would be no direct contact with the public and hence no public health implications were identified as it only involves workers in the field. Moreover, the latter reuse option will mostly utilize rejected (saline) water from the advanced wastewater treatment plant (WWTP) which will protect the marine environment from the discharge of saline water. The third accepted (applicable) TWW practice (95%) was reusing TWW in Industrial Processes (IP) including Industry and Construction and Firefighting. Specified reasons for this option were investment and water conservation.

TWW reuse in agricultural irrigation (AI) has a very long history of reuse practice and was the fourth TWW reuse option (92.5%). This reuse option can be practiced using secondary, tertiary or advanced TWW when effectively assessed and managed. Finally, Artificial Wetlands (AW) was the fifth accepted (applicable) TWW reuse option (87%). The reasons for rejecting this option are mainly associated with the environmental health risks (e.g. public health risk, risks involved with ecological habitat and land degradation) as well as high initial and maintenance costs, technological and operational difficulties, and the high salary costs to support a workforce for what was considered to be a risky project.

The sixth accepted (applicable) TWW reuse option is reusing advanced TWW in groundwater recharge (GWR) which was found to be controversial (debatable). The total acceptance was positive (70%), however, different views were found amongst the EP as represented in Figure 5-10.

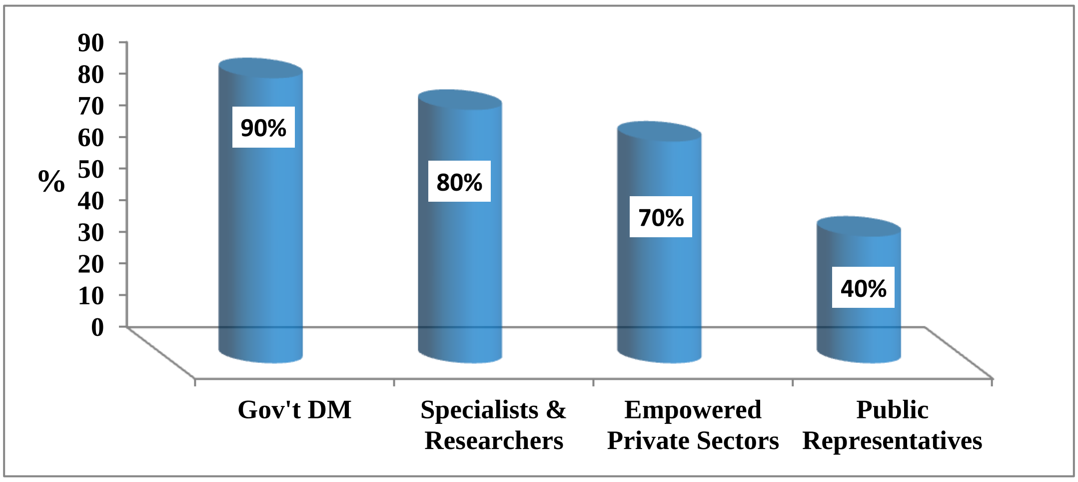

Figure 5-10: Expert Perception of TWW Reuse for GW Recharging

The percentage of government experts and decision makers' acceptance for TWW reuse in GWR was the highest (90%). However, the percentage of "Specialists and Researchers" and the "Empowered Private Sectors' participants" acceptance fell to 80% and 70% respectively and the acceptance by percentage of the PRs was low (40%). The main reason for rejecting this option (reusing TWW in GWR) by the public was human health. Since desalinated fresh water for potable uses (drinking water) in Kuwait is mixed with GW (10%), public concerns were reflected in their perceptions. Thus, "uncertainty" regarding the quality and safety of water for potable uses (unknown or unpredicted risk) should be handled according to the "precautionary principle" as highlighted by most of the EP.

5.2.3 Constructing Criteria and Structuring AHP for MCDM

As previously mentioned the six preliminary suggested criteria together with associated factors (sub-criteria defined for each criterion) listed in section (5.1) and illustrated in Figure (5-1) were reformed and divided into four criteria for the pilot study as detailed in sub-section (5.1.1). Within and after the pilot study, some changes and reformations were suggested so that these four criteria were more compatible with Kuwait case study prior to MCDM process. The four final selected criteria and their factors (sub-criteria) are:

1. <u>Human Health Criteria:</u> referring to environmental health problems that are predicted to occur from TWW reuse options which might cause direct or indirect effects on human health. Human Health issues include effects on public health including water-related health problems and diseases, epidemiological outbreaks and other human health risks. The TWW reuse practices can be a source of chemical, physical or biological pollution on air, marine environment and land that in turn could affect human health. There may also be an effect on food and other TWW products which may directly or indirectly affect human health and present risk to human, animal and plant life. Extracted human health sub-criteria are: (A) Water Quality, (B) Dermal Effects, (C) Inhalation (Lung Diseases) and (D) Gastrointestinal Diseases.

2. Environmental Impacts Criteria: referring to chemical, physical, and biological environmental impacts that are predicted to occur from TWW reuse options which might affect the environment (e.g. air and marine pollution, and land degradation) and ecosystem services. Environmental Impacts include effects on the quality of surface water, groundwater, coastal environment and soil. Extracted environmental Impacts sub-criteria are: (A) Marine (Water & Fish), (B) Animals, Birds and Plants, (C) Landscape and (D) Groundwater.

3. Social Impacts Criteria: referring to the effects of TWW reuse options on the community and social groups including the degree of public satisfaction (acceptance, reuse with safe precautionary measures or rejection) for any educational, attitudinal, belief or religious reason as well as the compliance with socio-cultural issues such as effects on employment and human well-being. Socio-political conflicts or socio-cultural crisis predicted from practicing the TWW reuse options are also included. Socio-political issues (e.g. public acceptance and participation, political safety and stability during practicing such TWW reuse option, public perceptions toward any TWW reuse option) and expected socio-political risks from improperly TWW reuse planning and management should also be considered. Extracted social impacts sub-criteria are: (A) Public Acceptance, (B) Socio-Cultural Effects, (C) Effects on Social Groups and (D) Socio-Political Conflicts.

4. <u>Economic Burdens Criteria:</u> referring to all economic, financial and logistic factors required for TWW reuse options including the feasibility, affordability, and ability to fund such options. In addition, the technology required operating and process the TWW reuse options (e.g. WWTP's, pumping stations, monitoring and sampling techniques, and laboratories) are included. Although wastewater treatment (WWT) costs are less than for water desalination, TWW reuse practice costs are high, in terms of the initial costs of implementation and incremental costs of monitoring and maintenance. Technology and operational requirements alongside their availability and reliability are important aspects of TWW reuse practice (including wages of the qualified experts, specialists, engineers, technicians and laboratory staff). Extracted economic burdens sub-criteria are: (A) Cost (Affordability), (B) Benefit (Feasibility), (C) Technology, (D) Operation.

As can be detected (changes and reformation suggested within the expert judgement process), technological and operational criteria were recognized and considered as part of economic burdens criterion (excluded from the four main criteria) and included within its sub-criteria (factors). Thus the four constructed criteria alongside the six (selected) applicable TWW reuse options were structured into an analytical hierarchy process (AHP) as presented in Figure 5-11.

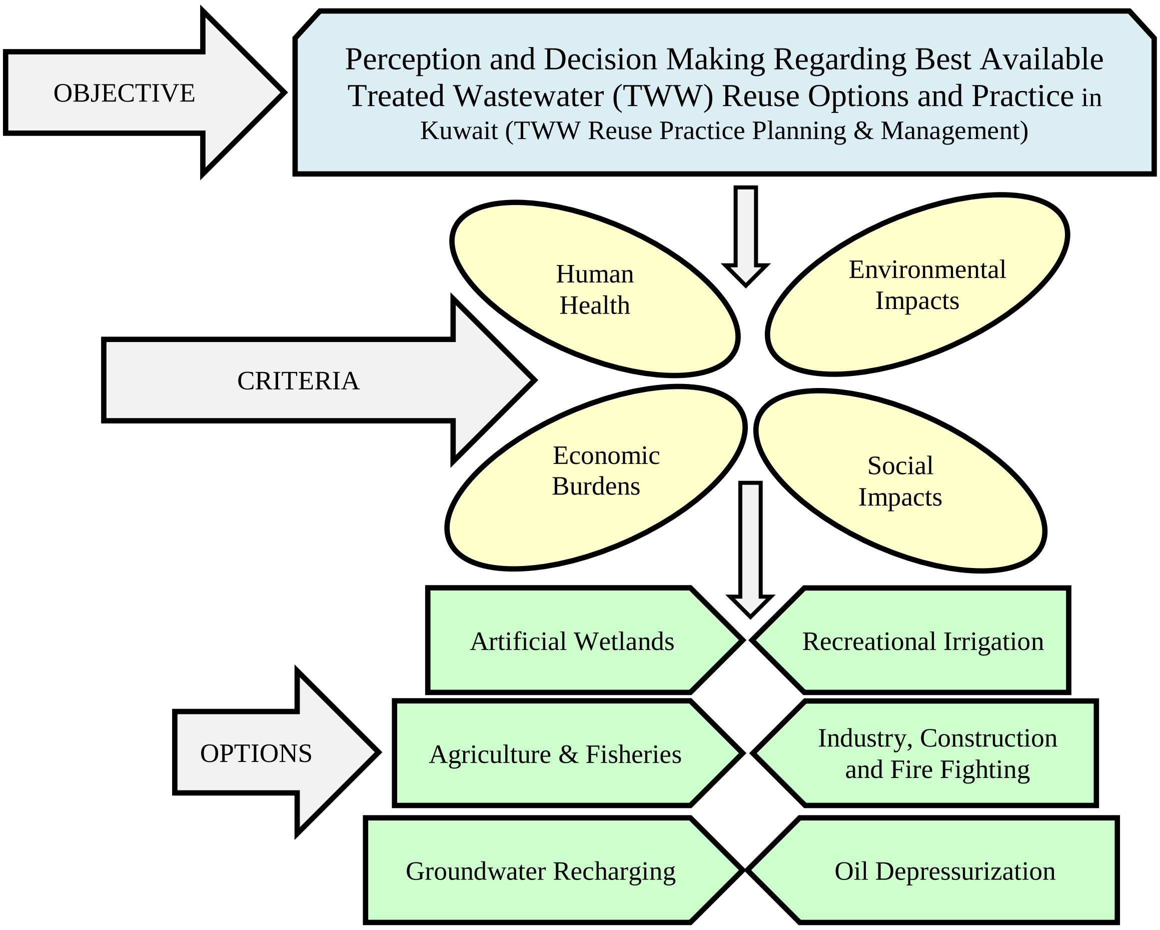

Figure 5-11: Structural Diagram of Analytical Hierarchy Process (AHP)

The degree of effect and influence of each selected TWW reuse option (positive or negative) on the selected four criteria (criteria significance) and their associated factors (sub-criteria) were surveyed and weighed as percentage (%) fractions within a short survey questionnaire for further MCDA as presented in Table 5-4. The total of the four selected criteria must equal to 100%. The total of the portions (sub-criteria) for each criterion must also equal to 100%.

Table 5-4: Main and Sub-Criteria Weightings (Ranking) Process for MCDA

Main-Criteria (MC)	**MC Weightings (%)**	**Sub-Criteria (SC)**	**SC Weightings (%)**
C1 Human Health		Water Quality	
		Dermal Effects	
		Inhalation (Lung Diseases)	
		Gastrointestinal Diseases	
		Total	100%
C2 Environmental Health		Marine (Water & Fish)	
		Animals, Birds and Plants	
		Landscape	
		Groundwater	
		Total	100%
C3 Social Impacts		Public Acceptance	
		Socio-Cultural Effects	
		Effects on Social Groups	
		Socio-Political Conflicts	
		Total	100%
C4 Economic Burdens		Cost (Affordability)	
		Benefit (Feasibility)	
		Technology	
		Operation	
Total	100%	Total	100%
Remarks:			

This short survey questionnaire (SSQ) for main and sub-criteria weighing is based on their "IMPORTANCE" percentage for ranking (where importance = degree of significance of each main or sub-criteria when practicing any of the six specified TWW reuse options). This MCDA was stimulated and manipulated (as required within the survey for the MCDM by the Simple Multi-Attribute Ranking Technique used by Konidari and Mavrakis (2007) rather than the pairwise comparison between the criteria used by Saaty (2008).

The method of pairwise comparison between the criteria used by Saaty (2008) and summarized in Appendix (9) was conducted on a few participants prior to changing it to a ranking process. It was found to be difficult and confusing and took a long time to complete. The results of the obtained surveys were considered to assess the weakness of the method (of bias preference and illogical results) and led to the use of a ranking method (average %) rather than the pairwise comparison returns to strength and weakness (simplicity and difficulty) of each method as discussed by Linkov and Steevens (2008) and summarized in Table 2-2 (chapter 2; section 2-7).

5.3 Results of MCDM of the 6 TWW Reuse Options for Kuwait

(1) Artificial Wetlands (AW)

There is no surface water in Kuwait as mentioned earlier in Chapter 4; the climate is dry, arid and desert extends over most of the country. Therefore, Artificial Wetlands (AW) could be a feasible project for deserts (particularly in peri-urban areas around cities) in Kuwait using advanced TWW. It was agreed that this was an applicable option for TWW reuse (the result of the discussion to the most applicable TWW reuse options). Although human health and social communities will not be affected by AW formation and development as predicted by the expert participants (EP), the future economic burdens (38%) and environmental impacts (33%) can be essential factors when starting to reuse TWW for AW as presented in Figure 5 – 12. The main reason for the future economic burdens is that there will be no investment in this option and it was anticipated that the government would be responsible for all the project expenses.

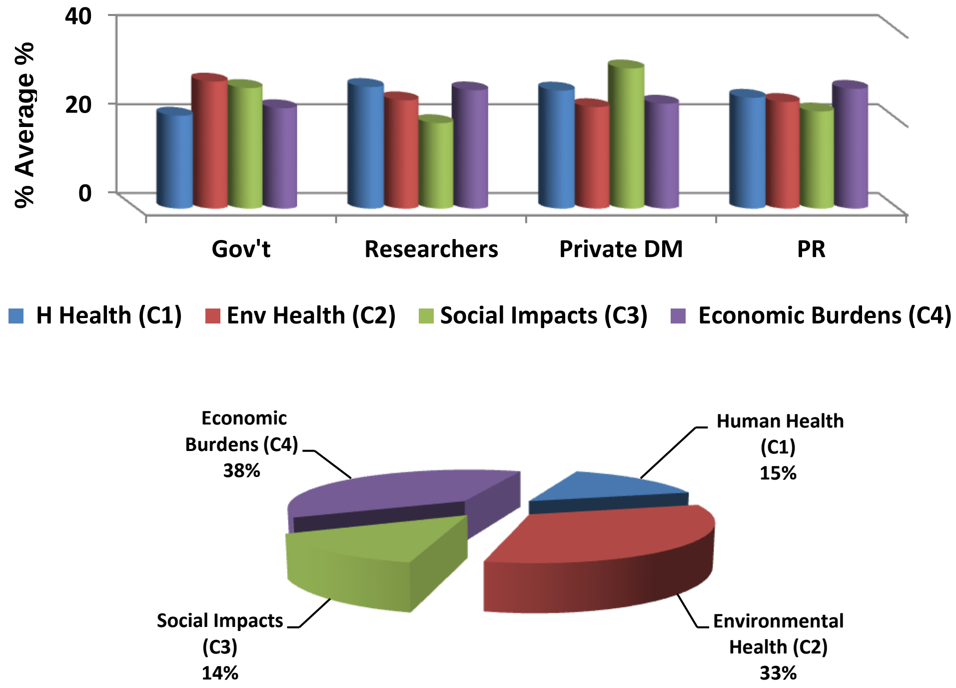

Figure 5-12: Main-Criteria Weights of TWW Reuse in Artificial Wetlands

It is also likely that when reducing the financial support for AW (including operational, monitoring and maintenance), then environmental impacts will arise due to water quality deterioration (e.g. effect on groundwater, waterborne diseases and land degradation). The interaction between the main and sub-criteria, as well as the environmental health consequences can be predicted from the importance or weight (%) of each sub-criterion as illustrated in Figure 5 - 13.

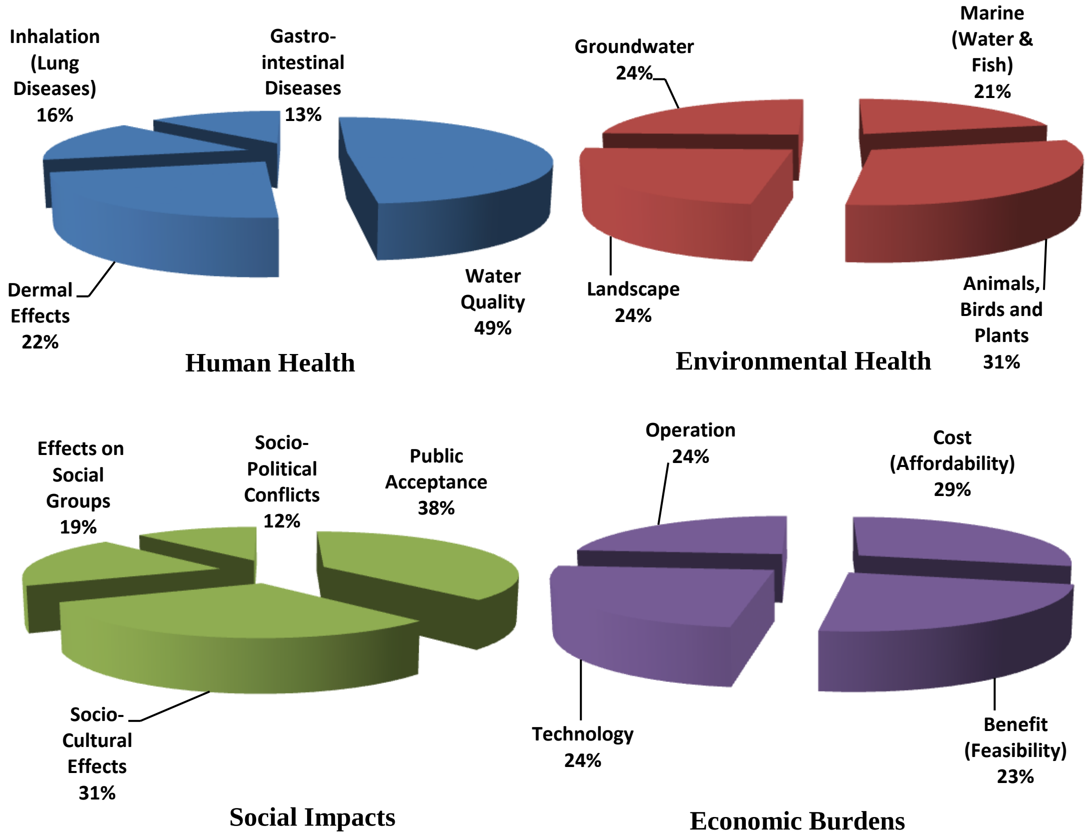

Figure 5-13: Sub-Criteria Weights of TWW Reuse in Artificial Wetlands

(2) <u>Recreational Irrigation (RI)</u>

Recreational irrigation (RI) of green spaces, public parks, golf courses and sport areas is technically easy to manage as highlighted in Chapter 2. No serious human health, social problems or environmental health risks are anticipated from practicing this option as shown in Figure 5-14. This option is currently practiced in Kuwait and does not require an advanced level of treatment and can utilize secondary or tertiary TWW. TWW reuse in RI, as pointed out by the EP, can be one of the best options which substitutes freshwater utilization (can be considered as water resource for national water strategies) in water scarce countries like Kuwait.

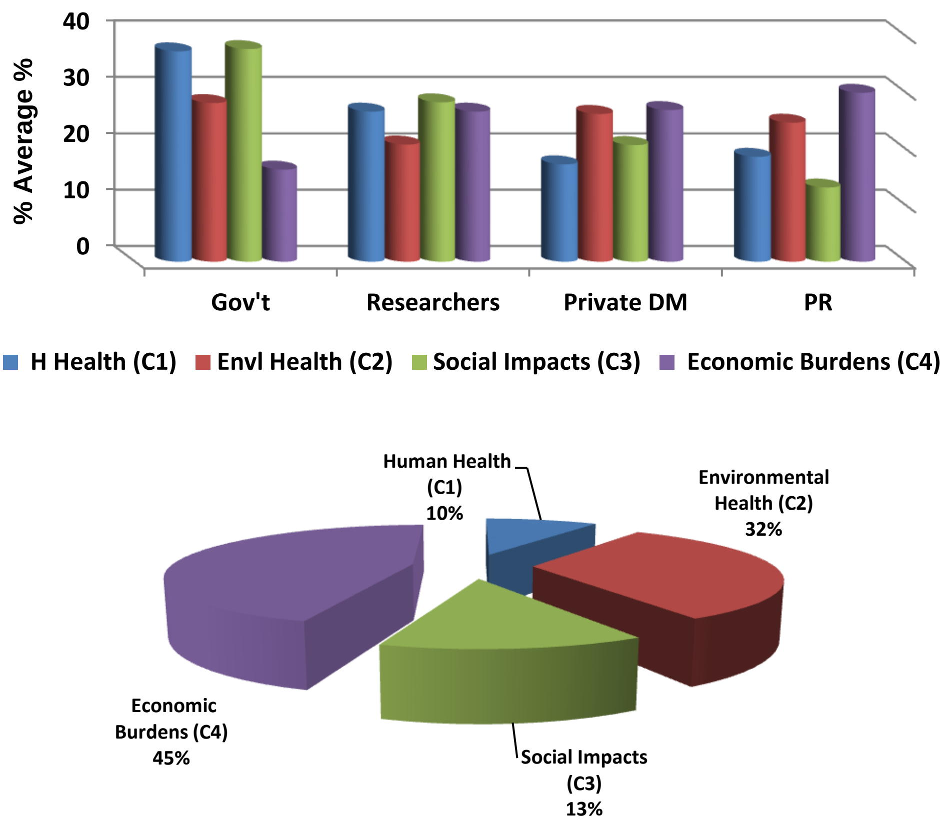

Figure 5-14: Main-Criteria Weights of TWW Reuse in Recreational Irrigation

As can be seen in Figure 5 – 14, the economic burden is perceived as the most important criterion (45%) associated with RI in Kuwait. Once again, the main reason is that the government is totally responsible for this option and there is no investment nor economic benefit. In contrast, sub-criteria weights can distinguish areas of concern for each main criterion as demonstrated in Figure 5-15. For example, dermal effect is the most important sub-criterion of human health which mostly affects workers and farmers but not necessarily the public. Landscape is the major environmental health concern especially over the long term due to low water quality excessive usage, and water contamination from improperly treated wastewater.

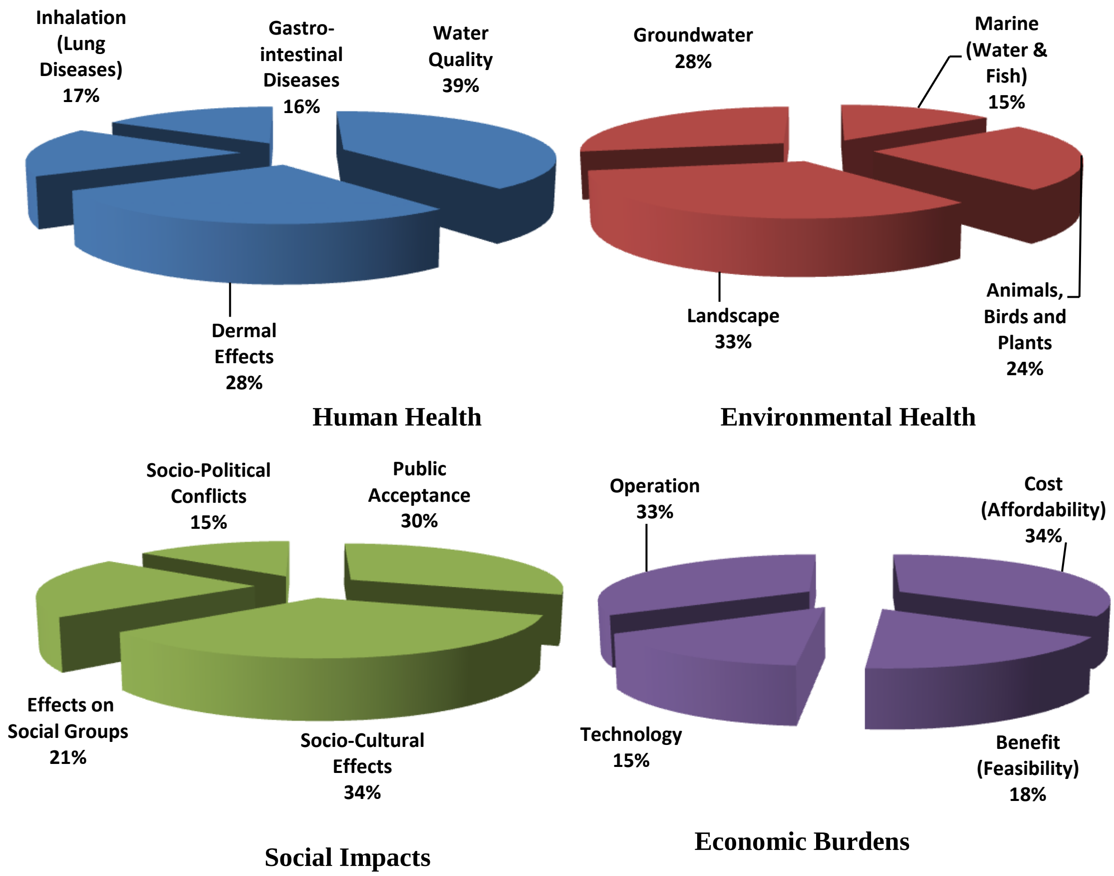

Figure 5-15: Sub-Criteria Weights of TWW Reuse in Recreational Irrigation

(3) <u>Agricultural Irrigation & Fishery Products (AI)</u>

In addition to human health concerns of 40% which are the most critical factor when utilizing TWW in Agricultural Irrigation (AI), all other criteria (environmental health of 18%, social impacts of 21% and economic burden of 21%) are important and almost equally weighed as shown in Figure 5-16. TWW reuse in irrigation can affect food products and be a source of risk to human health and the environment when using improperly treated TWW. Appropriate guidelines for crop type must be set. Therefore, human health is given the highest weight (especially by public representatives). Public perception is usually more subjective (and varying according to individual's knowledge and attitudes) compared to expert opinion which is more objective. Moreover, water-related pollutants (from improperly TWW reuse in AI) filtered through soil can accumulate in long-term irrigation waters causing significant degradation to groundwater.

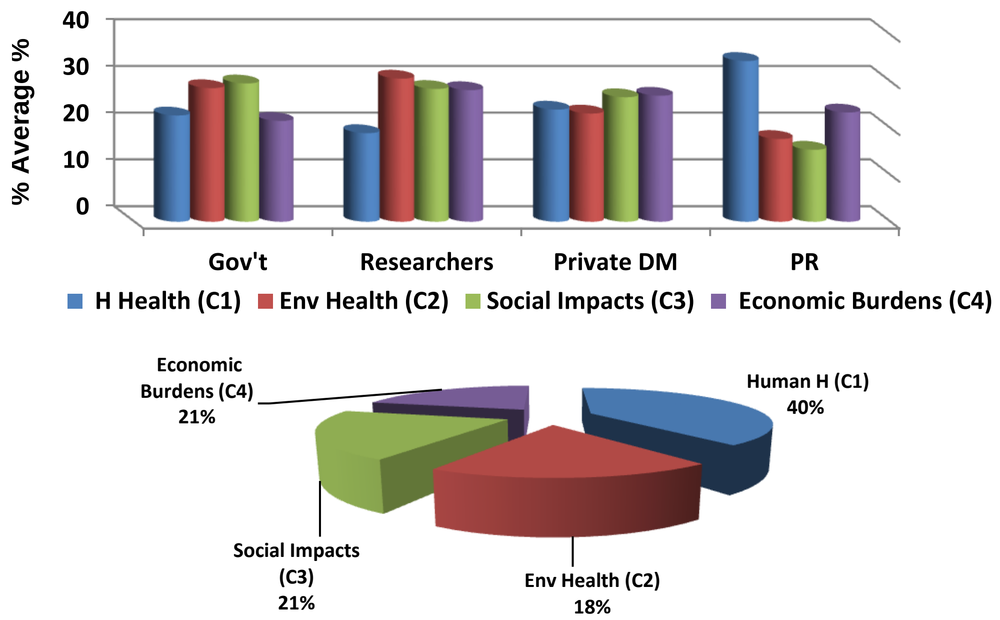

Figure 5-16: Main-Criteria Weights of TWW Reuse in Agricultural Irrigation

Figure 5-17 indicates that each major criterion has at least one factor that affects other aspects. The most important sub-criterion for human health is water quality. This factor (particularly water quality used in agriculture) will in turn affect other sub-criteria (factors) in the same main criterion and interact with sub-criteria in other categories. For example, low water quality or contaminated TWW reused in agricultural irrigation could cause dermal effects or allergies in workers, farmers, and other beneficiaries coming onto contact with the water or using crops irrigated with TWW. Irrigated water will infiltrate through soil to groundwater (GW) causing land and GW deterioration. Further, animals, birds and plants will also be affected, become contagious and transfer infections to other animals and human through the food chain.

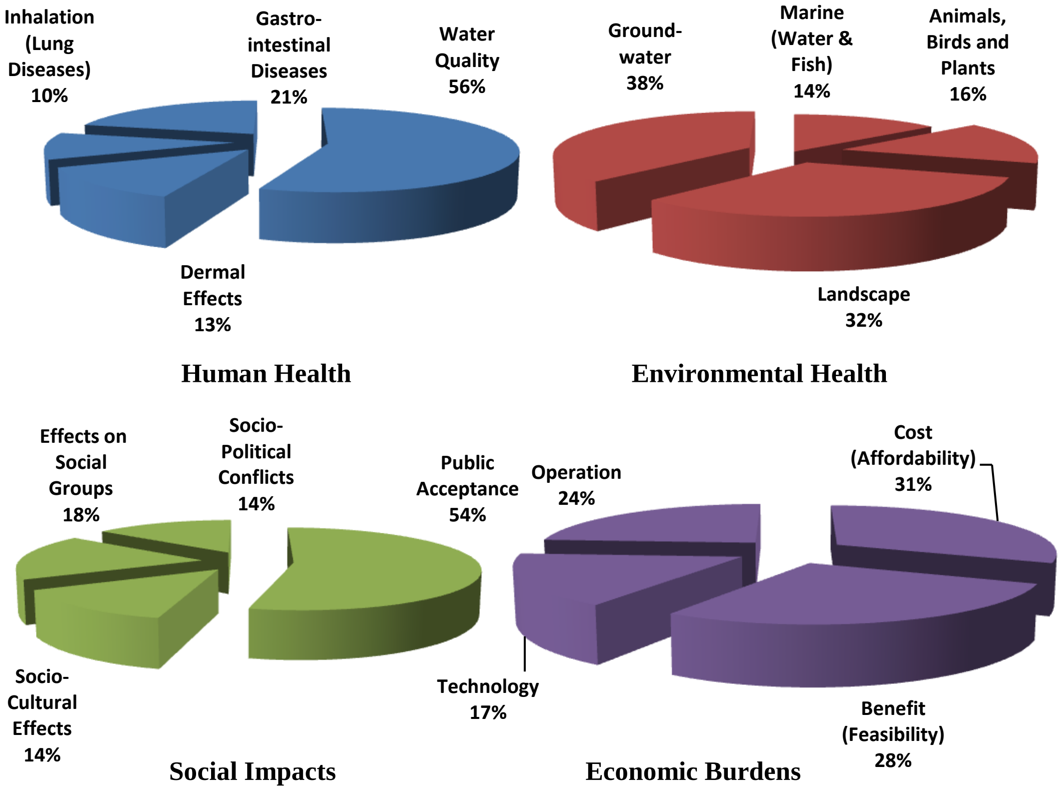

Figure 5-17: Sub-Criteria Weights of TWW Reuse in Agricultural Irrigation

As can be seen from Figure 5-17, GW and landscape are the most essential sub-criteria of the Environmental Health category that must be considered when using TWW for agricultural irrigation. In contrast with the social impacts criterion, the EP considered public acceptance (54%) the most critical issue for this option. Public satisfaction with both TWW and food product quality has an important role in TWW reuse practice in agricultural irrigation. Some EP participants remarked that involving the public in decision making could avoid future socio-political conflicts and would usually produce the best result in TWW reuse management. The economic burden was found to be a neutral criterion when reusing TWW in AI. Most sub-criteria (operation, affordability and feasibility) were closely weighed at 24%, 31% and 28%

respectively in importance. Technology was weighed the least sub-criterion associated with the future economic burden of using TWW in AI.

(4) Industrial Processes, Construction and Fire Fighting (IP)

As evaluated and weighed by the EP, when reusing TWW in industrial processes (IP), the main-criterion to be considered is the future economic cost (64%). The reason is that WWT and distribution for IP (e.g. water coolants or chillers, boiler waters, construction, and firefighting) will be mostly funded by government. This means there will be no investment or benefit except avoiding TWW discharge to the sea and wasting a potentially invaluable source of water. The other three main-criteria (human health, environmental health and social impacts) had low weights as seen in Figure 5-18 because there will be no serious effects associated with TWW reuse practice in such activities.

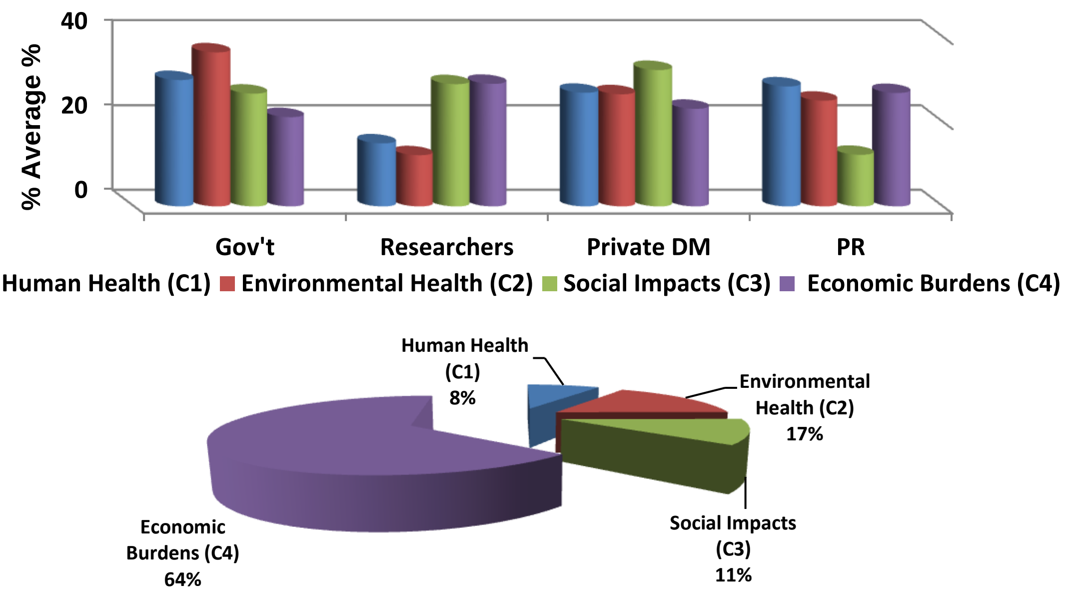

Figure 5-18: Main-Criteria Weights of TWW Reuse in Industrial Processes

Sub-criteria associated with reusing TWW in IP are directed towards critical factors of each main-criterion. The most important sub-criterion of human health is water quality whereas environmental health criterion is concerned mostly with landscape. Strict laws and regulation are required to protect both the public and the environment from any future adverse effects when reusing TWW in IP. As previously highlighted, public acceptance (participation) is considered a vital factor which plays an essential role in TWW reuse practice for any option. Finally, the sub-criteria weights of economic burdens are almost equal as can be seen from Figure 5-19.

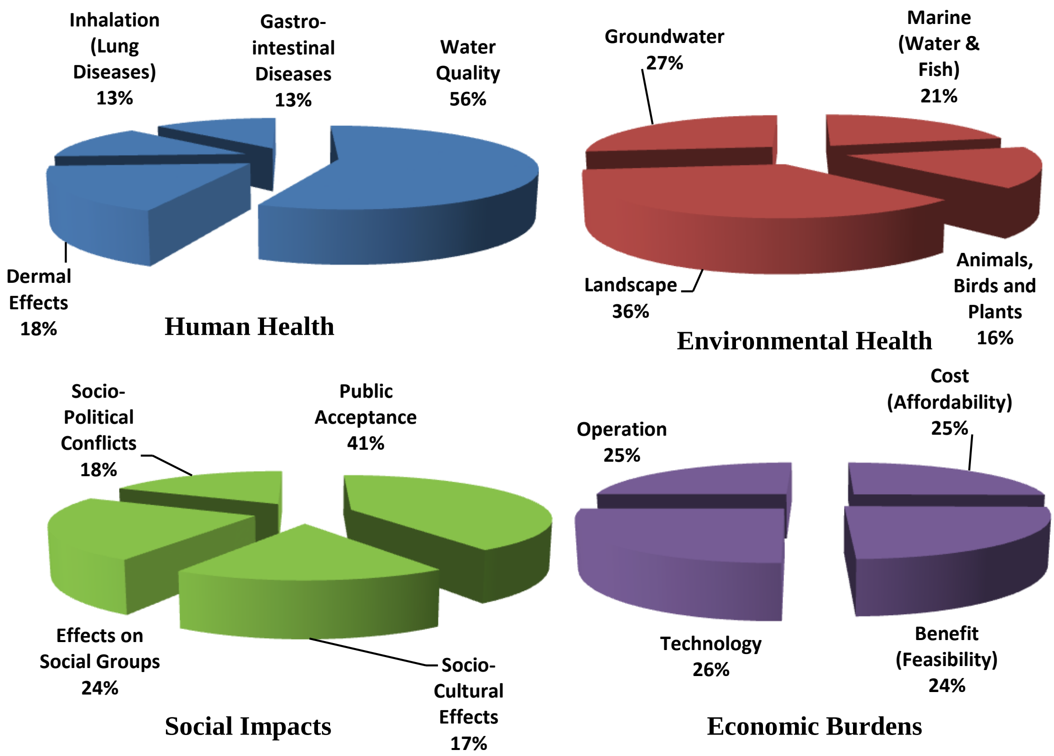

Figure 5-19: Sub-Criteria Weights of TWW Reuse in Industrial Processes

(5) <u>Oil Depressurization (OD)</u>

Oil Depressurization (OD) is one of the applicable (accepted) TWW reuse options for Kuwait. This option was preferred by most of the EPs. This option has a double perspective because of its advantages for both water conservation and environmental protection. The first advantage is conserving groundwater (GW) by utilizing TWW in oil discovery and using TWW rather than GW to pump oil from deep oil wells. The second advantage is to protect the environment by reusing saline water (the rejected saline water from R.O. WWTP). Some private companies (mainly oil companies) are willing to use saline water, as well as TWW, to reduce the pressure on GW and protect land and marine environments from the discharge of saline waters.

As can be seen from Figure 5–20, the two critical, significant main-criteria when practicing TWW reuse for this option (OD) are environmental health (41%) and economic burden (52%). Handling brine water in desert areas and landscapes where GW wells are situated is considered an important issue, which requires experienced engineers and technicians. The economic cost can be predicted and are a challenge for this TWW reuse option. The other two main criteria (human health and social impacts) are nearly neglected and given very low weights of 4% and 3% respectively as shown in Figure 5-20.

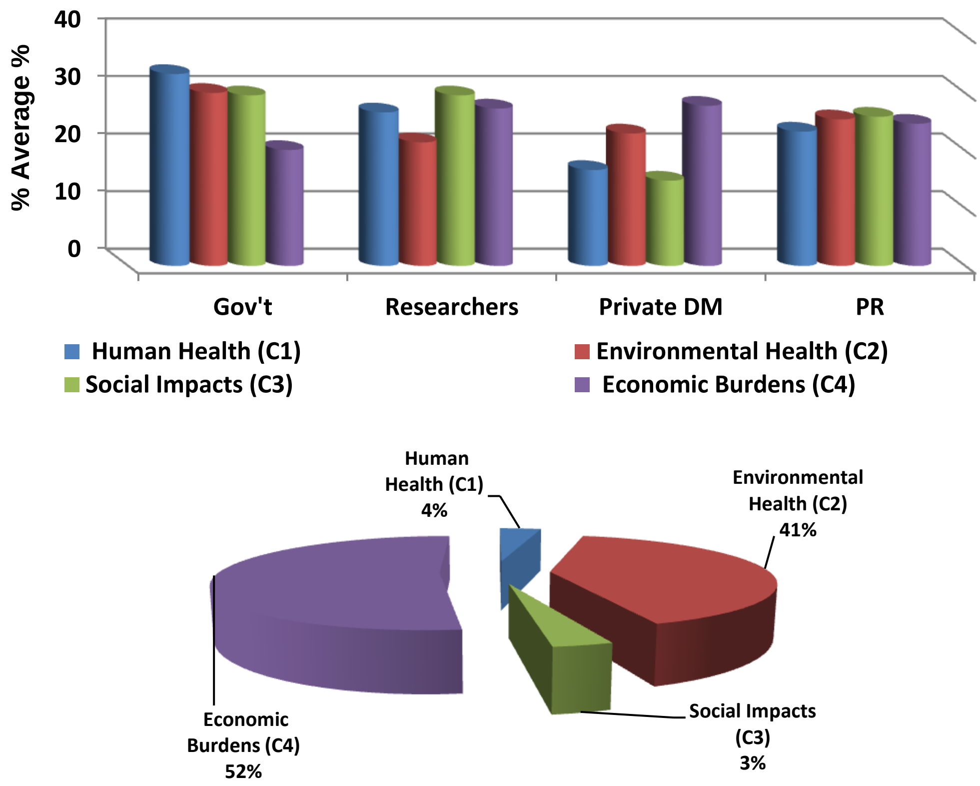

Figure 5-20: Main-Criteria Weights of TWW Reuse in Oil Depressurization

In contrast, Figure 5-21 gives an interpretation of which sub-criteria of the previously discussed main-criteria are important or can be affected when practicing this option. For example, water quality is the most significant sub-criterion of human health associated with TWW reuse in OD (38%). Eventually, all other sub-criteria (dermal effects, lung and gastro-intestinal diseases) will be influenced by water quality. Some effects on human health (mostly WWTPs' and oil companies' workforce) especially dermal and lung effects are likely. As previously highlighted, GW (44%) and landscape (38%) are the most important sub-criteria of environmental health that might be affected by this option. The remaining two sub-criteria (which involve marine and land environments and ecosystems) are of least significant.

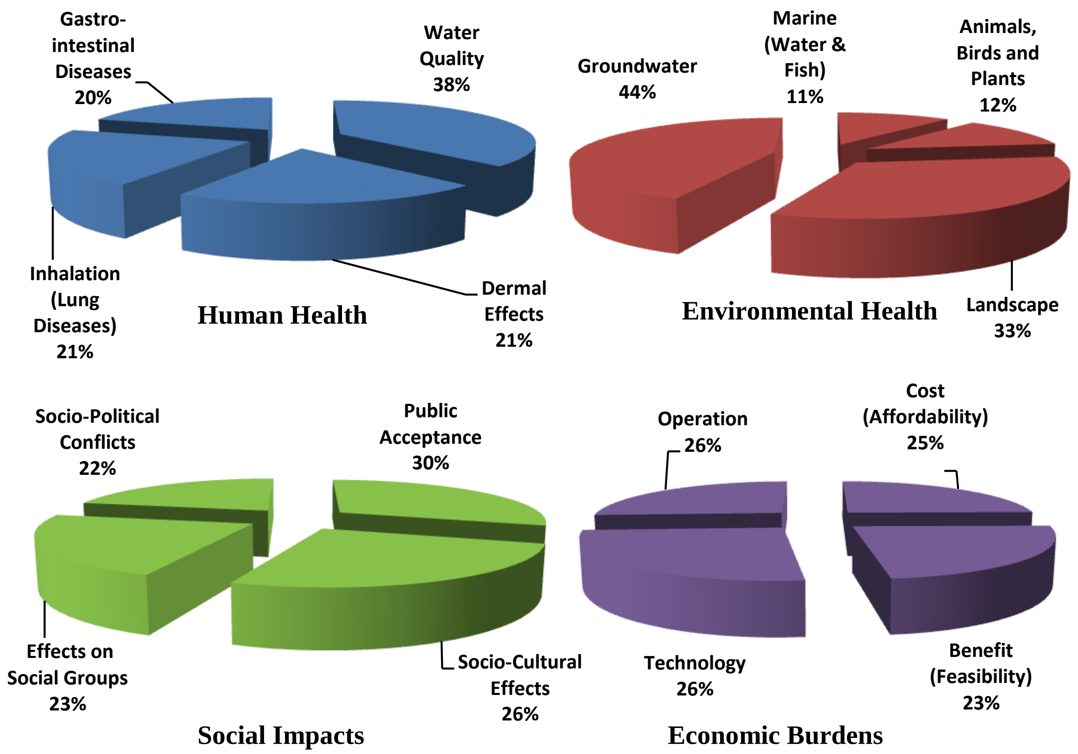

Figure 5-21: Sub-Criteria Weights of TWW Reuse in Oil Depressurization

Similarly, the economic burden is an important criterion when reusing TWW for OD and its sub-criteria are also critical factors. All four sub-criteria of economic burdens (technology, operation, affordability and feasibility) are almost equally weighed; with weights of 26%, 26%, 25% and 23% respectively. Since human health and social impacts criteria are not essential when practicing TWW reuse in OD as weighed and evaluated by the EP, their sub-criteria are also of less concern.

(6) **Groundwater Recharge (GWR)**

As explored in previous section 5.2 (sub-section 5.2.2) of this chapter, TWW reuse in groundwater recharging (GWR) was found to be controversial. The result of the earlier pilot study for its decision making was almost equal between those in favour of the option and those against it. Further investigation and survey also found contrasting views amongst EP. The acceptance averages of government DM, specialist and researches, and experts from private sectors were between 70% and 90% as discussed in the previous section. Public representatives (PRs) were the only EP to nearly reject this TWW reuse option with 40% acceptance. Human health criterion was the main reason for rejecting this option by the public. Figure 5-22 provides an estimated overview of main-criteria weights of TWW reuse in GWR.

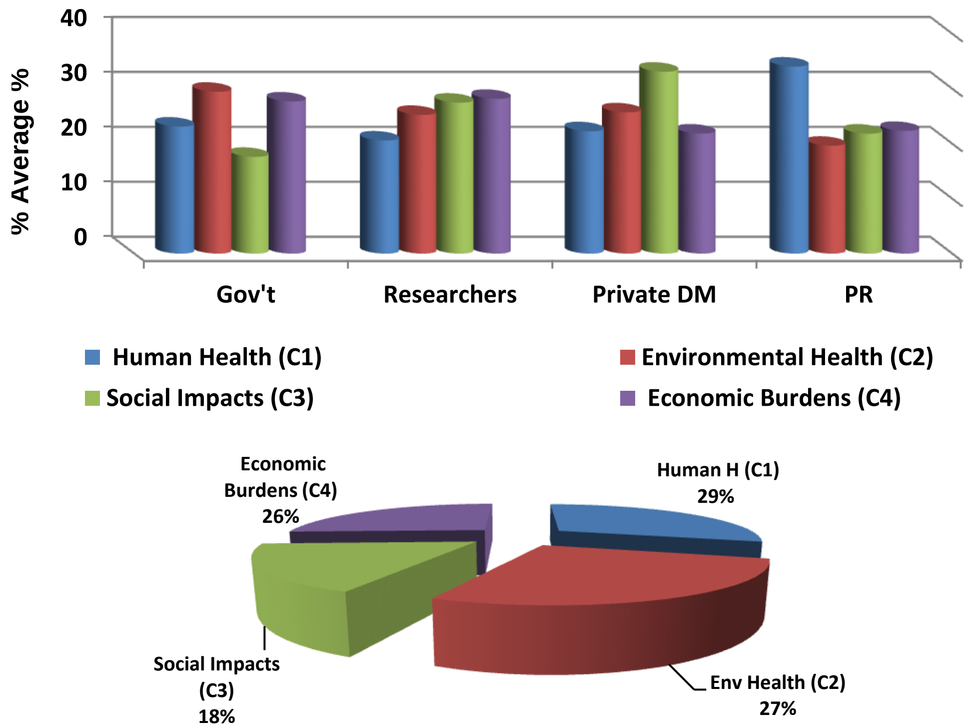

Figure 5-22: Main-Criteria Weights of TWW Reuse in Groundwater Recharge

It can be seen from Figure 5-22, that all main-criteria are significant when practicing TWW reuse in GWR. The most three important main-criteria are human health (29%), environment (27%) and the economic burden (26%). The least important main-criterion, however, is the main-criterion associated with public (social impact) which was given a weight of 18%. This weighting of the main-criteria would reflect the significance of sub-criteria as demonstrated in Figure 5-23.

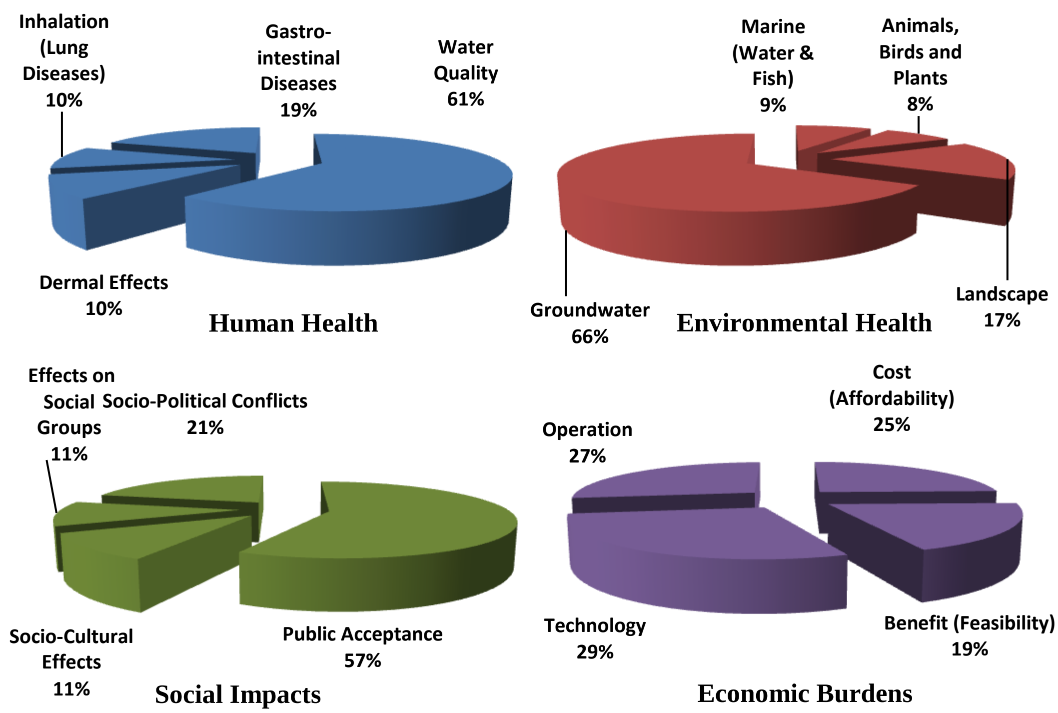

Figure 5-23: Sub-Criteria Weights of TWW Reuse in Groundwater Recharge

Based on expert opinion and judgement, water quality is the most critical factor associated with reusing TWW for GWR. As commonly known, groundwater (GW) will be further used for human services (in households) and agriculture. Water quality, therefore, affects both human health and the environment. Thus GW is considered the most significant sub-criterion of environmental health. As mentioned above, public acceptance is considered the most important factor (sub-criterion) within the "Social Impacts" Criterion. Therefore, with the public acceptance, there will be no serious effects on all other sub-criteria associated with this criterion. Socio-political conflicts, effects on social groups and socio-cultural effects would all be contained (controlled) thus ensuring successful public participation and acceptance. However, most expert and experienced participants believe that this option (TWW reuse in GWR) would not be accepted by the public unless they participated in a transparent effective decision making process.

In contrast, unlike the other main-criteria, all the economic burden sub-criteria were found to be essential. Technology (29%), operation (27%), and affordability of other costs (25%) such as logistics, monitoring and control costs of such TWW reuse option would undoubtedly result in a future financial burden since there will be no benefit or investment. Therefore, the feasibility sub-criterion was given the least weight of 19% within the economic burden criterion. Moreover, besides the comprehensive investigation and study that must be conducted prior to reusing TWW in GWR, most EP are mostly concerned with monitoring and control of GW while practicing TWW reuse option in GWR.

Chapter 6

Rapid Impact Assessment Matrices (RIAM)

After the multi-criteria analysis of the six accepted TWW reuse options identified by the Multi-Criteria Decision Making study (MCDM) described in Chapter 5, this chapter introduces another assessment tool (Rapid Impact Assessment Matrix) that can be used to assist decision makers when assessing environmental projects or activities. The chapter applies the Rapid Impact Assessment Matrix (RIAM) to assess each TWW reuse option, and then tests and compares the results with the MCDM results. RIAM (components and categories) results for each TWW reuse option are provided and analysed for further discussion, findings and conclusions.

The current situation; the Driving Forces, Pressures, State, Impacts and Responses (DPSIR) framework of Kuwait, TWW reuse options surveys using Multi-Criteria Decision Making (MCDM) and Environmental Impact Assessment (EIA) of the six accepted TWW reuse options using the Rapid Impact Assessment Matrix (RIAM) are analysed in detail in Chapters 4, 5 and 6 respectively. The results of the latter chapters are discussed here and prepared for higher level of analysis, synthesis and evaluation in Chapter 7 and Chapter 8 (Conclusions and Recommendations).

6.1 RIAM Application and Phases

6.1.1 Selected TWW Reuse Options

Following MCDM, six (6) out of the twelve (12) selected applicable TWW reuse options for Kuwait are presented in Table 6-1. These are Artificial Wetlands (AW), Recreational Irrigation (RI), Agricultural Irrigation (AI), Industrial Processes (IP) (including reuse in Constructional processes and firefighting), Oil

Depressurization (OD) and Groundwater Recharge (GWR). Each TWW reuse option is assessed based on certain criteria (almost similar to those used in MCDM) within the previously gathered data.

Table 6-1: Reuse Practice & Options Perception (Kuwait Case Study)

<table>
<tr><td rowspan="3">TWW Reuse Practice
(Option)</td><td>Expert Judgment</td><td colspan="4">Reason</td></tr>
<tr><td rowspan="2">Applicability
(A or N/A)
Acceptance
(Agree=1 or Disagree= 2)</td><td>C1
(Human H)</td><td>C2
(Environmental)</td><td>C3
(Social)</td><td>C4
(Economic)</td></tr>
<tr><td>Public H.
H. Risk
Diseases
Outbreaks</td><td>Water Conservation
Marine Pollution
Ecosystem Services
Land Degradation.</td><td>Accept.
Psycho.
Attitude
Religion</td><td>Technology
Operation
Feasibility
Investment</td></tr>
<tr><td>(1) Artificial Wetlands</td><td rowspan="7">A</td><td colspan="4" rowspan="7">Accepted</td></tr>
<tr><td>(2) Recreational Irrigation</td></tr>
<tr><td>(3) Agriculture & Fisheries</td></tr>
<tr><td>(4) Industry & Construction</td></tr>
<tr><td>(5) Fire Fighting</td></tr>
<tr><td>(6) Oil Depressurization</td></tr>
<tr><td>(7) Groundwater Recharging</td></tr>
<tr><td>(8) Yards & Car Washing</td><td rowspan="5">N/A</td><td colspan="4" rowspan="5">Rejected</td></tr>
<tr><td>(9) Toilet Flushing</td></tr>
<tr><td>(10) Showering & Bathing</td></tr>
<tr><td>(11) Cooking</td></tr>
<tr><td>(12) Drinking</td></tr>
</table>

As shown in Table 6-1, the reasons for accepting or rejecting any TWW reuse option for Kuwait were classified using four criteria; C1 (Human H), C2 (Environmental), C3 (Social) and C4 (Economic). These criteria were weighted using a short Survey Questionnaire (SSQ) by the expert opinion provided by groups of experts and experienced researchers and specialists in the first part of the TWW reuse options decision making and assessment process. The second part uses an EIA tool (RIAM) which includes four categorized criteria similar to those that were previously weighted as described below.

6.1.2 RIAM Categories and Components

The Four Categories within the RIAM (EIA) Process are:

(1) Physical / Chemical: Covering all physical and chemical aspects of the environment, including finite (Non-Biological) natural resources, and degradation of the physical environment by pollution.

(2) Biological (Health) / Ecological (Environmental): Covering all biological aspects of the environment (causes of diseases, health problems and environmental impacts), including renewable natural resources, conservation of biodiversity, species interactions, and pollution of the biosphere.

(3) Sociological / Cultural: Covering all human aspects of the environment, including social issues affecting individuals and communities together with cultural aspects, including conservation of heritage, and human development.

(4) Economic / Operational: Covering economic consequences of environmental change, both temporary and permanent, as well as the complexities of project management within the context of the project activities.

6.1.3 RIAM Criteria and Scoring System

Important assessment criteria within RIAM fall into two groups as listed and described in Table 6 - 2.

Table 6 - 2: The Assessment Criteria for RIAM

Group	Category	Scale	Description
A	(A1) Importance of Condition	4	International Importance
		3	National Importance
		2	Outside of Local Condition
		1	Local Condition
		0	Not Important
	(A2) Magnitude of Change-Effect	+3	Major Positive Benefit
		+2	Significant Improvement
		+1	Improvement in (?)
		0	No change
		-1	Negative Change to (?)
		-2	Significant Negative effect
		-3	Major Negative Effect
B	(B1) Permanence	1	No Change (not applicable)
		2	Temporary
		3	Permanent
	(B2) Reversibility	1	No Change (not applicable)
		2	Reversible
		3	Irreversible
	(B3) Cumulative	1	No Change (not applicable)
		2	Non-Cumulative (single)
		3	Cumulative (synergistic)

Source: Youssef et al. (2009); Shoili et al. (2011); Baby (2011)

The scoring system requires multiplication of the scores associated with each criterion in group (A). Scores for the value criteria group (B) are added together to provide a single sum. This ensures that the individual value scores do not influence the overall score and that the collective importance of all values in group (B) is fully taken into account. The sum of the group (B) scores is then multiplied by the result of the group (A) scores to provide a final assessment score (ES) for the condition. The process can be carried out as follows: (A1) x (A2) = **AT**, (B1) + (B2) + (B3) = **BT** and (AT) x (AT) = **ES**.

Where:

- (A1) and (A2) are the individual criteria scores for group (A).
- (B1) to (B3) are the individual criteria scores for group (B).
- **AT** is the result of multiplication of all (A) scores.
- **BT** is the result of summation of all (B) scores.
- **ES** is the environmental assessment score for the condition.

Positive and negative impacts can be demonstrated using scales ranging from negative to positive values while Zero (0) refers to No-Change or No-Importance as demonstrated in Table 6 - 2. The value Zero is avoided in the group (B) criteria. If all group (B) criteria score zero, the final score of the environmental assessment (ES) will also be zero. The final result of the ES with its both alphabetic and numeric range values are described in Table 6 - 3.

Table 6 - 3: Range Bands Used for RIAM

Environmental Score (ES)	Range Value (RV) (Alphabetic)	Range Value (RV) (Numeric)	Description of Range Band
72 to 108	E	5	Major Positive Change
36 to 71	D	4	Significant Positive Change
19 to 35	C	3	Moderate Positive Change
10 to 18	B	2	Positive Change
1 to 9	A	1	Slight Positive Change
0	N	0	No Change
-1 to -9	-A	-1	Slight Negative Change
-10 to -18	-B	-2	Negative Change
-19 to -35	-C	-3	Moderate Negative Change
-36 to -71	-D	-4	Significant Negative Change
-72 to -108	-E	-5	Major Negative Change

6.1.4 Checklists for Experts' Judgements on RIAM Components

As previously mentioned, the four Criteria for Multi-Criteria Decision Analysis (MCDA) are similar to the four RIAM categories (Table 6-4). However, the components used to assess each RIAM category differ from the sub-criteria used in the MCDM method. To assess the six accepted available TWW reuse option, a matrix is produced for each TWW reuse option to be assessed within the four RIAM categories. RIAM is performed by surveying the expert participants (EP) groups to determine for their expert opinion (expert judgement). To collect views and suggestions (remarks) of experts in the field of environmental health impact assessment (EHIA) regarding TWW reuse practice and options, a checklist of components and factors of influence were prepared. The four categories of RIAM are defined in Table 6-4 and all criteria scores were explained to all participants (all EP groups) as summarized in Table 6-5. Around 40 academic specialists and experts in the field (Water and TWW assessment and management) participated in determining the RIAM components and designing the matrices. Selected components are listed and defined in Table 6 – 6.

As can be seen from Table 6 -5, for each of the four RIAM categories, four components are identified (4 components x 4 Categories = 16 components). Thus, a total of 16 components for every TWW reuse option will be assessed within the four categories of RIAM. For each option, the RIAM checklist for scoring components was distributed amongst the EP groups to be completed for all six TWW reuse options. Based on the above numeric references, the EP ranked the degree effect on the critical environmental components' of RIAM for each selected TWW Reuse option. The designed RIAM for each TWW reuse option is listed in Table 6 -7.

Table 6 -4: The Four Categories within RIAM (EIA) Process

Physical / Chemical	Biological (Health) / Ecological (Environmental)	Sociological / Cultural	Economic / Operational
Physical and chemical aspects of the environment, including finite (Non-Biological) natural resources, and degradation of the physical environment by pollution.	Biological aspects of the environment (causes of diseases, health problems and environmental impacts), including renewable natural resources, conservation of biodiversity, species interactions, and pollution of the biosphere.	Human aspects of the environment, including social issues affecting individuals and communities together with cultural aspects, including conservation of heritage, and human development.	Economic consequences of environmental change, both temporary and permanent, as well as the complexities of project management within the context of the project activities.

Table 6 -5: The Assessment Criteria for RIAM

Group A		Group B		
Importance of Condition (A1)	**Magnitude of Change-Effect (A2)**	**Permanence (B1)**	**Reversibility (B2)**	**Cumulative (B3)**
A measure of the importance of the condition, which is assessed against the spatial boundaries or human interests it will affect.	A measure of the scale of benefit or dis-benefit of an impact or a condition.	A measure of the temporal status of the condition (a permanent condition or a temporary condition).	A measure of the control over the effect of the condition (a reversible condition or an irreversible condition).	A measure of whether the effect will be a single direct impact or a cumulative effect over time or a synergistic effect with other conditions.
4= International Importance 3= National Importance 2= Outside of Local Condition 1= Local Condition 0= Not Important	+3= Major Positive Benefit +2= Significant Improvement +1= Improvement in (?) 0= No change -1= Negative Change to (?) -2= Significant Negative effect -3= Major Negative Effect	1= No Change (not applicable) 2= Temporary 3= Permanent	1= No Change (not applicable) 2= Reversible 3= Irreversible	1= No Change (not applicable) 2= Non-Cumulative (single) 3= Cumulative (synergistic)

Table 6-6: Critical Environmental Components of RIAM for TWW Reuse Options

1. Physical / Chemical Components

Component	Description
1. Surface Water Quality	Effects of high quantities of rejected (brine) wastewater on marine and or coastal water, and desalination seawater intakes.
2. Groundwater Quality	Effects of high quantities of recharged (injected) TWW into GW.
3. Soil Quality	Effects of TWW components (quality) on soil components and characteristics, which in turn affects food and other agricultural products that are irrigated by such TWW.
4. Coastal and Seashore Environment	Effects of WW effluents on seashore ecosystem (living environment) and coastal water quality. Effects of WW effluents on coastal activities such as beaches, households, and other industrial activities, projects, and developments.

2. Biological (Health) / Ecological (Environmental) Components

Component	Description
1. Land Ecosystem	Effects on soil quality from TWW reuse practice. Land Degradation from improperly treated or untreated WW effluents and other rejected / disposed materials such as brine water and sludge.
2. Aquatic Ecosystem	Effects on seashore and coastal environment.
3. Human, Animal & Plant's Health (Long-Term Epidemical Disease Occurrence)	Effects of biological agents (bacteria, viruses, fungi) and other diseases' vectors such insects and rodents (being directly or indirectly affected from improperly treated or untreated WW effluents) on human health, animal, and plants (which can either be inhaled or be swallowed directly or through food and fishery products when utilizing such TWW).
4. Developmental Projects Activities (Industrial, Constructional, & Firefighting)	TWW quality can intern affect industrial products and construction materials alongside workers utilizing TWW within the industrial and operational production processes.

3. Sociological / Cultural Components

Component	Description
1. Products' Quality	Welfare Issue. Effect of produced water or TWW reused products on socio-cultural components and environment such as greenery areas, landscape deterioration, wetlands, trees, gardens, beaches, etc.
2. Public Health	Well-being Issus. Effect on the general health status of communities and correlational health problems caused by TWW reuse practice that in turn lead to unhealthy communities and environment.
3. Public Acceptance	Public rejection and acceptance to such TWW reuse practice and or option for various reasons such as environmental health risk, socio-economic, environmental protection (water conservation), psychological, religion, and or any other socio-cultural reasons.
4. Public Participation	Public involvement and contribution in such practice based on knowledge, and awareness. Human development issues such as national workforce (jobs) opportunities that based on variety of qualifications and specialty.

4. Economic / Operational Components

Component	Description
1. Technology & Treatment Cost	Cost of technology, equipment and treatment alongside benefits, profit and other investments.
2. Logistics' Cost	Cost of storage tanks and or reservoirs, transportation, pumping stations, etc.
3. Cost of Operation and Maintenance	Cost of operation and processes of WWTP's alongside their periodical maintenance and regular checkup cost.
4. Cost of Control and Monitoring	Cost of pollution mitigation and rehabilitation, sampling and monitoring techniques, equipment and devices, laboratories staff and various testing apparatus and analysis (chemical, physical, biological analysis), etc.

Table 6 -7: The Designed RIAM for Each TWW Reuse Option

1. Physical / Chemical Components' Matrix

Component	A1	A2	B1	B2	B3
1. Surface Water Quality					
2. Groundwater Quality					
3. Soil Quality					
4. Coastal and Seashore Environment					

2. Biological (Health) / Ecological (Environmental) Components' Matrix

Component	A1	A2	B1	B2	B3
1. Land Ecosystem					
2. Aquatic Ecosystem					
3. Human, Animal & Plant's Health (Long-Term Epidemical Disease Occurrence)					
4. Developmental Projects Activities (Industrial, Constructional, & Firefighting)					

3. Sociological / Cultural Components' Matrix

Component	A1	A2	B1	B2	B3
1. Products' Quality					
2. Public Health					
3. Public Acceptance					
4. Public Participation					

4. Economic / Operational Components' Matrix

Component	A1	A2	B1	B2	B3
1. Technology & Treatment Cost					
2. Logistics' Cost					
3. Cost of Operation and Maintenance					
4. Cost of Control and Monitoring					

6.2 Results of RIAM and Trade-offs amongst the Expert Participants (EP)

RIAM categories and components involve specific scientific (chemical, physical and biological) and environmental terminologies and issues. Therefore, the RIAM survey was distributed amongst 14 members of the expert participants (EP) groups (academic specialists and other experienced persons in the field) for their expert opinions and judgement. Further to reflect possible differences in perception between participants, the EP researches and specialists (in Water, TWW assessment and management and other associated fields) were divided into two groups: government (G) and non-government (NG). They were also distinguished within the total results (sum of components = total result of categories). In this way, the results total of categories should identify possible trade-off issues between stakeholders.

Tables 6-8, 6-9, 6-10, 6-11, 6-12, and 6-13 list the RIAM results (components and categories) for the six TWW reuse options: Artificial Wetlands (AW), Recreational Irrigation (RI), Agricultural Irrigations (AI), Industrial Processes (IP), Oil Depressurization (OD) and Groundwater Recharging (GWR) respectively. The components results listed within RIAM will briefly be discussed after presenting TWW reuse options' Tables. The total results for all categories: Physical / Chemical (P/C), Biological (Health) / Ecological (Environmental) (B/E), Sociological / Cultural (S/C), and Economic / Operational (E/O) regarding each option are also included.

Table 6-8: RIAM Result (Environmental Components and Categories) for TWW Reuse in AW

Categories	All				G				NG			
Physical / Chemical Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Surface Water Quality	0	N	0	No Change	3	A	1	Slight +ve Change	-4	-A	-1	Slight -ve Change
2. Groundwater Quality	-3	-A	-1	Slight -ve Change	5	A	1	Slight +ve Change	-17	-B	-2	-ve Change
3. Soil Quality	-14	-B	-2	-ve Change	-12	-B	-2	-ve Change	-14	-B	-2	-ve Change
4. Coastal and Seashore Environment	-8	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change	-17	-B	-2	-ve Change
Biological / Ecological Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Land Ecosystem	-3	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change	0	N	0	No Change
2. Aquatic Ecosystem	-2	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change
3. Human, Animal & Plant's Health	-5	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change	-9	-A	-1	Slight -ve Change
4. Developmental Projects Activities	7	A	1	Slight +ve Change	2	A	1	Slight +ve Change	15	B	2	+ve Change
Sociological / Cultural Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Products' Quality	8	A	1	Slight +ve Change	8	A	1	Slight +ve Change	8	A	1	Slight +ve Change
2. Public Health	-4	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change	-7	-A	-1	Slight -ve Change
3. Public Acceptance	-2	-A	-1	Slight -ve Change	-4	-A	-1	Slight -ve Change	1	A	1	Slight +ve Change
4. Public Participation	5	A	1	Slight +ve Change	4	A	1	Slight +ve Change	6	A	1	Slight +ve Change
Economic / Operational Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Technology & Treatment Cost	2	A	1	Slight +ve Change	-3	-A	-1	Slight -ve Change	10	B	2	+ve Change
2. Logistics' Cost	0	N	0	No Change	0	N	0	No Change	0	N	0	No Change
3. Cost of Operation and Maintenance	-4	-A	-1	Slight -ve Change	0	N	0	No Change	-8	-A	-1	Slight -ve Change
4. Cost of Control and Monitoring	-6	-A	-1	Slight -ve Change	2	A	1	Slight +ve Change	-12	-B	-2	-ve Change

Table 6-9: RIAM Result (Environmental Components and Categories) for TWW Reuse in RI

Categories	All				G				NG			
Physical / Chemical Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Surface Water Quality	0	N	0	No Change	2	A	1	Slight +ve Change	-1	-A	-1	Slight -ve Change
2. Groundwater Quality	-1	-A	-1	Slight -ve Change	4	A	1	Slight +ve Change	-7	-A	-1	Slight -ve Change
3. Soil Quality	1	A	1	Slight +ve Change	12	B	2	+ve Change	-7	-A	-1	Slight -ve Change
4. Coastal and Seashore Environment	-1	-A	-1	Slight -ve Change	1	A	1	Slight +ve Change	-4	-A	-1	Slight -ve Change
Biological / Ecological Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Land Ecosystem	5	A	1	Slight +ve Change	4	A	1	Slight +ve Change	5	A	1	Slight +ve Change
2. Aquatic Ecosystem	0	N	0	No Change	0	N	0	No Change	0	N	0	No Change
3. Human, Animal & Plant's Health	-2	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change	-4	-A	-1	Slight -ve Change
4. Developmental Projects Activities	2	A	1	Slight +ve Change	0	N	0	No Change	6	A	1	Slight +ve Change
Sociological / Cultural Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Products' Quality	11	B	2	+ve Change	17	B	2	+ve Change	7	A	1	Slight +ve Change
2. Public Health	3	A	1	Slight +ve Change	3	A	1	Slight +ve Change	3	A	1	Slight +ve Change
3. Public Acceptance	8	A	1	Slight +ve Change	12	B	2	Slight +ve Change	4	A	1	Slight +ve Change
4. Public Participation	7	A	1	Slight +ve Change	9	A	1	Slight +ve Change	5	A	1	Slight +ve Change
Economic / Operational Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Technology & Treatment Cost	16	B	2	+ve Change	12	B	2	+ve Change	19	C	3	Moderate +ve Change
2. Logistics' Cost	7	A	1	Slight +ve Change	5	A	1	Slight +ve Change	9	A	1	Slight +ve Change
3. Cost of Operation and Maintenance	5	A	1	Slight +ve Change	4	A	1	Slight +ve Change	5	A	1	Slight +ve Change
4. Cost of Control and Monitoring	4	A	1	Slight +ve Change	2	A	1	Slight +ve Change	5	A	1	Slight +ve Change

Table 6-10: RIAM Result (Environmental Components and Categories) for TWW Reuse in AI

Categories	**All**				**G**				**NG**			
Physical / Chemical Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Surface Water Quality	0	N	0	No Change	1	A	1	Slight +ve Change	0	N	0	No Change
2. Groundwater Quality	-18	-B	-2	-ve Change	-14	-B	-2	-ve Change	-23	-C	-3	Moderate -ve Change
3. Soil Quality	-13	-B	-2	-ve Change	-8	-A	-1	Slight -ve Change	-17	-B	-2	-ve Change
4. Coastal and Seashore Environment	-2	-A	-1	Slight -ve Change	0	N	0	No Change	-7	-A	-1	Slight -ve Change
Biological / Ecological Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Land Ecosystem	-2	-A	-1	Slight -ve Change	-6	-A	-1	Slight -ve Change	3	A	1	Slight +ve Change
2. Aquatic Ecosystem	-1	-A	-1	Slight -ve Change	0	N	0	No Change	-1	-A	-1	Slight -ve Change
3. Human, Animal & Plant's Health	-6	-A	-1	Slight -ve Change	-6	-A	-1	Slight -ve Change	-5	-A	-1	Slight -ve Change
4. Developmental Projects Activities	1	A	1	Slight +ve Change	1	A	1	Slight +ve Change	2	A	1	Slight +ve Change
Sociological / Cultural Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Products' Quality	3	A	1	Slight +ve Change	2	A	1	Slight +ve Change	3	A	1	Slight +ve Change
2. Public Health	-6	-A	-1	Slight -ve Change	-5	-A	-1	Slight -ve Change	-8	-A	-1	Slight -ve Change
3. Public Acceptance	14	B	2	+ve Change	19	C	3	Moderate +ve Change	7	A	1	Slight +ve Change
4. Public Participation	9	A	1	Slight +ve Change	15	B	2	+ve Change	2	A	1	Slight +ve Change
Economic / Operational Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Technology & Treatment Cost	5	A	1	Slight +ve Change	2	A	1	Slight +ve Change	8	A	1	Slight +ve Change
2. Logistics' Cost	-2	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change
3. Cost of Operation and Maintenance	-4	-A	-1	Slight -ve Change	0	N	0	No Change	-8	-A	-1	Slight -ve Change
4. Cost of Control and Monitoring	-7	-A	-1	Slight -ve Change	-5	-A	-1	Slight -ve Change	-8	-A	-1	Slight -ve Change

Table 6-11: RIAM Result (Environmental Components and Categories) for TWW Reuse in IP

Categories	All				G				NG			
Physical / Chemical Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Surface Water Quality	-2	-A	-1	Slight -ve Change	-4	-A	-1	Slight -ve Change	0	N	0	No Change
2. Groundwater Quality	-5	-A	-1	Slight -ve Change	-4	-A	-1	Slight -ve Change	-7	-A	-1	Slight -ve Change
3. Soil Quality	-3	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change
4. Coastal and Seashore Environment	-5	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change	-7	-A	-1	Slight -ve Change
Biological / Ecological Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Land Ecosystem	-1	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change	1	A	1	Slight +ve Change
2. Aquatic Ecosystem	-2	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change
3. Human, Animal & Plant's Health	-6	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change	-11	-B	-2	-ve Change
4. Developmental Projects Activities	3	A	1	Slight +ve Change	1	A	1	Slight +ve Change	6	A	-1	Slight -ve Change
Sociological / Cultural Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Products' Quality	-1	-A	-1	Slight -ve Change	0	N	0	No Change	-2	-A	-1	Slight -ve Change
2. Public Health	-2	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change
3. Public Acceptance	3	A	1	Slight +ve Change	5	A	1	Slight +ve Change	1	A	1	Slight +ve Change
4. Public Participation	1	A	1	Slight +ve Change	-1	-A	-1	Slight -ve Change	5	A	1	Slight +ve Change
Economic / Operational Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Technology & Treatment Cost	1	A	1	Slight +ve Change	-2	-A	-1	Slight -ve Change	3	A	1	Slight +ve Change
2. Logistics' Cost	-2	-A	-1	Slight -ve Change	-4	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change
3. Cost of Operation and Maintenance	-6	-A	-1	Slight -ve Change	-5	-A	-1	Slight -ve Change	-5	-A	-1	Slight -ve Change
4. Cost of Control and Monitoring	-5	-A	-1	Slight -ve Change	-6	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change

`Table 6-12: RIAM Result (Environmental Components and Categories) for TWW Reuse in OD

Categories	**All**				**G**				**NG**			
Physical / Chemical Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Surface Water Quality	0	N	0	No Change	1	A	1	Slight +ve Change	0	N	0	No Change
2. Groundwater Quality	-17	-B	-2	-ve Change	-13	-B	-2	-ve Change	-20	-C	-3	Moderate -ve Change
3. Soil Quality	-8	-A	-1	Slight -ve Change	-6	-A	-1	Slight -ve Change	-9	-A	-1	Slight -ve Change
4. Coastal and Seashore Environment	-1	-A	-1	Slight -ve Change	0	N	0	No Change	-3	-A	-1	Slight -ve Change
Biological / Ecological Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Land Ecosystem	-5	-A	-1	Slight -ve Change	-11	-B	-2	-ve Change	-2	-A	-1	Slight -ve Change
2. Aquatic Ecosystem	0	N	0	No Change	0	N	0	No Change	-1	-A	-1	Slight -ve Change
3. Human, Animal & Plant's Health	-1	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change
4. Developmental Projects Activities	3	A	1	Slight +ve Change	-1	-A	-1	Slight -ve Change	8	A	1	Slight +ve Change
Sociological / Cultural Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Products' Quality	-1	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change	1	A	1	Slight +ve Change
2. Public Health	0	N	0	No Change	0	N	0	No Change	0	N	0	No Change
3. Public Acceptance	1	A	1	Slight +ve Change	1	A	1	Slight +ve Change	0	N	0	No Change
4. Public Participation	0	N	0	No Change	0	N	0	No Change	0	N	0	No Change
Economic / Operational Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Technology & Treatment Cost	3	A	1	Slight +ve Change	-1	-A	-1	Slight -ve Change	9	A	1	Slight +ve Change
2. Logistics' Cost	-2	-A	-1	Slight -ve Change	-2	-A	-1	Slight -ve Change	0	N	0	No Change
3. Cost of Operation and Maintenance	-9	-A	-1	Slight -ve Change	-9	-A	-1	Slight -ve Change	-7	-A	-1	Slight -ve Change
4. Cost of Control and Monitoring	-7	-A	-1	Slight -ve Change	-9	-A	-1	Slight -ve Change	-5	-A	-1	Slight -ve Change

Table 6-13: RIAM Result (Environmental Components and Categories) for TWW Reuse in GWR

Categories	All				G				NG			
Physical / Chemical Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Surface Water Quality	0	N	0	No Change	5	A	1	Slight +ve Change	0	N	0	No Change
2. Groundwater Quality	19	C	3	Moderate +ve Change	33	C	3	Moderate +ve Change	3	A	1	Slight +ve Change
3. Soil Quality	-1	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change
4. Coastal and Seashore Environment	0	N	0	No Change	0	N	0	No Change	0	N	0	No Change
Biological / Ecological Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Land Ecosystem	0	N	0	No Change	0	N	0	No Change	1	A	1	Slight +ve Change
2. Aquatic Ecosystem	2	A	1	Slight +ve Change	1	A	1	Slight +ve Change	3	A	1	Slight +ve Change
3. Human, Animal & Plant's Health	-5	-A	-1	Slight -ve Change`	-6	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change
4. Developmental Projects Activities	1	A	1	Slight +ve Change	0	N	0	No Change	1	A	1	Slight +ve Change
Sociological / Cultural Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Products' Quality	4	A	1	Slight +ve Change	6	A	1	Slight +ve Change	3	A	1	Slight +ve Change
2. Public Health	-3	-A	-1	Slight -ve Change	2	A	1	Slight +ve Change	-9	-A	-1	Slight -ve Change
3. Public Acceptance	1	A	1	Slight +ve Change	4	A	1	Slight +ve Change	-3	-A	-1	Slight -ve Change
4. Public Participation	1	A	1	Slight +ve Change	0	N	0	No Change	2	A	1	Slight +ve Change
Economic / Operational Components'	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
1. Technology & Treatment Cost	-11	-B	-2	-ve Change	-7	-A	-1	Slight -ve Change	-15	-B	-2	-ve Change
2. Logistics' Cost	-5	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change	-7	-A	-1	Slight -ve Change
3. Cost of Operation and Maintenance	-9	-A	-1	Slight -ve Change	-5	-A	-1	Slight -ve Change	-13	-B	-2	-ve Change
4. Cost of Control and Monitoring	-10	-B	-2	-ve Change	-7	-A	-1	Slight -ve Change	-13	-B	-2	-ve Change

6.2.1 Artificial Wetlands (AW)

The only environmental category which shows a considerable change in its components for TWW reuse in AW is the P/C category. Components such as GW and soil quality have been given a negative evaluation which means that TWW reuse in AW will cause future negative changes to GW and soil quality. In contrast, all components of the three other categories (B/E, S/C and E/O) were given evaluations ranging from "no change" to "slight negative" or "slight positive" changes except for two components (the "Developmental Projects Activities" of B/E showed a positive change and "Cost of control and monitoring" of E/O showed a negative change). The total results of all environmental categories regarding reusing TWW in AW are shown in Table 6-14.

Table 6-14: The Total Results of Environmental Categories for TWW Reuse in AW

FG	All				G				NG			
Scores Types	ES	RV(A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV(A)	RV(N)	Description
Total P/C	-25	- C	-3	Moderate -ve Change	-7	-A	-1	Slight -ve Change	-52	-D	-4	Significant -ve Change
Total B/E	-3	-A	-1	Slight -ve Change	-3	-A	-1	Slight -ve Change	4	A	1	Slight +ve Change
Total S/C	7	A	1	Slight +ve Change	6	A	1	Slight +ve Change	8	A	1	Slight +ve Change
Total E/O	-8	-A	-1	Slight -ve Change	-1	-A	-1	Slight -ve Change	-10	-B	-2	-ve Change

6.2.2 Recreational Irrigation (RI)

Most components of the environmental categories regarding TWW reuse in RI range from "slight positive" to "moderate positive" changes. A few components had a negative evaluation such as human, animal and plant's health, GW quality and coastal and seashore environment. Most negative responses were from NG participants. Thus, the total of all other categories regarding reusing TWW in RI had a positive evaluation (ranges from "slight positive" to "significant positive" changes). The only category that had a negative evaluation is the P/C (ranges from "slight negative" to "moderate negative" changes) although the G participants' final result was positive ("moderate positive change). This final negative result was largely from the NG participants' decision (evaluation) as listed in Table 6-9. The total results of all environmental categories regarding reusing TWW in RI is shown in Table 6-15.

Table 6-15: The Total Results of Environmental Categories for TWW Reuse in RI

FG	All				G				NG			
Scores Types	ES	RV(A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV(A)	RV(N)	Description
Total P/C	-1	-A	-1	Slight -ve Change	19	C	3	Moderate +ve Change	-19	-C	-3	Moderate -ve Change
Total B/E	5	A	1	Slight +ve Change	3	A	1	Slight +ve Change	7	A	1	Slight +ve Change
Total S/C	29	C	3	Moderate +ve Change	41	D	4	Significant +ve Change	19	C	3	Moderate +ve Change
Total E/O	32	C	3	Moderate +ve Change	23	C	3	Moderate +ve Change	38	D	4	Significant +ve Change

6.2.3 Agricultural Irrigation (AI)

Although TWW reuse in AI has long been practiced worldwide, Kuwait, it is still considered a critical issue. Most environmental categories (P/C, the environmental health components B/E, and E/O) had negative final results except for S/C (which mostly had positive responses ranging from "slight positive" to "moderate positive" changes except for the "public health" component that had an evaluation of "slight negative change from all of the EP; both G and NG groups). This result reflects human and environmental health concerns.

Associated human health and environmental aspects of P/C components (e.g. GW and soil quality, coastal and seashore environment) are considered important factors in ensuring safe and healthy food production. Therefore, the final decision (evaluation) was negative (ranging from "slight negative" to "moderate negative" changes) to avoid any human and/or environmental health risk in the case of improper wastewater treatment. Moreover, B/E components (e.g. land and aquatic ecosystems and human, animal and plant's health) mostly had a "slight negative" change evaluation. The only B/E component that had a positive evaluation was "developmental projects activities" (which had a final result of "slight positive" by all of the EP including both G and NG groups).

In Kuwait, wastewater is treated and distributed entirely by the government. TWW is highly subsidized for farmers, livestock companies and other agricultural beneficiaries and is available at very low prices. Therefore, expert perception toward most S/C component turned out to be positive (from "slight positive" to "moderate positive" changes). The only component of S/C category that had a final result of "slight negative" changes evaluation was for "public health". This appears to be due to concerns that improperly treated wastewater will be reused in AI.

The environmental category associated with economy, technology and further logistic aspects (E/O) also had some negative responses. The final results were mostly evaluated "slight negative", except for the "technology and treatment cost" component (which had a final evaluation of "slight positive"). The reason for this evaluation (judgment) as noted by most experts is that the government is entirely responsible for wastewater treatment and there is no investment in this option except for the purposes of reducing pressures on fresh-water consumption. The total results for all environmental categories regarding reusing TWW in AI are given in Table 6-16.

Table 6-16: The Total Results of Environmental Categories for TWW Reuse in AI

FG	All				G				NG			
Scores Types	ES	RV(A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV(A)	RV(N)	Description
Total P/C	-33	-C	-3	Moderate -ve Change	-21	-C	-3	Moderate -ve Change	-47	-D	-4	Significant -ve Change
Total B/E	-8	-A	-1	Slight -ve Change	-11	-B	-2	-ve Change	-1	-A	-1	Slight -ve Change
Total S/C	20	C	3	Moderate +ve Change	31	C	3	Moderate +ve Change	4	A	1	Slight +ve Change
Total E/O	-8	-A	-1	Slight -ve Change	-4	-A	-1	Slight -ve Change	-10	-B	-2	-ve Change

6.2.4 <u>Industrial Processes (IP)</u>

As described in Section 6.2.2, there will be no serious risk to human health and environmental impacts when reusing TWW in IP (there will be no direct human contact) and TWW will not be reused in any industrial production line. For example, the most "negative" response (particularly from the NG group) was in the environmental health category (B/E). Components such as "human, animal and plant health result ranged from "slight negative" to "negative" due to environmental health concerns. However, TWW reuse in IP will conserve fresh-water and no other critical concerns were expressed in the expert judgments. Most components in all categories of the final results (i.e. evaluation) ranged from "no change" to "slight negative" or "slight positive" changes.

The quality and fate of the products' and location of TWW reuse and discharge were all considered critical issues by the FG especially the NG group. The total results in all environmental categories regarding reusing TWW in IP are shown in Table 6-17.

Table 6-17: The Total Results of Environmental Categories for TWW Reuse in IP

FG	All				G				NG			
Scores Types	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
Total P/C	-15	-B	-2	-ve Change	-14	-B	-2	-ve Change	-17	-B	-2	-ve Change
Total B/E	-6	-A	-1	Slight -ve Change	-4	-A	-1	Slight -ve Change	-7	-A	-1	Slight -ve Change
Total S/C	1	A	1	Slight +ve Change	2	A	1	Slight +ve Change	1	A	1	Slight +ve Change
Total E/O	-12	-B	-2	-ve Change	-17	-B	-2	-ve Change	-5	-A	-1	Slight -ve Change

6.2.5 Oil Depressurization (OD)

The Drilling Department if the Kuwait Oil Company (KOC) uses groundwater (GW) in the oil depressurization (OD) process. The GW is of low to moderate salinity and is abstracted from wells within the oil fields. Therefore, high salinity TWW derived, for example, from R.O. WWTP can be reused for this purpose rather than GW. Thus, the most critical component in this case is the "GW quality" within P/C environmental category. The total environmental score (ES) was -17 (from all EP groups) which means there will be negative changes associated with reusing saline TWW in OD. The ES of G group was -13 which reflects the total result of all EP groups (which is "negative changes" evaluation).

In contrast, the NG group's ES score for reusing saline TWW for OD was -20 which equates to "moderate negative" changes to GW quality. "Land ecosystem" as an environmental health component of B/E category, especially around areas where such TWW will be reused is also important and negatively evaluated.

Since there are no social concerns regarding TWW reuse for OD, the responses (ES) to S/C components were mostly zero (no change). E/O components' had a "slight negative change" evaluation since there would be no investment under this option.

The only E/O component (technology and treatment cost), in contrast, had an evaluation of a "slight positive change" especially by the environmental NG expert group. The reason as remarked by some of the specialists was that reusing harmful saline TWW rather wasting it or discharging it to the sea would protect the environment. Therefore, this option (TWW reuse in OD) is considered economic, feasible and an environmentally friendly option.

The total results of all environmental categories regarding reusing TWW in OD is shown in Table 6-18.

Table 6-18: The Total Results of Environmental Categories for TWW Reuse in OD

FG	All				G				NG			
Scores Types	ES	RV (A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV (A)	RV (N)	Description
Total P/C	-26	-C	-3	Moderate -ve Change	-18	-B	-2	-ve Change	-32	-C	-3	Moderate -ve Change
Total B/E	-3	-A	-1	Slight -ve Change	-14	-B	-2	-ve Change	4	A	1	Slight +ve Change
Total S/C	0	N	0	No Change	-2	-A	-1	Slight -ve Change	1	A	1	Slight +ve Change
Total E/O	-15	-B	-2	Slight -ve Change	-21	-B	-2	-ve Change	-3	-A	-1	Slight -ve Change

6.2.6 <u>Groundwater Recharge (GWR)</u>

Similar to TWW reuse in OD, the most critical issue regarding reusing TWW in GWR is considered to be GW quality. However, unlike reusing the byproduct of high saline TWW for OD, the advanced TWW product (fresh R.O. TWW) will be used for GWR. Therefore, "GW quality" ES from all EP groups was 19 (equivalent to numeric range value of 3 and alphabetic range value of C) which means there will be a "moderate positive change" to GW quality when advanced TWW is used for GWR. However, this positive environment score (ES) was apparently controversial between the G and NG groups as evident in Table 6-13. The G group ES was 33 (C), meaning there will be a "moderate positive change", but the NG group ES was 3 (A) which is rather low and means there will be only a "slight positive change" in GW quality. In contrast, "soil quality" was evaluated as a "slight negative change" by both G and NG groups. The reason for this negative judgment from the EP was their opinion that TWW will accumulate in the soil over time due to the filtration process.

Components of environmental concern (category B/E) had results ranging from "no change" to "slight positive change". The only component with a "slight negative change" was the "human, animal and plant health". For fresh-water scarcity and conservation, most components of S/C category had a "slight positive change" with the exception of a "slight negative change" for "public health" and "public acceptance" by the NG group. The only zero evaluation in this category was for the "public participation" which means "no change". All E/O components had an evaluation results ranging from "slight negative" to "negative" changes. Components of most concerns were "operation and maintenance" and "control and monitoring" costs. The total results for all environmental categories regarding reusing TWW in GWR is shown in Table 6-19.

Table 6-19: The Total Results of Environmental Categories for TWW Reuse in GWR

FG	All				G				NG			
Scores Types	ES	RV(A)	RV(N)	Description	ES	RV(A)	RV(N)	Description	ES	RV(A)	RV(N)	Description
Total P/C	18	B	2	+ve Change	37	D	4	Significant +ve Change	2	A	1	Slight +ve Change
Total B/E	-2	-A	-1	Slight -ve Change`	-5	-A	-1	Slight -ve Change`	2	A	1	Slight +ve Change
Total S/C	3	A	1	Slight +ve Change	12	B	2	+ve Change	-7	-A	-1	Slight -ve Change`
Total E/O	-35	-C	-3	Moderate -ve Change	-22	-C	-3	Moderate -ve Change	-48	-D	-4	Significant -ve Change

Chapter 7

Results and Findings

In this chapter, the results from chapters 4, 5 and 6 will be discussed and prepared with a higher level of analysis, synthesis and evaluation. Further critical findings of research will be explored before providing the conclusions and recommendations in Chapter 8.

7.1 Current Situation (DPSIR Framework)

By consolidating all associated information regarding water and TWW management in Kuwait and having addressed the pressures, state and impacts, the major problems of TWW resource and reuse have been recognized. It is suggested that current responses are inadequate to satisfy the increasing water demand in Kuwait. TWW management and reuse practice gaps must be resolved by updating, reorganizing and representing more effective responses to conditions of water scarcity. It is also suggested that TWW can be reused in several available (applicable) options to reduce stress on other fresh-water resources (sources) such as desalinated water and groundwater.

Kuwait's population has increased progressively over the past five decades and the current population is estimated at 4 million. Conventional water resources are limited to groundwater (GW). The annual mean precipitation over the last five decades in Kuwait has been around 112 mm and annual mean evaporation about 10 mm. In order to meet the increasing demand for freshwater due to population and socio-economic growth, Kuwait relies on water desalination as the only additional source of freshwater to supplement the available limited GW resource. In addition to the population and socioeconomic growth, lifestyle changes and some government policies (e.g. water subsidies) have led to an increase in per capita water consumption to about 440 liters/day (500 m^3 / Year). Currently, over 70% of the freshwater is consumed by the municipal (domestic) sector of which up to 90% is derived from desalinated water (DW).

Until 2011, of the total volume of water (1157 million m^3), TWW reuse was less than 10%. Currently, about half (48%) of TWW total amount (687 m^3 / day) is treated by advanced technology Ultra Filtration (UF) and Reverse Osmosis (RO) membrane filtration. The remaining half (52%) is treated by tertiary level treatment (rapid sand filtration and chlorination). The largest beneficiary of TWW is the agricultural sector (around 65% of advanced R.O. and 35% of tertiary TWW). The remaining quantities of TWW are discharged to the sea.

Currently, freshwater consumption exceeds 1.5 million m^3 / day of which ultimately is more than 1 million m^3 / day is lost as wastewater. The current scenario of expanding the capacity of water desalination plants and increasing groundwater abstraction rates to increase availability of freshwater and meet water demands will increase the future economic burden contributing to a water crisis. Due to a lack of effective planning and management, the challenges in reducing water stress on both fresh (DW) and GW resources is ongoing.

The second largest water consuming sector (the agricultural sector) requires high quantities of water for food production. The increase in GW withdrawal for agriculture within Kuwait imposes a critical impact on available water resources. Indirectly, this could have a serious impact in increasing food prices and raising energy costs. With large amounts of TWW discharged to the sea, reducing the pressure on fresh (DW) and GW production and the negative environmental consequences is an ongoing challenge.

7.2 <u>Perceptions toward Treated Wastewater (TWW) Reuse Practice and Options</u>

Acceptance of wastewater reuse practice has been directed toward non-potable applications, especially those with no direct contact to public, such as artificial wetlands (AW), recreational irrigation (RI), agricultural irrigation (AI), industrial processes (IP) including cooling, construction and fire extinguishing, oil depressurization (OD) and to a certain extent groundwater recharge (GWR). However, indirect and direct potable reuse options (where there will be direct contacts with the public) such as irrigation of household properties, car washing, toilet flushing, clothes washing, showering and drinking were found to be a serious public concern. The main reasons for not accepting wastewater reuse for potable applications are safety and health issues and uncertainty over water quality alongside reasons related to attitudes, beliefs and religion.

In Kuwait, public perceptions towards wastewater risk are usually based on an individual's personal knowledge, attitudes, and beliefs. Perception of the environmental health risks associated with wastewater reuse practice differs between the experts and public. The public typically reflect unconfident views and opinions that oppose risk because of uncertainty, fear, and for health reasons. However, the risk perception by experts is associated with "probability". The latter usually deal with subjective risk factors within a continuous chain and consider questions of cost-effectiveness. The expert view is that the accidental occurrence of risk can influence public attitudes towards a risk once they have more knowledge and information about the issue. However, since the risk is uncertain and TWW is not clearly reliable for reuse (there are no guarantees of the safety of TWW and no adequate efficient research studies of TWW reuse options), TWW reuse practice and options will continue to be a controversial issue.

Besides their perceptions and opinions, the expert participants' (EP) groups in decision making and assessing TWW reuse practice and options provided suggestions for the different TWW reuse options for this case study. EP groups' remarks and suggestions for each TWW reuse option are as follows:

7.2.1 Artificial Wetlands (AW)

Artificial Wetlands (AW) were considered a good investment for both the government and private sectors. It is regarded as an applicable option when effectively practiced and well organized and managed. While it is an attractive option especially for new cities, it might be difficult to practice in Kuwait. Difficulties include economic reasons (e.g. high initial and incremental costs of technology, operation, control and monitoring, and logistics), environmental health risk and climate situation. All criteria (human health, environmental health, social impacts and economic burdens) are important for this option. Environmental health is considered the most important criteria which include bad odors, diseases vectors, landscape degradation and probability of groundwater pollution. Therefore, AW water quality is considered a critical factor especially when it is established within a public recreation area or close to residential areas.

7.2.2 Recreational Irrigation (RI)

This option is already practiced and is an on-going TWW reuse practice in Kuwait. Depending on researchers' definition and classification, recreational and environmental uses under this category include lakes, ponds, marsh enhancement, stream-flow augmentation and snowmaking and landscaping irrigation (e.g. public parks, school yards, golf courses, and greenbelts). Within this study, in Kuwait, RI mainly comprises landscape irrigation. Since the government of Kuwait is responsible for all wastewater treatment costs, TWW transportation and distribution and networks' pipelines, the economic burden is the most important criterion for this option. Water quality is also critical for workers and the public (especially children) when contacting such water in public greenery areas and gardens. Therefore, warning signs, fences and other precautionary protective ways must be provided.

7.2.3 Agriculture Irrigation (AI) and Fisheries

Currently large-scale agricultural areas started practicing this reuse option in Kuwait (at Al-Abdaly in the North and Al-Wafra in the South) using both Tertiary and advanced TWW (R.O. and U.F. technology). Human health (health risk) is considered the most important criterion for this option. Water quality is the critical sub-criterion involved with human health. Types of irrigated plants (crops) and vegetables must strictly follow standards and guidelines. Strict monitoring must be conducted before and after the distribution of irrigated (food) products. Samples of irrigated plants, vegetables and fruits must be tested daily (for distribution) or periodically (for further evaluation) by public health and environmental laboratories.

In contrast, fishery products must also be controlled and monitored if they are to be used for human consumption. In addition, certain standards and handling guidelines must be set when reusing TWW for aqua-cultural purposes. Rather than public health considerations, no other criterion is influenced by this option except for the cost of wastewater treatment, which is subsidized by the government for farmers and private beneficiaries.

7.2.4 Industrial Processes (IP) and Construction

Environmental health risks within TWW reuse practice in industrial processes (IP) are minimal. TWW will not be reused as potable-water within the production line (e.g. manufacturing activities and mixing with industrial products). This option is feasible for water conservation. However, the economic burden criterion is considered critical given the lack of investment. Economic factors associated with reusing TWW for industrial processes (e.g. feasibility, technology and operation) are also involved.

Although the environmental health criterion is minimal and TWW will not be reused as potable-water, water quality is an essential factor when reusing TWW in IP. Standards and guidelines must be set for each type of industry (or industrial activity). Adequate studies and investigation must be conducted prior to practicing this TWW reuse option. Water characteristics (physical and chemical composition) may affect the industrial process, machinery materials or products' quality. For example, water salinity will affect the product quality (especially for construction purposes which require freshwater and therefore advanced TWW must be used in IP).

7.2.5 Fire Fighting

Fire-fighting can be classified as IP. Water quality is also an essential factor for fire-fighting activities. Improperly treated TWW may affect the health of fire-fighters (e.g. dermal or by inhalation), and the fire-fighting machinery and equipment (e.g. corrosion). Like other IPs, this option can conserve water by reducing the pressure on freshwater. There will be no further economic burden since wastewater is treated anyway.

7.2.6 Oil Depressurization (OD)

Environmental health and economic burdens are important criteria for this option. Within this option, both TWW (tertiary or advanced R.O. or UF) and rejected (brine) water can be utilized. The environment within oil discovery areas will be affected (especially landscape and groundwater). Economic factors such as technology and operation are critical. This option is feasible for both water conservation (since GW is used for OD) and the environment since rejected brine water is discharged onto land or to sea.

By solving the problem of rejected brine water, this option would be a good response for reducing marine pollution and landscape degradation (due to discharging excessive quantities of rejected high salinity or brine water). Therefore, it is environmentally preferred when managing water resources and minimizing pollution. This reuse is away from public areas and communities. Therefore, there will be no essential (serious) human health problems and social impacts.

7.2.7 Groundwater Recharge (GWR)

Groundwater recharge is the most critical option for Kuwait. The advanced (R.O. / UF) WWTP has been established mainly for GWR in Kuwait (since GW is the only conventional water resource in Kuwait, GWR is considered an effective option for GW sustainability). This option was the major reason for benefiting from the R.O. / UF WWTP; however, it is rejected from the public representatives (PRs) such as non-governmental organizations (NGOs) and members of parliament.

All criteria are important regarding TWW reuse in GWR. It is associated with both human beings and the environment. Since GW is mixed with desalinated potable-water, human health is considered an important criterion (public acceptance is considered a critical issue). Strict precautionary measures control and monitoring is required for this option. Environmental Health Risk Assessment studies must be conducted prior to reuse TWW for GWR. Even though the economic burden is also an important criterion, issues of cost effectiveness can be neglected when dealing with human and environmental health and safety.

7.2.8 Households' Front & Backyards and Car Washing

Reusing TWW for household irrigation can also be classified within recreational and environmental uses. In contrast, car washing can also be classified as an IP. However, within this section, it is associated with households' and private buildings' front and backyards as well as car washing. This option can be feasible but it is rejected for Kuwait for infrastructural and logistic reasons (e.g. TWW distribution and networks) as separate pipeline systems are required in houses and buildings.

7.2.9 Toilet Flushing

Like other options associated with TWW reuse in households, this option is rejected for infrastructural and logistic reasons as separate pipeline systems are required in houses and buildings. This might be difficult to provide in old or recently constructed houses, but may be feasible for new houses, government institutions and large buildings.

7.2.10 Showering and Bathing, Cloth-Washing, Cooking and Drinking

Although these options are applicable (for Kuwait or other case studies), they are all rejected given possible health risks, and for psychological and religious reasons. Uncertainty of TWW quality is considered a critical reason for declining TWW reuse for these options. Therefore, since the public disagree and reject these options, they cannot be considered applicable options for Kuwait.

7.3 Multi-Criteria Decision Making / Rapid Impact Assessment Matrix

7.3.1 MCDM

The importance percentage (%) used for the main and sub-criteria weightings was found to be a simple basis for ranking and determining the magnitude of probable (predicted) risk of each TWW reuse option (where importance = degree of significance of each main or sub-criteria when practicing any of the six specified TWW reuse options). Ranking in this study was not associated with arranging the options in ascending or descending order as usual. Rather, in this case, it is for evaluation and assessment. The MCDM is stimulated and manipulated from different surveying methods (e.g. the Analytical Hierarchy Process (AHP), the Simple Multi-Attribute (MUAT) Ranking Technique and the Outranking) to simplify the process and strengthen the results obtained. Thus, the difficulties in surveying and the method's weak (illogical) or bias results will be reduced. The diagnostic (analytical) results of MCDM process are summarized in Table 7-1.

Table 7-1: Summary of MCDA Results

TWW Reuse Option	Important Criteria	% Degree of Significance	Critical Factors (Essential Sub-Criteria)
AW	Economic Burden	0.38	Initial and Logistics' Costs & Operation
	Environmental Health	0.33	Animal, Birds & Plants (Biodiversity)
RI	Economic Burden	0.45	Cost & Operation
	Environmental Health	0.32	Long Term Effects on Landscape
RA	Human Health	0.40	Water Quality
IP	Economic Burden	0.64	Technological Factors & Feasibility
OD	Economic Burden	0.52	Technological Factors & Feasibility
	Environmental Health	0.41	Effects on GW and Landscape
GWR	Human Health	0.29	Water Quality
	Environmental Health	0.27	GW Contamination
	Economic Burden	0.26	Cost, Technology & Feasibility

7.3.2 RIAM

The environmental components within each category of RIAM are defined differently from the sub-criteria used in MCDM although the criteria in the MCDM and the RIAM are similar. Even though the sub-criteria in MCDM and components of RIAM are defined differently, the factors are mostly interrelated since the criteria in the MCDM and the categories of RIAM were almost similar. Positive and negative environmental health impacts were demonstrated using scales that pass through Zero (referring to No-Change or No-Importance), and range from negative to positive values. The final environmental score (ES) reflects the evaluation of categories for each option as well as the total assessment. The diagnostic (analytical) results of the RIAM are summarized in Table 7-2.

Table 7-2: Summary of RIAM Results

TWW Reuse Option	Significant Category	Critical Components	Total ES Description of the Category
AW	P/C	Landscape and Soil Degradation	Moderate Negative
RI	S/C	Water Quality (Effects on & from Irrigated Areas)	Moderate Positive
	E/O	Technology & Treatment Cost (Feasibility)	Moderate Positive
AI	P/C	GW contamination & Soil Quality	Moderate Negative
	S/C	Public Acceptance	Moderate Positive
IP	P/C	None	Negative
	E/O	None	Negative
OD	P/C	GW Deterioration & Landscape Degradation	Moderate Negative
GWR	P/C	GW Refreshing	Positive
	E/O	ALL	Moderate Negative

Whereas P/C = Physical/Chemical, B/E = Biological (Health)/Ecological (Environmental), S/C = Sociological/Cultural, and E/O = Economic/Operational

In general, there are no significant differences in total ES (between all participants, government (G), and non-government (NG) focus groups). The RIAM results were found to be relatively rational and logical except for the P/C category of TWW reuse in RI. As assessed by all participants, the total ES found to be -1 (-A), which numerically also equals -1 and refers to a "Slight Negative Changes". However, the Trade-off between G and NG focus groups (FG) appeared to be irrational and illogical (significantly opposite to each other). The total ES of the government FG was 19 (C), which numerically also equals 3 and refers to "Moderate Positive Changes". In contrast, the total ES of non-governmental FG was -19 (-C), which numerically equals -3 and refers to "Moderate Negative Changes".

Other highlights in the RIAM results include the notable difference between G and NG participants' final ES results for some components as shown in Table 7-3. The differences between G and NG participants (FG) final ES of components might in turn (in some cases) affect the total results of environmental categories of the assessed TWW reuse options as shown in Table 7-4. In general, although such differences are notable, they do not affect the decision making regarding any options since they are in the same direction of change (negative or positive). Such results are considered normal and logical since the degree of effect is reflected from expert participants with different specialities and degree of knowledge. However, when there is a notable difference in final results in opposite changes' direction as previously mentioned in Chapter 6 (Section 6.3) in the ES of P/C category of TWW reuse in RI (G final result was +19 and NG final result was -19), might be considered to a certain point illogical and might in turn significantly affects the decision making.

Table 7-3: Differences between G and NG Expert Participants (EP) Groups in Some of RIAM Components' Environmental Score (ES) Results

TWW Reuse Option	**Component**	**Total (ES of All FG)**	**ES of G (FG)**	**ES of NG (FG)**
AW	-	-	-	-
RI	Tech. & Treatment (E/O)	16 (B) + Change	12 (B) + Change	19 (C) Moderate + Change
AI	Public Acceptance (S/C)	14 (B) + change	19 (C) Moderate + Change	7 (A) Slight + Change
IP	-	-	-	-
OD	GW Quality (P/C)	-17 (-B) - Change	-13 (-B) - Change	-20 (-C) Moderate – Change
GWR	GW Quality (P/C)	19 (C) Moderate + Change	33 (C) Moderate + Change	3 (A) Slight + Change

Table 7-4: Differences between G and NG Expert Participants (EP) Group in Some of RIAM Categories' Total Environmental Score (ES) Results

TWW Reuse Option	Component / Category	Total (ES of All FG)	ES of G (FG)	ES of NG (FG)
AW	P/C	-25 (-C) Moderate - Change	-7 (-A) Slight - Change	-52 (-D) Significant - Change
RI	-	-	-	-
AI	S/C	20 (C) Moderate + Change	31 (C) Moderate + Change	4 (A) Slight + Change
IP	-	-	-	-
OD	-	-	-	-
GWR	P/C	18 (B) + Change	37 (D) Significant + Change	2 (A) Slight + Change

This approach of environmental health and socio-economic assessment can contribute to risk management by evaluating the best available alternatives. Assessment of TWW reuse practice and options can supports decision makers in directing their efforts towards the best options which are more efficient and less risky. Risk managers depend on risk assessments within regulatory decisions such as setting drinking and irrigating water standards, developing plans and setting proactive actions to avoid TWW practice risks and select safe alternatives.

There is lack of adequate data and information regarding such issue in Kuwait. This makes it difficult to investigate the interrelated (direct and indirect) impacts from different sources (Untreated or Improperly TWW). TWW reuse practice requires a clear identification of both direct and indirect uses to accordingly determine the magnitude as well as the positive and negative changes of each probable impact.

Chapter 8

Conclusions and Recommendations

This Chapter summarizes the main conclusions from this research, outlining the findings that have been documented in the thesis. The chapter concludes by considering the significance of this research and the main findings from the case study in relation to the research approach adopted. It also assesses the implications for the practical application more widely. By contributing to knowledge within different, but related fields of study, this chapter demonstrates how the research questions were addressed and how further critical issues were identified. It shows how the research aims and objectives contributed to further work in different areas. Finally, the chapter ends with implications, recommendations and further research.

8.1 General Conclusions

This thesis investigated critical risks and benefits perceptions of TWW reuse practice and options. It argued that unless an effective and reliable assessment of TWW reuse practice and options is conducted, it will be not be possible to reuse TWW as an alternative water resource for different purposes. The thesis also sought to satisfy the gaps in assessing and managing perceptions toward TWW reuse practice and options that can support decision makers by efficient assessment. It is suggested that uncertainty and complexity issues regarding TWW reuse practice and options will be minimized if there is a comprehensive determination of both positive and negative effects on human health and environment.

By emphasizing the potential risks that the TWW reuse might cause to future environmental health and socio-economic, the managers of TWW can proactively plan for TWW reuse practice and options as an alternative water resource. This thesis has created an optimized assessment framework for managing TWW reuse practice that targets the potential and future risks associated with this environmental issue. The outcome of this research has been accomplished by consolidating several objectives to achieve the main aim of the study. First, previous studies associated with TWW reuse practice and options assessment and management were reviewed in detail. Second, current TWW reuse practice in Kuwait was documented and available applicable TWW reuse options (with respect to critical criteria of any case study) were analyzed. Finally, a suitable model framework for conducting an effective assessment of the available TWW reuse options was developed.

This research represents a baseline study for strategic planning and management of TWW reuse practice and options. Potential environmental health and socio-economic risks that may be caused by practicing TWW reuse can be predicted and proactively managed. Accordingly, the outcome of this research can both support decision makers and assisting in trade-off issues among stakeholders. Accordingly, the research approach utilized the consolidated data and information in a compatible manner achieving such outcome. Attaining the aims and objectives, the research has contributed to the following key conclusions:

- Expert participant (EP) groups found the framework and investigation through the research phases to be effective and to cover most aspects of the issue. Their degree of knowledge regarding TWW reuse practice and options as evaluated were deemed dependable and trustworthy which strengthened the survey results of methodology and tools used (MCDM and RIAM).

- The assessments, as well as the results, of TWW reuse practice and options were successfully validated by the empowered expert decision makers and identified potential trade-offs among stakeholders.
- The available and applicable TWW reuse options were conclusively assessed for the management (with all components, factors and criteria) within an integrated model. Further strategic studies can be conducted to include such accepted TWW as an alternative freshwater.
- Utilizing a DPSIR framework to analyse the current situation, and combining this with MCDM (to assess the available and select the best applicable TWW reuse options) and RIAM (to assess selected applicable TWW reuse options) has identified data quality limitations associated with each tool that supports efficient decision making as well as minimizing complexity and uncertainty issues.
- Hence, further planning and management can depend upon the assessment of environmental health risk and socio-economic perception assessment for the TWW reuses practice and options.

8.2 DPSIR, MCDM and RIAM Specific Conclusions

8.2.1 DPSIR Framework Conclusions

- The Driving Forces, Pressure, State of Environment, Impact, and Response (DPSIR) framework (as highlighted by Gabrielsen and Bosch (2003); Kristensen (2004); UNEP (2005) and Svarstada et al. (2007) amongst other studies used the DPSIR framework) not only presents the current situation of the case study, but also offers the basis for analysing inter-related factors that impact the environment.

- This approach provided data and information on the case study on all interrelated factors associated with TTW reuse and estimated the degree of effectiveness of responses.
- The holistic overview of the DPSIR framework structured the information that visualizes the link between the causes of environmental problems associated with TWW reuse practice and options as well as the current responses of resolution.
- DPSIR analysis indicated that responses regarding water and TWW reuse management are directed toward the pressure of high water consumption rates by expanding wastewater treatment plants (WWTPs) and the impact on marine environment by reducing quantities of improperly treated or untreated wastewater discharge to the sea while the dynamic process of DPSIR suggests that responds must be directed to all elements of the framework (as illustrated in Figure 3-1 (Chapter 3, section 3.2).

Thus, to consider TWW reuse as an alternative water resource within the national water strategy, responses to driving forces, pressures, state and impacts must be taken into consideration before working on an efficient assessment of TWW reuse practice and options for the final decision making for their management.

8.2.2 MCDM / RIAM Conclusions

- The expert participant (EP) groups participating in MCDM were interested in the new modified method for criteria weighing (the simple ranking to weigh criteria) and found it to be suitable and sufficient for the survey.
- The results were considered reliable and logical with limited bias and no incorrect final results.

- Unifying RIAM categories' components (selection of most interacted / interrelated components that are affected or influenced by all TWW reuse options) showed a positive reaction toward RIAM checklist and survey (selecting similar criteria of RIAM for MCDM to compare and test the final results reduced the uncertainties and strengthened the final results according to the expert's perceptions, opinions and assessment).
- Comparing between the government (G) and non-government (NG) participants for trade-offs identified critical factors which affect decision making.

The research approach of these two combined methods (MCDM and RIAM) alongside the analysis of the current situation (DPSIR) was found to be successful and feasible. It produced dependable results in assessing TWW reuse practice and options. While MCDM mostly represented the positively or negatively affected (influenced) criteria and sub-criteria, RIAM (as an EIA tool) tested such positive or negative results and distinguished between them more clearly offering the probable degree of effect (impact magnitude).

8.3 Achievement and Further Findings

Thus, by combing MCDM and RIAM, testing MCDM final results and findings with RIAM and returning (considering) DPSIR analysis, the available (applicable) TWW reuse options for this case study Kuwait (accepted or rejected options) can be diagnosed and assessed as follows:

8.3.1 Artificial Wetland (AW)

Artificial wetlands (AW) were not considered an option that Kuwait can pursue and it is environmentally not preferred. Kuwait has an arid climate with high potential evapotranspiration rates (mean annual is 3000 mm). In addition, mean annual precipitation is very low (116 mm) and unsustainable. This option will require a large land area and a network of long pipelines to serve TWW from storages and pumping location to the AW. This requires a huge initial cost for project implementation and operation as well as continuous logistical constraints. Moreover the current practice of TWW reuse for irrigation in farms is unable to supply enough water, and so this option (as one of recreational irrigation option) is considered hypothetical.

8.3.2 Recreational Irrigation (RI)

Recreational Irrigation (RI) includes green developments that suit Kuwait environment (e.g. parks, schools' yards, streets and freeways, Golf Courses, cemeteries, greenbelts and residential front and backyards or open areas). It also includes environmental uses which might not suit Kuwait's environmental conditions (e.g. lakes and ponds, marsh enhancement, stream-flow augmentation, fisheries and snowmaking). It is an option where TWW can effectively be utilized. In most cases this option will have no effect on surface water quality, and no effect on groundwater quality and coastal and seashore environment (will have no relevance to aquatic ecosystem). As for Kuwait, all listed economic factors do not affect this option as the government is entirely responsible for all expenses and costs of water treatment, distribution (transportation by networks or tanker) and irrigation.

8.3.3 Agriculture Irrigation (AI)

Agriculture Irrigation (AI) has hardly any direct relation to any development project, aquatic ecosystems, the coastal and seashore. This option has no bearing on any of these components as Kuwait has no agriculture in coastal areas. Groundwater (GW) can be affected by this option only when untreated or improperly treated wastewater is used (in high quantities for long periods) especially in areas of shallow GW. Relevant health problems (e.g. epidemic diseases) may be locally relevant with no more than slight to negative changes which can be controlled within a short period of time. AI is already practiced in Kuwait, so public acceptance or participation has no relevance in this case, however as shown from results, it can play an important role within this option.

8.3.4 Industrial Processes (IP) and Oil Depressurization (OD)

There are similar environmental and economic concerns between industrial processes (IP) and oil depressurization (OD). Both are considered feasible for Kuwait. TWW can be slightly negative or have no effect when reused in IP, firefighting or for OD. However, there may be considerations regarding TWW reuse in construction (water quality might critically affect constructional materials). GW is mostly concerned when TWW is reused for OD because highly saline waters will be used in this case rather than fresh TWW.

8.3.5 Groundwater Recharge (GWR)

Groundwater recharge (GWR) is a good option even with secondary treatment, but water quality is the most critical factor for this option, and hence TWW components must be seriously monitored and controlled. “Paleo-geomorphology, infiltration capacity, intervening layer presence, elevation and spatial disposition" must all be considered when practicing TWW reuse for GWR as suggested by some expert participants (experts in water resources and GW field).

8.3.6 Potable Uses (e.g. Cloth washing, Showering, Cooking and Drinking)

Given Kuwait's population characteristics, these TWW reuse options were all considered non-applicable since they were rejected (declined) by the public. In addition to health related reasons (health risk perceptions) for not accepting TWW reuse (given their direct contact to the public), psychological and attitudinal (social) reasons were also found to be critical. Uncertainty of TWW quality is considered an essential reason for declining TWW reuse for these options. As an influential factor, religion also plays an important role in this case study. From a religious perspective, TWW is considered by some religious groups as non-immaculate (sinful) water which is not possible for potable uses but can be used for non-potable purposes. More than one third of the Kuwaiti population (Kuwaitis) and a large groups of non-Kuwaitis are unwilling to use this type of water for potable uses because of their religion. Therefore, these options cannot be considered applicable options for this case study (Kuwait).

Thus water quality (or the uncertainty behind the quality of such water) is the most critical factor (sub criteria) within most of these options. Water quality significantly reflects future environmental changes and plays an important role in the decision making process regarding TWW reuse practice for most available options.

8.4 Research Approach Critical Remarks and Limitations

8.4.1 Methods and Tools Remarks

- The DPSIR methodology was found to be a useful method of assessing the management of environmental issues which involve a risk to human health and the environment. However, it requires accurate distribution within its framework. The first element of the framework that must be recognized is the State or the State of Environment which is the environmental issue to be studied before investigating other elements. Any confusion between DPSIR elements as well as any misperception regarding current and further (future) suggested responses might affect the analysis of the current situation.
- Minimizing uncertainty was one of the foci of the research study. As pointed out by Alessandri (2004); Klinke and Renn (2004) and Forsyth et al. (2010a and 2010b) amongst others, uncertainties involving environmental risk cannot be assessed efficiently without the use of experts and professionals (within the field of study) for the decision making process. Therefore, managers and experts in the field, specialists, experienced personnel from private stakeholders and other empowered decision makers involved in this study and assured minimization of uncertainty and complexity issues.
- MCDM was found to work well with quantitative and qualitative data and information by assisting and regulating stakeholders' participation within the assessment and supporting in decision making process as highlighted by Ellis et al. (2011).
- As discussed in the literature review (Chapter 2, section 2.6), illustrated in Figure (2-6) and approved by several recent studies, Walker et al. (1999)

highlighted that EIA tools, expert system (expert judgement) within MCDM and RIAM (that has been used within this research) include both “scoping and impact identification techniques” and “evaluation techniques”. Therefore, it comprises all indirect, accumulative or interacted impacts that might occur and predicts the magnitude and degree of the effects of such impacts which consequently strengthens the assessment of the final results.

8.4.2 Subjective Qualitative Opinions vs. Objective Quantitative Results

As discussed by Ellis et al. (2011) and as developed and employed within this research approach, matrices have been widely used as assessment tools in environmental methodologies. Such tools and methods involve many factors to reform quantitative and qualitative information to produce reliable results that support decision makers. RIAM as an improving planning decision tool, as highlighted by DHI (2009a) represented an effective useful EIA within this approach (for TWW reuse practice and option assessment).

Pastakia (1998b), DHI (2009a) and DHI (2009b) attempted to demonstrate the ability of RIAM to produce dependable assessment results. In this case study, RIAM reliably converted the subjective judgments of experts and professionals (in this environmental issue that involves uncertainty and complexity) to clear reasonable objective results with little criticism. For this reason, RIAM has been applied in this study converting qualitative data (descriptive data based on subjective opinions and judgments) to quantitative data (measurable data based on numerical objective records).

8.4.3 Expect vs. Public Perception

Perceptions of issues involving environmental health risks and socio-economic impacts (such as TWW reuse) need clear and transparent assessment in order to satisfy wastewater and water management processes. Research has found that most participants think that "no one can guarantee the safety of recycled water" (Po et al, 2005). Although their opinions and reaction are significant, the public in many cases lack awareness of the quality of the water they receive and use in their homes. As previously mentioned (Chapter 2, section 2.5), the perception of risk reflects individual values, beliefs, and experiences as indicated by previous studies (by Robison et al., 2005; Abu-Madi et al., 2008; AL-Humoud and Madzikanda, 2010; and others). However, experts and specialists try to assess all aspects and regard risk as a probable negative factor within the management process.

Having reviewed the literature on public perceptions on wastewater and TWW reuse practice and options (Appendix 2), apparently unresolved issues and gaps persist and recommendations were raised that have been addressed in this thesis. This research approach, with its new creative and innovative methodology, sought to not only use expert judgement but also public perception regarding TWW reuse practice and options. It involved the public by representative groups and meditative specialist and experts in the field (reliable and trustworthy representatives).

Qualitative interviews of all stakeholders can play a successful role in water resources management and can be valuable and beneficial as data are obtained from a combination of field observations, laboratory experiments, and extensive literature reviews (Babbitt et al, 2015). However, decision making in areas affecting human and environmental health (environmental health risk), public perception and participation must be guided and relied upon where found to be applicable (Elghali, 2002).

In critical cases, the public must be provided with environmental health risk management awareness prior to their involvement (Redding et al, (2000). Hence, public participation (perception) within risk assessment and management process (for the decision making in environmental health) requires expert and professional assistance groups as recommended by previous research on this issue (Appendix 2; Appendix 4).

Considering trade-offs between economic benefits and environmental capacity or reversible impacts are also essential (Du et al, 2013). This thesis recognized that the right of the public with none or basic knowledge towards any serious issue (where environmental health risk is predicted, certain or probable) must be reserved and protected by their trusted representatives. Therefore, besides involving public representatives, this approach recognized the necessity of trade-offs when assessing environmental activities or projects that involve risks and benefits of different aspects (environmental health and socio-economic aspects). Comparing between government (G) and non-government (NG) expert opinions and judgements in this research would assist in efficient decision and public satisfactory.

8.4.4 Research Study Limitations

One limitation of the research approach is that when dealing with multi-disciplines or issues that involve multi-criteria, the expert participant (EP) groups can be from different backgrounds and specialists might be expert (i.e. experienced) in one or couple of fields but not in all study areas. However, this is not always a complex issue within the assessment process and might be a positive factor. As Rey et al. (2014) suggest, the more diverse the body of experts and professionals (of fields and backgrounds from government, non-government organizations (NGOs), environmental institutions, and other private stakeholders), the more successful the assessment process for management decision making. In addition, for the latter reason, before starting MCDM and RIAM with expert judgement, an efficient evaluation to reflect the degree of knowledge of the (EP) groups was conducted.

Another limitation of the study is the time required for surveying and investigating (using checklists, questionnaires and interviews) recognizing:

- Difficulty of meeting the EP groups (which is considered a negative factor).
- The number of meetings required through the survey.
- The number of matrices to be completed which takes a long time to be accomplished. This makes researchers avoid using experts as such approaches frequently require more than one meeting with participants.
- Several checklists, matrices and questionnaires for investigation and surveying are required through the different phases of the research.

However, with diverse information from scientists, experts and local people, and by incorporating the subjective preferences, it is a worthwhile experience and ultimately adds a vital number of references to the citied research reference of previous literature and studies.

Thus this research thesis aimed to develop an integrated assessment framework by expert perceptions (opinions and judgement) using a combination of tools and methods (DPSIR, MCDM and RIAM) to conclusively assess the management of TWW reuse practice and options. This study approach has taken into account most critical criteria that can be influenced or affected by TWW reuse practice and options. This assessment study can play an important role in decision support to develop successful TWW reuse practice and options that assist in planning and management.

It is believed that this turned out to be an innovative and successful approach that involved several phases of investigation with significant investment of time and effort. The study is argued to have presented an effective assessment framework that can be applied by any authority responsible for TWW reuse management, in addition, can potentially be utilized for any environmental activity or project that involves risk and benefits.

8.5 Recommendations

The research study found the following recommendations as critical issues to be further taken into consideration:

- The environmental carrying capacity should be considered while assessing TWW reuse in any option (environmental impacts of TWW reuse options).
- Excessive quantities of TWW discharged to the sea or land will have serious effects on biodiversity, marine environment or soil quality. Wastewater levels of treatment have different characteristics and concentrations of biological, physical, and chemical agents that must be monitored and investigated.
- In the marine environment (seashore water for example), desalination plants will be influenced by such practices as their water intakes will be polluted and require more treatment considerations, monitoring and protection.

- There is a lack of scientific and academic research regarding TWW reuse practice and options generally, and particularly in Kuwait. Without efficient studies regarding each TWW reuse option, there will be no efficient or feasible practice for such an option.
- Strategic planning must be conducted to ensure reliable prediction of TWW reuse efficiency (how much freshwater can be saved within a certain period by any TWW reuse option). Concrete data information regarding TWW quality and quantities must be continuously recorded and provided. In the absence of adequate water and TWW resource assessment and management, TWW cannot be considered as a reliable water resource that reduces pressures on freshwater consumption and support in national water demand.
- Research studies that assist in setting laws and regulations, standards and guidelines regarding TWW reuse practice and option must be conducted (i.e. setting level of treatment, characteristics and concentrations for each option).
- Practicing TWW reuse without adequate assessment can present risks to human health and the environment. Therefore, efficient monitoring and control regarding TWW reuse must be assured.
- Kuwait usually responds reactively to the environmental impacts of an issue rather than responding to driving forces, pressures or the state of environment. Proactive measures for in case of any environmental health risk from any TWW reuse option must be defined earlier.
- Public awareness is critical. As suggested by Redding et al. (2000), Health Belief or Behavior Models (HBM) can be adopted to achieve self-efficacy of the public with respect to the probable environmental health risks of TWW reuse practice. The concept of HBM is when the individual is vulnerable, the

risk is serious and precautionary measures or behavior can prevent the impacts of such risk, then taking preventive action would be natural and spontaneous. Believing that benefits of reducing threats would be more than taking action would also assist in solving the problem. Thus, HBM research studies are recommended to raise the public health awareness and can be used as an assessment tool that assists in decision making.

8.6 Further Research

Having assessed the management of TWW reuse practice and options, this thesis has covered the recommended research areas and offers a benchmark study for any strategic water or TWW planning and management study in Kuwait. Future research can utilize this study as a baseline for the following research areas:

1. Comprehensive assessment and management of each TWW reuse option.
2. Life Cycle Assessment (LCA) of each (or any) TWW reuse (as a water byproduct) based on "from cradle to grave" principle.
3. Environmental carrying capacity of TWW reuses practice and options' impacts (accumulative impacts on groundwater, soil and marine environment).
4. Projection study (Strategic planning) of how much freshwater can be saved by utilizing TWW reuses options as an alternative water resource.
5. HBM regarding TWW reuse practice and options.

Reference

Abu-Madi, M., Mimi, Z., and Abu-Rmeileh, N., (2008). Public Perceptions and Knowledge towards Wastewater Reuse in Agriculture in Deir Debwan. First Symposium on Wastewater Reclamation and Reuse for Water Demand Management in Palestine, 2-3 April 2008, Birzeit University, Palestine.

Ackley, M., (2008). Evaluating Environmental Risks in Mining: A Perceptual Study at the Vatukoula Gold Mine Fiji. Unpublished MSc. Thesis, Faculty of the Graduate College. The University of Vermont, USA.

Akpor, O. B. and Muchie, M. (2011). Environmental and public health implications of wastewater quality. African Journal of Biotechnology, Vol. 10 (13), pp. 2379-2387.

AL-Anzi, B., Abusam, A., and Shahalam, A., (2011). Wastewater Reuse in Kuwait and Its Impact on Amounts of Pollutants Discharge into the Sea. Journal of Environmental & Analytical Toxicology, S3 (3), 1 - 8.

AL-Anzi, B., Abusam, A., and Shahalam, A., (2012). Assessment of Wastewater Reuse in Kuwait and Its Impact on Amounts of Pollutants Discharged into the Sea. Journal of Environmental Protection, 3, 935-939.

Al-Awar, F., (2005). Formulation of a Medium-Term for Sustainable Development of Agriculture and Fisheries. FAO project, Final Mission Report.

Alessandria, T.M., Ford, D.N., Landerc D.M., Leggiod, K.B. and Taylore, M., (2004). Managing Risk and Uncertainty in Complex Capital Projects. The Quarterly Review of Economics and Finance, 44, 751–767.

Al-Eisa, I., Al-Shayji, Kh. A., and Al-Jarallah, R., (2011). Residential Wastewaters Treatment System in Kuwait. 2nd International Conference on Environmental Science and Technology, IPCBEE vol.6, 285-V1-289.

Al-Ghanim, K. M., (1994). Changes in Domestic Water Consumption Pattern Before, During and after Kuwait Invasion. Unpublished MSc. Thesis, Arabian Gulf University, Bahrain.

Al-Ghusain, I., (2013). The Sulaibiya Wastewater Treatment and Reclamation Plant. The 6th Shaikh Zayed Seminar, Green Economy, Manama, May 2013.

Al-Humoud, J.M., and Al-Ghusain, I., (2003). Household Demand for Water: A Case Study in Kuwait. Kuwait Journal of Science & Engineering, vol. 30, 197 - 211.

Al-Humoud, J.M., Behbehani, H.S. and Abdullah, T.H., (2003). Wastewater Reuse Practices in Kuwait. The Environmentalist, Volume 23 (2),117-126.

AL-Humoud, J. M. and Madzikanda, D., (2010). Public Perceptions on Water Reuse Options: The Case Of Sulaibiya Wastewater Treatment Plant In Kuwait. International Business & Economics Research Journal, Vol. 9 (1), 141 – 158.

Allen, L., Christian-Smith, J. and Palaniappan, M., (2010). Overview of Greywater Reuse: The Potential of Greywater Systems to Aid Sustainable Water Management. Pacific Institute, Oakland, California. www.pacinst.org.

AL-Maskati, H. H. (2011). Water Demand Management: A Case Study of Kingdom of Bahrain. Unpublished PhD Thesis, Loughborough University, United Kingdom.

Al-Murad, M., Uddin, S. and Al-Dousari, A., (2010). Fresh-water Situation in Kuwait - Remote Sensing Inputs on Possibility of Artificial Recharge. Physics International, 1 (1), 69-76.

Al-Ruwaih, F., Al-Harbi, M., and Eidan, H., (2012). Urban Water Sector Vulnerability and Adaptation to Climate Change in the State of Kuwait. 3rd Kuwait & UNEP workshop, Oct 1st, 2012.

AL-Saffar, A., (2012a). Utilization of Treated Effluents in the State of Kuwait. Sanitary Engineering Division, Ministry of public works, Kuwait.

AL-Saffar, A., (2012b). Environmental Health Impacts of Sewage Wastewater. Sanitary Engineering Division, Ministry of public works, Kuwait.

Al-Salem, S.M. and Lettieri, P., (2009). Life Cycle Assessment (LCA) of Municipal Solid Waste Management in the State of Kuwait. European Journal of Scientific Research, Vol.34 No.3, 395-405.

Al-Shammiri, M., (2014). Assessment of the Sustainability of the Water Management System in Municipal Sector in the State of Kuwait. A Thesis Submitted in Fulfillment of Requirement for the Master Degree in Environmental Management, Arabian Gulf University (AGU), Bahrain.

Al-Shammiri, M., AL-Saffar, A., Bohamad, S. and Ahmad, M., (2005). Wastewater quality and Reuse in Irrigation in Kuwait Using Micro-Filtration Technology in Treatment. Desalination, 185, 213 – 225.

American Society of Civil Engineers (2011). Failure to Act: The economic impact of Current Investment Trends in Water and Wastewater Treatment Infrastructure. Executive Summery, Economic Development Research Group, Inc. in association with Downstream Strategies, Washington DC.

Asano, T., (2001). Water from Wastewater; the Dependable Water Resource. Stockholm Water Prize Laureate Lecture, 11. Stockholm Water Symposium, Stockholm, Sweden, 13.08. 2001.

Asano, T., (2002). Multiple Uses of Water Reclamation and Reuse; In: Water and Efficiency, GAIA 11, No. 4, 277 - 280.

Asano, T., Burton, F. L., Leverenz, H. L., Tsuchihashi, R., and Tchobanoglous, G., (2006). Water Reuse; Issues, Technologies, and Applications. Metcalf & Eddy AECOM, New York, USA, 1 – 35.

Astaraie-Imania, M., Kapelanb, Z. and Butler, D., (2012). Risk-based Water Quality Management in an Integrated Urban Wastewater System under Climate Change and Urbanisation. International Environmental Modelling and Software Society, International Congress on Environmental Modelling and Software Managing Resources of a Limited Planet, Sixth Biennial Meeting, Leipzig, Germany.

Australian Government, (2005). Risk Analysis Framework. Department of Health and Ageing, Office of the Gene Technology Regulator, Australia.

Australian Government, (2008). Risk Assessment and Management "Learning Practice Sustainable Development Program for the Mining Industry". Department of Resources Energy and Tourism, Australia.

Baawain, M., Treiky, H. and Al-Sabti, A., (2012). Reusing Treated Wastewater in Muscat: Social Survey. Department of Civil and Arch. Engineering, Sultan Qaboos University / Haya Water, Oman.

Babbitt, C. H., Burbach, M., and Pennisi, L. (2015). A Mixed-Methods Approach to Assessing Success in Transitioning Water Management Institutions : A Case Study of the Platte River Basin , Nebraska, Ecology and Society, 20 (1): 54.

Baby, S., (2011). Assessing and Evaluating Anthropogenic Activities Causing Rapid Evolution in the Coastal Morphological Landscape Changes (CMLC) of Kuwait Using RIAM. Environment and Natural Resources Research Vol. 1, No. 1, December, 2011.

Bahri A., (2012). Policy Paper 10: Managing the Other Side of the Water Cycle: Making wastewater an asset (Based on GWP-TEC Background Paper 13). www.gwpforum.org.

Balkema A. J., Preisig, H. A., Otterpohl, R., and Lambert, F. J.D., (2002). Indicators for the Sustainability Assessment of Wastewater Treatment Systems. Urban Water, 4, 153–161.

Barbagallo, S., Cirelli, G. L., Consoli, S., Licciardello, F., Marzo, A., Milani, M., and Toscano, A., (2012). Agricultural wastewater reuse in Sicily. A Paper Describes a Long - Term Study on Constructed Wetland Treatment and Wastewater Reuse for Irrigation in Sicily, Sustainable Sanitation Practice Issue, 4 – 7.

Barjoveanu, G., Comadaru, I.M., and Teodosiu, C., (2010). Life Cycle Assessment of Water and Wastewater Treatment Systems: An Overview. Buletinul Institutului Politehnic Din Iasi, Univeritatea Tehnica, Gheorghe Asachi din Iasi Tomul LVI (LX), Fasc. 4, 73 – 86.

Beecher, N., Harrison, E., Goldstein, N., McDaniel, M., Field, P., and Susskind, L., (2005). Risk Perception, Risk Communication, and Stakeholder Involvement for Bio-solids Management and Research. J. Environ. Qual. 34, 122-128.

Berbel, J., Manuel, G., and Lopez, M.J., (2002). Survey of Current Institutional Framework for Water Management in European Irrigated Systems. University of Cordoba, Spain.

Butler D., Farmani, R., Fu, G., Ward, S., Diao, K., and Astaraie-Imani, M., (2014). A New Approach to Urban Water Management: Safe and Sure. Procedia Engineering (89), 347 – 354.

California Environmental Protection Agency, (2000). A Guide to Health Risk Assessment, Office of Environmental Health Hazard Assessment, Sacramento, CA, USA.

Cash, D., Clark, W., Alcock, F., Dickson, N., Eckley, N., Guston, D., Jager, J. and Mitchell, R., (2003). Knowledge Systems for Sustainable Development. PNAS, vol. 100, No. 14, 8086–8091.

Cash, D., Clark, Borck, J. and Patt, A., (2003). Countering the Loading-Dock Approach to Linking Science and Decision Making: Comparative Analysis of El-Nino Southern Oscillation (ENSO) Forecasting Systems. Science, Technology and Human Values, Vol. 31 No. 4, 465-494.

Center of Sustainable Systems (CSS), (2011). U.S. Wastewater Treatment; Complete Set of Factsheets. University of Michigan, USA.

Chen Z., Ngo H.H. and Guo W., (2013a). A Critical Review on the End Uses of Recycled Water. Critical Reviews in Environmental Science and Technology, 43:14, 1446 - 1516.

Chen Z., Ngo H.H. and Guo W., (2013b). Risk Control in Recycled Water Schemes. Critical Reviews in Environmental Science and Technology, 43:22, 2439 - 2510.

Choukr-ALLAH, R., (2010). Wastewater Treatment and Reuse; Water-Sustainable Management of a Scarce Resource; Chapter 7. The Third Report on the State of Arab Environment, the Arab Forum for Environment and Development (AFED), 107 – 124.

Choukr-ALLAH, R., (2011). Regional Experience of Wastewater Treatment and Reuse in the Arab Countries. International Centre for Bio-saline Agriculture (ICBA). Expert Consultation Wastewater Management in the Arab World 22-24 May 2011, Dubai-UAE.

Christchurch City Council (2005). Water & Sanitary Services Assessment. Christchurch City Council of Civic Offices, New-Zealand, www.ccc.govt.nz.

Commonwealth of Australia, (2002). Environmental Health Risk Assessment "Guidelines for Assessing Human Health Risks from Environmental hazards". The enHealth Council and Department of Health and Ageing, Population Health Division, Australia, p. 227.

Danish Hydraulic Institute (DHI), (2009a). Environmental Health Assessment (EHA); Solutions and Services. Preliminary Version, pp. 1 - 9.

Danish Hydraulic Institute (DHI), (2009b). Introduction to RIAM: Rapid Impact Assessment Matrix by DHI: A Description of the RIAM System. Appendix, pp. 10 – 16.

Darwish, M.A., Al-Najem, N.M., and Lior, N., (2009). Towards Sustainable Seawater Desalting in the Gulf Area. Desalination, vol. 235, pp. 58 - 87.

De los Cobos, G. (2015). A Historical Overview of Geneva's Artificial Recharge System and its Crisis Management Plans for Future Usage. Environmental Earth Sciences, 73(12), 7825–7831.

DGCA, (2014). Directorate General of Civil Aviation, Meteorological Department, State of Kuwait.

Dolnicar, S., and Saunders, C., (2006). Recycled Water for Consumer Markets: A Marketing Research Review and Agenda. Desalination, 187(1-3), 203-214.

Dolnicar, S., and Schafer, A.I., (2009). Desalinated Versus Recycled Water - Public Perceptions: Likelihood of Adaptation and Profiles of Early Adopters, Journal of Environmental Management, 90, 888 – 900.

Dreizin, Y., (2007). Wastewater Reuse in Israel - Risk Assessment. Decision Making and Environmental Security, pp. 297 – 303, jossefdr10@water.gov.il.

Du, P., Li, Y. P., and Huang, G. H. (2013). Inexact Chance-Constrained Waste-Load Allocation Model for Water Quality Management of Xiangxihe River. Journal of Environmental Engineering, 139 (9), 1178–1197.

Eidan, H., (2008). Strategic Alternatives for the Management of Municipal Water Sector in the State of Kuwait**.** Unpublished MSc. Thesis, Environmental Management, Arabian Gulf University, Bahrain.

El-Ashry M., Saab, N., and Zeitoon B., (2010). Arab Environment Water - Sustainable Management of a Scarce Resource: 2010 Arab Forum for Environment and Development (AFED). Technical Publications and Environment & Development Magazine.

Elghali, L., (2002). Decision Support Tools for Environmental Policy Decisions and their Relevance to Life Cycle Assessment. CES Working Paper 2/02, Centre for Environmental Strategy, University of Surrey, UK. www.surrey.ac.uk/CES.

Ellis J. B., Lundy, L. and Revitt M., (2011). An Integrated Decision Support Approach to the Selection of Sustainable Urban Drainage Systems (SUDS); Decision Support Tools; 24th – 26th January 2011. SWITCH Conference: The Future of Urban Water; Solutions for Liveable and Resilient Cities. UNESCO, Paris.

ESCWA (Economic and Social Commission for Western Asia), (2003). Wastewater Treatment Technologies: A General Review. United Nations, N.Y. 2003.

European Commission DG ENV, (2007). Public Perspective of Wastewater Reuse in Urban Areas. Science for Environmental Policy – DG Environment News Alert Service. BIO-Intelligence Service, 31 May 2007.

Esposito1, K., Tsuchihashi, R., Anderson, J. and Selstrom J., (2005). The Role of Water Reclamation in Water Resources Management in the 21th Century. Water Environment Federation (WEFTEC), 8621 - 8633.

Fatta, D., Arslan Alaton, I., Gockay, C., Rusan. M.M., Assobhei, O., Mountadar, M., and Papadopoulos, A., (2005). Wastewater Reuse: Problems and Challenges in Cyprus, Turkey, Jordan, and Morocco. European Water, 11/12: 63 – 69.

Fatta, D., Arslan Alaton, I., Gockay, C., Skoula, I., Papadopoulos, A., and Loizidou, M., (2004). Wastewater reuse in the Mediterranean Basin – Problems and Challenges. EWRA Symposium, September 2004.

FAO (Food and Agriculture Organization) of the UN (United Nations), (1992). Wastewater Treatment and Use in Agriculture - FAO Irrigation and Drainage Paper 47.

FAO / UNW-DPC / UNU-INWEH, (2011). Capacity Development Project on Safe Use of Wastewater in Agriculture. Joint FAO / UNW-DPC / UNU-INWEH Capacity Development Project, Stage 1, July, 2011, p.14.

Fitzgerald, K. S., (2005). Wastewater Treatment Plant Technology Review. TSG Technologies, Inc. Gainesville, FL, USA, p. 13.

Forsyth, A., (2008). Rapid Health Impact Assessment Toolkit; Design for Health. University of Minnesota, USA.

Forsyth, A., Slotterback, C.S. and Krizek, K., (2010a). Health Impact Assessment (HIA) for Planners: What Tools Are Useful? Journal of Planning Literature. First Published (Online) on February 4, 2010.

Forsyth, A., Slotterback, C. S., and Kezic, K. J., (2010b). Health Impact Assessment in Planning; Development for the Design for Health HIA Tools. Environmental Impact Assessment Review, 30, 42 – 51.

Gabrielsen, P., and Bosch, P., (2003). Environmental Indicators: Typology and Use in Reporting. European Environment Agency (EEA), EEA internal working paper: August, 2003.

Ganoulis, J., (2012). Risk Analysis of Wastewater Reuse in Agriculture. International Journal of Recycling of Organic Waste in Agriculture, 1:3, 1 - 9.

GEO Resource Book, (2006). Draft for Training Module 4 (Monitoring, Data and Indicators).

Graham, J., (2000). Medical Officer of Environmental Health Advice; Environmental Health Risk Needs Analysis. Environmental Health Quarterly Report, Vol. 3, Issue 3.

GWP-TEC (Global Water Partnership-Technical Committee), (2009). Managing the other side of the water cycle: Making wastewater an asset. Policy Brief 10: Background Paper 14: Water Management, Water Security and Climate Change Adaptation: Early Impacts and Essential Responses, 2009.

Haering, K. C., Evanylo, G. K., Benham, B., and Goatley, M., (2009). Water Reuse: Using Reclaimed Water for Irrigation. Communications and Marketing, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, USA, p. 11.

Hajeeh, M., (2010). Technical Note: Water Conservation in Kuwait: A Fuzzy Analysis Approach. Journal of Industrial Engineering, Vol. 6, No. 10, 90 - 105.

Hamoda, M. F., (2013). Advances in Wastewater Treatment Technology for Water Reuse. Journal of Engineering Research, Vol.1 (1), 1 - 27.

Haoran, W., (2006). Decentralized Wastewater Reclamation in Beijing; An assessment of the performance of 4 systems and the drivers and barriers for implementation. Unpublished Master Thesis, Environmental Science, Wageningen, University, Netherlands.

Hartley, T.W., (2006). Public Perception and Participation in Water Reuse. Desalination 187, 115 – 126.

Harvett, C.M., (2013). A Study of Uncertainty and Risk Management Practice Relative to perceived Project Complexity. Unpublished PhD Thesis, Institute of Sustainable Development and Architecture, Bond University, Australia.

Hastuti, E., Medawaty, I., and Pamekas, R., (2011). Application of Domestic Wastewater Treatment Using Fixed Bed Bio-Film and Membrane Bio-Reactor for Water Reuse in Urban Housing Area. Journal of Applied Sciences in Environmental Sanitation, Vol. 6 (3), 367 - 376.

Hazra, M., Avishek, K. and Pathak, G., (2011). Developing an Artificial Wetland System for Wastewater Treatment: A Designing Perspective. International Journal of Environmental Protection, Vol.1 (1), 8 - 18.

Health and Safety Excusive, (2006). Five Steps to Risk Assessment "Leaflet aims in assessing health and safety risks in the workplace". Health and Safety Executive Information Services, Caerphilly Business Park, Caerphilly, United Kingdom.

Hespanhol, I., (1997). Water Pollution Control - A Guide to the Use of Water Quality Management Principles: Chapter 4 - Wastewater as a Resource. United Nations Environment Program (UNEP), the Water Supply & Sanitation Collaborative Council and the World Health Organization (WHO).

Higginsa, J., Warnkena, J., Shermanb, P.P. and Teasdalea, P.R., (2002). Survey of Users and Providers of Recycled Water: Quality Concerns and Directions for Applied Research. Water Research 36, 5045 – 5056.

Hochstrat, R., Wintgens, Th., and Melin, **Th., (2008).** Development of Integrated Water Reuse Strategies. Desalination, 218 (2008) 208–217.

Holt, P., James, E., and Wong, T., (2006). Wastewater Reuse in the Urban Environment: Selection of Technologies. A Final Report of a study by Landcom and Ecological Engineering: 04_05/2108 (2006).

Hussain, I., Raschid, L., Hanjra, M.A., Marikar, F., and Hoek, W., (2001). A Framework for Analyzing Socioeconomic, Health and Environmental Impacts of Wastewater Use in Agriculture in Developing Countries. Working Paper 26, International Water Management Institute (IWMI).

Ishizaka, A., and Labib, A., (2009). Analytic Hierarchy Process and Expert Choice: Benefits and Limitations. OR-Insight, 22 (4), 201 – 220.

Jamwala, P., and Mittalb, A.K., (2010). Reuse of Treated Sewage in Delhi City: Microbial Evaluation of STPs and Reuse Options. Resources, Conservation and Recycling 54, 211 – 221.

Jeuland, M., (2015). Challenges to Wastewater Ruse in the Middle East and North Africa, Middle East Development Journal, 7 (1), 1 - 25.

Jhansi, S.C., Shah M. and Mishra, S.K., (2013). Wastewater Treatment and Reuse: Sustainability OptionsThe Journal of Sustainable Development, Vol. 10, Iss. 1 (2013), pp. 1 – 15.

Kajenthira A., Siddiqi, A. and Anadon, L.D., (2012). A New Case for Promoting Wastewater Reuse in Saudi Arabia: Bringing Energy into the Water Equation. Journal of Environmental Management, 102, 184 - 192.

Kantanoleon N., Zampetakis L., and Manios T. (2007). "Public Perspective towards Wastewater Reuse in a Medium Size, Seaside, Mediterranean City: A Pilot Survey, Resources, Conservation and Recycling, 50:282-292.

Keremane, G.B., and McKay, J., (2006). Successful Wastewater Reuse Scheme and Sustainable Development: A Case Study in Adelaide. School of Commerce, Centre for Comparative Water Policies and Laws, CRC Irrigation Futures Scholar, University of South Australia, Adelaide, Australia.

Kiera, S., Fitzgerald, P.E., (2005). Wastewater Treatment Plant Technology Review. TSG Technologies, Inc. December, 2005, Gainesville, FL, USA.

Kiker, G.A., Bridges, T.S., Varghese, A., Seager, Th.P. and Linkov, I., (2005). Application of Multi-Criteria Decision Analysis in Environmental Decision Making. Integrated Environmental Assessment and Management, Vol. 1 (2), 95 – 108.

Klinke, A. and Renn, O., (2004). Systemic Risks: A New Challenge for Risk Management. Science and Society, Vol. 5, 1 - 10.

Konidari, P. and Mavrakis, D., (2007). A Multi-Criteria Evaluation Method for Climate Change. Energy Policy, 35, 6235–6257.

Kuwait EPA, (2012). Kuwait's Initial National Communications under the United Nation's Framework Convention on Climate Change. November, 2012.

Lili, Y., Wentao, J., Xiaoning, C., Weiping, C., (2011). An overview of reclaimed water reuse in China. Journal of Environmental Sciences, 23 (10), 1585 – 1593.

Linkov, I., and Steevens, J., (2008). Cyano-Bacterial Harmful Algal Blooms: State of the Science and Research Needs. Chapter 35 Appendix A: Multi-Criteria Decision Analysis. Springer Science + Business Media, NY, USA, pp. 815 – 829.

Li, Y.P., and Huang, G.H., (2012). Electric-Power Systems Planning and Greenhouse-Gas Emission Management under Uncertainty. Energy Conversion and Management, 57, 173 – 182.

Malallah, F., and Daifullah, A., (2008). Feasibility of Using Tertiary treated Effluents in Irrigation Systems. Twelfth International Water Technology Conference, IWTC, December, 2008, Alexandria, Egypt.

Massouda, M.A., Scrimshawa, M.D., and Lester, **J.N., (2003).** Qualitative Assessment of the Effectiveness of the Mediterranean Action Plan: Wastewater Management in the Mediterranean Region. Ocean & Coastal Management, p.25.

McDaniels, T. L., Gregory, R.S. and Fields, D., (1999). Democratizing Risk Management: Successful Public Involvement in Local Water Management Decisions. Risk Analysis, Vol. 19 (3).

McKenzie, C., (2005). Wastewater Reuse Conserves water and Protects Waterways. The National Environmental Services Center (NESC), pp. 46 - 51.

Memon F. A., Zheng, Z., Butler, D., Shirley-Smith, C., Lui, S., Makropoulos, C. and Avery, L., (2007). Life Cycle Impact Assessment of Greywater Recycling Technologies for New Developments. Environmental Monitoring and Assessment, 129:27–35.

Mendonca, E., Picado, A., Cunha, M.A. and Catarino, J., (2011). Environmental Management of Wastewater Treatment Plants – the Added Value of the Eco-Toxicological Approach. Environmental Management in Practice. www.intechopen.com.

Merzthal, G., and Bustamante, E., (2008). Using Treated Domestic Wastewater for Urban Agriculture and Green Areas; The Case of Lima. Urban Agriculture Magazine, (20), 7 - 9.

Mfune, O., (2012). From Fortresses to Sustainable Development: the Changing face of Environmental Conservation in Africa, the Case of Zambia. Thesis Submitted for the Degree of Doctor of Philosophy (PhD), School of Geographical and Earth Sciences, College of Science and Engineering, University of Glasgow.

Ministry of Planning, (2010). General Framework of Development Plan "Final Mid-Range Plan 2010/2011-2013/2014", State of Kuwait.

Ministry of Planning, (2011a). Annual Statistical Abstract “Edition 48”, Central Statistical Bureau, State of Kuwait.

Ministry of Planning, (2011b). Statistical Review “Edition 34”, Central Statistical Bureau, State of Kuwait.

Ministry of Planning, (2015). SCPD, Kuwait Med-Term Plan (2015 – 2016 / 2019 – 2020). Kuwait.

M/J Industrial Solutions, (2003). Municipal Wastewater Treatment Plant Energy Baseline Study. Pacific Gas and Electric New Construction Energy Management Program, San Francisco, California, USA.

Mohammed-said, S., (2009). Application of Reuse of Wastewater for Irrigation in Middle East Countries, Particularly in Jordan. Unpublished MSc. Master Thesis in Land and Water Resources Engineering, Royal Institute of Technology (KTH), Stockholm, Sweden.

Muller, M. (2015). The ' Nexus ' As a Step Back towards a More Coherent Water Resource Management Paradigm, 8 (1), 675–694.

Murni, Po., Juliane, D.K., and Blair, E.N., (2003). Literature Review of Factors Influencing Public Perceptions of Waster Reuse. Australian Water Conservation and Reuse Research Program / Victorian Smart Water Fund. CSIRO Land Water: Technical Report 54/03, December 2003.

Murtaugh, K.A., (2005). Analysis of Sustainable Water Supply Options for Kuwait. Unpublished MSc. Thesis in Civil and Environmental Engineering, Massachusetts Institute of Technology, University of Michigan, USA.

Mustajoki1, J., Marttunen1, M., Karjalainen, T.P., Hokkanen, J. and Vehmas, A., (2013). Developing Practices for Supporting EIA with Multi-Criteria Decision Analysis. The 33rd Conference of the International Association for Impact Assessment (IAIA13), May 13-16, 2013, Calgary, Alberta, Canada.

O'Flynn, M., (2010). Impact Assessment: Understanding and Assessing our Contributions to Change **- M&E Paper 7.** International NGO Training and Research Centre. www.intrac,org.

Ogilvie, R., Ogilvie, L., and Asher, J. (Ogilvie, Ogilvie & Company), (2010). Stakeholder/Public Attitudes towards Reuse of Treated Wastewater: Public Acceptance of Reusing Treated Wastewater. Final Report Prepared by Ogilvie, Ogilvie & Company for Lake Simcoe Region Conservation, March 31, 2010.

Qiting, Z., Junxia, M., and Jie, T. (2013). Chinese Water Resource Management and Application of the Harmony Theory. Journal of Resources and Ecology, Vol. 4 (2), 165–171.

Ordonez, R., Hermosilla, D., Pío, I.S., and Blancoa, A., (2011). Evaluation of MF and UF as Pre-treatments prior to RO applied to Reclaim Municipal Wastewater for Freshwater Substitution in a Paper Mill: A practical Experience. Department of Quality and Development, Madrid, Spain.

Ortiz M., Raluy, R. G., Serra, L., and Uche, J., (2007). Life Cycle Assessment of Water Treatment Technologies: Wastewater and Water-Reuse in a Small Town. Desalination, 204, 121 – 131.

Oswaldo, V.C. and Brian D.F., (2010). Assessing the Environmental Impacts of Urban Growth Using Land Use/Land Cover, Water Quality and Health Indicators: A Case Study of Arequipa, Peru. American Journal of Environmental Sciences, 7 (2), 90 - 101.

Pastakia, Ch. M. R., (1998a). The Rapid Impact Assessment Matrix (RIAM): A New Tool for Environmental Impact Assessment. VKI, Agern Alle 11, DK - 2970 Horsholm, Denmark.

Pastakia, Ch. M. R., (1998b). Rapid Impact Assessment Matrix. In: Jensen, K. (editor), Environmental Impact Assessment using the rapid impact assessment matrix (RIAM). Olsen & Olsen, Fredensborg, 8 – 19.

Peasey, A., Blumenthal, U., Mara, D., and Ruiz-Palacios, G., (2000). A Review of Policy and Standards for Wastewater Reuse in Agriculture: A Latin American Perspective. Water and Environmental Health: London and Lough-borough (WELL) Study, Task No. 68 part II.

Pelesikoti, N., (2003). Sustainable resource and Environmental Management in Tonga: Current Situation, Community Perceptions and a Proposed New Policy Framework. Unpublished PhD Thesis in Environmental Sciences, University of Wollongong, Australia.

Pescod, M.B., (2004). Wastewater Treatment and Use in Agriculture. FAO Irrigation and Drainage Paper 47, FAO of the United Nations (UN). http://www.fao.org/docrep/T0551E/t0551e0c.htm. 15/09/2004.

Kristensen, P., (2004). The DPSIR Framework. Paper presented at the 27-29 September 2004 workshop on a comprehensive / detailed assessment of the vulnerability of water resources to environmental change in Africa using river basin approach. UNEP Headquarters, Nairobi, Kenya.

Po, M., Kaercher, J. D., and Nancarrow, B. E., (2005). Literature Review of Factors Influencing Public Perceptions of Water Reuse. CSIRO Land and Water, Technical Report 54/03, 1 - 39.

Pomeroy, Ch. A., Roesner, L.A., Coleman, J.C., and Rankin, Ed., (2007). Protocols for Establishing Wet Weather Impacts and Urbanization Patterns. www.iwaponline.com/wio/2008/11/wio200811WF03WSM3.htm .

Pope, J., Bond A., Morrison-Saunders A., Retief, F., (2013). Advancing the Theory and Practice of Impact Assessment: Setting the Research Agenda. Environmental Impact Assessment Review 41, 1 – 9.

Radcliffe, J.C., (2006). Future Directions for Water Recycling in Australia. Desalination, 187, pp. 77 – 87.

Randall, J. and Jowett, E., (2010). Environmental Impact Assessment Tools and Techniques. World Wildlife Fund (WWF), Inc. and American National Red Cross. http://creativecommons.org/licenses/.

Raschid-Sally, L., Hoek, W., and Ranawaka, M., (2001). Wastewater Reuse in Agriculture in Vietnam: Water Management, Environment and Human Health Aspects. Working Paper 30, International Water Management Institute (IWMI).

Redding, C.A., Rossi, J.S., Rossi, S.R., Velicer, W.F., and Prochaska, J.O., (2000). "Health Behavior Models". The International Electronic Journal of Health Education, Vol. (3), 180 - 193.

Rey, J., Tengnas, a., Levite, H., and Ouedraogo, I. (2014). Integrated Water Resources Management Performance Analysis: Results of a Pilot Study in West Africa. Journal of Water Supply: Research and Technology - AQUA, 63 (8), 661.

Robinson, K. G., Robinson C. H., and Hawkins, S. A., (2005). Assessment of public perception regarding wastewater reuse. Water Science and Technology, Water Supply, Vol. 5 (1), 59 – 65.

Saaty, Th. L., (2003). Decision-Making with the AHP: Why is the Principal Eigenvector Necessary? European Journal of Operational Research, 145, pp. 85–91.

Saaty, Th. L., (2008). Decision making with the analytic hierarchy process. Int. J. Services Sciences, Vol. (1), 83 – 98.

SAI Platform, (2010). Water Conservation Technical Briefs. TB7 – Wastewater Use in Agriculture for Internal Information Purposes, SAI platform members, June 2010.

Salgota, M., Huertasa, E., Weberb, S., Dottb, W., and Hollenderb, J., (2006). Wastewater Reuse and Risk: Definition of Key Objectives. Desalination, 187, 29 - 40.

Salinas, A. (2015). Integrated Water Resources Management under a New Global Scenario. Water Science & Technology: Water Supply, 15 (2), 215.

Schafer, A.I. and Beder, S., (2006). Relevance of the Precautionary Principle in Water Recycling. Desalination, 187, 241 – 252.

Scheierling S.M., Bartone, C., Mara, D.D. and Drechsel, P., (2010). Improving Wastewater Use in Agriculture: An Emerging Priority - Policy Research Working Paper. The World Bank, Water Anchor, Energy, Transport, and Water Department, September, 2010.

Schultz, T.E., (2005). Bio-treating Process Wastewater: Airing the Options. Chemical Engineering Magazine, October 2005, p44. www.che.com.

Shoili1, A.G., Farrokhi1, M., Neizehbaz, H. and Alizadeh, H., (2011). Selection of Optimum Option for Sludge Disposal in the Guilan Province of Iran Using Rapid Impact Assessment Matrix (RIAM). International Journal of Water Resources and Environmental Engineering, Vol. 3 (12), pp. 288-297.

Simpson, J., and Stratton, H., (2011). Talking About Water: Words and Images That Enhance Understanding. Commonwealth of Australia. National Water Commission, Waterlines Report Series No 49, May 2011.

Slotterback, C.S., Forsyth, A., Krizek, K.J. Johnson J. and Pennucci, A., (2010). Testing Three Health Impact Assessment Tools in Planning: A Process Evaluation. Environmental Impact Assessment Review (2010), p.10.

Smith, P. G. and Scott, S. G., (2005). Dictionary of Water and Waste Management: Second Edition. Co-published by IWA Publishing, London, UK. p. 486. Web: www.iwapublishing.com.

Smoot, J.L., Cuffney, T.F., and Bryant, Jr., W.L., (2004). Effects of urbanization on Stream Ecosystems; Proceedings of the 1st annual Stormwater Management Research Symposium. Stormwater Management Academy, Orland, Fl. October 12-13th, pp. 127-136.

Sokile, C.S., Kashaigili, J.J., and Kadigi, R.M.J., (2002). Towards An Integrated Water Resource Management in Tanzania: The Role of Appropriate Institutional Framework in Rufiji Basin. WARFSAWATERNET/WARFSA Symposium: Water Demand Management for Sustainable Development, 30-31, October 2002.

Steinel, A., and Margane, A., (2011). Best Management Practice Guideline for Wastewater Facilities in Karstic Areas of Lebanon - for the protection of ground and surface waters. Technical Report No.2, German-Lebanese Technical Cooperation Project Protection of Jeita Springs. Federal Ministry for Economic Cooperation and Development.

Stephens, F., (2005). Public Perception of Potable Water Reuse: Science, Risk and Necessity. Water Resources Conference, April 25-26, 2005, the University of Georgia, Athens, Georgia.

Surendran S., Linford T., Evans E., MCGAHEY C., SAYERS P., and WICKS J., (2008). System Based Risk Modelling and Decision Support for the UK's Catchment, Coastal and Estuary Flood Management Planning. Environment Agency / Defra Flood & Coastal Management Conference, 1st – 3rd July 2008, Manchester University.

Svarstada, H., Petersenb, L., Rothmanc, D., Siepeld, H., and Watzold, F., (2007). Discursive Biases of the Environmental Research Framework DPSIR. Journal of and Use Policy, Vol. 03 (005).

Tansel, B., (2008). New Technologies for Water and Wastewater Treatment: A Survey of Recent Patents. Recent Patents on Chemical Engineering, 1, 17 - 26.

Tare, V., Bose, P., Hait, S., Philip, L., and Kazmi, A.A., (2011). Review of Wastewater Reuse Projects Worldwide; Collation of Selected International Case Studies and Experiences. Report Code: 012, GBP-IIT-EQP-SOA, 01: Ver. 1, Dec. 2011.

Templeton, M. and Butler, D., (2011). Introduction to Wastewater Treatment. www.bookboon.com.

The National Academy of Sciences, (2012). Water Reuse Potential for Expanding the Nation's Water Supply through Reuse of Municipal Wastewater. http://dels.nas.edu/wstb.

The Rio Declaration on Environment and Development, (1992). The United Nations Conference on Environment and Development, Reaffirming the Declaration of the United Nations Conference on the Human Environment, Adopted at Stockholm on 16 June 1972, Rio de Janeiro from 3 to 14 June 1992.

The World Bank, (1997). Assessing the Environmental Impact of Urban Development; The Environmental Assessment Source Book Update. Environment Department, Washington D.C., USA.

Umuhoza Mbateye, F.A., Nhapi, I., Wali, U.G. and Banadda, N., (2010). Assessment of Wastewater Management Practices in Kigali City, Rwanda. The Open Environmental & Biological Monitoring Journal, Vol. 3, 21 - 28.

UNDESA, (2007). Indicators of Sustainable Development: Guidelines and Methodologies. Third Edition, October 2007. United Nations Department of Economic and Social Affairs. New York, USA.

UNDESA, (2012). Sustainable Development in the 21st century (SD21); Review of Implementation of Agenda 21 and the Rio Principles. United Nations Department of Economic and Social Affairs, Division for Sustainable Development.

UNEP, (1997). Source Book of Alternative Technologies for Freshwater Augmentation in Latin America and the Caribbean. United Nations Environmental Technology Centre, Unit of Sustainable Development and Environment, General Secretariat, Organization of American States, Washington, D.C., 1997.

UNEP, (2005). Water and Wastewater Reuse; an Environmentally Sound Approach for Sustainable Urban Water Management. Division of Technology, Industry and Economics (DTIE), Osaka, Japan.

UNEP, (2005). Working Document on Priority Environmental Indicators in West Asia, Arab Africa Reigns, October 13th – 15th, 2003. Kingdom of Bahrain.

UNEP / UN-HABITAT, (2011). Sick Water? The Central Role of Wastewater Management in Sustainable Development. A Rapid Response Assessment. UNEP / UN-HABITAT, GRID-Arendal, p.88.

UNESCO, (2012). Managing Water under Uncertainty and Risk. The United Nations World Water Development Report 4 (WWDR4), Volume 1, United Nations World Water Assessment Programme (WWAP).

United Nations University and Institute of Advanced Studies (UNU / IAS), (2003). Urban Ecosystem Analysis Identifying Tools and Methods. 53 - 67 Jingumae 5 - chome Shibuya - ku, Tokyo 150 - 8304 Japan.

United States Coast Guard, (2004). Risk Assessment Matrix “Standard for Auxiliary Aviation”. National Operational Department, Aviation Division Standardization Team, the United States.

USEPA, (2004). Primer for Municipal Wastewater Treatment Systems. Office of Water / Office of Wastewater Management, Washington DC 20460, EPA 832-R-04-001, September, 2004.

USEPA, (2012). Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources. Progress Report, Office of Research and Development, 601/R-12/011, December, 2012. www.epa.gov/hfstudy.

USEPA / Heat and Power, (2011). Opportunities for Combined Heat and Power Wastewater Treatment Facilities: Market Analysis and Lessons from the Field. USEPA Combined Heat and Power Partnership, October 2011. www.epa.gov/chp.

Walker, L. J., Johnston, J., Napier, H., Clark, D., (1999). Guidelines for the Assessment of Indirect and Cumulative Impact as well Impact Interactions. European Commission (EC), Directorate-General XI, Environment, Nuclear Safety and Civil Protection, NE80328/D1/3: May 1999, p. 172.

Winpenny, J., Heinz, I., Koo-Oshima, S., Salgot, M., Collado, J., Hernandez, F., and Torricelli, R., (2010). The Wealth of Waste: The Economics of Wastewater Use in Agriculture. Food and Agriculture Organization (FAO) of the United Nation (UN), Roma, 2010, p.129.

WHO, (2006). Compendium of standards for Wastewater Reuse in the Eastern Mediterranean Region. World Health Organization (WHO), Regional Office for the Eastern Mediterranean (EM), Regional Centre for Environmental Health Activities (CEHA), 2006.

WHO, 2009. Kuwait Country Profile of Environmental Burden of Disease. Public Health and the Environment, Geneva, 2009.

WHO and UNICEF, (2000). Global Water Supply and Sanitation Assessment: 2000 Report. The WHO and UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP), p.80.

WHO and UNICEF, (2012). Estimates for the use of Improved Drinking-Water Sources - Kuwait. The WHO and UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP).

Wirth, N., (2010). Wastewater Re-use in Lima Metropolitan: A Concept for an Integrated and Sustainable Water and Wastewater Management. University of Applied Sciences, Lima, Peru.

Yang, J. and Shi, P., (2002). Applying Analytic Hierarchy Process in Firm's Overall Performance Evaluation: A Case Study in China. International Journal of Business, Vol. 7 (1).

Yousefi, H., Ehara, S., Yousefi, A., Seiedi, F., (2009). Environmental Impact Assessment of Sabalan Geo-Thermal Power Plant, NW IRAN. The Thirty-Fourth Workshop on Geothermal Reservoir Engineering, February 9th -11th, Stanford University, Stanford, California, USA.

Yu, X., Geng, Y., Heck, P., and Xue, B. (2015). A Review of China's Rural Water Management. Sustainability, 7 (5), 5773–5792.

Zhang, B., Song, X., Zhang, Y., Han, D., Tang, C., Yang, L., and Wang, Z.-L. (2015). The Relationship Between and Evolution of Surface Water and Groundwater in Songnen Plain, Northeast China. Environmental Earth Sciences, 73 (12), 8333–8343.

Zhang, Ch., (2004). A Study on Urban Water Reuse Management Modeling. Unpublished MSc. Thesis in Applied Science, The University of Waterloo - Ontario, Canada.

Zhang, Ch., (2006). An Assessment of Centralized and Decentralized Wastewate Reclamation Systems in Beijing. www.switchurbanwater.eu/outputs/results.php, PhD and MSc Theses / Reports. Accessed January, 2013.

Appendix (1)

<u>TWW Reuse Options and Guidelines Worldwide</u>

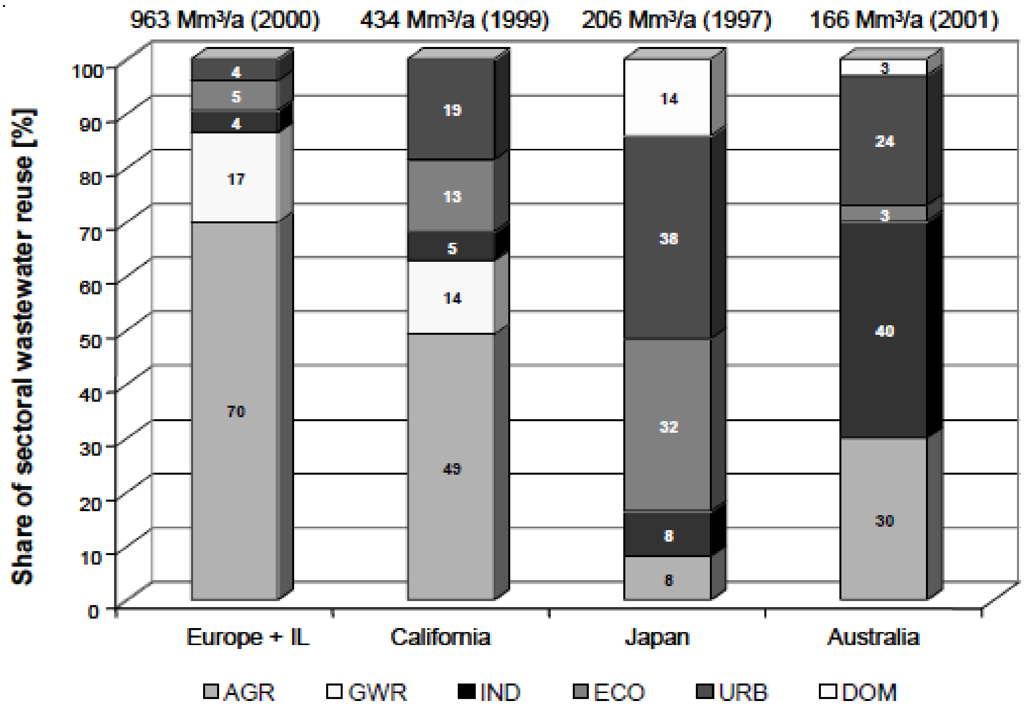

Figure (1A): Comparison of water reuse pattern in different regions (IL: Israel), where AGR: agricultural irrigation, GWR: groundwater recharge, IND: industrial uses, ECO: ecological/environmental applications, URB: urban applications, DOM: domestic applications (Hochstrat et al, 2008)

Table (1A): USEPA (1992) Guidelines for Three of Common TWW Reuse

Types of Reuse	Treatment	Reclaimed Water Quality	Reclaimed Water Monitoring	Setback Distances
Urban Reuse Landscape irrigation, vehicle washing, toilet flushing, fire protection, commercial air conditioners, and other uses with similar access or exposure to the water.	Secondary[1] Filtration[2] Disinfection[3]	pH = 6–9 ≤10 mg/L biochemical oxygen demand (BOD) ≤ 2 turbidity units (NTU)[5] No detectable fecal coliform/100 mL[4] 1 mg/L chlorine (Cl_2) residual (min.)	pH – weekly BOD – weekly Turbidity – continuous Coliform – daily Cl_2 residual – continuous	50 ft (15 m) to potable water supply wells
Agricultural Reuse For Non-Food Crops Pasture for milking animals; fodder, fiber and seed crops.	Secondary Disinfection	pH = 6–9 ≤ 30 mg/L BOD ≤ 30 mg/L total suspended solids (TSS) ≤ 200 fecal coliform/100 mL[5] 1 mg/L Cl_2 residual (min.)	pH – weekly BOD – weekly TSS – daily Coliform – daily Cl_2 residual – continuous	300 feet (90 m) to potable water supply wells
Indirect Potable Reuse Groundwater recharge by spreading into potable aquifers.	Site specific Secondary and disinfection (min.) May also need filtration and/or advanced wastewater treatment	Site specific Meet drinking water standards after percolation through vadose zone.	pH – daily Turbidity – continuous Coliform – daily Cl_2 residual – continuous Drinking water standards – quarterly Other – depends on constituent	100 ft (30 m) to areas accessible to the public (if spray irrigation) site specific

Source: McKenzie (2005)

1. **Secondary treatment processes include activated sludge processes, trickling filters, rotating biological contactors, and many stabilization pond systems. Secondary treatment should produce effluent in which both the BOD and TSS do no exceed 30 mg/L.**
2. **Filtration means passing the effluent through natural undisturbed soil or filter media such as sand and/or anthracite.**
3. **Disinfection means the destruction, inactivation or removal of pathogenic microorganisms. It may be accomplished by chlorination, or other chemical disinfectants, UV radiation or other processes.**
4. **The number of fecal coliform should not exceed 14/100 mL in any sample.**
5. **The number of fecal coliform should not exceed 800/100 mL in any sample.**

Source: USEPA, 1992. Guidelines for Water Reuse - (EPA)/625/R-92/004

Table (1B)**:** TWW Reuse Practice & Options in Some Mediterranean Countries

Country	**TWW Reuse Practice & Options**
Spain	**TWW is regenerated in water cycle to provide farm irrigation and improves river water quality** (secondary WWT). Other reuse purposes include golf course irrigation, agricultural irrigation, groundwater recharge (primarily to stop saltwater intrusion in coastal aquifers), and river flow augmentation.
Greece	**Integration of treated wastewater into water resources management.** Almost 60% of the Greek population is connected to WWTPs.
France	Irrigation of crops and landscaped areas is limited especially in Paris. Attention to increase TWW reuse for farming. Other reuse activities include market garden crops, orchards, cereals, tree plantations and forests, grasslands, gardens and golf.
Italy	Agricultural irrigation has become a common practice. **Several WW reuse systems were implemented in Southern and Northern Italy to sustain water resources.** Wetlands, a natural WW treatment system combined with conventional WWTPs seem to be a suitable solution to improve water quality.
Cyprus	Reuse TWW for football fields, parks, hotel gardens, and for the irrigation of certain types of crops has become a common practice in Cyprus. TWW reuse practice for agriculture and landscape irrigation is increasing. **Environmental Health Impacts of such practice are minimal due to effective monitoring and strict standards and guidelines.**
Turkey	TWW is mainly discharged into water bodies such as rivers, creeks, and coastal and deep sea environment. **TWW reuse for agriculture is increasing to augment their current limited water resources as well as to solve marine pollution discharges to the sea.**
Albania	Water related epidemics such as cholera and poliomyelitis have occurred. **Untreated wastewater in Albania is used for irrigation leading not only to health problems but also adversely affecting the soil quality, vegetation and aquatic resources.**
Malta	80% of sewage is used to be discharged without treatment directly into the sea. The sewage flows in close proximity to the shore and has resulted in the contamination of the surrounding coast. Over 4000 tons of chemicals are discharged to the Mediterranean Sea from sewage outflows in Malta. **Only one tertiary WWTP exists in Malta which TWW reused for agricultural purposes is common.**
Monaco	**Only one secondary WWTP exists with limited treated TWW practice.**
Yugoslavia	Recently sanitation sector facing serious deterioration because of inadequate maintenance.
Croatia	Around 45% of Croatian cities (5 cities) are lack WWT and the **only kind of treatment reported is the primary level of treatment.**
Israel	Secondary and tertiary WWTs are predominant now in Israel. Due to severe water shortage, water resources contamination, urban growth and increased agriculture irrigation, **TWW started to be widely utilized for irrigation.**

Source: Massouda et al (2003), Fatta et al (2005), Wirth (2010), Tare et al (2011), and Barbagallo et al (2012)

Table (1C): TWW Reuse Practice & Options in Some USA States

Country	**TWW Reuse Practice & Options**
California	Over 90% of Los Angeles (LA) county WW used to be discharged into the San Gabriel River then to ocean, or directly into the ocean at San Pedro Bay. **Therefore, TWW reuse for irrigation purposes within WWTP with an Integrated Aquaculture Wetland Ecosystem was established in LA. Tertiary WWTP for TWW reuse inland as an alternative to ocean disposal in order to maintain integrated water resources management.**
Florida	Water Reuse Program was utilized for several purposes such **as land application and residential irrigation, groundwater recharge and indirect potable reuse and industrial use**. Efforts were made to conserve freshwater supplies from rivers, streams, lakes, and aquifers. **Irrigation and groundwater recharge to reduce the use of existing potable water supplies and tackle the water shortages.** Figure 2 – 5 demonstrates TWW utilization by flow in Florida as per water reuse 2009 inventory.
Virginia	Based on Level of wastewater treatment included, USEPA selected reuse type for variety of purposes listed and distinguished in table 2 – 5.

Source: Haering et al (2009) and Tare et al (2011)

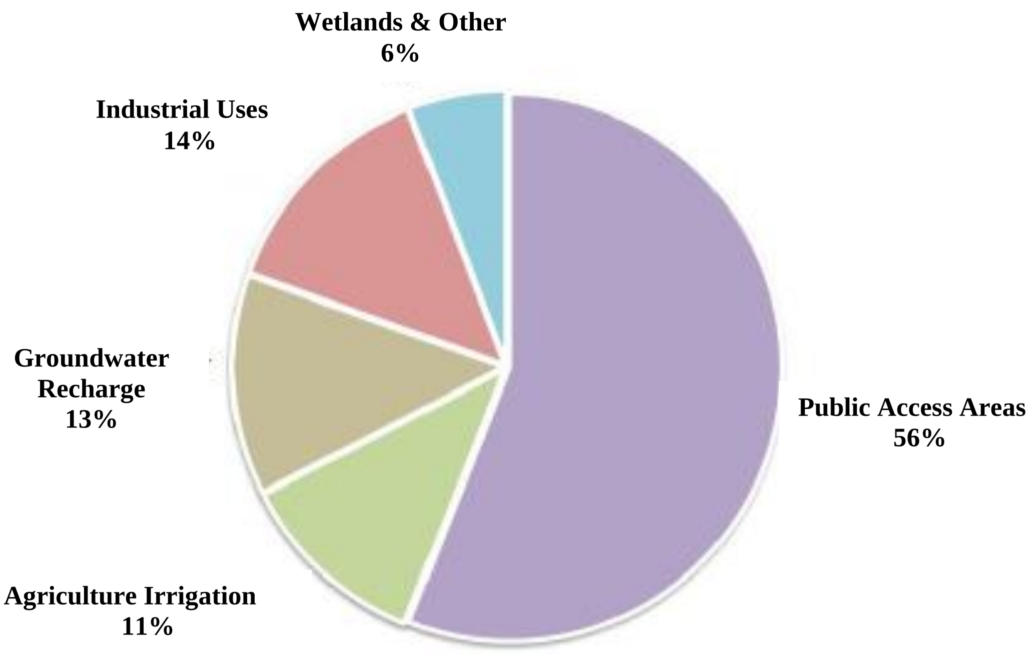

Figure (1B): TWW Utilization by Flow in Florida as per Water Reuse 2009 Inventory (Tare et al. 2011)

Table (1D): Minimum Treatment Requirements for Irrigation and Landscape Reuse of Reclaimed Water in Virginia

Level of Treatment	TWW Reuse Option
Secondary Treatment with Filtration and Higher – Level Disinfection	**1. Food crops that are commercially processes and any food that will be eaten raw. 2. Container nurseries. 3. Landscape irrigation including golf course, parks, athletic fields, school yards, cemeteries and impoundments with public access.**
Secondary Treatment Standard Disinfection	**1. Food crops that are commercially processes. 2. Non-food crops. 3. Pasture. 4. Decorative nursery (non-container). 5. Sod farms. 6. Landscape.**

Source: Haering et al (2009)

Table (1E)**:** TWW Reuse Practice & Options in Australia and Latin America

Country	TWW Reuse Practice & Options
Australia	TWW is reused in two coastal for an irrigation purpose. Such coastal area is a popular beaches area and known for its flora and fauna diversity. Therefore, it was an important issue for the public to minimize environmental health risk and negative impacts of released wastewater to the environment
Peru	Due to water scarcity, the TWW reuse as an alternative water resource for human consumption, agriculture, industry, and green areas has become a critical issue. Therefore, **TWW is used for a variety of purposes such as agriculture and aquaculture** which represent 77% of the total area irrigated with treated wastewater mainly in semi-urban areas (suburbs and countryside). The second significant option **is recreational activities like green areas, sports fields and public parks**, which make up just 23% of the total irrigated area mainly in the city. The remaining percent of treated wastewater (34%) is reuses for some other activities. **The technologies used for treating wastewater have been grouped into five types: stabilization ponds (29%), aerated lagoons (29%), activated sludge (24%), artificial wetlands (12%), and percolated filters (6%).**

Source: Merzthal and Bustamante (2008), Wirth (2010) and Tare et al (2011)

Table (1F): TWW Reuse Practice & Options in China and Some East Asian Countries

Country	**TWW Reuse Practice & Options**
China	Due to water shortage and pollution, to reduce stress on water demand, **TWW reuse practice started to be applied for recreational plantation ponds and lakes in public parks, sustain or augment stream flows, create man-made wetlands, etc.** When secondary level of wastewater treatment was began during 1985 and1990, **TWW started to be utilized widely in landscape irrigation.** Industrial reuse such as **cooling-water, processing, and boiler feed water** also started back then. TWW reuse practice in groundwater (GW) recharge is considered a new practice in China even though it is common around the world.
Vietnam	TWW reused has been practiced in Vietnam both for **agriculture and aquaculture.** However such practice was not effectively managed due to **environmental health risks and economic burdens.** Currently an **integrated water management considering TWW reuse into an analytical framework** is being adopted.
Singapore	**R.O. WWTP** is established to consider TWW reuse as an alternative source of water to address Singapore's water scarcity challenge.
Indonesia	For water conservation, **new strategies were adopted to reuse TWW in order to reduce the pressure on freshwater demand and protect it alongside the environment from untreated wastewater discharges.**

Source: Hastuti et al (2001), Raschid-Sally et al (2001), McKenzie (2005), Lili et al (2011), and Tare et al (2011)

Table (1G): TWW Types and Reuse Practice in Some Arab Countries (ME)

Country	**TWW Types & Reuse Practice**
Egypt	An integrated model of WW management for semi-urban and isolated regions was implemented to obtain close cycle of water from different sources to flow in final tourism and other recreational facilities which are not connected to a central WWT. Many coastal cities have WWTPs of primary and secondary levels of treatment. Strict regulations are set to avoid TWW reuse for any food or fiber crops including cotton.
Tunisia	Back In 1989, an Act to set standards for treated wastewater reuse for agricultural purposes was adopted. TWW reuse in agriculture has been practiced for several decades and become a part of their national water resources strategy. TWW is mixed with GW before being applied to irrigate citrus and olive trees, forage crops, cotton, golf courses and hotel lawns.
Morocco	Irrigation with raw wastewater is a common practice in Morocco.With annual volume of urban WW of 500 million m^3 in 1999 (expected to reach 900 million m^3 by 2020), only 5 to 8% is treated and 60% of it is discharged into the sea. Remaining quantity is discharged into surface water and or reused for irrigation. Since, TTWPs for only secondary treatment it does not comply with the standards for reuse in agriculture. There are no WWTPs in any of the large cities. Lately TWW standards were set to be considered before reuse practice.
Algeria	Percentage of TWW is almost as low as Morocco since most of the treatment plants are out of use. About 55% of the cities (21 cities) are without wastewater treatment plants. Currently, authorization is required for TWW reuse for vegetables that might be eaten raw.
Libya & Syria	TWW reuse is currently limited, but expected to increase in the near future. Same as many developing countries, issues related to sanitation tend to receive less attention and fewer financial resources than the provision of a water supply.
Jordan	WWTPs are located in big cities to serve the city and the surrounded areas. There are plans for new WWTPs to serve more areas and communities. TWW is reused directly for irrigation or stored in reservoirs and dams prior to reuse. National standards and guidelines still need to be developed and improved for different TWW reuse practice.
Lebanon	Urban and rural areas in Lebanon are commonly using septic tank systems. Untreated wastewater is discharged directly into rivers, irrigation channels, valleys, and ravines. This method of wastewater disposal has been practiced since long time resulting in severe risk to the public health and environment.

Source: Massouda et al (2003), Fatta et al (2005), and Tare et al (2011)

Appendix (2)

Research Gaps and Recommendations of Some Cited Studies Regarding Public Perceptions toward & Assessment and Management of TWW Reuse Practice and Options

Table (2A): Previous Studies Regarding Public Perception toward TWW Reuse

Reference Citation	Study Subject Area	Research Gap / Recommendation
Beecher et al, 2005	Risk Perception	Recommending effective evaluation for stakeholders' involvement in risk communication.
Robinson et al, 2005	Assessment of Public Perception of TWW Reuse	No reliable perceptions' results. No DM or assessment of any reuse options.
Stephens, 2005	Public Perception of Potable Water Reuse	There is lack of environmental and socio-economic baseline, epidemiological and health-risk assessment studies on indirect potable reuse. Absence of regulations for direct potable reuse.
Hartley, 2006	Public Perception and Participation in TWW Reuse	Fair sound DM and decisions is the key for building public confidence toward TWW reuse options and planning.
Schafera and Bederb, 2006	Precautionary Principle in TWW Reuse	The precautionary principle can improve TWW practice and ecosystem sustainability. Also can play an essential role in DM by dealing with interacted uncertain risks.
Kantanoleon et al, 2007	Public Perception of TWW Reuse in Greece	Major knowledge gap affecting public perception of TWW reuse. There must be a clear and adequate scientific perception on TWW reuse practice.
Abu-Mahdi et al, 2008	Public Perceptions and Knowledge towards TWW Reuse in Agriculture in Palestine	No perception of other TWW reuse options. Public concern is mainly regarding health risk.
Dolnicar and Schafer, 2009	Public Perception of Desalinated versus Recycled Water	Personal characteristics affected the research investigation. Public attitudes and experiences affect the reliability of results.
Al-humoud, and Madzikanda, 2010	Public Perceptions On the Advance (R.O.) TWW Reuse Options	No assessments or DM studies for any reuse option. Public perceptions influence with culture, attitudes and religious believes. Qualitative research with experts regarding the way the project is managed
Baawain et al, 2012	Social Survey of Reusing TWW in Muscat	Respondents lack of knowledge regarding WWT and TWW reuse. Public perceptions support DM but do not assess in TWW reuse options.

Appendix (3)

Table (3A): Comparison between Different Planning Analysis Tools and Health Impact Assessment (Forsyth et al, 2010)

Tool / Method	Scope	Content	Outcomes
Health Impact Assessment	**M**easures policies, plans, and projects at a variety of scales	**F**ocuses on human health - some consider a very wide range of issues potentially related to human health and others a narrower range with more specific evidence	**P**ublic awareness about human health issues **P**ublic engagement in decision making about health **C**ommunication among stakeholders **M**itigation measures
Environmental Impact Analysis	**M**easures impacts of projects, plans, programs, policies **M**easures impacts of large projects with potentially significant effects	**N**atural and built environment **H**uman health **E**nvironmental sustainability **S**ocial environment **E**conomy **C**umulative impacts	**P**ublic awareness of environmental impacts **C**hanges or abandonment of project **I**ncreases in perceived environmental quality **I**mplementation of mitigation measures
Social Impact Analysis	**M**easures impacts of projects, plans, programs, policies conducted at various jurisdictional levels or affecting certain sectors of the population	**P**opulation characteristics **C**ommunity and institutional structures **P**olitical and social resources **I**ndividual and family change **C**ommunity resources	**E**xtensive engagement of the public **P**rovide information to assist marginalized groups in negotiating agreements **C**hanges or abandonment of project
Sustainability Indicators	**M**easures impacts of integrated or distributed set of projects, plans, programs, or policies, often conducted at various jurisdictional levels or system levels by a local government or non-profit organization	**E**conomic **E**nvironmental **S**ocial / **E**quity	**I**ncreased awareness of environmental issues **I**nform changes to a policy or program **P**rovide information to individuals to help them make decisions

Appendix (4)

Table (4A): Previous Studies on TWW Reuse Assessment and Management

Reference Citation	Study Subject Area and Methodology	Research Gap / Recommendation
Al-Humoud and Al-Ghusain, 2003	Water Management (Household Demand for Water in Kuwait)	Recommending TWW Reuse, but no assessment of any reuse options.
Alessandri et al, 2004	Managing Risk and Uncertainty in Complex Capital Projects	Complex environmental issues with uncertainty require effective (qualitative and quantitative) approached for strategic management.
Asano, 2004	Water Reclamation and Reuse	Growing need for reliable TWW with environmental concerns regarding its discharge into fragile ecosystems.
Al-Shammiri et al, 2005	Water Quality and Reuse in Irrigation in Kuwait	Further research is needed to predict the accumulation rate of trace metals in the soil.
Asano, 2006	Water Reuse - Issues, Technologies, and Applications	Much of the research that addresses direct and indirect potable TWW reuse is becoming equally relevant to unplanned indirect potable reuse.
Keremane and McKay, 2006	TWW Reuse in Australia	Preparing specific guidelines for TWW reuse, involving private sectors in TWW management and enhancing public participation.
Radcliffe, 2006	Future Directions for TWW in Australia	Recommending effective decision support system for TWW reuse practice and options.
Zhang, 2006	An Assessment of TWW systems in Beijing	Economical and Technical descriptions of TWW reuse options. No assessment of socio-economic and environmental factors regarding TWW reuse practice and options.
Dreizin, 2007	Risk Assessment of TWW Reuse in in Agriculture in Israel.	Recommending environmental, public health, and or regulative guidelines to prevent risks of TWW reuse.
Ortiz et al, 2007	LCA of TWW reuse	Advanced WWT meet most discharge criteria and often suitable for direct reuse
Ackley, 2008	Evaluating Environmental Risks in Mining – Fiji Case Study in the South Pacific	Public participation, moderation and strategic (proactive) planning is required with the various interacted risk communication aspects.

Tansel, 2008	Assessing New Technologies for Water and WWT (A Survey of Recent Patents)	No specific regulations (standards) for TWW. Safety of TWW is still uncertain. Improving WWT technologies for more reusable quality water.
Al-Murad et al, 2010	Freshwater Situation in Kuwait-Remote Sensing for GWR option.	More study required (detailed investigations for determining the rate of recharge and locating the shallow wells.
Barjoveanu et al, 2010	LCA of Water and TWW Systems	Developing appropriate indicators and weighting scales for a reliable EIA.
Hajeeh, 2010	MCDM for Water Conservation in Kuwait	Accelerating wastewater treatment and reuse.
Slotterback et al, 2010	A process evaluation -Testing HIA Tools in Planning	HIA can be effectively integrated within DM system and make relationships with new stakeholders. Environmental health Impacts in this case can provide new approach for issues with community conflicts.
Umuhoza et al, 2010	Assessment of TWW Management Practices in Rwanda	Professionals and practitioners developing in TWW management by government and educational institutions will improve TWW reuse practice and options management.
Akpor and Muchie, 2011	Environmental Health Impacts of TWW Quality	Enhance a science-based DM. Ensure the sustainability of the environment and the health of plants and animals when reusing TWW.
Al-Anzi et al, 2011	Impacts and Pollutants of TWW Reuse Discharged into the sea in Kuwait	Storage capacity and TWW reuse limitations (in agricultural and landscape irrigations only) are the main reasons for wasting the TWW and discharging it into the sea.
Choukrallah, 2011	TWW Reuse in Arab Countries	Arab countries should develop a comprehensive plan for reusing TWW with clearly assigned roles. Recommending Integrated TWW assessment for sustainability of any reuse project.
Ordonez et al, 2011	Evaluation of Advance WWT (MF, UF and RO) for Fresh-Water Substitution in Spain	Water quality achieved is adequate to substitute fresh water.
Aleisa et al, 2011	Residential WWT System in Kuwait	Proactive plan is needed for handling WWTPs and TWW reuse in Kuwait
Al-Anzi et al, 2012	Assessment of Wastewater Reuse in Kuwait	No assessment for TWW reuse. Kuwait must accelerate the reuse of TWW with more options.
Barbagallo et al, 2012	Agricultural wastewater reuse in Sicily	Studies of specific experimental conditions required for constructing wetlands system. TWW reuse of such wetlands to irrigate crops is still a controversial issue.

Ganoulis, 2012	Risk analysis of TWW reuse in agriculture using Decision Support System (MCDA)	Quantifying TWW reuse risks by risk analysis approach (risk assessment and management).
Chen et al,2013a	End Uses of Recycled Water	An integrated approach to plan and manage all available water resources. A uniform TWW reuse guidelines for public confidence, and financial and political support will contribute to integrated water resource management.
Chen et al,2013b	Risk Control in Recycled Water Schemes	Risk assessment as well as cost and social analyses of TWW is essential for setting policies to sustainably minimize risk on human health and the environment.
Hamoda, 2013	Advance WWT Technology for TWW Reuse	The paper is a baseline for establishing regulatory TWW quality limits (compliances) and evaluating TWW reuse applications.
Harvett, 2013	A Study of Uncertainty and Risk Management	Further research in environmental management of uncertainty and risk in complex projects is recommended. Using phenomenological research approaches for strong visions, addressing with less uncertain results.
Jhansi et al, 2013	Wastewater Treatment and Reuse: Sustainability Options	Strategies for TWW reuse can improve water management. Therefore, assessing associated institutional and policymaking capacities and socio-economic factors is critical.

Appendix (5)

<u>Appendix (5A):</u> The short survey questionnaire (SSQ) that was conducted on 50 participants for a Pilot Study (14 from specialists and researchers, 17 from private sectors and other stakeholders, and 19 from public as public representatives)

Table (1): Knowledge Perception

Knowledge towards Certain Aspects	(1) None	(2) Basic	(3) Good	(4) Very Good	(5) Excellent
Treatment					
Guidelines					
Health Risk					
Environmental Impacts					
Risk Transmission					
Reuse Practice					

Table (2): Reuse Practice & Options Perception

Reuse Practice (Option)	**Specialists / Experts**		**Public / Stakeholders**		**Reason**
	A	**NA**	**Agree**	**Disagree**	**<u>A or Agree</u>** (Environment, Economics, Water Conservation) or **<u>NA or Disagree</u>** (Environmental and or Health Risk, Religion, Psychological, Economics and or Logistics)
(1) Artificial Wetlands					
(2) Recreational Irrigation					
(3) Agriculture & Fisheries					
(4) Industry & Construction					
(5) Fire Fighting					
(6) Oil Depressurization					
(7) Groundwater Recharging					
(8) Yards & Car Washing					
(9) Toilet Flushing					
(10) Showering & Bathing					
(11) Cooking					
(12) Drinking					

The Different Aspects of Knowledge Perception toward Wastewater Treatment (WWT) & Treated Wastewater (TWW) Reuse Practice:

1. **Wastewater Treatment:** Concept, technology and levels of treatment.
2. **Guidelines:** Safe standards and guidelines (maximum concentrations of chemical, physical and biological components of TWW) – different reuse practices require different standards and guidelines.
3. **Health Risk:** Expected (probable) risk to human health (both direct and indirect causes of health risks associated with such TWW reuse practice) and whether precautionary principle must be considered or not.
4. **Environmental Impacts:** Types of possible environmental impacts that might occur while practicing any of the TWW reuse option.
5. **Risk Transmission:** How health risk can be transmitted to human, directly (by inhaling polluted air from contaminated improperly treated or untreated wastewater or swallowing such water) or indirectly (by eating agricultural or fishery products that are utilized such water).
6. **TWW Reuse Practices:** Knowledge and information regarding TWW reuse practices in general and any current TWW reuse in Kuwait.

Appendix (5B): Changes in the short survey questionnaire (SSQ) suggested from some participants (the focus group of the Pilot Study)

Table (1): Knowledge Perception

Knowledge towards Certain Aspects	(1) None	(2) Basic	(3) Good	(4) Very Good	(5) Excellent
Treatment					
Guidelines					
Health Risk					
Environmental Impacts					
Risk Transmission					
Reuse Practice					

Table (2): Reuse Practice & Options Perception

TWW Reuse Practice (Option)	**Expert Judgment**		**Reason**			
	Applicability (A or N/A)	**Acceptance (Agree=1 or Disagree= 2)**	**C1**	**C2**	**C3**	**C4**
			Environmental Health Risk Water-Conservation	**Economic Investment Beneficial**	**Technological Infrastructure Logistics**	**Social Religion Psychological**
(1) Artificial Wetlands						
(2) Recreational Irrigation						
(3) Agriculture & Fisheries						
(4) Industry & Construction						
(5) Fire Fighting						
(6) Oil Depressurization						
(7) Groundwater Recharging						
(8) Yards & Car Washing						
(9) Toilet Flushing						
(10) Showering & Bathing						
(11) Cooking						
(12) Drinking						

Appendix (6)

Result of each classified group in the Pilot Study; Experts (including Decision Makers, Specialists and Researchers), Other Stakeholders and Public Representative (PR) Respectively

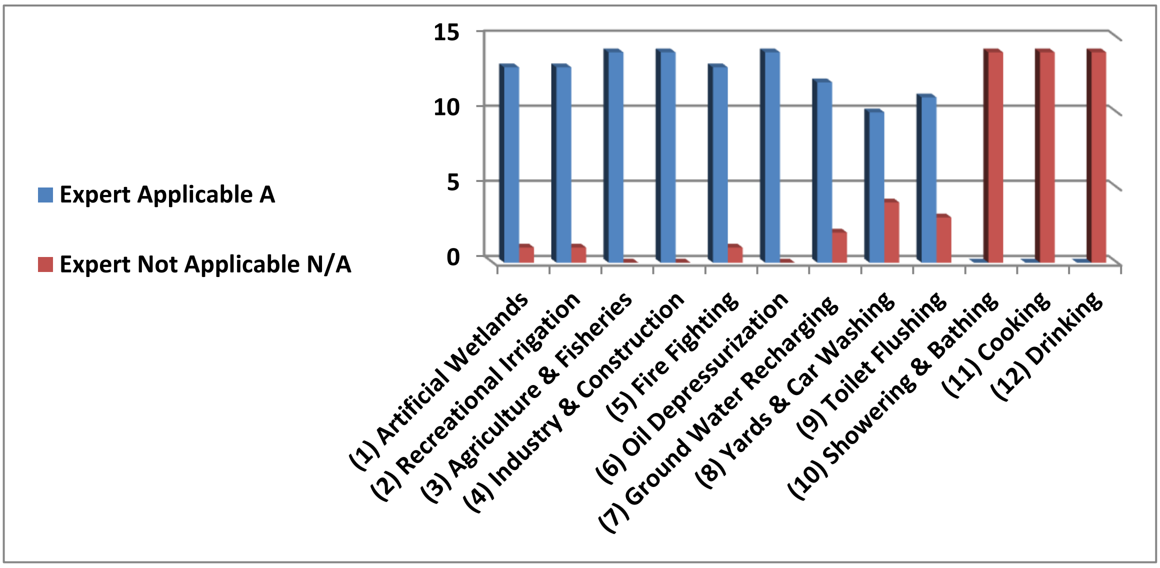

Figure (6A): **Result of Experts' EHR & SE Perception toward TWW Reuse Options in Kuwait**

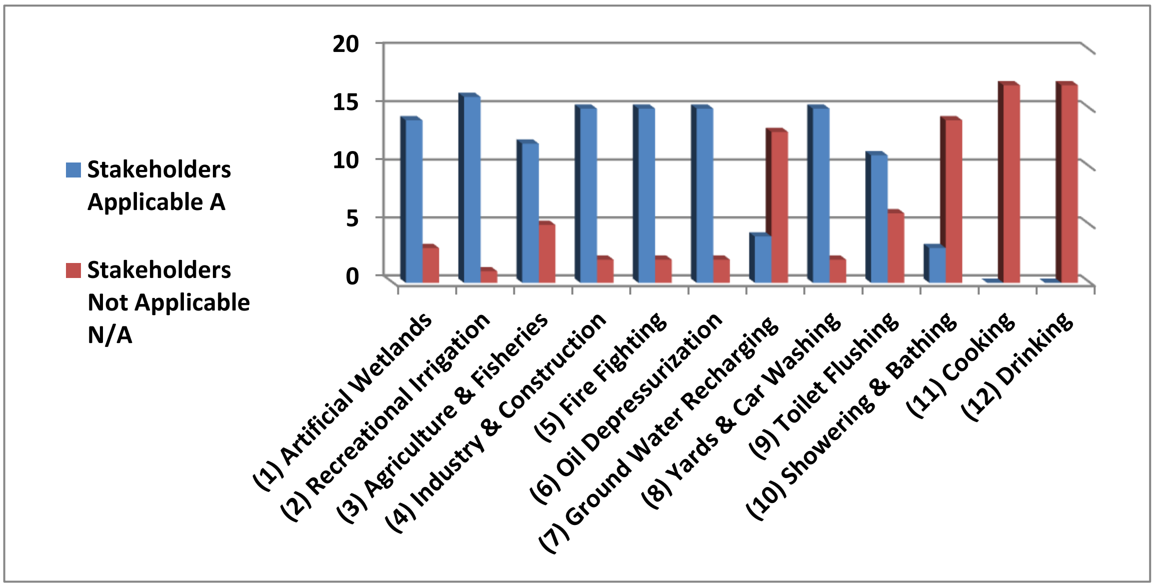

Figure (6B): Result of Other Stakeholders' EHR & SE Perception toward TWW Reuse Options in Kuwait

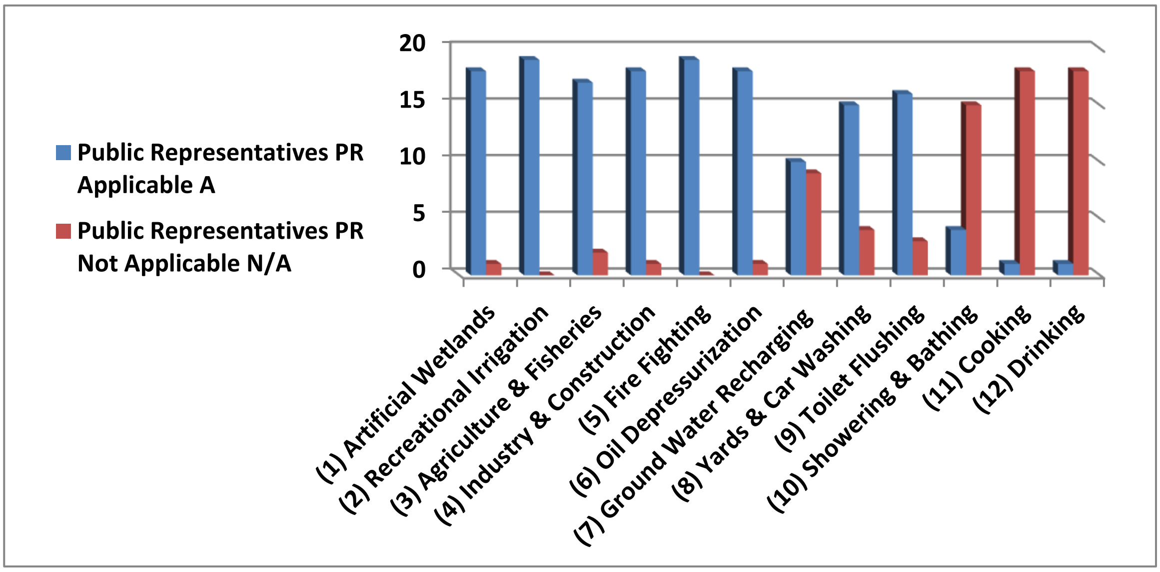

Figure (6C): Result of Public Representatives' EHR & SE Perception toward TWW Reuse Options in Kuwait

Appendix (7)

Expert Participants (EP) of the Pilot Study for Criteria Weighing (14 / 50 Participants)

Name	Specialty	Job Title
Ibrahim Abdel Gelil	**PhD - Chem Eng**	Prof in Env Management - AGU
Waleed Al-Zubari	**PhD - Water Resources**	Prof in Water Management - AGU
Adel Al-Saffar	**Sanitary Eng**	Head of Sanitary Eng Dept (WWTP's) - MPW
Husain Mohammed Gh	**Env management**	Researcher at Env Strategic Office (Kuwait EPA)
Salah Al-Saffar	**Sanitay Eng**	Head of Data Monitoring Center (DMC) - MPW
Hamed Eidan	**Env Management**	Researcher at Future Studies Dept (Ministry of Planning)
Adel Al-Doukhi	**Env Sciences**	Senior Eng at Sanitary Eng Dept - MPW
Baqir Darweesh	**Chem Sciences**	Director of Env Affairs Dept - MPW
Waleed Al-Saied	**Env Sciences**	Senior Eng at Env Affairs Dept - MPW
Nagla Attia	**PhD - Chem Eng**	Water & Wastewater Process Specialist at UDC
Ibrahim Al-Ghusain	**PhD - Env Eng**	WWTP General Manager at UDC
Sadeq Muqeem	**Env Management**	Env & Occupational Health Specialist (The Researcher)
Mohammed Al-Zaidi	**Business Adm**	Social Researcher
Isam Al-Sultan	**Env Supervision**	Supervisor at Cleaning & Agricultural Section - MOSAL

Appendix (8)

Targeted Expert Participants (EP) Groups' List
(Decision Makers, Specialists and Researchers, Expert Private Stakeholders and Experienced Public Representatives)
(MCDM and RIAM)

Name	Position / Job Title
1. Adel Al-Doukhi ***(M&R)G***	Senior Engineer - Sanitary Engineering Sector - MPW
2. Waleed Al-Saeid ***(M&R)G***	Senior Engineer - Environmental Affairs Department - MPW
3. Adel Al-Saffar ***(M&R)G***	Head of Sulaibiya WWTP (R.O. WWTP) – Sanitary Engineering Sector - Ministry of Public Work (MPW)
4. Salah Al-Saffar ***(M)***	Head of Data Monitoring Center (DMC) - Sanitary Engineering Sector - Ministry of Public Work (MPW)
5. Baqir Darweesh ***(M&R)G***	Director of Environmental Affairs Department - Ministry of Public Work (MPW)
6. Munthir Abu-Abbas ***(M)***	Head of Division - Environmental Affairs Department - Ministry of Public Work (MPW)
7. Abdullah Al-Onaizi ***(M)***	Senior Engineer at WWTP's – Sanitary Engineering / MPW
8. Hamed Eidan ***(M&R)G***	Head of Regional and Global Changes Monitoring Division - Future Study Department – Ministry of Planning
9. Husain Mohammed ***(M&R)G***	Head of Division – Kuwait Environment Public Authority (Kuwait EPA) - Environmental Strategic Planning Office
10. Ibrahim Thiab ***(M)***	Water Pollution Monitoring Consultant – Kuwait EPA
11. Prof. Saleh Al-Muzaini ***(M)***	Director of Environment and Urban Development Division - Kuwait Institution for Scientific Researches (KISR)
12. Yasser Qaffas ***(M)***	Doctoral Researcher in Urban Planning(UOB) - UK
13. Hussain Makki ***(M)***	Head of studies in National Oil & Gas, Former Environmental Specialist in Environmental Agency (Kingdom of Bahrain)
14. Prof. Ibrahim Abdel-Gelil ***(M&R)NG***	Environmental Management – Arabian Gulf University (AGU) – Kingdom of Bahrain
15. Prof. Waleed Alzubari ***(M)***	Water Resources Management – Arabian Gulf University (AGU) – Kingdom of Bahrain
16. Lamya Haider ***(M)***	Cartographer / MA in Environmental Sciences

17. Dr. Shaker Al-Hazeem ***(M&R)NG***	Associate Research Scientist in Marine Biology - KISR
18. Dr. Yousif Al-Osairi ***(M)***	Associate Research Scientist in Environmental Hydraulics - KISR
19. Habib Al-Qallaf ***(M)***	Hydro-geologist - Senior Research Associate - KISR
20. Dr. Abdu'ALLAH Abusam ***(M)***	Researcher in TWW at Kuwait Institution for Scientific Researches (KISR)
21. Dr. Ibrahim Al-Ghusain ***(M)***	General Manager - Utilities Development Company (UDC) – Sulaibiya (R.O.) WWTP
22. Dr Ahmad Agwa ***(M)***	Senior Drilling & W/O Engineer [Kuwait Oil Co.] (KOC)
23. Fadel Al-Koot ***(M)***	Senior Engineer at Kuwait National Petroleum Co. (KNPC)
24. Hassan Ashour ***(M)***	Senior Engineer Inspector at Project & Construction Department / KNPC
25. Hosam Jamal ***(M)***	Environment Engineer at Environmental, Safety and Health Department / KNPC
26. Saleh Muqeem ***(M)***	Senior Engineer / Drilling Dept. / KOC
27. Jalal Al-Teho ***(M&R) NG***	Public Authority of Agriculture Affairs and Fish Resources (PAAF)
28. Mohammed Al-Nasr ***(M)***	Public Authority of Agriculture Affairs and Fish Resources (PAAF)
29. Mohammed Atash ***(M)***	Public Authority of Agriculture Affairs and Fish Resources (PAAF)
30. Mohammed Tawfiq ***(M)***	Production Deputy Manager/ The United Agricultural Production Co. (UAPC)
31. Isam Al-Sultan ***(M)***	Supervisor at Cleaning & Agriculture Dept. / MOSAL
32. Saad Al-Dhufeeri ***(M)***	Supervisor at Cleaning & Agriculture Dept. / MOSAL
33. Mohammed Al-Zaidi ***(M)***	Social Researcher with Experience in Investment
34. Sahar Al-Terkait ***(M)***	Head of Medical Examinations at Occupational Health Dept. / MOH
35. Fuad Al-Saffar ***(M)***	Senior Lab. Technician at Occupational Health Dept. / MOH
36. Mahmoud Alkadhi ***(M)***	Senior Lab. Technician at Occupational Health Dept. / MOH
37. Hossam Al-Koot ***(M)***	Pharmacist - Teacher Assistant at Health Sciences College - Kuwait
38. Dr Fatma ***(M)***	FRCPC Physician at AL-Amiri Hospital in Kuwait

39. Yousef Al-Blooshi ***(M)***	Fire-Fighter at Kuwait Fire-Fighting Service Directorate
40. Yousef Al-Shuwaiye ***(M)***	Supervisor at Sanitary Eng. Dept. / MPW
41. Dr Hamdy Al-Gamily ***(M&R) NG***	Director of GIS Centre at KISR
42. Eng Shareef Al-Khayat ***(M&R) NG***	Head of Climate Change Section - Air pollution Department / Kuwait EPA
43. Eiman Mohamed ***(M&R)NG***	Researcher at Kuwait EPA / Water Management Dept.
44. Dr Abdul Nabi Al-Ghadban ***(M&R) NG***	Environmental Sciences Centre at KISR
45. Dr Yousef Al-Wazzan ***(M&R) G***	Desalinated Water and TWW Specialist and Research at KISR / MOE

Whereas:

M = Multi-Criteria Decision Making (MCDM)

R = Rapid Impact Assessment Matrix (RIAM)

G = Government Expert Participant (G-EP)

NG = Non-Government Expert Participant (NG-EP)

Appendix (9)

Method of Pairwise Comparison Between the Criteria (Saaty, 2008)

MCDM-AHP can be used for a wide variety of application. It can be used for strategic planning, resources allocation, source selection, business and public policy, program selection, etc. AHP can represent a reliable strong evaluation for both quantitative / qualitative criteria and alternatives on the same scale of nine levels (Figure 9A). Table (9A) represents the fundamental scale of absolute numbers.

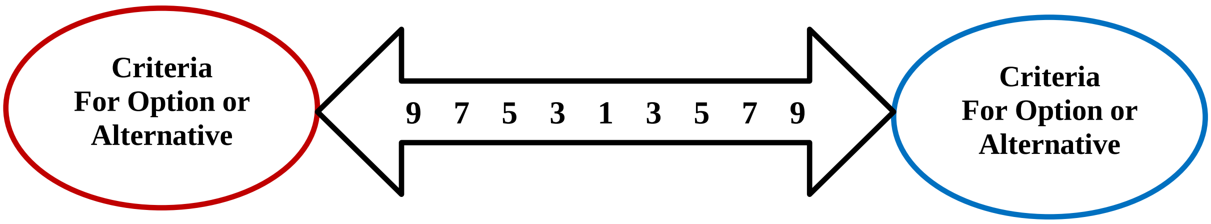

Figure 9A: Numeric Scale of Criteria Weighting (The Nine Levels)

Table (9A): The Fundamental Scale of Absolute Numbers

Intensity of Importance	Definition	Explanation
1	**Equal Importance**	Two activities contribute equally to the objective
3	**Moderate Importance**	Experience and judgment slightly favour one activity over another
5	**Strong Importance**	Experience and judgment strongly favour one activity over another
7	**Very Strong Importance**	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	**Extreme Importance**	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6 and 8 are Intermediate values when compromise is needed		

Decision process starts with generating priorities then organizes them into steps:

1. Defining and clearly specifying the problem.
2. Structuring the decision hierarchy into three levels; the goal on the top, criteria affecting alternatives in the middle, then the alternatives to the lowest level.
3. Constructing a set of comparison matrices (each criteria or element in an upper level is used to compare those in the level immediately below).
4. Weighing the priorities in the level immediately below using the priorities obtained from the comparisons.
5. Repeating step (4) for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority.

Continue this process of weighing and adding until the final priorities of the alternatives in the bottom are obtained. For reliabile priorities, they must be derived from consistent or near consistent matrices. A consistency check must be applied. The proposed consistency index (CI), which is related to the eigenvalue method:

$CI = (\lambda\ max-n) / (n-1)$, where λ max = maximal eigenvalue

The consistency ratio, the ratio of CI and RI, is given by:

$CR = CI / RI$, where RI is the random index

The random index is the average CI of 500 randomly filled matrices. If CR is less than 10%, then the matrix can be considered as having an acceptable consistency.

Table (9B): Random indices

n	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49