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Sustainable Water Management in Urban Environments (Gestão sustentável da água em ambiente urbano)

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Dissertação para a obtenção do grau de Mestre em Engenharia Civil

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ABSTRACT

Freshwater resources face serious challenges resulting from population growth and the requirements of global social, industrial and agricultural development in addition to climate change, which, in their entirety, cause the shortage/scarcity of available freshwater resources and the deterioration of their quality. These challenges are exacerbated in urban centres as focal points for water activities and needs. Therefore, the need for sustainable water management has emerged, especially in urban environments, through the efficient use of available water resources and the search for alternatives to natural fresh ones.

In this thesis, it is tried to outline the reality of water in urban areas, its development trends as a result of demographic and economic growth, and potential future challenges. It also presents some measures that can be implemented to increase the efficiency of water use in the urban environments, in terms of both the demand and the availability of water, which in turn will reduce the pressure on resources and meet the increasing water demand of social and economic development, thus improving the management and sustainability of water resources in urban areas.

Keywords: Water resources management, urban growth, sustainability, water use efficiency.

RESUMO

Os recursos de água doce enfrentam sérios desafios decorrentes do crescimento populacional e das exigências do desenvolvimento social, industrial e agrícola global, além das mudanças climáticas, que, na sua totalidade, causam a escassez dos recursos de água doce disponíveis e a deterioração de sua qualidade. Esses desafios são exacerbados nos centros urbanos como pontos focais para as atividades e necessidades hídricas. Portanto, surge a necessidade de uma gestão sustentável dos recursos hídricos, principalmente em ambientes urbanos, por meio do uso eficiente dos recursos hídricos disponíveis e da busca por alternativas aos recursos naturais de água doce.

Nesta dissertação, procura-se caraterizar a realidade da água em áreas urbanas, tendências de desenvolvimento tendo em conta o crescimento demográfico e económico, e potenciais desafios futuros. Também se apresentam algumas medidas que podem ser implementadas para aumentar a eficiência do uso da água nos ambientes urbanos, tanto em termos da procura de água como da sua disponibiliadade, o que por sua vez irá reduzir a pressão sobre os recursos de água doce e atender à procura crescente de água em consequência do desenvolvimento social e económico, melhorando, assim, a gestão e a sustentabilidade dos recursos hídricos nas áreas urbanas.

Palavras-chave: Gestão de recursos hídricos, crescimento urbano, sustentabilidade, eficiência do uso da água

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ABBREVIATIONS

DMAs - District Metered Areas

ESCWA - Economic and Social Commission for Western Asia

EWR - The Environmental Water Requirements

FAO - Food and Agriculture Organization of the United Nations

GAP - South-Eastern Anatolia Project

GDP - Gross Domestic Product

GHG - Greenhouse Gas

IBNET - The International Benchmarking Network

IEA - International Energy Agency

IHP - International Hydrological Program

IPCC - Intergovernmental Panel on Climate Change

IWA - International Water Association

MEA - Millennium Ecosystem Assessment

MNRW - The Manager’s Non-Revenue Water Handbook

NOAA - National Oceanic and Atmospheric Administration

NRW - Non-Revenue Water

OECD - Organisation for Economic Co-operation and Development

PRVs - Pressure Reducing Valves

UN - United Nations

UNDESA - United Nations Department of Economic and Social Affairs

UNEP - United Nations Environment Programme

UNESCO - United Nations Educational Scientific and Cultural Organization

UN-ESCWA - United Nations Economic and Social Commission for Western Asia

UNGA - United Nations General Assembly

UN-Habitat - United Nations Human Settlements Programme

UNICEF - United Nations Children’s Fund

UNWDPC - United Nations Water Decade Programme on Capacity Development

US - United States

USCB - United states Census bureau

WHO - World Health Organization

WRG - Water Resources Group

WSS - Water Supply System

WWAP - United Nations World Water Assessment Programme

CHAPTER 1

INTRODUCTION

Global socio-economic and technical growth and the resulting pressures on natural resources, especially water, have prompted both utilities and decision-makers, who are concerned with securing water demand, to question the amount of current water use, its use efficiency, and how they will evolve through the coming decades. However, obtaining accurate answers is not easy due to the multiple factors affecting water uses, such as social mores, cultural heritage, population and economic growth, the subsequent technological development, prosperity, and food regimes change, which determine the current and future water demands. The evolution trends of these factors and how they affect water demand in the future is fraught with uncertainty.

One of the most important goals of water management is to supply water in the appropriate quantity and quality for each one of the different uses. With the occurrence of water stress in many regions of the world, the need to improve the management of the water sector has grown, so programs to reduce demand and improve the efficiency of use, depending on technical and administrative measures, especially in developed countries, have appeared. While developing countries are still experiencing difficulties in applying similar measures due to the limited availability of capabilities and technical skills, which are accompanied by poor infrastructure and management systems (Sharma & Vairavamoorthy, 2009).

Increasing demand for water is one of the most serious challenges faced by urban centres due to the rise in the needed water requirements to secure food, energy, and water-related services, as well as industrial demand. Thus, it is necessary to improve traditional solutions and to seek alternative water resources and improve the efficiency of limited supplies used to meet the water demand.

The global water demand was estimated at 4,600 km^3 in 2016, and is expected to grow at a rate of 1% per year (Burek *et al.*, 2016), which threatens to expand the areas exposed to water scarcity, and thus an increase in the number of people who would live in scarcity conditions. However, the uncertainty of future expectations related to the availability of water resources on the one hand and the demand on the other hand cannot be ignored, due to the multiplicity of controlling factors and the dimensions of their impact.

Demographic growth, urbanization, and the resulting increase in industrial and agricultural production and consumption are causing the rapid growth of water demand, which undermines the planet's ability to meet demand and immediate access to freshwater resources.

During the last century, with the gradual rise of incomes and improved living standards, development plans focused on expanding food and energy production, which constituted a burden, especially in areas suffering from water scarcity and / or mismanagement of water resources in terms of allocation, distribution and pricing (WWAP, 2012). Therefore, the world is likely to face a deficit in meeting future water demand if it continues to follow a business-as-usual approach.

Urbanization increases the challenges faced by water utilities and development planners, especially in developing countries that cannot keep pace with the rapid growth of urban centres and absorb the numbers of arrivals. Slums appear and the problems of servicing them aggravate, in addition to the exacerbation of the water shortage dilemma due to the limited resources and deterioration of its quality, due to the impacts of diverse and concentrated urban activities, coupled with the increase in demand and inefficiency of managing the water sector, which impedes securing a regular and sustainable supply of safe water to ensure the well-being and dignity of users.

According to the report of the World Economic Forum (2015), water scarcity and supply crisis are considered among the most serious issues humanity faces, as they constitute obstacles in the way of social and economic development. The overlap and complexity between the water sector and the different use cycles create the difficulty of accurately estimating the problem of scarcity. For this reason, water scarcity has been addressed from social, economic, and environmental perspectives, seeking to deepen understanding of the problem and trying to find effective solutions. It can be noted that the areas which suffer from severe water scarcity are often areas with high population density (urban centres), irrigated agricultural areas, or arid areas, and the problem of scarcity is more serious if these conditions occur simultaneously in the same place, as is the case in the Arab regions. One of the clearest indications of the occurrence of water scarcity is the decrease in the river flows, lake levels and groundwater tables, because of higher consumption compared to available quantities (Shi *et al*., 2014).

Global climate change is also considered one of the most important factors affecting the quantitative and qualitative availability of water and impedes the efficient and sustainable management of the water sector (IPCC, 2014). Despite the uncertainty of all dimensions of the climate change impact accurately, given that it is a phenomenon that is constantly evolving and affected by many factors, it can be said that its most important manifestations are extreme events and the temporal, spatial and quantitative difference of precipitation that play a main role in determining the proportion of renewable water resources (Alavian *et al*., 2009), as well as an increase in temperature rates (Hipsey and Arheimer, 2013). It is clear that the recurrence of extreme events and their direct and indirect impacts during the past decades have drawn the features of the emerged water policies, which aim to achieve sustainable and flexible water management, which adapts to the variables, especially climatic ones (Lemonsu *et al*., 2013).

With the growth of human and natural activities, attention has also turned to the water quality and to all activities that cause its deterioration, which would reduce the quantities of water available for safe use, thus increasing the possibility of exposure to water scarcity and impeding development in all related areas (UNEP, 2010). The various kinds of pollutants and their concentrations, the impacts of ecosystems, hydraulic cycle and climate change, the patterns of uses and discharged liquid wastes and how to manage and dispose them are essential elements for understanding and solving pollution problems, thus, improving the quality of water and increase its availability.

In this thesis, an attempt will be made to mention the most important factors affecting water supply and demand. The first part of this thesis aims to give an idea about some issues related to water availability and the drivers of water demand, how both have evolved over time, and their effect on the ecosystems that play a fundamental role in the hydrological cycle. In addition to the phenomenon of urbanization and the challenges it poses, water scarcity and the factors that exacerbate it, climate change and an attempt to clarify some of the links between it and the water sector are also discussed. Also, the importance of water quality as a critical criterion of safe use will be argued and some of the most common pollution causes will be mentioned. Besides, some examples of fighting for water and using water as a tool of conflict are cited. Then, the most important water management practices are presented, and some of the challenges which facilities and managers face. After that, the second part of the thesis deals with some of the measures and techniques that could be implemented to manage water in urban areas in a more sustainable way and with more efficient use. It starts by describing the mechanism and nature of each measure, the benefits that can be obtained and the weaknesses of each one, including rainwater harvesting, wastewater reuse, water losses management and desalination, which would provide alternative water resources with an appropriate quality for the intended uses. The thesis will then discuss managing and reducing the demand as a measure that would contribute to conserve water and reduce the burden on water resources and facilities.

CHAPTER 2

WATER IN URBAN ENVIRONMENT (CURRENT SITUATION AND FUTURE CHALLENGES)

The planet's hydrosphere, lithosphere and atmosphere are integrated through the interlocking cycles that accompany the different planetary processes. Despite the existence of this integrated system, human interventions have diverted the path the planet used to take. The challenges of the last century (most of which continue into the present century) imposed pressures and relatively new situations that made it difficult to deal with planetary issues in the same way. These challenges of environmental degradation, limited resources, economic and financial crises, religious conflicts, political and economic disparities within and between countries, thus creating conflicts to achieve strategic goals and other issues were a result of the accelerating global demographic, economic and technological trends.

Since the environment is our main incubator that sustains us, interest has begun to explore the effects that human activities impose on the environmental elements and deepen our understanding of them, with the aim of finding the best ways to mitigate them and limit as much as possible the practices that may exacerbate them.

Although countries' awareness of the environmental degradation that has appeared and continues to evolve, the first step at the global level came relatively late through the United Nation (UN) Environmental Conference held in 1972 (UN,1972). This conference is considered the seed of international cooperation in the field of the environment, as it referred to the global environmental risks resulting from human activities, and it called on the international community to cooperate in the field of improving and developing the environment by supporting serious and organized work and exploiting human creativity in the field of science and technology, with the aim of protecting the environment and sustaining Ecosystems to serve future generations.

The UN Water Conference of 1977 focused on water as an environmental and vital resource, discussed the causes of the imbalance of water systems and the consequent environmental, social and economic impacts, in a serious attempt to address the global crises related to water and try to bridge the gap caused by the increasing and accelerating demand for water. Meetings and conferences dealing with water resource issues continued to provide the international community with developments, to deepen understanding of the challenges and expected risks, and to develop programs and strategies to mitigate and confront their effects.

In 1998, the UN Commission on Sustainable Development launched the principle of "strategic approaches to freshwater management", regarding water as an essential component of sustainable development (UN, 1998). The critical role that water plays in all political, economic, social, and environmental sectors has been recognized, and its reflection on the sustainability of stability and well-being.

Achieving sustainable water management requires knowledge and understanding of the quantity and quality of available water resources on the one hand and the areas and methods in which these resources are consumed on the other hand, in order to know the current and future effects of the administrative tools and methodologies used and strive to improve them in order to achieve the goal of sustainability.

The sectors of agriculture, industry, energy production and human consumption are the primary users of water. However, what is of concern is the mismatch between the water needs of these activities and the available water resources in different regions of the world, and thus the deficit in meeting the needs has led to the so-called water scarcity. There is no doubt that the phenomenon of water scarcity has expanded in recent years. Consequently, water scarcity was and is still a reason impeding economic and social development in many regions, prompting a focus on water scarcity research to find effective plans and use them to manage water in a sustainable manner. As a result, knowledge of the amount of water available and an understanding of how it is used has been deepened. However, facing water scarcity is still under discussion because it requires a deepening awareness of all relevant factors such as climate change, population growth, human activities and their interaction, and their effects on water demand on the one hand and on water availability and quality on the other.

2.1. Water availability

As mentioned earlier, the hydrosphere is one of the components of the planet and is essential to ensuring survival and well-being. It constitutes 71% of the planet's surface, of which 3% is freshwater, while the rest is seas and oceans' water. Eighty percent of the total daily use water is drawn from surface water (lakes, rivers, streams, and seas). In theory and as studies indicate, the global supply of freshwater can cover current and future needs, but research confirms that the heterogeneity in spatial and temporal distribution exposes many regions due to insufficient resources to meet their domestic, economic and environmental needs. This disparity in distribution made many regions unable to provide basic water needed for drinking and sanitation purposes. It has been observed that about a third of the population worldwide do not have access to clean, easily available water at houses and that 2.3 billion suffer from a lack of basic sanitation services (WHO, 2017). This, as a whole, negatively affects human health and productivity, which in turn is reflected in economic development, health of ecosystems and environmental cleanliness.

It can be said that the amount of available surface water is relatively constant at the global level, as freshwater resources are replenished through the water cycle which consists mainly of evaporation, condensation, precipitation, infiltration and surface runoff processes. If the available freshwater is distributed around the world equally, the per capita share will range between 5,000 - 6,000 m^3 per year, but the truth is that the distribution of these resources varies from one place to another, as is the case for the population and its activities. It is observed the quantitative changes of renewable water resources at the regional level that is more pronounced at the national level, especially in cases of transboundary basins, and this apparent change is often the result of climate change and extreme climatic events (Burek *et al*., 2016).

Water scarcity is a regional, national and local phenomenon, and to clarify it, thresholds have been set for the annual per capita share of renewable water at the national level in order to be able to estimate the level of scarcity to which the country is exposed (Falkenmark and Widstrand, 1992), but this criterion faces inaccuracies in terms of the difference in demand pressure on water resources (the ratio of withdrawals for agricultural, industrial and municipal uses to renewable water) from one region to another within the same country, thus the per capita variation (which is apparent and large in countries spanning vast areas such as China, Australia and the United States)does not appear .

Likewise, the seasonal variation in the quantities of available water, which has a strong influence on supply and demand (varies between dry months and wet months) in many countries, is ignored according to the previous criterion, which mainly depends on annual averages of available water (Sadoff *et al*., 2015).

The hydraulic variability of the water cycle is primarily influenced by climate. Evaporation rates and precipitation patterns are critical factors for the availability of water resources. Climate change drives these factors to volatility, which affects the water demand / supply ratio. The higher the demand to supply ratio, the greater the region’s exposure to water stress and water scarcity. However, the heterogeneity between supply and water demand is not the only cause of water scarcity, as many areas suffer from water scarcity regardless of the amount of water available, and this is due to reasons related to failure of water service providers distributing water equitably to users (institutional scarcity) and / or inadequate water system infrastructure for operational financial or technical reasons (economic scarcity) (FAO, 2012).

Thus the seasonal availability of freshwater follows the distribution of precipitation and surface runoff, which is uneven, as different regions of the world receive precipitation that vary according to the different arid and wet climates, which is reflected in the quantities of available water from one place to another, and also directly or indirectly reflected in the hydrological cycle as a whole (surface runoff, recharge of aquifers, water quality, etc.) (Alavian *et al*., 2009). This temporal and spatial disparity of precipitation can expose regions to drought / flood risks unless adequate infrastructure is available (economic scarcity) supported by regulatory frameworks and institutions (institutional scarcity) to ensure the rational management of the water provided.

These surface resources are used when they are available while resorting to groundwater that represents reservoirs which provide the necessary quantities to meet the water supplies needed for social, environmental, and economic development in times of drought (WWAP, 2012). Groundwater supplies about 2.5 billion people with the basic daily needs of water, while hundreds of millions of farmers depend on this resource to sustain their agricultural activities, which contributes to the food security of others (UNESCO, 2012). Data provided by the World Water Assessment Programme (WWAP, 2012) indicates that the rate of groundwater withdrawal is increasing at a rate of 1-2% annually at the global level, and that 20% of aquifers are subject to overuse in regions such as China, India and the United States (Gleeson *et al.*, 2012), and through studies it was found that areas exposed to groundwater stress are often the same as areas exposed to severe surface water stress. This increase in the rates of groundwater extraction exposes this resource to the risk of depletion in many areas, especially in light of the uncertainty of its availability and rates of replenishment (van der Gun, 2012). Due to the importance of this resource in various areas of development, especially the environment (sustaining the flows of rivers and important ecosystems), it is important to secure appropriate management for it through sustainable withdrawal and recharge (natural or artificial) (WWAP, 2012).

Water quality is an important factor affecting and determining the amount of resources available for various uses. As found recently, human activities such as industrial production, agriculture (especially industrial agriculture in which large quantities of fertilizers are used), mining, wastewater and other sources of pollution have caused many problems related to water quality, which has led to an environmental and health threats. Likewise, the ecosystems on which the water cycle relies mainly for purification and storage have been degraded by deforestation, the increase in impervious areas (urban areas) and pollution, and they are no longer able to perform their function, which in turn is reflected in the quality and availability of water (UNDESA, 2012). The deterioration of ecosystems and their approach to the thresholds of collapse have made the global environmental situation critical (UNDESA, 2012) due to the failure of administrative and executive decisions taken in the past, economic policies often dominated those decisions without taking into account the environmental impacts and social repercussions. Despite all international efforts seeking to create cooperation in the field of environmental development at all levels, the logic of achieving economic goals (albeit short-term) overshadows the long-term environmental development goals in many of the countries` policies.

2.2. Water demand

The demand for water has increased six-fold over the past century (Wada *et al.*, 2016) as a result of the increasing population, development requirements, changing feeding patterns and the trend towards animal products (which consume more water) (Falkenmark *et al.*, 1989; Vörösmarty *et al.*, 2000). This increased pressures on water resources and exposed many areas to water scarcity (the inability of some / all sectors to meet water demand), which made the water supply crisis one of the most important threats the glob face (World Economic Forum, 2015). Understanding the dimensions and causes of water scarcity and the deterioration of its quality is a key to find the solution and to develop appropriate policies starting from the international level and ending with the local one (UN, 2015). The global demand for water in 2016 is estimated at approximately 4,600 km3 annually, and it is expected to continue to increase by about 1% annually, to range between 5,500 and 6,000 km3 per year in 2050 (Burek *et al.*, 2016). The increase in demand will be accompanied by a possible expansion of water-scarce areas and exposing more people to conditions of scarcity of water resources. In 2050, it is expected that between 4.8 - 5.7 billion people will live in different regions of the world exposed to water scarcity for at least one month annually, 69% of them are distributed in the regions of South and East Asia, while most of the rest is concentrated in Africa (North in particular) (Burek *et al.*, 2016).

The world demand for water is shared by the agricultural, energy, industrial, domestic, and ecological sectors. The agricultural sector, for example, is the largest consumer by about 70% of the global level (UNWWD, 2017). It is expected that demand in 2050 will increase by 5.5% more than it was in 2008. This increase, although seemingly insignificant, is a cause for concern, as it will occur mainly in areas already vulnerable to water scarcity (FAO, 2011a). However, it is worth noting that uncertainty always accompanies water-related issues, for example the prediction of water needs for agricultural irrigation is affected by many factors, including the difference in the quantities of water used depending on the type of crops, the season of cultivation, the soil, the climate, growing food demand, and the irrigation techniques used (WWAP, 2009).

Industry and energy as a whole rank second at the global level, with a rate of about 20% of global consumption, 20% of which is used for industrial production, while the largest consumption, estimated at 75%, is for energy production (WWAP, 2014). Global water withdrawal for industrial production is expected to increase in 2050 by four times than it was in 2000 (OECD, 2012), but the distribution of this demand varies from one region to another depending on economic development conditions. For example, in the regions of South, Central, East and West Africa, where the amount of water consumed for industrial production was small compared to other sectors, the demand for water to boost industrialization will double to about eight times compared to what it was in 2000 due to the acceleration of economic development, while water withdrawal for this sector will reach up to 250% compared to what it as in 2000 in the Eastern and Southern parts and the Centre of Asia (Burek *et al.*, 2016). In contrast, Burek *et al*. (2016) believe that there is no increase in the demand for industrial water in North America and Southern and Western Europe.

By researching the water needs for energy sector, it is found that the water supply (consumed and non-consumed) amounted to 583 billion m^3 in 2010, and according to the International Energy Agency (IEA, 2012), 66 billion m^3 of those were consumed. And the agency predicted that this use would increase at a rate of one-fifth until 2050. It is observed in Europe that 43% of the total water withdrawals are used to produce electricity from thermal power (Rübbelke and Vögele, 2011), while the percentage reaches 50% of the total withdrawals in the United States. In developing countries, the amount of water used in the various stages of energy production is low compared to agricultural water needs (World Bank, 2012b).

The percentage of water used for domestic purposes of the basic needs of the family (drinking water, hygiene, sanitation, etc.), schools, hospitals, municipal needs, and small to medium-sized activities represents about 10% of the total global water demand, and this use is expected to increase by 130% in 2050 (OECD, 2012). This increase is worldwide except for Western Europe, which is expected to maintain constant rates of domestic consumption. Meanwhile, different regions of Asia and Africa (where population growth rates are the highest in the world, as will be explained later) are expected to experience an increase that could exceed three times the volume of their consumption in 2010 (Burek *et al.*, 2016) The expansion in the supply of water services is likely to be the main reason for this increase.

Regarding the environment and ecosystems sector, the Environmental Water Requirements (EWR), which is quantities of water needed to maintain water bodies and provide ecosystem services, have been estimated to be equivalent to 20-50% of the annual river flows into a basin (Boelee, 2011). The environment has been neglected for a long-time during development and decision-making processes, considering environmental development as separate from other areas of development until the effects of ecosystems degradation began to appear, which led to increased interest and research, and the realization that preserving ecosystems and sustaining environment guarantee human needs and well-being.

Increasing agriculture, industry, energy, and domestic water demand

The demand for freshwater is constantly increasing because of population growth, urbanization, and the consequent increase in production and consumption in the fields of industry, energy, and agriculture. All this undermined the planet's ability to meet the growing demand and immediate access to freshwater resources. During the twentieth century, with the gradual rise of incomes and improved living conditions for the middle class, development plans for water resources were mainly directed towards expanding food and energy production, which was to some extent unsustainable, especially in regions that suffer from scarcity of water resources or mismanaged them in terms of allocation, distribution and pricing (WWAP, 2012). The world is expected to face a deficit in meeting the growing demand by 2030, if management strategies continue to adhere to the business-as-usual scenario, equivalent to 40% of the available water (2030 WRG, 2009). The population growth coincided with the growth of income, has led to a change in consumption patterns related to food and housing (large homes with gardens and swimming pools) and the ownership of amenities such as cars, electrical appliances, etc., which was directly reflected in the quantities of water required for using or energy production (WWAP, 2012).

Population around the world, which is expected to reach approximately 9.3 billion in 2050, with an increase rate of 33% over what it was in 2011 (UNDESA, 2011), will contribute to increasing pressure to produce goods and provide services and water needs for the increasing numbers. The World Health Organization(WHO) (UNICEF / WHO, 2015) estimated that the equivalent of 1.8 billion people are deprived of access to safe water for human consumption and that more than 2.4 billion people lack improved sanitation facilities, one billion of them still use the open air.

As a result of the increased demand for food, industrial crops, and biofuels, agricultural activities increased. Agriculture uses 70% of global water withdrawals, and the percentage in less developed countries reaches 90% (FAO, 2011a). The volume of groundwater extracted globally for irrigation purpose in 2010 was estimated as 800 km^3, when 67 % of this was used in the US, Iran, China and Pakistan, but it is expected to undergo a significant increase in 2050, reaching 1,100 km^3 annually, at a rate of up to 39% compared to 2010 (Burek *et al*., 2016). Also, the growth of industrial production was accompanied by an increase in the amount of water used during production processes or polluted as a result of the absence of regulatory frameworks and standards that guarantee the preservation of ecosystems and the environment.

2.3. Ecosystem status

The various human activities and their interventions in the natural cycles, including the hydraulic one, directly affected the environment and the ecosystems. The area of the world's forests is estimated at about 30% of the land, but more than two-thirds of these forests are in a state of degradation (FAO, 2010). Work has started since the eighties to discourage deforestation and compensate for lost areas through cultivation (FAO, 2016). Grasslands also spread naturally in dry or very cold areas, while efforts to expand these areas have been done by humans with the aim of grazing and / or crop production.

Davidson (2014) wrote in his report that the proportion of wetlands that were already lost ranges between 64-71% of the area they occupied in 1900, and that the loss was concentrated in the interior regions. The rate of loss was very high in Asia, while it tended to decrease in North America regions since the eighties of the last century and European countries by taking effective measures, were able to make the rate of loss slow down. It is difficult to quantify the effects of losing wetlands at the global level due to the diversity of their properties and services, and their direct effect on the hydraulic cycle (Bullock and Acreman, 2003). Human practices from agriculture and overgrazing pose a major threat to wetlands, which are an essential part of the ecosystem. The role of grazing activities in compressing the soil and reducing its permeability has been proven (Bilotta *et al*., 2010), thus increasing surface runoff and inability to mitigate the risks of floods and droughts (Jackson *et al*., 2008), which has a negative impact on water quality (McIntyre and Marshall, 2010).

Water flows have an important role in maintaining ecosystems and thus the continuation of their services that ensure the sustainability of water resources. The quality and quantity of these flows and their temporal distribution are critical factors for ensuring the health and efficient functioning of ecosystems. Water flows maintain soil moisture, wetlands, and water levels in the floodplains, as for floods, they recharge groundwater (some types of natural water storages). Therefore, it is important to include keeping EWR in water bodies while setting the water management strategies, so that the ecosystem can serve the water cycle, which in turn supports human activities (Boelee, 2011). Many studies indicated that the natural water storages can be more efficient than an artificial infrastructure from an economic and sustainable perspective (OECD, 2016).

Land use or changing the forms of its use are among the most important factors causing the degradation of ecosystems, increasing their vulnerability and exposure to hazards (Renaud *et al*., 2013). For example, in the Mississippi River, the construction of a dam upstream resulted in impeding sediment flows needed to preserve coastal wetlands, including mitigation systems and protection services from storms and floods in the delta region and that was one of the most important factors of vulnerability to face Hurricane Katrina in 2005 (Batker *et al*., 2010). Consequently, the degradation of ecosystems coupled with climate change and extreme climatic events exposes many areas (such as delta areas where human populations and activities are concentrated) to risks (Munang *et al*., 2013). Confronting this reality requires the wise management of water and land.

2.4. Urbanization

The population of urban areas constitutes about 54% of the world's population (3.9 billion (UNDESA, 2014)). In 2015 there were 23 cities with a population exceeding 10 million, 19 of which were in developing countries (UN-Habitat, 2006).

As previously mentioned, the world population is expected to reach 9.1 billion by the year 2050 (UNDESA, 2009), and this growth is expected to be concentrated in urban areas, where its population is likely to reach 6.3 billion, an increase of about 2.9 billion more than it was in 2009 (UNDESA, 2011), which means that forecasts indicate that urban areas will absorb most of the population growth and will also be centres of attraction for a large number of rural residents (WWAP, 2012). The cities of developing countries, in both Asia and Africa, will be centres to accommodate most of the urban growth (UN-Habitat, 2010). This increased growth will be the main reason for the exacerbation of the problems facing urban centres (megacities), especially in developing countries that are unable to keep pace with this rapid growth. This variation between the increase in demand for housing or/and freshwater resources (especially in drought-prone areas), pollution, changing the use of lands (e.g. impervious areas) and their implications. Urban expansion and migration from the countryside to the city imposed the emergence of slums and illegal residences in the margins of cities, which posed a challenge in the areas of expanding drinking water and sanitation services to reach residents of crowded slums, in order to achieve the principle of equality in the distribution of services and to prevent the spread of water-borne diseases (WHO / UNICEF, 2006, p. III). In addition to the challenges of planning the expansion of water services, urban growth will require an increase in the amount of water withdrawn for domestic use and for energy and food production (agriculture and food industry) (WWAP, 2014), thus exacerbating water scarcity mainly at the local level, which can expand to include the national or regional level. Previous pressures parallel to environmental pollution caused the degradation of ecosystems, which tend to be unable to secure a regular and sustainable supply of clean water (UNDESA, 2012).

This urbanization led to a doubling of the demand for water (Shiklomanov, 1999; USCB, 2012), which was faster than efforts to improve water and sanitation services that service providers, municipalities, and related institutions sought to secure in a manner that guarantees the well-being and dignity of users (UNDESA, 2009).

To meet the water demand in urban areas, it is necessary to import water from watersheds and streams located in the vicinity of urban centres (surface water) or pump out groundwater, which is the main source in many areas that suffer from scarcity of surface water (UNEP / GRID-Arendal, 2008). However, the unfair exploitation of groundwater resources has led to a decrease in their levels and a decline in its quality, as happened, for example, in Shanghai, Beijing and Manila (Foster *et al*., 1997). Low water tables of coastal aquifers can lead to saline water penetration and pollution of fresh groundwater resources. In Europe, for example, studies have shown that there is an overlap between salt water and ground freshwater in 53 coastal regions as a result of the unwise employment of groundwater in most of these places to supply activities in urban areas (Chiramba, 2010).

The WHO estimated the proportion of urban population with access to improved drinking water at about 94% (WHO / UNICEF, 2010), and it indicated that this percentage does not take into account factors of service quality (such as intermittent supply), the ability to cover the cost, or even an inaccuracy of counting the urban population that was lacking an adequate supply of drinking water due to the lack of reliable data (noting that their number is constantly increasing with urban expansion (UN-Habitat, 2003, 2010)). The WHO reported that 2.6 billion do not have access to improved sanitation facilities even after 1.3 billion people were provided with these services during the period between 2000 and 2008, 64% of them lived in urban areas (WHO / UNICEF, 2010), and that people who obtain water from sources different from household faucets or sources close to their residence have increased during the same period (2000-2008) by 114 million (AquaFed, 2010).

Also, urban expansion in light of failure to manage water resources and services exacerbate urban pollution problems. Urban centres (especially megacities) are points of spreading pollution and causing environmental degradation from untreated or partially treated domestic and industrial wastewater in most regions of the world. Corcoran *et al*. (2010) reported that more than 80% of the world wastewater is untreated or uncollected and that this percentage increases in developing regions to 90% of wastewater discharged to water bodies or marginalized and neglected lands without proper treatment, causing contamination with chemicals, organic matter, pesticides, heavy metals pathogenic bacteria, etc.., and this pollution can also transmit to groundwater (UNEP / GRID-Arendal, 2008).

Based on the aforementioned and with the addition of the fact that most cities import food, commodities and energy from outside their boundaries and the additional water demand accompanying the production and transportation processes reaching the user, the impact of urban centres exceeds their administrative boundaries and their water needs outweigh the direct uses (Hoekstra and Chapagain, 2006).

2.5. Water Scarcity

According to the World Economic Forum 2015 report on global risks 2015 (World Economic Forum, 2015), water scarcity and the supply crisis were considered the greatest risk and the highest impact on humanity today, due to the inability of all sectors in many regions to meet the necessary and increasing water demand for different uses, in line with population growth and economic development, which led to scarcity or stress on water resources and deterioration of their quality (Falkenmark *et al.*, 1989; Alcamo, *et al*., 2000; Vörösmarty *et al.*, 2000).

Water scarcity has attracted attention since the late 1980s, after the obstacles it poses in the way of social and economic development, and the threats it poses in different regions of the world, were recognized. so, it was necessary to realize and enhance knowledge of the concept of water scarcity and its environmental dimensions (availability of resources, their quality and water flows required to maintain ecosystems ... etc.) and social (basic needs of water, food, work, etc.) as well as economic (such as industry, energy, virtual water trade and globalization). Despite the multiplicity of studies, accurately assessing water scarcity, it remains a difficult matter due to the complex relationship between population growth and water availability and its uses on the one hand, and the ramifications and overlaps between the water sector, other sectors and their mutual influences on the other hand. Likewise, the temporal and spatial distribution of precipitation and the consequent variation in patterns of demand and consumption add a critical factor to understanding and estimating water scarcity. This is why water scarcity has been explored from economic, social, hydrological and environmental points of view in many researches seeking to complete the picture and deepen the understanding of the problem in order to reach effective policies from the global to the local level to solve the problem of water scarcity as stated in the International Hydrological Program (IHP-VIII). This deals with water security (2014-2021) (Montanari *et al.*, 2013) and reducing the number of people affected by water scarcity as stated in the sustainable development goals adopted by the UN (UN, 2015a).

As mentioned earlier, the freshwater needed to meet the increasing demand resulting from population growth and changing consumption patterns as a result of the improvement in the standard of living (Vörösmarty *et al.*,2000; Ercin and Hoekstra, 2014) is available at the global level, but the variation in spatial and temporal distribution coupled with the difference in demand constitutes an obstacle to achieving a balance between supply and demand which leads to problems of water scarcity as is the case in different parts of the world (Postel *et al.*, 1996; Savenije, 2000). Hence, the estimation of water scarcity must consider the temporal factor and spatial extension, for example the annual estimates ignore the seasonal or even the monthly variation of available water, so that the estimation of water scarcity reduces. Also, the studies of water scarcity at the regional and national level (in countries with large areas) proved that the estimates of water scarcity departed from the realistic situation due to several factors including the irregular distribution of the population, the diversity of activities and their different needs, the variation in precipitation quantities and the diversity of climatic regions, (Hanasaki *et al.*, 2008; Hoekstra *et al.*, 2012). In addition, the inclusion of water flows necessary to maintain the sustainability of ecosystems and their services while water scarcity investigating and estimating global vulnerability is an important factor (Hoekstra *et al.*, 2012).

It is noticeable that areas of severe water scarcity are often the same areas with high population density (urban centres) or areas where irrigated agriculture is widespread or both together, as well as in areas that suffer from scarcity of natural water resources such as arid areas, and the matter gets worse if it meets the three together, as is the case in some Arab regions.

The decrease in river flows, lake levels and groundwater tables are the inevitable result of the high amount of water consumption compared to the available quantities, especially in periods of drought, which exposes some rivers to drought or a severe decrease in the rate of their flow before reaching their final estuaries such as the Yellow River in Northern China (Shi *et al.*, 2014). An example of lake, that is exposed to a significant drop in the level, is Chad lake in Africa (MEA, 2005; Coe and Foley,2001), while groundwater depletion is spreading in different countries such as India, Iran, Saudi Arabia and the United States (Gleeson *et al.*, 2012; Wada *et al.*, 2012).

Urban areas are more vulnerable to water scarcity due to the rapid population growth and receiving emigrants from rural areas (searching for better living conditions) and the growth of individual water consumption demand due to economic growth. This has caused the relative concentration of water demand in small regions, and the emergence of the challenges of the deficit of both infrastructure and water resources to meet the necessary water services for social and economic development. The countries of the Middle East and North Africa provide a clear example of the consequences of water shortage. The rapid population growth in parallel with poor living conditions, insufficient access to water and sanitation, and the existence of most of them in arid or semi-arid regions, exposes the region to complex water crises and challenges (World Bank, 2019).

The Middle East constitutes 5% of the world's land area and is home to 4.4% of the global population, while its renewable water resources are estimated at 1.1% of the renewable water resources worldwide. The average annual per capita quota in the region is 16.66% of the global average, which is equivalent to 720 m^3 (World Bank, 2007). The physical scarcity of water is particularly increasing in the Arabian Peninsula, which occupies 47% of the entire Middle East with renewable water resources not exceeding 1% of the Middle East's renewable resources (Kuwait, for example, does not have renewable internal water resources). As a result, it has been directed to exploit groundwater until it reached the threshold of unsustainable use (especially for irrigation, which uses 80% of the withdrawn water). Also, transboundary rivers and groundwater pose additional challenges that require finding effective forms of international cooperation in managing these resources (ESCWA, 2013). There are nine shared river basins, including the Tigris and Euphrates basins, which occupy 10% of the Middle East area and the Jordan River basin that flows towards the Dead Sea. In addition to 20 common aquifers between at least two countries, the stock of which is estimated at 2000 km^3 with a renewal rate of 0.05% of stock size (ESCWA, 2013). Estimates in the Middle East indicate a decrease in the supply of water resources by 12% by 2050 (Droogers *et al.*, 2012), thus the deficit in meeting the increasing demand is expected to increase from 37% in the third decade of the current century to 51% by 2050 (World Bank,2011).

Given that water stress is expressed by the ratio of water withdrawal for various uses to the available water (FAO, 2018), it is found that most countries in the Middle East, according to the World Resources Institute, suffer from very high water stress (Bahrain, Qatar and the United Arab Emirates) and high stress (the rest of the Middle East countries with the exception of Egypt), and with the continuation of business-as-usual strategies, water stress will continue to rise (2030 WRG, 2009). So, the current trends of water use are not sustainable and predict the continuous deterioration of the water situation in the region.

2.6. Climate change

The hydrological cycle is directly affected by global climate change, which is reflected in the quantitative and qualitative availability of water resources which are necessary to meet basic human needs. Climate change increases the pressures on water resources in many regions of the world, and thus increases challenges in the face of sustainable and effective management of these resources (IPCC, 2014). This requires commitment to policies of adaptation to climate change and mitigation of its effects in all sectors that depend on water (industrial, social, health, economic and environmental). The effect of the change in climatic patterns on water resources is represented by the temporal, spatial and quantitative variation of precipitation, which is reflected in the proportion of renewable water resources and water availability (Alavian *et al*., 2009). Increased temperature rates lead to increased evaporation and transpiration (vegetation cover). It also leads to a decrease in the percentage of dissolved oxygen in the water (deterioration of water quality) (Hipsey and Arheimer, 2013). The Intergovernmental Panel on Climate Change (2014) stated in its fifth report that 7% of the world's population will suffer from a reduction of more than 20% of renewable water resources (Döll *et al*., 2014; Schewe *et al.*, 2014) for each degree of global warming.

It is difficult to determine the total impact of climate change on the hydrological system due to the interaction between the climate and other factors (human, industry, agriculture, and pollution) (IPCC, 2014). Within the framework of our study, this section seeks to make the relationship between urban areas, climate change and water issues understandable.

It is noticeable in the previous decades that extreme weather events such as torrential rains, heat waves, droughts and severe storms repeated in varying degrees from one place to another in the world (IPCC, 2007, 2012; Hunt and Watkiss, 2011; Romero-Lankao and Dodman, 2011; Rosenzweig *et al*., 2011). These events have a direct or indirect impact on the water sector in urban environments. For instance, the recurrence of heat waves would increase the demand for energy (high water uses in the energy sector for cooling) (Lemonsu *et al*., 2013).

Water shortage is the first expected effect of the recurrence of the phenomenon of drought, followed by a number of challenges, including low energy production (cooling systems in production plants / hydropower production), food insecurity (lack of agricultural and industrial production / high prices as a result of limited food products), disease outbreaks (pathogens carried by contaminated water), and migration from the countryside towards cities (as centres of economic activities). These effects negatively affect the socio-economic and health reality of urban centres (Vairavamoorthy *et al*., 2008; Herrfahrdt-Pähle, 2010; Farley, 2011).

The phenomenon of drought has long-term effects, which makes the confronting of it more difficult and necessary at the same time (Low, 2013). It is estimated that the number of people who suffer from permanent water shortages caused by drought (less than 100 litres per person per day within their urban range) may exceed one billion by 2050 (McDonald *et al*., 2011).

Hurricanes, floods and sea level rise in coastal urban areas pose a serious threat due to the high population densities in these areas and their low-elevation (McGranahan *et al*., 2007), and so, these phenomena cause erosion of river banks and beaches, degradation of ecosystems and natural protections against extreme phenomena, threatening the safety of the population and their properties, disrupts industrial and commercial activities, and suspension of livelihoods (Nicholls, 2004; Dossou and Gléhouenou-Dossou, 2007;Zanchettin *et al*., 2007; El Banna and Frihy, 2009; Carbognin *et al*., 2010;Pavri, 2010; Hanson *et al*., 2011). As mentioned above, low-lying areas are more vulnerable to flooding risks such as Mumbai and Mombasa (Awuor *et al*., 2008; Revi, 2008; Adelekan, 2010), and the losses and impacts increase in cities with ports and heavy industries (such as petrochemicals and energy, especially nuclear energy) (Hallegatte *et al*., 2013). According to a simulation model created by Hanson and others in which they assumed that a sea level rise of 50 cm and scenarios for population and economic growth and storm recurrence (knowing that these assumptions will actually differ from one place to another), that means the largest port cities are expected to be exposed to coastal flooding, and the proportion of people at risk may increase to 300% and assets to 1000% (Hanson *et al*., 2011). They also found that most of these cities are concentrated in the delta regions, low-lying areas and developing countries such as Mumbai, Shanghai, New York, Ho Chi Minh, Tokyo and Alexandria.

Floods are not exclusive to coastal cities, as heavy rains in interior areas can also expose them to flood risks which can destroy infrastructure, property, businesses, and threaten the lives and health of residents as well (pollution of water sources) (Adelekan, 2010; Sharma and Tomar, 2010; Shepherd *et al*., 2011).

Willems *et al.* (2012) have argued that the intensity of short-term rainfall in urban areas could increase by 10-60% during the period from 1999 to 2100, which would cause disruption of drainage services and devastating floods, and human activities will exacerbate this, such as the expansion of impervious urban areas and changing land use patterns that eliminate natural drainage paths and increase runoff.

However, despite all the research and studies to explore the dimensions of climate change on urban environments in general and the water sector in particular, water availability and demand are still greatly affected by extreme climatic events due to the complexity and uncertainty of the severity of the events and the different patterns of recurrence and circumstances from one place to another on the one hand, and the shortcomings in adaptation policies and preparedness to address them on the other hand.

2.7. Pollution and water quality

There is no pure water in nature, but there is water whose quality can be classified according to the purpose of its use, the degree of its contamination and the type of pollution follow the concentrations of its contents. It can be said that meeting the demand for safe water is a fundamental factor for the health of societies and ecosystems, and thus, the development in all related sectors. Water quality directly affects the amount of available water, both of which are essential in the supply process to meet the necessary environmental and human demands, so the availability of water that cannot be used in a particular sector translates in some way to the lack of water available for use (UNEP, 2010).

Stellar (2010) discussed the forms of the relationship between the quality and quantity of water, and found that the quality of the groundwater deteriorates whenever the withdrawal of water depletes the aquifers through the increase in the concentrations of naturally occurring compounds or through the penetration of salt water into the groundwater in coastal areas, as happened in The Gaza Strip, which reduced the amount of water available for human use, and affected the agricultural and industrial sectors as well. In the same context, the concentration of pollutants in surface water bodies, such as rivers and lakes, increases with a decrease in the amount of their water, which is mainly caused by overuse or in conjunction with dry seasons.

Polluted water is a major cause of the degradation of ecosystems and the harmful impact on the multiple services they provide (such as natural wastewater treatment). This has increased the threats facing development in the social and economic sectors, especially in poor and developing countries that are still heavily dependent on the services of these systems. While developed countries have become aware of these threats, the environment and the health of ecosystems are among the drivers in planning processes.

Pollution in water bodies has worsened since the early 1990s, including most rivers in Asia, Africa, and Latin America (UNEP, 2016). Areas of high population density and expanding economic activity were more vulnerable to pollution threats. The situation is expected to get worse in the coming decades, according to scenarios that take into account the main current pollution causes and slow and insufficient responses, thus increasing the problems related to human health, ecosystems and development sectors (Veolia / IFPRI, 2015).

Excess nutrient flows from agriculture are among the most common global challenges causing water pollution (especially groundwater) (UNEP, 2016; OECD, 2017). As agriculture exports high concentrations of nitrogen and phosphorus (the most common pollutants in freshwater in the world (WWAP, 2009)) to the environment, thus their loads exceed the standard thresholds set by the WHO in many regions. For example, 15% of groundwater monitoring stations that are relied upon for domestic use in Europe documented an excess of nitrogen above the rates recommended by the organization (WHO, 2002), and according to UNDESA (2012), freshwater is expected to continue to be polluted with nutrients in most parts of the world until 2030, when it could stabilize in the developed countries while the deterioration is likely to continue in developing countries. Agricultural intensification approaches lead to an increase in the use of chemicals such as herbicides and pesticides, which increases the risk of pollution (De *et al.*, 2014), and requires caution in developing agricultural policies, especially with regard to the use of pesticides (UNGA, 2017).

As mentioned previously, areas of high population density (urban centres) have a fundamental role in pollution, as they are considered point-sources of pollution, as domestic and industrial wastewater is one of the most important sources of this pollution. According to (WWAP, 2017), 80% of the total global wastewater is discharged to the environment without prior treatment, while this percentage increases to more than 90% in developing countries due to their lack of the necessary infrastructure to collect and treat wastewater before discharging to water bodies (rivers, lakes, seas, etc.) (Corcoran *et al.*, 2010). This has led to the deterioration of water quality and consequently its availability, threat of health and ecosystems, and the release of gases that contribute to global warming (such as methane).

Continuing research in the field of water quality has presented emerging pollutants that are found in relatively high concentrations, such as pollutants resulting from medicines, industrial chemicals, heavy metals, detergents and anti-bacterial cleaning materials, personal care products and others (Sauvé and Desrosiers, 2014), which subjected the water utilities to more pressure in order to ensure that water meets quality standards (Corcoran *et al.*, 2010). Most of the effects of pollutants are transferred to humans and the biological component by water (WWAP, 2017).

As for climate change, it plays the role of a multi-effects factor. Changing precipitation patterns affect water flows and pollutants concentration, and the warming causes increased evaporation (water availability), plant transpiration (increased agricultural demand) and increased water demand for energy production (e.g. cooling purposes) (Hipsey and Arheimer, 2013), as well as depletion of oxygen dissolved in water (deterioration of quality), while the occurrence of surface runoff or floods can transfer greater quantities of pollutants to the water bodies, especially in urban areas and specifically when the drainage capacity of combined sewer collapses (IPCC, 2014).

Based on the current situation indicators, it is expected that low- to middle-income countries will be the countries most exposed to increased pollution rates as a result of being centres of rapid population and economic growth (UNEP, 2016) and deficiencies in organizing and managing issues related to wastewater (WWAP, 2017).

2.8. Water disputes

Issues of water scarcity and stress are among the matters that constantly affect stability and development in societies. Water has always been used as a strategic pressure tool and has been the cause of some conflict situations throughout history. Transboundary waters constitute one of the most important water issues that have attracted attention, especially after spreading the climate change effects, causing uncertainty in freshwater supplies.

The National Intelligence Council report (2012) mentioned the possibility of exacerbating the risks of local instability and the intensification of regional tensions due to the problems of the water sector, such as shortage, deterioration of quality, floods and droughts, which result in deficiencies in the capacities of production and economic development.

The first decade of the current century witnessed some regional conflicts and tensions, as well as local disputes, in which water was used as a pressure element to achieve political aspirations. For example, the Darfur region in Sudan witnessed tribal conflicts, during which, wells were destroyed and polluted (Amnesty International, 2004), while water was the cause of disputes in other cases, as is the case, for example, in Kenya and Ethiopia, where the drought (2004-2006) that struck East Africa caused the death of large numbers of livestock and affected 11 million people in one way or another, creating tribal conflicts over water (wells in particular). The two governments were forced to intervene militarily to calm the situation, and the outcome of these conflicts resulted in the killing of 250 people in Ethiopia and many wounded. Whereas conflicts between nomads and settled communities in North-Western Kenya (Maasai and Kikuyu) resulted in 90 deaths up to July 2005 (Pacific Institute, 2012).

As for the regional and international level, there is no doubt that water was in many cases a source of concern and threat in the relations of the countries that share the basin, especially in the absence of agreements or treaties that determine how to manage the shared water resource (whether it was a river or an aquifer ... etc.). Many countries exert political pressure on neighbouring countries depending on their control of the sources or their participation in the transboundary basin.

The Middle East faces exacerbating water scarcity problems, tensions resulting from basic water resources shared by at least two countries, and the change in climate increases pressures and affects the availability and quality of water (Anders Jägerskog, 2006). The situation is worsened, due to the presence of the problem of demarcating the borders in the disputed or occupied territories, which prevented the creation of clear formulas stipulated in a water-sharing agreement, as is the case between Israel and its neighbours, for example (Anders Jägerskog, 2005).

In the Tigris and Euphrates basins, water has been politicized, Turkey has always tried to blackmail the neighbouring countries (Syria and Iraq), which share the two basins with Turkey, to achieve political and economic goals. This was evident in some statements made by Turkish officials, referring to Turkey's right to exploit the water of the two rivers in its lands as source country with indifference to the right of the riparian states. Turkish Prime Minister Tansu Ciller said when he was presenting Turkey’s plan to sell Israel and the Gulf states water from the Euphrates through the Peace Pipeline Project: “This is our waters and our right to sell our water to those who we want”, while Prime Minister Masoud Yilmaz, who followed Chiller, likened the water resource to oil resources and considered them indivisible/unshareable, saying, “Our water is our oil and if there is someone who is satisfied of sharing his oil with others, Turkey is ready to share its waters” (Bilen, 2009).

The data indicates that the annual recorded flow rate of the Euphrates River at the Jarablus station on the Turkish-Syrian border witnessed a decrease from 30 billion m^3 annually before 1973 to approximately 22.8 billion after 1990. This decrease was justified by the effects of climate change (repeated drought), and the South-Eastern Anatolia Project (GAP) aimed to establish a group of dams to meet the requirements of Turkish national development (UN-ESCWA and BGR, 2013), that prompted both Syria and Iraq to transfer this issue to the international community through the UN and regional organizations. Syria has also used the Kurdish issue to pressure Turkey (Mansour, 2016).

On the other hand, it is found that Israel is striving to employ water issues to achieve development at the domestic/local level and achieve political weight at the international level, while Israel is seeking to conclude unfair agreements with Jordan and Palestine (such as the 1995 interim agreement in which the Palestinians in the West Bank are granted their portion of a class Mountain ground water, but this agreement was unfair to the Palestinians (Bilen, 2009)). In addition, it is making attempts to intervene in countries' issues as part of strategic planning, as it did when it provided financial support to Ethiopia to establish dams on the Nile River with the aim of influencing Egypt and Sudan shares, and harm their interests. It cannot be denied that Israel alerted early on to the water-related challenges and rushed to establish a group of water projects to alleviate and address the water crises afflicting its region (Mahmoud Mohamad *et al*., 2009).

By observing the indicators that predict the continuing challenges of water scarcity and its exacerbation, the threats of climate change and extreme events, the pressures of demographic and economic growth and the expansion of poverty and marginalized societies, it is found that water will be a critical factor for development and the criterion of food and economic security at local, regional and international levels. This will make transboundary water issues the focus of greater attention, and it cannot be denied that water may be a cause of tension, dispute, and conflict locally or between countries, and thus a threat to security.

2.9. Urban water management

Previously, it was presented the most important factors that affect water resources and water demand, and the challenges that these factors may cause in the future if appropriate measures are not taken and the capabilities and resources are not effectively employed.

It cannot be overlooked of some challenges that other limitations create, which societies face that prevent the effective management of water resources and achieving sustainability in development. Therefore, they must be taken into consideration when addressing water issues considering administrative policies and development strategies.

Poverty is at the forefront of these limitations, which can translate into limited income or limited resources (such as water, food, sanitation, etc.). The solution to poverty often begins with securing safe water, food, and access to improved sanitation facilities, which are considered the basics of health care, education, and work. International organizations have always worked to improve the reality and try to eradicate extreme poverty, which was one of the most important of the Millennium Development Goals, and despite this, the number of people under the extreme poverty line was 1.2 billion in 2012 (Lockhart and Vincent, 2013), most of them are concentrated in poor neighbourhoods and informal housing in urban areas, especially in the developing regions, which has exacerbated the inability to meet the demand for water and provide sanitation services (UN-Habitat, 2011), and the health consequences that follow. In Cambodia, for example, 54% of the urban population in the poorest quintile still defecates in the open (WHO and UNICEF, 2014).

The suffering of poor people increases as they are more vulnerable to extreme climate phenomena, and therefore this reality creates challenges in the face of current and future water management. Nevertheless, there are models that have made progress in finding some solutions, as happened in Mombasa, for example, where the local communities, in cooperation with the private sector, supplied improved water from the kiosks. The percentage of those who received improved water reached 80% while only 15% were provided with water from the network (WHO and UNICEF, 2014).

Poverty forms part of inequality issues at the social, economic, and service level, which as a whole constitutes an obstacle to the development of societies and economies (Donat Castelló *et al.*, 2010). There are many women, old people, children and people with special needs and other categories that face discrimination and exclusion, who suffer from limited access to water and sanitation services in a way that preserves their dignity, which is considered a human right. This lack of access to services has consequences related to the persistence and exacerbation of the phenomenon of poverty, and a decline in available educational and work opportunities, and this is exacerbated in urban environments as a result of the inability of many governments to keep pace with urban growth and the expansion of services to meet the growing demand (UN-Habitat, 2011).

It is noted that most countries' efforts and financing in the field of water resources management are low. Although the water sector is a key factor in economic and social development, development projects related to water supply and sanitation services do not receive the required development support and adequate national spending compared to the education and health sectors, despite awareness of their decisive impact on development and their role in enabling human rights, such as the human right to water and sanitation for all without discrimination (UNDESA, 2013).

The reliance of water services management on government funding, or international support as in developing countries, is an insufficient and unsustainable approach to improving the efficiency of the infrastructure and developing its services. In addition, these projects’ planners and designers disregard some costs related to operating and maintaining the water infrastructure (this is strongly observed in developing countries) and this causes impeding of maintenance actions and the expansion of the service. This harms the functional performance of the infrastructure in terms of the quality and quantity of services provided and the number of beneficiaries (WHO, 2012).

In order to ensure sustainable development, it is imperative to monitor and record data related to the availability and quality of water, its uses, related factors (climate change, conflict, migration, demographic growth, etc.) and their effects, which is considered one of the great challenges, especially considering that these data vary with the change of time and place. Therefore, it is found that most of the available information, if available at all, is at the local level or at the basin level, and it lacks details related to the uses of different sectors and its impact on economic, environmental and human growth and well-being.

Getting a general idea of water availability and use, makes the data unable to give a good understanding and prediction of the direction of changing the different dimensions of water and its effects, this in turn creates difficulties in formulating effective policies and decision-making to reach the desired development goals (WWAP, 2014).

Undoubtedly, the importance of water and its impact on national economies and industrial development in the long term has been recognized (WWAP, 2015), which prompts development in the water sector through monitoring, collecting and processing data on water (availability, quality, use, treatment, management, ecosystems and others), developing approaches and techniques for saving water, finding alternative resources (such as treatment and desalination), and improving water productivity to ensure the efficiency of development policies (WWAP, 2012).

The progress made in the field of collecting information and data after activating satellite services and remote sensing, and employing mobile phone networks and smart digital equipment (such as smart meters) that allow the transfer of information to and from the database where the information is processed and interpreted and then decisions are made. These advantages can be invested in different stages of management processes, for example, remote sensing can be employed to monitor climate change and extreme events, while telephone networks can be used for earlier warning, preparation, adaptation and mitigation of the effects of these events (UN-Water, 2015).

There is no doubt that the urban water sector is part of the wider hydraulic cycle, as it is a point of consumption of water drawn from the catchments of all kinds (rivers, lakes, groundwater, etc.), and an export point for urban waste. However, the water management process is often carried out for each urban area separately to facilitate dealing with the components of the water system from the resource, supply systems, sewage services, rainwater and treatment, and understanding the overlap between them, as well as recognizing the deep links between the water sector and other sectors (food, energy and industry) for which any decision on one of them affects the rest in one way or another (WWAP, 2014). If the reality of these mutual influences is taken into consideration, a more efficient, sustainable, and integrated management will be achieved.

Integrated urban water management seeks to meet the water demand and find a balance between the industrial, social, and environmental sectors in the short and long term. This requires uniting efforts between scientists and experts in the field of water, economics, sociology, and environment, in addition to engaging civil society (SWITCH, 2006).

Urban centres are points of increasing population density and increasing challenges that impede development plans, especially in developing countries whose plans are unable to keep pace with this rapid growth. However, urban centres are at the same time good environments for implementing the sustainability approach (UNDESA, 2014), as the concentration of the population in the relatively limited space means lower costs of establishing and operating water supply and sanitation networks (less space and serving a larger number), lower cost of providing services per person. The ease of spreading and monitoring the application of preservation and treating techniques, increases the chances of monitoring and evaluating the services provided and the efficiency and validity of the infrastructure.

CHAPTER 3

TECHNOLOGIES AND MEASURES THAT CONTRIBUTE TO EFFICIENT WATER MANAGEMENT IN URBAN AREAS

In light of the scarcity of water resources affecting different regions of the world and its results which are clearly evident in many urban areas that have depleted their surface and ground water resources, urban centres started searching further for new sources of surface water or digging deeper to reach additional stocks of groundwater (WWAP, 2015). Where the primary tendency of administrations and water service providers has been to invest IN new freshwater resources instead of working on finding alternatives and more innovative solutions and employing advanced technologies to increase the productivity and efficiency of water use.

In this chapter, it will be listed some of the methods used, albeit in a limited way, to provide and reclaim water that can be used according to its quality for multiple uses.

3.1. Rainwater harvesting

It is a technique aiming to collect water in times of precipitation so that it can be used according to its quality for different purposes. Passive and active rain harvesting systems can alleviate the challenges of heavy stormwater and provide water supplies for various uses and thus relieve pressure on ground and surface water resources. Passive harvesting systems secure water for the plants through overland runoff after collecting precipitation water in natural depressions, while active systems employ collected surface water in urban needs (Sarah Sojka *et al*., 2016). Since our research deals with urban areas, active water harvesting systems will be focused on.

Rainwater harvesting can be applied with simple tools at a relatively low cost and with minimal knowledge. It can also be complex as the area covered increases, as is the case when the system includes an entire residential area. Countries such as China, India, Germany, Australia, and the United States, have implemented rainwater harvesting projects, particularly in the residential and commercial sectors from densely populated cities.

Thus, it can be said that the collected water using rainwater harvesting technology can be complementary to other water resources, especially in cases of scarcity, low water tables or drought (Hatum & Worm 2006). It is worth noting that rainwater is considered one of the clean sources because it is usually free of pollutants except of dissolved carbon dioxide or dust before it falls on catchments (WHO, 2008). This has encouraged the spread of this technology in recent times in some poor or rich countries distributed in wet and dry areas (Domènech and Saurí 2011a; Farreny *et al*., 2011c; Morales-Pinzón *et al*., 2012).

Rainwater harvesting technology is closely related to the pattern of rainfall throughout the year, the feasibility of this technique depends on the abundance and quality of other water resources, water demand and quality standards required. According to (Hatum & Worm, 2006), water harvesting technology is environmentally feasible when the precipitation rate is not less than 50 mm / month for 6 months annually or 300 mm / year, and the tropical environment with its frequent and heavy rainstorms and short dry periods provides the best conditions for water harvesting.

The basic components of water harvesting systems start with the catchment area, where the water is directed to a group of gutters / pipes to transport the water to tanks in which the water is kept until it is used (figure 1), and depending on the purpose for which the water is used, stages for water treatment and purification may be added to this system. The chain ends with equipment for extracting water, such as a tap, a pump, or devices designed to recharge the groundwater (if the aim is to use the collected water for artificial recharge of the aquifers).

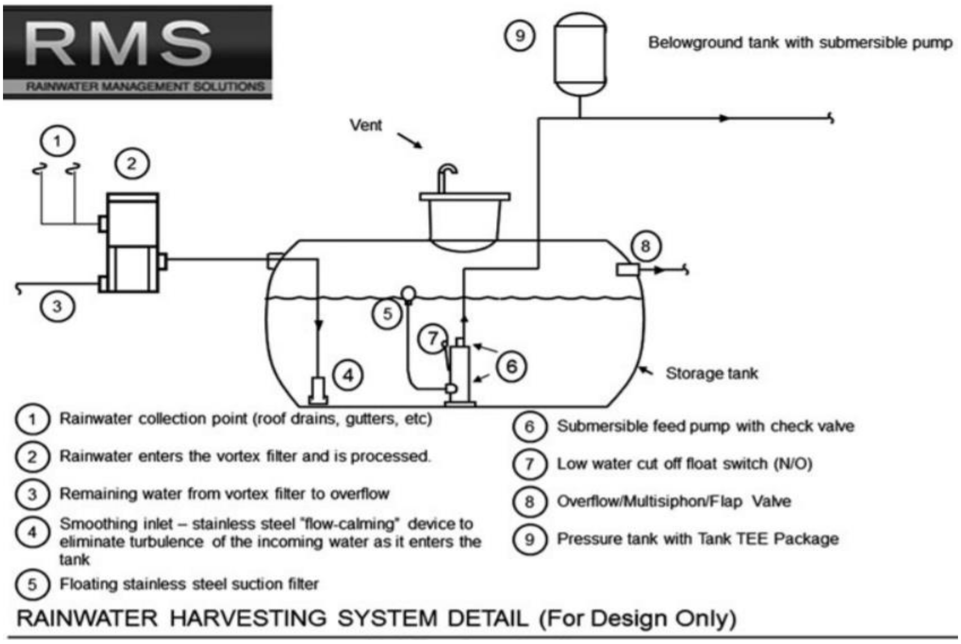


Figure 1 - Schematic of a modern rainwater harvesting system with underground storage (Source: Rainwater Management Solutions).

Catchments

Precipitation water can be collected from building roofs, roads, lawns, and other urban impervious surfaces, and since the global rooftop areas constitute a considerable of the total urban area (Jacobson and Ten Hoeve, 2012), the amounts of rain captured by these roofs can be relatively large, taking into account the difference in the spatial distribution of precipitation

(NOAA, 2015). Roofs of buildings are considered to be the best in terms of flowing water quality due to the low probability of contamination compared to other surfaces (such as roads exposed to contamination with pet waste or cars' oil, etc) (Sarah Sojka *et al.*, 2016).

Nevertheless, the materials used to construct the building roofs influence the quality of the flowing rainwater, as studies have proven that they are sources of pollution. By conducting tests on a group of roofing materials (such as asphalt sheets and metals), it was found that they were sources of pollutants such as copper and lead (Clarke, 2008), and the proportions of these pollutants can be influenced by the acidity of the rainwater (Zobrist, 2000), as well as by the age of the construction material (Chang *et al.*, 2004; Clarke, 2008; Adeniyi and Olabanji, 2005), and even the inclination of the surface which can increase the pollutant loads in the flowing water (Gikas and Tsihrintzis, 2012). Therefore, the design of the roofs and the selection of suitable construction materials are essential factors in a rainwater harvesting system because of its impact on the quality of the effluent water and thus on the design of the treatment and purification systems, taking into account the intended end use.

Tanks

In the same context, the material used to construct the tanks has an important role in the quality of stored water, as polyethylene and fiberglass tanks have proven efficient in maintaining water quality, while cement tanks have shown a tendency to leach materials into the water and adjust their acidity (Sarah Sojka *et al.*, 2016). On the other hand, the size of the tank plays a fundamental role in the economic and environmental viability of the rainwater harvesting system (Ghimire, 2014), as it is often the most expensive part, and determining the optimum volume requires knowing the relationship between the tank size and the return period. As the size of the tank increases, the recovery period decreases to reach the optimum volume, after which, the recovery period begins to increase as the volume increases (Silva, 2015), and this logic is correct as long as the daily demand does not exceed the average daily rainfall (Campisano and Modica, 2015), as the amount of water supplied from the rainwater harvesting system depends on the size of the tank.

The size of the tank is a controversial issue due to the economic burdens it can cause. Modelling and testing of different tanks volumes under different operating conditions in terms of precipitation rates, catchment areas and the demand that needs to be met will help find the optimal size of the system tank.

Treatment

The flow of water on surfaces pollutes it, which prompted the designers of rainwater harvesting systems to propose a range of solutions to improve the quality of the collected water. Given that the concentration of pollutants (sediments, bacteria, minerals, etc.) is high in the flowing water after the first precipitation following a relatively long dry period (van Metre and Mahler, 2003; Lee *et al.*, 2012; Zobrist *et al.*, 2000). The designers have proposed forcing a certain quantity of the initial flow to bypass the tank by means of fittings installed before the tank called the first flush devices (figure 2) (Gikas and Tsihrintzis, 2012). The existence of a first flush shifting away from storage, and the amount of water that must be disposed of, depends on the period between one precipitation and another (He *et al.*, 2001), the type and quantity of pollutants (Kus *et al.*, 2010) and the materials that make up the surfaces (Mendez, 2011). This procedure, if implemented, raises the water quality, and reduces concentration of pollutants (such as metals) that threaten the level of safety (Stump *et al.*,2012; Huston *et al.*, 2012).

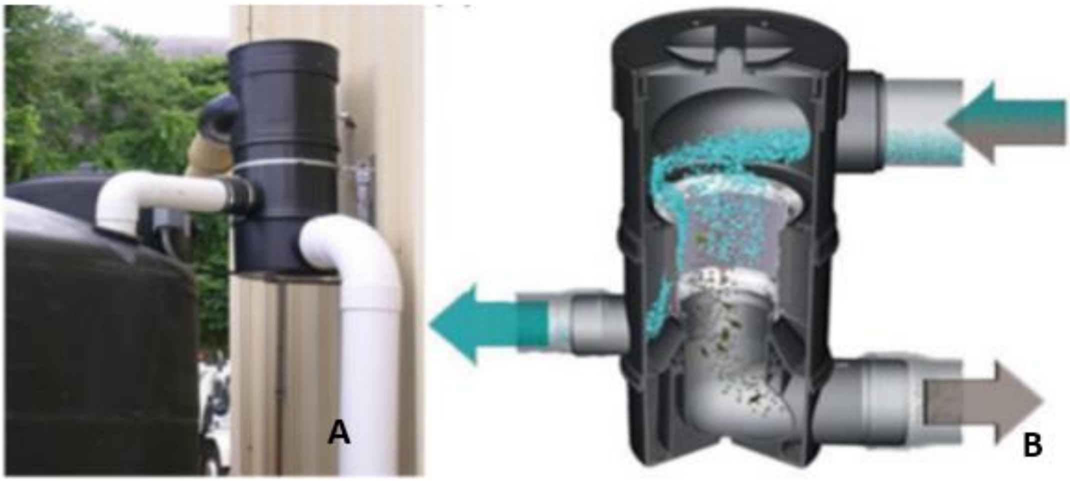


Figure 2 - Typical rainwater pre-tank filter installed (a) and cutaway view (b) (Source: Rainwater Management Solutions)

Apart from the first flush concept, designers have found it beneficial to add a filtration stage before the tank, as this can prevent sediment and debris build-up in the tank and thus reduce cleaning and maintenance expenses (O'Hogain *et al.*, 2012), as well as contribute to removing pollutants in particular organic matter that causes proliferation of bacteria in the tank. O'Hogain *et al.* (2012) confirmed this based on their experience which proved that the quality of the filtered water before storing it in the tank was higher compared to the absence of the pre-filtration. It is recommended that the filters must be easy / self-cleaning, not able to be clogged or eroded (Abbasi and Abbasi, 2011). There are some studies that have searched the effectiveness of the sedimentation process in the tank, depending on the period of residence of the water in the tank and the introduction of water into the tank without stirring these sediments, on improving water quality and reducing the concentration of some pollutants (Magyar *et al.*, 2011). Nevertheless, pre-filtration is an essential stage in most modern rainwater harvesting systems due to its apparent effectiveness.

Depending on the ultimate use for which the stored water is to be employed, some designers suggest a micro-sediment filtering and disinfection stage that would control the microbial content and heavy metals whose presence is in proportions higher than the standards required for safe use (especially in indoor use). Chlorine or ultraviolet rays are commonly used for disinfection, and sometimes ozone, and reverse osmosis technology can be used for filtering, and one of these is certified based on the required quality.

Impacts

Rainwater harvesting technology is an important component of rainwater management and mitigating the effects of floods, especially in areas with impervious surfaces, as it reduces surface runoff and provides additional water resource at the local level. This, in turn, reduces the financial and economic losses resulting from floods, and the consequence of this is that it may exceed the benefit of saving municipal water as result of using harvested water (Zhang and Hu, 2014). The reduced volume of water from runoff provides an opportunity to preserve drinking water that is used in activities that do not require such high-quality water. Studies have shown that rainwater harvesting technique is effective in managing rainwater in the event of small storms, but in the case of very intense storms it cannot be considered effective if it is applied alone. The intense rain events often require providing the harvesting system with larger tanks, which may be considered economically inefficient (Petrucci *et al.*, 2012).

Rainwater harvesting tends to be more efficient when combined with an integrated stormwater management system (Damodaram *et al.*, 2010). The integrated management enables finding solutions to drain the quantities of excess water beyond the capacity of the harvesting systems and their tanks, such as directing the surplus to recharge the groundwater. This would reduce some of the urban expansion effects, such as the infiltration reduction due to the increase of impervious areas and excessive withdrawal of water to meet increased social and economic demand. Thus, taking into account the necessary purification of the water used to feed the aquifers, to prevent contamination (Grady and Younos, 2010).

There are several factors that determine the economic and environmental benefits of rainwater harvesting systems, their dependence on the roofs of buildings mainly and the provision of modern systems with stages of filtration and purification according to the intended use (often uses that do not require high quality such as horticulture, cooling and cleaning toilets (Ward *et al.*, 2012; Hammerstrom and Younos, 2014)). In addition, the absence of the need to transport water from / to distant places, making it an energy-saving technology compared to municipal drinking water which require a big amount of energy for treatment and pumping processes. In South Korea, a rainwater harvesting system has been implemented that consumes only 10% of the energy consumed by the municipal water supply system (Han and Mun, 2011).

On the other hand, there are some elements that affect the cost of rainwater harvesting projects and their economic and environmental feasibility. As mentioned above, the size of the tank has a major role in the project cost, as well as on the project's energy and life cycle. Also, the design of the system, the stages it contains, the materials used, the need for maintenance and the final use of the collected water are all factors that play a fundamental role in assessing rainwater harvesting projects and their economic and environmental benefits. For example, it has been found that the use of harvested water in developing regions has significant economic and environmental benefits when used in high-efficiency toilets (Anand and Apul, 2011). Therefore, the use of rainwater harvesting systems is effective and feasible if it is researched and analysed all the conditions of the area in which the project is going to be implemented, how the harvested water will be used, the effect that has on the project design, and how the quality of the stored water and the project capacity and feasibility are going to be affected by the design.

It can be said that this is a promising technology, and it becomes more and more important in urban areas due to climate change, increasing of the impervious surfaces, variability in precipitation and the scarcity of water resources.

3.2. Wastewater reuse

The growth in water demand is accompanied by an increase in wastewater that is discharged into the environment without proper treatment in most regions, which contributes to the degradation of ecosystems and threatens water quality and public health. Wastewater has always been viewed as a burden to be disposed of, instead it is more appropriate to consider it as an alternative source of freshwater and moving from treatment policies before discharge just to mitigate the wastewater negative impacts to recycling and reuse policies.

The world faces challenges related to water availability, which is closely related to water quality. Pollution can prevent the use of many available resources for specific uses (banning the use of polluted water for drinking purposes). The household, agricultural or industrial wastewater discharged without adequate treatment is one of the most important causes of this pollution. The continuation of this trend threatens the continuing deterioration of ecosystems and water quality, endangering public health and exacerbating water scarcity problems in the coming decades, and thus impedes sustainable development, especially in areas suffering from lack of water resources.

Wastewater management still faces special difficulties in light of the lack of data related to wastewater generation and the quantities that are collected and treated for use or disposal with the least negative impact on the environment and public health, as well as data on the infrastructure, its performance and the level of treatment it provides (Sato *et al*. 2013).

Although the data are not sufficient to give detailed information, the percentage of treated wastewater in a particular country follows the level of its income. High-income countries treat about 70% of their wastewater, while the percentage drops to 8% in low-income countries (Sato *et al*., 2013). These numbers do not contradict the assessments issued by both the World Water Resources Assessment Program (WWAP, 2012) and the UN-Water (2015a), which indicate that more than 80% of wastewater is discharged without treatment. One of the challenges facing wastewater treatment is the inability of some countries (developing countries in particular) to cover the costs of installation, operation, maintenance, and energy provision for these plants (Libhaber and Orozco-Jaramillo, 2012). For example, some African countries face difficulties in developing the infrastructure and treatment facilities for wastewater due to financing problems, which make them more vulnerable to the challenges and risks of wastewater mismanagement (Sato *et al*., 2013).

The volume of wastewater grows with the growth of population and the growth of industrial production, which increases the pressure on the available wastewater facilities. So, in some cases, the performance of the facilities will be poor, as is the case when floods occur and wastewater exceeds the capacity of the drainage systems and treatment plants, which leads to overflow and discharge of the wastewater without treatment /inadequate treatment, and thus the wastewater forms a source of pollution and threats.

There are many sources that produce wastewater, and its contents vary accordingly. The treatment process is intended to separate the water from the rest of the contents, in order to reuse each of them for specific purposes or to be discharged into the environment in a safe way. The treatment process comes as part of the wastewater management process, which starts at the source, whereby restrictions are placed to prevent / reduce the use of some materials (industrial wastewater) by using some technological or regulatory means, as well as reduce produced wastewater quantities by committing the standards of water efficient usage and water demand management. After that, comes the treatment phase, where the water is separated from the rest of the components in a variety of ways depending on the type of pollutants and the intended end use of the effluent. The wastewater department is responsible for monitoring and ensuring the safe use of treated or semi-treated water. It must ensure that the quality of the liquids flowing after the treatment process meets the intended end-use standards. It is also concerned with the extraction of useful components that have been separated from the liquid waste directly (such as nutrients or minerals) or indirectly (such as extracting biogas from sludge) to be used in development processes (Andersson *et al*., 2016).

If this wastewater management is implemented optimally, this will mitigate the negative effects on the social, environmental and economic sectors, and contribute in food security (the use in agriculture of the treated water and the fertilizers extracted, according to studied standards) and energy production (biogas and biofuels) as well as alleviating pressure on water demand (for example, uses of treated water for cooling or gardening purposes), also, treated wastewater can be used to restore ecosystems and their services, which is environmentally and economically beneficial (Andersson *et al*., 2016). Thus, wastewater provides a sustainable usable resource, which reduces the burden on surface and ground freshwater sources, especially in areas with permanent or recurring water scarcity.

Treatment process: Treatment techniques are created according to the source of wastewater, its contents, and the desired end use (as it is indicated earlier). Also, cost plays a role in choosing the type of technology used. The physical treatment, such as gravity filters and membranes, which is characterized by producing high-quality treated water and effectively removing micro-organic materials (Liu *et al.*, 2009), chemical treatment that aims primarily to remove heavy metals and purify (UN-Water, 2015a), and biological treatment which represents a simulation of the decomposition that occurs naturally in water bodies, are combined.

Biological treatment is of two types, aerobic and anaerobic. The aerobic biological treatment is more energy-consuming to maintain appropriate aeration conditions, and results in sludge (biomass) and carbon dioxide. While anaerobic treatment requires less energy and produces less biomass, it produces a greater amount of methane gas in comparison with aerobic treatment. Methane gas is considered a cause of global warming (Cakir and Stenstrom, 2005), but it is also a good source of energy if an investment is made. The produced sludge from biological treatment of wastewater is a source of nutrients that can be used as fertilizers for the soil (Fleury and Ba,2005), and organic compounds which form sources of energy.

There are two types of treatment systems, the central system in which wastewater is collected for a group of users and transported to be treated by one station (as in the case of large urban areas), and in this case the cost of the collection network may exceed 60% of the project cost (Massoud *et al*., 2009), while a decentralized system is used in individual homes or low-density and small communities, and here the costs of wastewater collection are low, but it does not achieve the same benefits that the central systems provide.

Urban wastewater: Urban areas suffer from the challenges of rapid growth and expansion in informal settlements, the effects of climate change and extreme events, and migration from the countryside to city centres or from conflict areas, which exacerbates obstacles of services provision, including wastewater collection service (UN-Habitat, 2016).

Depending on the different institutional structures and the level of income, it is found a difference in the composition of wastewater and the method of its collection from urban areas. In general, a proportion of the wastewater is treated, while the remainder is discharged to surface water, stream or informal areas and depressions. It is also noted that in developing economies, wastewater from different sources is combined together before treatment, and often a large part of this transported mixture is lost due to the deterioration of the sewage network, and broken pipes, leading to pollution of both groundwater and surface water resources (UN-Habitat, n.d.).

Wastewater reuse: The possibility of using wastewater in urban areas depends on the level of wastewater pollution and the intended end use, as well as the availability of freshwater and the cost of finding alternative water sources which greatly influence the decision-making.

Treated wastewater is used for drinking purposes either indirectly, depending on the natural processes such as filtration, exposure to ultraviolet rays, sedimentation and other processes that help purifying the water before recharging ground and surface water, and this type of use requires monitoring and verifying the conformity of drinking water quality standards, or directly, through using high quality treated wastewater. The production of treated wastewater with high quality, requires advanced, high-precision technology and careful monitoring to ensure that the water is free from any threat to human health. The city of Windhoek in Namibia is a good example, where nearly a third of the wastewater is treated to the drinking water quality level to supplement the drinking water resources (Lazarova *et al*., 2013), and this method is gaining more social acceptance than the indirect methods.

While the use of treated/semi-treated or untreated wastewater (depending on the quality of use requirements) is more widespread in industrial and environmental fields, as well as in peri-urban and urban agriculture.

After the emergence of water scarcity problems, many cities sought to recharge water resources (ground or surface water). For example, the Torreele recharging groundwater facility in Belgium, which brings environmental benefits, including preventing saltwater intrusion into the groundwater and sustaining the management of this resource (van Houtte and Verbauwhede, 2013). Semi-treated wastewater has also been employed in constructing artificial ecosystems or restoring degraded biological systems and biodiversity (such as lakes or wetlands) (Otoo *et al*., 2015).

In the field of industry, treated municipal or industrial wastewater can be used as water for industrial processes such as in cooling or other purposes in the oil industry and metal industries. Technological progress in the field of industrial processes, treatment and recycling is a promising factor in closing the industrial water cycle, which can reduce industrial demand for water by 90% (Rosenwinkel *et al*., 2013).

Semi-treated and untreated urban wastewater is an important resource for agriculture, especially in the countries of the Middle East, North Africa, Australia, and others (AQUASTAT, n.d.b.). It can also be used in aquaculture and for livestock. So it can be said, investing in these resources in the agricultural field in urban areas is considered effective, especially with the availability of wastewater as well as the market for selling products (especially fresh green vegetables) which helps in achieving food security and improving livelihoods (Kessler, 2002).

Within all previous uses, the main factor on the basis of which wastewater is employed is its availability with the required quality for the intended use and this requires the existence of systems and institutions which monitor the compliance of the water used with the required standards, and contribute to develop appropriate policies to protect public health and the environment (WHO, 2006). Perhaps the most important concern relates to the risks of exposure of agricultural workers, transporters and sellers of products, and consumers to pathogens carried by untreated/semi-treated water (Moriarty *et al*., 2004).

The benefits of wastewater treatment are not only use the water, but also the nutrients and compounds of high value and energy which can be recovered. A great progress has been made in the field of extracting nitrogen and phosphorous from sewage, despite the need of this process to an advanced technology that is still under development. The technology has provided the ability to recover approximately 45-90% of the phosphorus present in wastewater, while the proportion of extracted nitrogen is still only 15% (Drechsel *et al*., 2015). However, Bangladesh, India, and Ghana present models of dewatering sludge to obtain nutrients (Nikiema *et al*., 2014), considering that phosphorous resources are tending towards scarcity (Steen, 1998; van Vuuren *et al*., 2010), phosphorus extracted from wastewater can provide a good alternative that can cover 22% of global demand (Mihelcic *et al*., 2011).

In addition, wastewater is a source for various forms of energy that have not been invested in efficiently yet (WWAP, 2014). As it was mentioned previously, biogas can be obtained through anaerobic treatment of organic materials, so that this gas can be used to generate electricity and heat which can be used to meet treatment plant needs. Also, the wastewater flow (hydraulic power) has the ability to generate electrical energy if turbines are used. In Jordan, the As-Samra treatment plant is self-supplied with the equivalent of 80-95% of the energy it needs depending on the biogas and hydraulic energy the plant recovers from wastewater (Otoo and Drechsel, 2015). It should be noted also that there are some examples that have achieved success in using thermal energy for wastewater. In Canada, Vancouver in particular, the Olympic Village was heated with liquid waste (carbon-neutral energy), which was brought from a treatment plant in a nearby village (Godfrey *et al*., 2009).

Thus, energy recovery represents an opportunity to move the treatment plants from an energy consumer to a self-sufficient or even an energy source.

Wastewater can also contain some metals and inorganic compounds, especially those produced by the industrial sector (such as mining industries), whose recovery constitutes an insurance for health and the environment from the risks which they may cause, provides financial benefits as result of the high economic value of those materials (Wang and Ren, 2014).

The use of wastewater of different quality levels continues to be rejected socially in many regions, not only due to health concerns but rather due to cultural and religious backgrounds that mainly affect perceptions and behaviours of individuals and societies. Facing these obstacles requires increased awareness and education campaigns which would deepen the understanding and correct perceptions about the use of wastewater and the resources recovered, thus modifying behaviour and promoting ideal practices that contribute to the success of the reuse policy (Karg and Drechsel, 2011). The availability of regulatory legislation and monitoring systems aimed at ensuring public health supports confidence in the use of wastewater and its components (Mancy *et al*., 2000).

As wastewater is a continuous resource, future wastewater management tends to focus on the reuse and recovery of wastewater resources, which will enable savings in operating and maintenance costs (Wichelns *et al*., 2015). Thus, achieving some environmental and economic benefits as well as covering part of the water demand for the different sectors. Management policies also seek to find integrated and innovative methodologies, which requires regulatory legal frameworks, studying marketing and demand, ensuring social acceptance, cooperation and coordination between decision makers, workers, and the market (Holmgren *et al*., 2015).

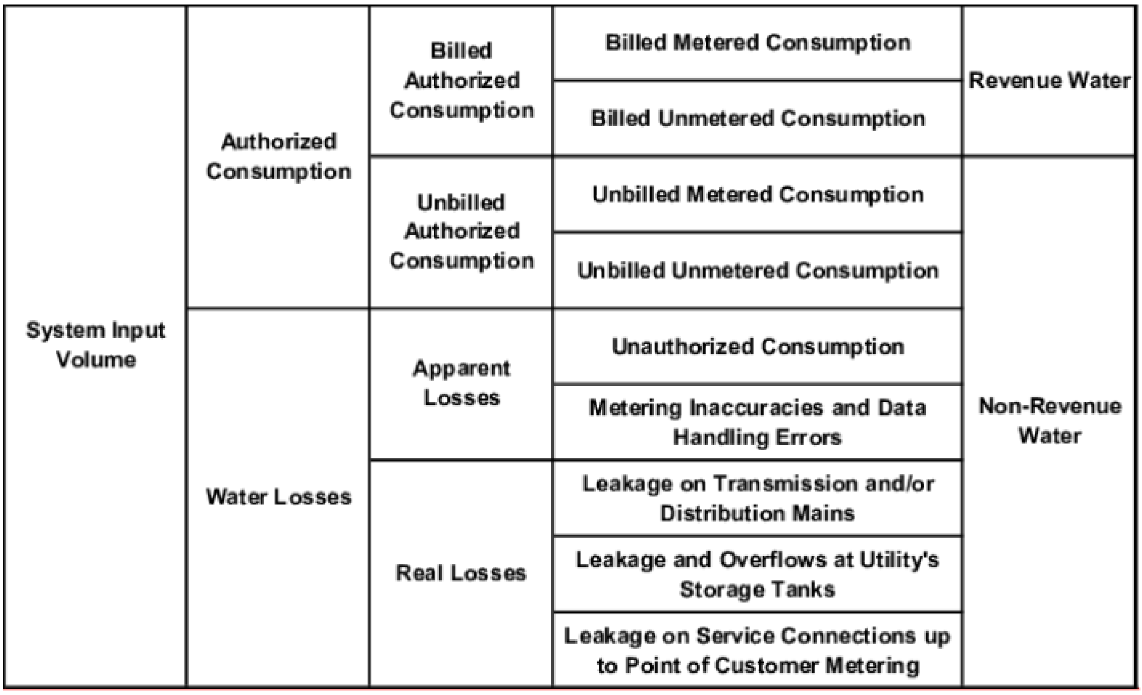
It can be concluded that improving wastewater treatment management does not rely only on the technology used and the quality of the water produced, but rather requires integration between legislations and institutions, optimal financial employment, utilization and development of knowledge and expertise, and defining the capabilities and conditions that govern each region. All of these factors enable decision-makers to choose the most appropriate solutions and involve stakeholders in the management process. This will enhance social acceptance by raising awareness of the gained benefits from the wastewater reuse policy, especially regarding environmental and economic development.

3.3. Water losses management

The acceleration of population growth, the rise in the standards of living, and urban expansion in parallel with the limited renewable water supply, are factors that will speed up the decline in the per capita share of water supply and disturb the balance between supply and demand. Climate change exacerbates the problem, as it increases the vulnerability to water scarcity, which is the main threat to many regions today (Jury *et al*., 2007). As water is a valuable natural resource, and the water of municipalities supply system is a high-quality resource (potable water), then water lost from distribution systems is an urgent issue that requires to be controlled (Kanakoudis and Muhammetoglu, 2014).

Therefore, the water infrastructure ought to be greatly feasible during its whole life, to secure adequate amounts of water that meet the good standards (Kingdom *et al*., 2006.). However, the municipalities found that the water billed at consumption points is less than the amount of water that enters the distribution system, which led them to research the reasons for this difference in quantity.

The term Non-Revenue Water (NRW) has been used to refer to water which represents the difference between the amount that enters the distribution system and the amount billed to the consumers. NRW does not provide any revenue to the water (Lambert, 2002). NRW consists mainly of water losses and unbilled authorized consumption (municipal uses of water such as firefighting water and public parks watering) (figure 3). As for water losses, they are either real (physical) or apparent (commercial) losses, and these type of losses can occur in all stages of the water supply system (WSS), containing processing procedures, pipelines, utility tanks, water meters and billing system (Lambert and Hirner, 2000). These water losses negatively affect the environment and the economy. The water that is lost also has costs of withdrawing, treating and pumping but is not delivered to the user and so it is not paid (economic impact), while the environmental impacts go beyond the loss of this valuable resource. The production, processing and distribution of this water requires energy, and generating this energy is one of the causes of greenhouse gas emissions (GHG). The release of these gases increases if treatment processes are adopted for alternative water resources such as desalination or wastewater treatment (Kanakoudis and Muhammetoglu, 2014).



System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Metering Inaccuracies and Data Handling Errors	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to Point of Customer Metering	

Figure 3 - International Water Association (IWA) water balance.

It is no longer hidden that sustainable water management cannot be achieved by finding new resources and developing alternatives (desalination and wastewater treatment) only, but also needs to develop efficiency of use, by reducing water losses, and reducing water demand as well (which will be reviewed later).

Water losses

The percentage of NRW varies from one place to another, while it may exceed 70% in developing countries, in some developed countries, it is found that its percentage may not exceed 10% (IBNET, 2017).

In general, physical losses account for about 60% of total losses while apparent losses constitute the rest (Muhammetoglu and Muhammetoglu, 2017). Real losses include all leaks along pipes and equipment of the distribution network till the consumers' meters, as well as leaks that can occur in the stage of purification, storage, and overflow of tanks. Leakage and water loss often occur in old infrastructure and networks. Apparent losses consist of unauthorized consumption, meter inaccuracies and data handling errors (McKenzie *et al*., 2007; Criminisi *et al*., 2009). However, it is no less important than the real losses, in addition to the fact that any action related to reducing apparent losses will give its results in real time in terms of increasing the value of the bills and financial revenues, (figure 4).

According to Liemberger and Wyatt (2019), water losses reach 126 billion m^3 annually, and these losses can be converted into a fruitful investment. Reducing water losses increases the amount of water available for consumption, decreasing the expenses of water pumping and treating, water financial revenue growth, delaying the demand for bigger infrastructures, thereby improving feasibility of water supply facilities.

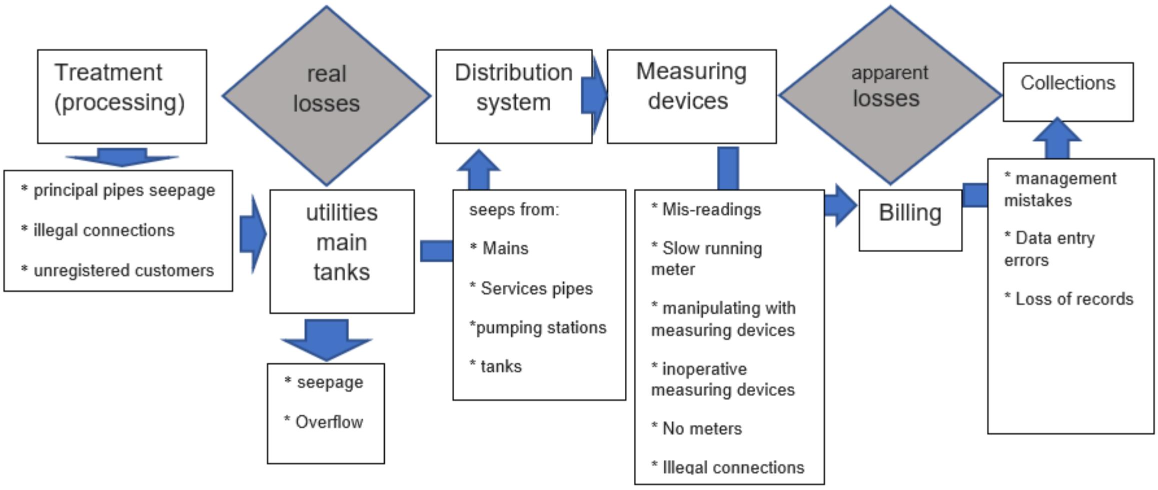


Figure 4 - Typical losses from water supply system (based on MNRW.2008).

The assessment of NRW and understanding and identifying its causes is the initial phase for controlling the water losses in urban areas. Perhaps the most important measures that can be implemented to reduce water losses are switching to digital equipment and linking it to Geographic Information Systems (GIS), redesigning the water distribution network into District Metered Areas (DMA), monitoring the flows and the pressures, assessing the annual water balance, performing hydraulic modelling, implementing pressure control, introducing active leakage control, documenting customers consumptions, decreasing measurement inaccuracies and illegal consuming of water as well (Puust *et al*., 2010; Hamilton *et al*., 2013).

In the following it will be presented some of the methods used to detect and reduce water loss.

Water balance: Determining the total water losses (physical and apparent) by finding the difference between the volume of water introduced into the supply system and the volume of legal water consumed (billed and unbilled metered, billed and unbilled unmetered), is done by checking the water balance in the supply system, which is often done on annual volume basis.

To ensure the accuracy of the calculations, and given the difficulty in identifying areas where leakage occurs in large quantities if the studied area is large, it has been recommended to divide the large areas into smaller sectors called DMAs (figure 5), which allow monitoring the quantities and quality of water and detecting the locations and causes of water loss, and thus facilitating taking measures to control water losses, as well as the implementation of the water balance procedure. It is indicated that the aim of this division is to supply the DMA with water from one (or more) point(s), so that the water pressure and flow rate at each of them can be monitored and controlled, thus achieving the intended results. Monitoring water flow at the entering points of the DMAs enables service providers to distinguish the locations of leakage, assess their dimension and quickly locate and repair them, reducing their duration and thus the volume of water lost (Malm *et al*., 2015).

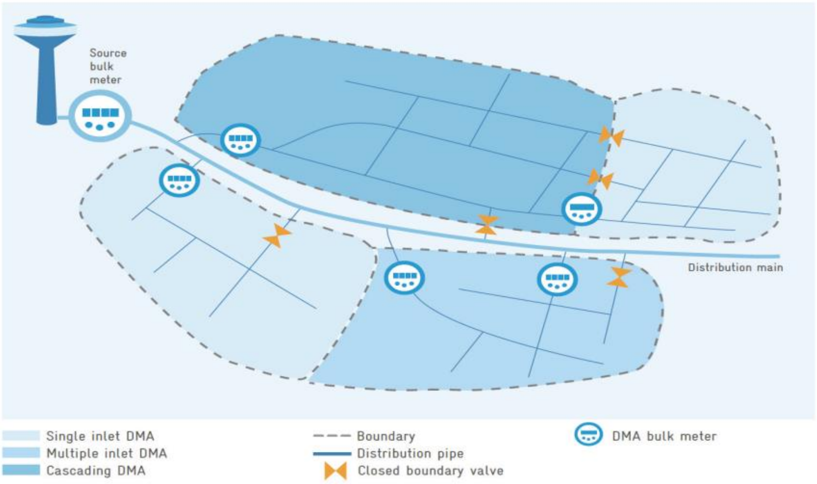


Figure 5 - Typical DMA layouts (Farley, 2001; Fallis *et al*., 2011).

Monitoring and Assessment: The aim is to continuously monitor and evaluate the volumes of water flowing into the water supply network, the water pressure at the main points and examine the water quality standards, monitor water levels in the tanks, the condition of the valves, the operating system of the pumps in the pumping stations, as well as the energy consumed to meet the demand of the water supply system. The monitored information is collected for use in assessment, interpretation, hydraulic modelling, and water quality modelling. Thus, providing the necessary data to identify network problems and find appropriate solutions to control quality and losses using modelling.

Determining the existence of water losses (leaks and bursts) and the area / pipeline in which the leaks occur, allows to proceed to the next step, which is to closely examine and detect the location of the leak. There are several techniques to locate the leaks, including:

a) Gas injection

In this method, a tracer gas is injected into the pipelines of the supply network in the area where the leaks are to be located. These pipes can be either empty or filled with water. To detect the location of a pipeline's leaks, it should be known the flow direction, and should be preserved the tracer gas in the pipeline where leaks are suspected by shutting off the branches of this pipeline. Then, the location of the gas leak, that is heading towards the surface after leaving the leak in the pipe, is detected with a gas detector. The used gas can be helium or hydrogen, but hydrogen is more often used because of its low cost, good performance, low weight and viscosity. This method can be used to detect leaks from pipes made of different materials, with diameters ranging from 75 to 1000 mm (it can be used for pipes of larger diameters, but this will require a greater amount of tracer gas) (Hamilton and McKenzie, 2014).

b) Manual listening stick

It is a technique that relies on listening the noise of leaks and locating them with an earpiece (figure 6). The stick may be made of wood, metal or plastic, and this technique can be used to detect leaks from pipes made of various materials, but the performance is more effective in the case of metal pipes with diameters ranging between 75 and 250 mm and water pressure greater than 10 meters. The factors which affect the accuracy of determination of the leak's location are the pressure of the water, the backfill materials, the sound pollution of the background, and the hearing ability of the person making the detection (Hamilton and McKenzie, 2014).

Figure 6 - Manual listening sticks.

c) Leak noise correlation

This technique is based on the principle of sound propagation, whereby the noise resulting from a leak travels in both directions at a constant speed (assuming that the pipe's material and its diameter are constant between the two points of the acoustic sensor fixation). If the leak position is not at an equal distance from both sensors, it is possible by measuring the time difference between receiving of the leak noise by the two sensors and knowing the speed of the sound (depending on the pipe's material and its diameter mainly) and the use of the relation between time and velocity and distance to determine the location of the leak. The changes of pipes material or their diameter should be considered in estimating the speed of sound. The location of the leak is confirmed with a ground microphone (geophone) after being determined by the leak noise correlation technique. It is worth noting that the sensor's reception of noise is a critical factor, which is greatly affected by background noise and water pressure (both make the leak noise clearer) (Hamilton and McKenzie, 2014).

There are two types of noise transducer that are used:

Accelerometers: respond to high frequencies. The sensor does not need to be in contact with the pipe's water (figure 7. A). Accelerometers are most effective in metallic pipes, where the noise signal is dissipated less, and the impedance matches between the pipe's material and the metallic equipment of the accelerometers. In addition, accelerometers are easy to use and cost less.

Hydrophones: They detect acoustic waves spreading in water by placing the sensor in appropriate fittings (such as fire hydrants) to be in direct contact with water (figure 7. B). Hydrophones are useful for locating leaks in cases of large pipes (thick walls relative to the diameter) and non-metallic ones (where high sound wave frequencies dissipate more quickly), as well as when there is a large distance between available detection points and when there is loud background noise.

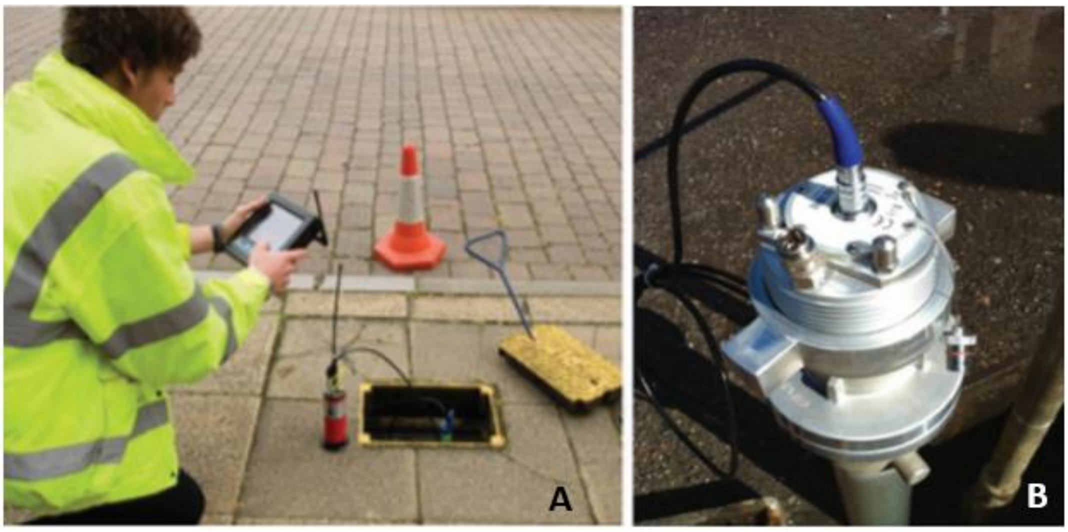


Figure 7 - Examples of accelerometer (A) and hydrophone (B).

d) In-line leak detection techniques

These technologies have advantages and disadvantages, and they mainly depend on passing the sensor next to the leaks, thus it is possible to detect small leaks, and distinguish multiple leaks in one pipe. This technology is designed for pipes with relatively large diameters and can be used in service mode (pipe under operation pressure). The equipment does not affect the quality of drinking water or the supply service (Hamilton and McKenzie, 2014).

There are two groups of in-line systems, the first group is called tethered swimming systems (figure 8. A). A hydrophone (sensor) is inserted into the pipe from specific points (such as air-valve connections and fire hydrants) and is connected to the signal processing unit via an umbilical cable. The parachute, which is installed in the front of the sensor, moves the sensor according to the direction of the water flow, and when the sensor passes close to a leak, it picks up the leak noise and sends it to the operator which controls the movement of the sensor. Once the sensor is installed near the leak, it can be located via a locating system, which enables the operator to track the path and location of the sensor.

Tethered swimming systems are preferred in relatively straight pipelines and they can scan lengths of up to 2 km from a single-entry point. Other types of sensors are available in addition to the hydrophone, such as ultrasonic pipe-wall inspection and video.

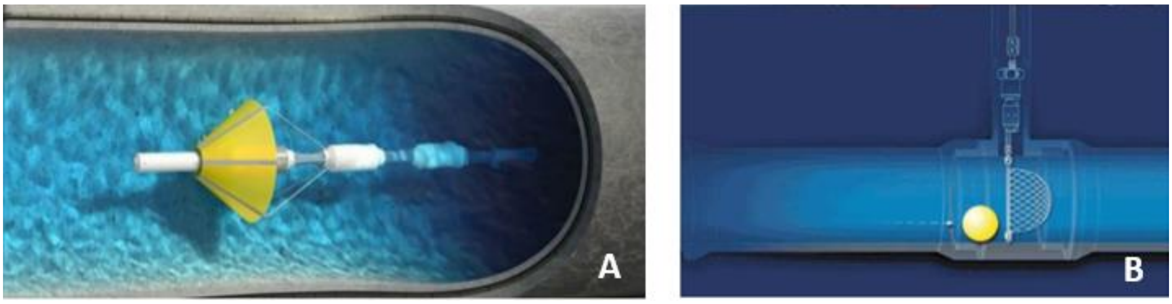


Figure 8 - Tethered (A) and free (B) swimming systems.

The second group is the free-swimming systems (figure 8. B), where the sensor is inserted into the pipeline, moved by the flow of water, or remote-control sensor which can move with/against water flow direction, and then the sensor is extracted by a capture device at the end of the inspection process. Sensors record noise during scanning, and the locations of the leaks are then determined by analysing the recorded free-swimming systems data. The pipeline length that can be inspected by These systems relate to the flow rate and the maximum operating life of the sensor. Generally, these systems cover larger distances compared to tethered swimming systems.

e) Noise loggers (non-correlating)

Leak noise loggers are usually fixed to the fittings using magnetic coupling. It detects leak noise which is louder and more consistent than background noise. The noise measurements are transferred with the graphical representation to the operator. To pinpoint the exact position of the leak, the leak should be located between two loggers. These systems are often programmed to perform night recording (when the background noise is lower and the pressure is higher) for more accurate monitoring of leaks. With the development of technology, wireless sensors and operators have been developed, which allow transferring and processing data automatically and enabling the expansion of inspection and increasing detecting effectiveness at lower costs (Hamilton and McKenzie, 2014).

f) Electronic amplified listening devices

It is known that in case of pipes with low water pressure, relatively large cracks and fractures, and large diameters, the leak noise is low, and gets lower with moving away from the leak location, so it becomes difficult to detect, especially with the noise of the background (such as traffic noises). The electronic amplified listening devices (electroacoustic microphone) amplify and filter the noise generated by leaks, which increase the efficiency of the detecting process. Thus, the electronic amplified listening devices are making progress in the field of detecting leaks and thus identifying water losses (Hamilton and McKenzie, 2014).

After determining the exact location of the leak, the water losses are controlled by one of the following methods:

a) Pressure Management

Water pressure is one of the most important hydraulic parameters in the water supply network, as it is mainly affected by the tank elevations and by the condition of pipes and other elements of the network. The presence of pumps also plays a main role in increasing the water head, while the difference in water consumption causes the difference in the velocity of the water and thus the variation in the water head due to head losses (Morrison *et al.*, 2007). Water pressure directly affects the water demand (the bigger the pressure the bigger the demand) and the leakage level (occurrence of new leakage or bursts).

Reducing water pressure until the optimum pressure is reached can provide an efficient and sufficient supply, reduces leakage, and avoids the exposure of pipes to burst, allowing the use of pipes, fittings, and other fixtures for longer periods. It can be said that the pressure reduction can be cost-effective (Grundfos, 2014). In a model provided by Khayelitsha in South Africa, the reduction of water pressure led to a reduction of water use by 43%, which enabled the return of the investment cost during the first two months of operation, and the network did not witness any significant damage for a long time (Mckenzie, 2002).

The water pressure is generally measured at the entrance of the water supply network (when the water is pumped) and at all critical pressure points, and the pressure is controlled using pressure reducing valves (PRVs), with the help of hydraulic models that provide predictions of pressure changes in time and space (Karadirek *et al.*, 2012). PRVs have been improved through technological development and the addition of electronic control units. It is worth noting that choosing the most appropriate form of pressure control to achieve a specific aim is one of the important issues facing water managers (there is no single model/solution that can be applied to all situations).

Therefore, pressure management has emerged as an effective tool for managing leakage, given the effect of pressure on flow rates, especially leaks from weak connections and corroded pipe walls (Gomes *et al*., 2012; Vicente *et al*., 2016).

b) Replacing and repairing

It is intended to replace and repair the worn out and corroded water supply network elements. If the maintenance procedures are a result of active leakage control, this increases the efficiency of water loss management, given that active leakage control monitors the network flows regularly, which facilitates early detection of leaks and pipe bursts, and thus taking the necessary measures quickly, which reduces losses, taking into account avoiding excessive maintenance periods and monitoring the quality of repair by the facilities in order to ensure reducing the possibility of recurring leakage (EU Reference document, 2015).

Renovation is part of infrastructure management that aims to reduce leakage as well as improve the water supply network by providing it with smart equipment (such as telemetry devices) in order to enhance the role of active leakage control, and to make adjustments and additions which are in line with the policies and strategies of the supply system management.

It should be noted that the choice between maintenance and replacement is controlled by several factors, such as the economic feasibility (the replacement is often more expensive), the importance of the element in the network and the level of damage, and whether it is possible to control through pressure management and active leakage control, knowing also that in some cases the replacement is albeit an expensive one, it is the most sustainable option.

Rapidly and accurately performing maintenance and replacement is an effective way to reduce the physical losses caused by leakage.

c) Hydraulic Modelling

The primary goals of using models in water supply systems are to simulate the conditions and the status of the studied model, and to test the scenarios and proposed solutions, and to predict their effects on the hydraulic parameters in the network, such as flow rate, water velocity and pressure, which enables control and reduce losses, and decline in water demand. It is worth noting that the models allow flexible testing for multiple locations of the supply system and at different times, seasons, and dates. Hydraulic models are carefully checked by using the detailed information gathered during the monitoring, to ensure the accuracy of the results produced by the models and thus the adoption of the predictions made by the models.

Benefits and Barriers

Managing water losses and striving to reduce them has many benefits, as it saves and provides additional amount of water for consumption and reduces the stress on available water resources, also reduces the energy used for water withdrawal, treatment, and distribution, contributes to the stability of the water supply service and improving its quality due to continuous monitoring and improvement of network performance. Through follow-up and monitoring, the management of water losses can make decisions related to improving service and determine the necessary actions in the specified place and time, which increases the effectiveness and efficiency of the supply system.

However, the management of water losses and the procedures of reducing them face some challenges and obstacles, especially with regard to administrative and technical affairs and the lack of awareness of losses importance as a resource and the importance of reduction measures, data limitations and lack of transparency in the real investment in the field of reducing water losses, and water pricing systems (such as subsidized water) which can limit the investing in network/system improvement (UNWDPC, 2011).

Water policy-makers' cooperation with utility administrators and workers and with the participation of stakeholders in parallel with deepening public awareness of the importance of water and the need to obtain stable water supplies can be among the most important keys to success and achieving the objectives of managing and reducing water losses and opening the door to innovation and development in this field (Hamilton and McKenzie, 2014).

3.4. Desalination

Desalination techniques have begun to receive more attention due to the increased crises of water scarcity and considering that many cities in the world are located on the coastline of seas and oceans. With the increasing water demand and the depletion of surface and underground natural freshwater resources, the oceans and seas represent a large water reservoir (about 97% of the planet's total water), which is not subjecting to direct consumption. Desalination has emerged as a promising technology for providing new freshwater resources, and it has been adopted in many regions (especially in the Middle East) to meet their freshwater needs. A study made by Khawaji *et al*. (2008) had sorted the top five producers of desalinated water, which are, in order, Saudi Arabia, the United States of America, the United Arab Emirates, Spain, and Kuwait.

Desalination technology aims to remove dissolved solid materials and compounds from the feed water (salt water, brackish water, or groundwater that is not totally fresh). Therefore, this technology can provide the world with a relatively unlimited resource of freshwater, which helps in solving the problems of water scarcity (Zander *et al*., 2008).

There are two basic groups of techniques according to which desalination is carried out: first group depends on thermal processes and the other depends on membrane processes (Miller *et al*., 2015).

The thermal processes adopt the principle of evaporation, where the raw water (to be desalinated) is heated and turns into vapor, then the vapor is condensed to produce freshwater free of salt, after which minerals are added in concentrations that make the water potable. Thermal process-based techniques include multi-stage flash, multi-effect distillation, and vapor compression.

i. Multi-stage flash technique

It is primarily used for desalination of sea water (Buros, 2000) and produces about 22% of the world's desalinated water (Miller *et al*., 2015; Ettouney *et al*., 2002). The two phases of the process are evaporation and condensation, which are coupled together to make use of the inherent thermal energy of the vapor to heat the raw water (figure 9) (Miller, 2003). One of the advantages of this technique is that the salinity of the raw water has no significant impact on the evaporation process or the costs of the multi-stage flash units, and it yields high quality water. Also, the necessary thermal energy can be obtained by combining a desalination plant with a power production plant. However, the direct exposure of the evaporator equipment to the raw water, which can cause corrosion and scaling, as well as the high cost of construction and operation, and the relatively low productivity (percentage of water recovered from condensation) are weak points for this technique (Saadat *et al*., 2018).

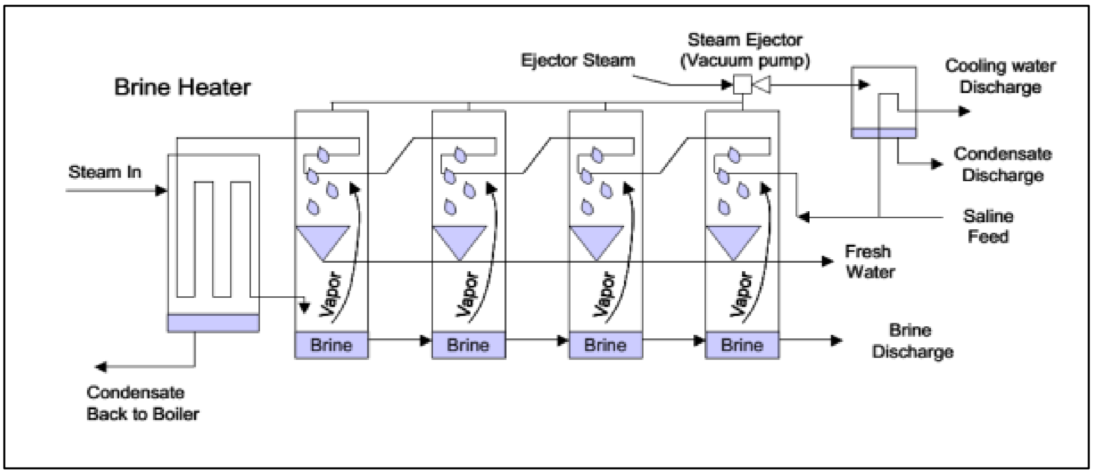


Figure 9 - The Schematic diagram of Multi-Stage Flash Distillation process (Miller, 2003).

ii. The multi-effects distillation technique

It has gained attention due to the effectiveness of use the thermal energy of vapor, as the vapor is condensed for each stage in the next stage, and thus the vapor heat helps to heat the walls of the pipes which transport it. The raw water is then sprayed on the pipes, and the evaporation occurs again in the next stage, and so on (figure 10) (Miller, 2003).

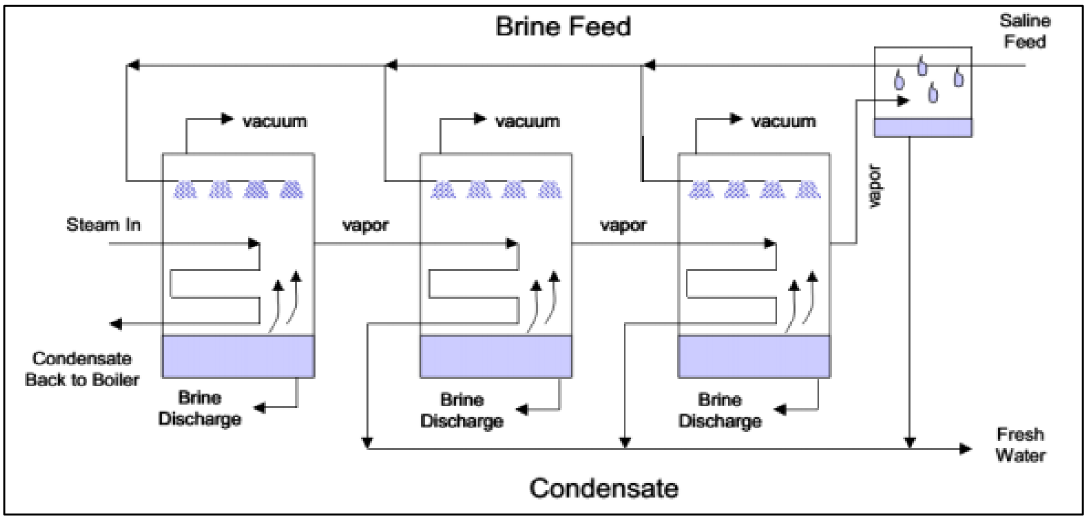


Figure 10 - Schematic diagram of multi-effect distillation evaporator desalination process (Miller, 2003).

Although the thermal performance is more efficient and the low operating cost compared to multi-stage flash technique (due to the use of waste heat of the distillation process) and desalinating lower quality raw water compared to the reverse osmosis technique, the multi-effect distillation technique is not widely used due to problems of corrosion and scale formations of vapor pipelines (Al-Shammiri and Safar,1999).

iii. Vapor compression

It begins with the process of evaporation and pressurization of vapor, and then use of pressurized vapor as a heat source to evaporate additional raw water (figure 11) (Miller, 2003; Mandani *et al*., 2000).

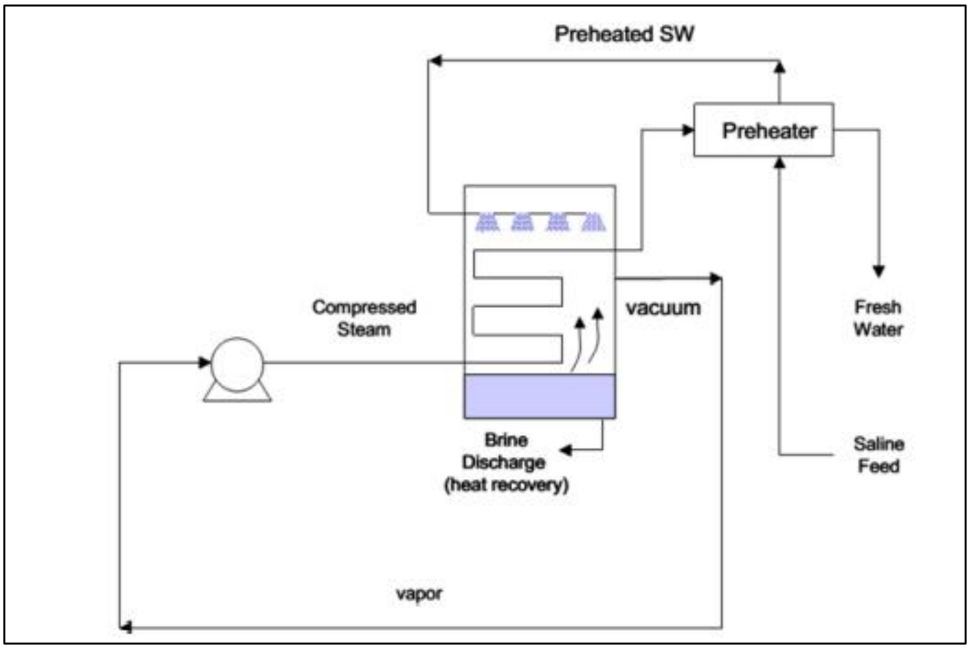


Figure 11 - Schematic diagram of single mechanical vapor compression distillation process (Miller, 2003).

The plants that rely on this technique are relatively small and affordable and can produce high-quality water from low-quality raw water (compared to the reverse osmosis), but they also require expensive vapor compressors, as well as the cost of corrosion and scaling (Buros, 2000).

Membrane processes are based on allowing one or more components to move across a membrane, which separates the two phases, more easily than other components. Among the techniques based on these processes are reverse osmosis, electrodialysis and forward osmosis (limited use).

i. Reverse osmosis

A pressure difference is created between both sides of the membrane, so that the pressurized raw water moves through a water-permeable membrane to the other side, where the pressure is close to the atmospheric pressure, and the membrane prevents the crossing of dissolved solids and organic and colloidal materials, and so the desalinated water is obtained on the other side of the membrane (figure 12).

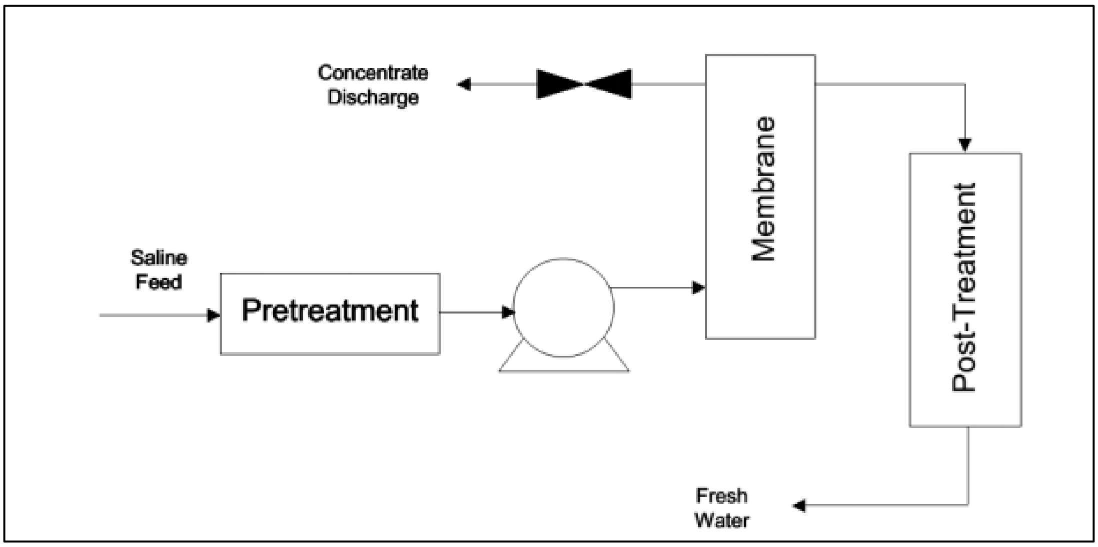


Figure 12 - Block diagram of reverse osmosis operations (Miller, 2003).

The basic energy required for this technique is used in the initial pressurization of the raw water, so efforts have been made to improve the membranes and reach the low pressure membranes that work efficiently based on a pressure of 50% less than the pressure required for normal membranes. This in turn helps to reduce energy costs (Buros, 2000). Usually, this technique is used for brackish water and it is necessary to pre-treat the raw water, so that the fine particles are removed (so as to reduce the risk of clogging the membranes) and increase the life of the membranes (reducing costs of maintenance and replacement) (Semiat, 2000).

ii. Electrodialysis

It is also a technique used to desalinate brackish water (Strathmann, 2010), which is based on separating ionic components; this technique cannot separate moderately charged materials such as organic and colloidal substances from water by attracting them by electrodes of opposite charge (figure 13) (Miller, 2003; Buros, 2000). The energy required to separate the ionic components increases with the increase in their concentration in the raw water, so it is preferable to use it in the case of brackish water, where the ionic components are less compared to sea water (Semiat, 2000).

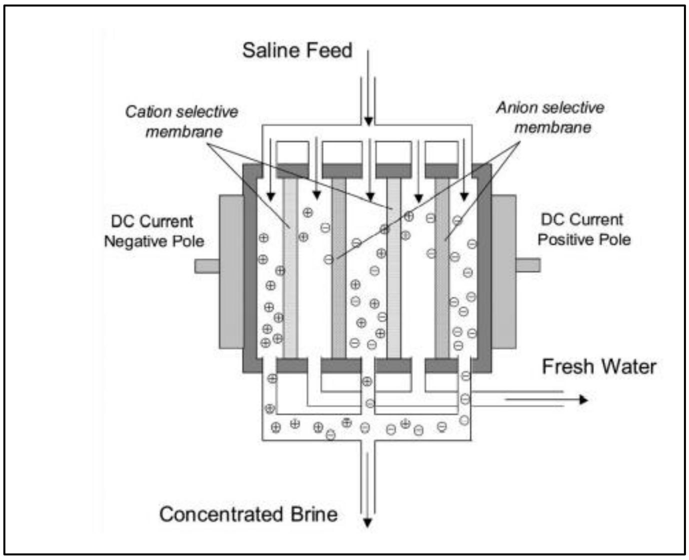


Figure 13 - Schematic diagram of electrodialysis desalination process (Miller, 2003).

iii. Forward osmosis

It is based on an osmotic pressure gradient, which allows only water to move from the raw water to the other side of the membrane where there is a high concentration solution (called draw solution), resulting in a less concentrated solution that is treated to obtain freshwater (figure 14) (Semiat and Hassan, 2008; McCutcheon *et al.*, 2006). This technique is characterized by low energy consumption, simplicity, and relatively low pollution potential (Cath *et al.*, 2005).

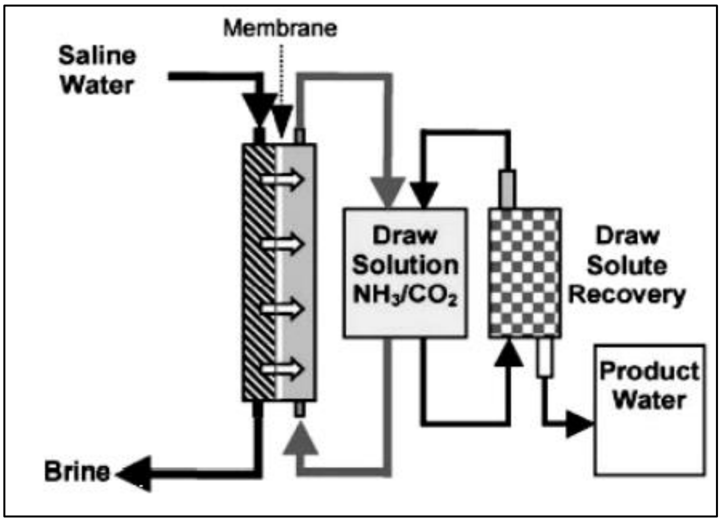


Figure 14 -Forward osmosis process schematic (Semiat and Hassan, 2008).

Making decisions, to adopt one of the previous desalination techniques, is based mainly on technical considerations (such as required energy, performance, quality of raw water, etc.) and economic factors (costs of construction, energy, etc.), in addition to the circumstances which are imposed by project's location and controls (Khawaji *et al*., 2002; Wade, 1993). However, from the technical point of view, it could be said that the thermal processes are characterized by a lower recovery rate and higher water quality compared to membrane processes (Eltawil *et al*., 2009), and that the use of energy in thermal processes is not related to concentrations of dissolved solids as is the case in membrane processes (Miller, 2003). Nevertheless, they consume higher rates of energy, and this should be taken into consideration in regions with limited-energy production. The previous features led to the popularity of the reverse osmosis technique (membrane process), especially after technological advances that enabled it to reduce operating pressure and recover energy (Miller, 2003).

Regarding the quality of the raw water, it is a decisive factor when choosing the technique to be used and the existence of the pre-treatment stage of the desalination processes, and thus determining the costs of the desalination process. Membrane processes require relatively good quality raw water which ensures that no failure in the desalination unit will occur (such as clogging of the reverse osmosis unit), and prolong their service life (Semiat, 2000), which makes the thermal processes of water desalination cheaper than the membrane processes in terms of treatment measures, as the thermal techniques do not need to carry out pre-treatment, but only require simple post-treatment (adding minerals to make them drinkable) and disinfection (normally with Chlorine) (Wagne, 2007).

In addition, the location of the desalination project, its characteristics, the production capacity of the plant, and the regulatory procedures play a role in determining the total expense of the desalination project (Younos and Contemp, 2005; Cost Estimating Procedures, 2003). Large-capacity plants require a relatively high initial construction cost, yet they may produce a water unit at a lower cost compared to smaller plants (Younos, 2004; LBG-Guyton Associates, 2003). Therefore, a cost analysis should be conducted for the different desalination techniques to know the impact of each one of those factors, and to make decisions that promote efficient investment and achieve the intended goals.

Desalination technology is still witnessing limited adoption, although investment in the field of water desalination has become a necessity for some countries suffering from water scarcity, but the fact that this technology is expensive prevents its use by many countries (especially developing countries). However, the rapid technological development, the exacerbation of water crises, the awareness of the value of water and the importance of using alternative water sources beside freshwater sources, increases the possibility of using desalination as one of the most important technologies to provide freshwater.

3.5. Demand management

Focusing on water resources and water utilities alone is no longer feasible and sustainable, as the required water needs and how to manage them have a major impact in light of the potential limitations of local water resources (Gleick, 2000). While most approaches were concerned with securing water demand as a necessity cannot be ignored by searching for new water resources and expanding and developing infrastructure to achieve this goal, the demand side, which is more flexible and susceptible to reduction, has been ignored (Inman and Jeffrey, 2006).

It was necessary to develop the concept of water demand management, which is concerned with improving and implementing policies and using applications to reduce water demand, which, in turn, helps the optimal allocation of water to ensure sustainable supply (Brooks, 2006), away from the development of high-cost infrastructure (such as dams) to provide more water (de Lange, 2016).

According to the water demand management approach, the resort to taking measures on the supply side (seeking to provide additional water resources) should only be applied after developing and implementing demand reduction strategies.

Water administrations usually use price (economic) (Kenney *et al*., 2008) and non-price (technological and behavioural) (Saurií, 2003) mechanisms as ways to decrease and control water demand. Studies indicate that the rates of demand reduction change according to the mechanism used (UK Environment Agency, 1999; Dandy *et al*., 1997), and thus to increase rates of reduction in water consumption and improving management and sustainability of water resources (depending on the demand side) it is imperative to develop integrated strategies and policies to use price and non-price mechanisms.

Pricing Mechanisms have emerged as one of the relatively effective tools in the process of reducing and managing water demand (Garcia and Reynaud,2004), which is based on the concept of the inverse relation between price and consumption (increasing the price of water unit reduces consumption). However, researchers in the field of demand management noticed that the value of the decrease in demand is not proportional to the increase in price, and that time and type of use play a fundamental role in the effect of price increase on consumption (Arbués, 2003; Mazzanti and Montini, 2006).

Espey *et al*. (1997) found through his research that pricing mechanisms are effective and achieve the intended results in the long term. Dalhuisen *et al*. (2003) study came to confirm that, as he found that the response of households to increasing prices is better the longer it takes them to adapt to the new prices. However, the household response and the decrease in consumption will continue until they touch the threshold of meeting the basic and essential needs, after which the response will decrease (Martínez-Espineira and Nauges, 2004). Thus, the effective response to the rise in prices will include limiting unnecessary activities (swimming pools, garden watering, etc), while water consumption for drinking or personal hygiene will be less responsive (Dalhuisene *et al*.,2003; Renwick and Green, 2000).

It was also possible to notice the difference in the impact of price increases according to the level of income, as families with low or high incomes are the least affected, while middle income families were the most affected, due to the inability of pricing policies alone to deter the practices of families with high financial capacity, or to force low-income families to forgo their drinking water and personal hygiene needs (UKWIR, 1998).

Technological mechanisms (**Water-saving appliances and meters)**: The water meters used are a critical tool for managing water demand (Lawton *et al*., 2008). They are a complement to pricing policies, as they record the quantities of water used by customers, then the bills are subsequently issued by the service provider depending on the records of water quantity used and on the pricing system. Accordingly, accurate meters must be associated with appropriate pricing systems, for example the increased rate of tariffs can be used, where each unit of water is priced at a specific value until consumption reaches a certain limit, after which it is moved to another level, in which the price of a unit of water is higher. This ensures access to water for basic uses at an affordable price, and exceeding the basic use is fined by an increase in the price.

Water metering can affect consumers by displaying their consumption data and detailing their bills, but traditional meters were not able to explain all the factors that affect how water is used (Bell, 2015), nor they were able to provide real-time usage information. This was the main incentive for the emergence of smart meters that record, collect and communicate the updated consumption data based on real time according to an automatic and electronic system (Idris, 2006).

As for water-saving devices, they are among of the most important and effective tools in the field of water demand reduction and management (Millock and Nauges, 2010), for several reasons, the most important of which are:

The bulk of household water is used through these applications (washing machines, showerheads, and toilets), in addition to their proven ability to save water (such as highly efficient toilets and washing machines), as well as the public acceptance of the use of these fixtures in comparison with pricing policies or restrictions on water use (Polycarpou and Zacharizdis 2013; Millock and Nauges 2010; Randolph and Troy 2008). This acceptance increases and the decline in consumption occurs if the use of some low-flow devices is encouraged by providing users with them at no cost (Campbell *et al.*, 2004). It should be noted that the decrease in consumption is closely related to the continued effectiveness of the use of installed water-saving equipment. For example, a high-efficiency toilet is not flushed twice, or using a shower for long period considering the shower head uses less water (Bell, 2015). However, establishing comprehensive programs which include replacing or retrofitting water-saving devices and implementing use reduction measures, can achieve sustainable management and development requirements at an economic level and can reduce water consumption by 35-50% (Inman and Jeffrey, 2006), taking into account that humans tend to use efficient and easy-to-use technological devices compared to complex technology (Morris *et al.*, 2012; Kayaga and Smout, 2008).

Restriction mechanism: Water restrictions are practices applied by water authorities to reduce water consumption, especially in times of water scarcity. These restrictions are usually designed according to two frameworks (Howe and Goemans, 2002). The first is concerned with the restrictions of water use outside the houses in terms of time and type of use, as the types of permitted activities such as car washing or garden watering (Frost, 2013), and the times of these activities during the day or according to specific days, are determined. In this context, the amount of used water is not controlled, so that its effect on the overall use may be limited. While the second framework is concerned with restricting the total domestic use, as the amount of water permitted to be used for each household is determined according to standards and considerations related to the conditions of each region (Alias, 2017).

Apart from the previous classification of restrictions, their implementation could be mandatory or voluntary. However, studies confirmed that mandatory restriction reduced water use rate between 16-31%, while the reduction in case of the voluntary implementation of restrictions did not exceed 16% (Kenney *et al.*, 2008; Renwick and Green, 2000; Wang,1999; Renwick and Archibald, 1998; Nieswiadomy, 1992).

The implementation of restriction programs requires determining the type and scope of water use restrictions and clarifying the seriousness of the water situation and the impact of restricted activities on this situation (noting that the greater the number of restricted activities the greater the expected reduction in use). Likewise, a plan must be put in place for implementing and monitoring and the penalties to be taken against the violators must be determined (Halich and Stephenson, 2009).

Municipal authorities can also issue legislation or restrictions that reduce water consumption, such as making landscape adjustments to suit the climate (Frost, 2013), or using weather-sensitive irrigation devices that can reduce consumption in times of drought (Tsai *et al.*, 2011). It is also possible, for example, to limit the use of water to fill swimming pools, which is a reason of a relatively large growth in household water use especially in rich areas (Siebrits, 2012), by covering it to reduce evaporation, and by using filtration devices that allow water to be filtered several times. In addition, it is not necessary to use high-quality municipal water (drinkable) for activities that do not require high quality water, such as watering gardens or swimming pools or washing cars (outdoor uses), as well as in household uses (flushing toilets) if there is an alternative resource of adequate quality for use.

Taken together, previous restrictions and practices ensure that excessive water use is minimized, especially if applied in drought periods and accompanied by appropriate awareness (Fisher-Jeffes *et al*., 2015).

Awareness and education: the most important obstacles that prevent societies from adopting water conservation behaviour are their cultural and/or religious backgrounds, and the lack of awareness of the true value of water as a limited natural resource (Dela Cruz and Gray, 2012) and the real costs and expenses of water services provided by the water authorities (Russell and Fielding, 2010). This has necessitated awareness and education campaigns and community involvement in water conservation issues (Howarth and Butler 2004), relying on introducing the benefits and advantages of water conservation to stimulate the will to adopt behaviours which achieve water conservation and reduce consumption (Russell and Fielding, 2010).

Awareness and education campaigns are conducted through schools (considering that children are the primary players in the future, and their scientific and behavioural upbringing has a fundamental role in future trends). Also, through advertisements, brochures, and providing water consumption bills with information about water saving procedures and the pricing system used to deter water overuse and increase knowledge. In addition, the workshops, lectures, and seminars, with the concepts they contain regarding wanted behaviours, water conservation mechanisms and the benefits that can be obtained, and other information that consumers should be aware of, such as water resources in local urban environments and the organizational structures and infrastructure needed to provide safe drinking water (Department of Sustainability and Environment, 2005), and the risks of water shortage and pollution, play a main role in changing societal norms and pushing consumers to follow more convenient water practices (Perren and Yang, 2015).

In order to effectively spread knowledge to increase awareness of water issues, the dimensions of the obstacles that prevent the shift towards water conservation behaviours must be understood and studied and then attempt to overcome them through legislative, social and psychological interventions (Hassel and Cary, 2007), and identifying the risks of water crises and their societal, environmental and economic impacts, as the radical change occurs upon knowledge of the dimensions of crises, in an attempt to mitigate or avoid their consequences (Gersick, 1991).

Implementing mechanisms to reduce water usage effectively in the long term helps manage short-term water crises. Managing water crises in the short term includes developing strategies and designing response plans to prepare in advance and deal with and overcome the crisis.

Hence, an attempt to mitigate or avoid impacts through the most efficient management of the available water resources (Alias *et al*., 2017).

The importance of pre-managing risks and foreseen future crises (albeit partially predictive) and their role in mitigating and avoiding unwanted outcomes and the potential for turning crises into opportunities were recognized. The traditional method of dealing with crises by responding in real-time and taking temporary measures to meet demand in proportion to the amount of water available brings about a short-term decrease in water use. To maintain a permanent decrease in the volume of water used, different strategies must be followed that promote a water conservation culture and behaviour and pre-preparedness for crises rather than adopting a momentary response approach. As it happened in Singapore, which was ranked by the UN among the countries suffering from water scarcity (UNESCO, 2006), so it has adopted price, awareness and education mechanisms to reduce the domestic demand for water. With this strategy, Singapore achieved a 16% reduction in consumption between 1994 and 2012 (Tortajada *et al*., 2013).

It can be said that the achievable decrease in water demand varies from one mechanism to another but integrating these mechanisms together in demand management programs is more effective in reaching the intended goals (Elias *et al*., 2017).

CHAPTER 4

CONCLUSION

As a result of each of the social and economic growth trends, improvement of the living standard, and urbanization, consumption patterns and needs will vary, which will increase the water, food, and energy demand. Climate change, rising the average of temperature, and changing precipitation patterns, in parallel with competition between different users for available water resources, may increase the number of people who will face scarcity of water resources and the stress of available ones. The previous factors, in addition to the resulted environmental degradation of the human activities expansion and their effects on the hydraulic cycle and ecosystems, are essential and interconnected factors with complex dimensions, that, together, threaten the availability and quality of water, and create obstacles that hinder developing water policies and improving the efficiency of water management and its technologies, and increase the possibility of the exposure to the Water Resources scarcity/stress.

Water problems in urban areas around the world vary depending on the circumstances of each region. There are areas that suffer from a shortage of water resources or difficulties to access, while other areas suffer from the uncontrolled pollution, and challenges could also be climatic (drought and flood), which could result in natural, human and economic losses. individually or together, coupled with the pressure imposed by population growth and the expansion of water services (drinking water and sanitation), these challenges may affect the reality of available water, its quality, allocation, use efficiency and productivity.

However, the greatest challenge is how to deal with and respond to these threats, and how to secure water, both quantitatively and qualitatively, to meet the different usage requirements, not only for current generations, but for future generations as well. The traditional bases of water policies and water demand management, which address challenges in real time and always seek to cover the increasing water demand through exploitation of new freshwater resources, are inefficient and unsustainable. Based on this vision, a set of measures emerged which mainly aim to provide alternative water resources and raising the efficiency of water use on one hand, and trying to control and mitigate the consequences of various human activities and climate change which affect environment and urban areas, such as the unsustainable use of water resources, extreme weather events and pollution on the other hand.

This thesis presented a set of measures and techniques that can contribute to improve water management, provide additional water resources and increase the efficiency of use, which in turn ensure water sustainability and raise the availability to meet future demand, especially when water policies are developed and executive plans are designed to be more flexible and capable to respond and find solutions to future challenges and risks.

Some of these measures address the supply side, by trying to find alternative water resources (such as rainwater harvesting, wastewater reuse and desalination) or by raising the efficiency of water use (such as managing water losses) while demand management tends to focus on uses as an essential component of the use cycle, and trying to present some technical and educational tools that would reduce the water demand.

Rainwater harvesting can cover the water needs of some household or outdoor activities or even some commercial centres demands, depending on the size of the rainwater harvesting system and the quality of the water produced, which reduces the burden on the municipal supply systems, relieves the impact of drought and rainstorms, while desalination is one of the most important measures that can supply cities (especially coastal) with large quantities of usable water, as it desalinates the water from oceans, seas and brackish water. Thus, desalination can be an effective solution to potential future water challenges (such as water scarcity, water pollution, etc.). Although the costs of desalination processes are relatively high, but technological and technical developments hold promise of cheaper, more efficient, and more productive desalination methods.

Wastewater is the end product of most use cycles in urban areas, so it is an important resource that can be relied upon if treated and reused according to standards that ensure public health, the health of ecosystems and development requirements. The management of water losses is a necessary and beneficial measure. In addition to the large amount of water that can be conserved when losses are reduced and controlled, the financial revenues are increased, and energy is saved. Also, water demand management is a measure that conserves water through reducing the demand and requires integration between the effectiveness and efficiency of water saving mechanisms and the behaviour of users to achieve the sustainability of available resources and enable them to meet future water needs.

The sustainable management of water in urban areas requires the implementation of one or more of the previous measures according to the circumstances of each region (within integrated water policies at the international, national and local levels), exchanging experiences, collecting and analysing data to know the trends of the evolvement of water availability, quality and demand, keeping pace with technological and technical developments, and raising awareness of the value of water and the challenges it faces, considering that feeling threatened can be an effective motivation to find the solutions before the problems occurrence.

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