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The need for integrated water management in Kuwait

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ABSTRACT

The water problem in Kuwait is outlined. The only natural water resource available is the ground water, which is extremely limited, exhausted, and non-replenished. Its exploitation not only should be stopped, but it should be recharged to serve as strategic water storage. The potable water demand is mainly satisfied by desalting seawater, using the multi stage flash MSF desalting system. This method is inefficient, energy wise, very costly, and should be replaced with more energy efficient desalting system such as seawater reverse osmosis SWRO system. This can save up three-fourth of the fuel energy used for desalination and substantially reduces the desalting water cost. Another non- conventional water resource is the treated wastewater. It should be fully utilized since its cost is much cheaper than desalting seawater or brackish water, and its amount increases with the increase of population and their consumption. The per capita water consumption in extremely high, and should be reduced through an effective water demand management program. The fresh water production in Kuwait can satisfy more than twice the water demand if the water is used wisely.

Keywords: Kuwait; Integrated water management

1. Introduction

Kuwait has a water problem as a result of many factors such as

- very limited natural water resources;
- over exploiting of almost non-replenished ground water, causing their depletion;
- almost full dependence on desalted seawater to satisfy potable water and household needs;
- use of high energy consuming desalting system and thus high cost of desalted water production;
- combining desalting units with steam turbines in power plants of limited water to power production ratio, and thus the inability to satisfy the high rate of water demand increase compared with that of electric power;
- lack of timely response to match the increase of water demand with installing sufficient desalination capacity;
- vulnerability of desalting water system;
- incomplete utilization of reclaimed treated wastewater;
- lack of strategic water storage capacity;
- high potable water consumption per capita;
- lack of measures and public incentives to conserve water;
- unrealistically low pricing of water and power to consumers;
- lack of awareness of the value of water in homes and public buildings such as mosques and schools, and other aspects;
- lack of institutions to carry integrated water managements.

To solve this water problem, suitable integrated water management plan IWMP for Kuwait is needed. The main objectives of the IWMP are the managing of both water resources and demand. This paper is looking for the factors affecting the adoption of an integrated water management plan to solve the water problem.

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2. History of water development in Kuwait

Kuwait is an arid land located at the north-western corner of the Arabian Gulf, between latitudes 28°30′ and 30°05′ north and longitudes 46°30′ and 48°30′ east. The country total estimated Actual Renewable Water Resources in 2005, by UN report [1] were 8-m^3/y per capita, the poorest country in natural water resources in the world. The reported renewable fresh water for some of close by countries, which depend partially or fully on desalination as non-conventional water resource in m^3/y per capita are: 96 Saudi Arabia, 49 United Arab Emirates, 86 Qatar, 157 Bahrain, 41 Gaza Strip, 106 for Libya, 340 Oman, 223 Yemen, 90 for Libya; and 250 for Israel [1]. Other neighboring countries with rich natural water resources (in m^3/y per capita) are Iraq 2920 and Iran 1970. It is noticed here that 1000 m^3/y capita marks the poverty line. The percentage of extraction to the resources in Kuwait is 2227%. Kuwaiti population increased from 2.234 in 2001 to 3.051 million in 2006, or 6.34% annual population increase [2]. The average annual rainfall is about 121 mm/y. Seventy-five percent (75%) of the rainfall occurs in the four months from November to February. There is also spatial variation of rainfall.

The mean annual potential evaporation values as measured by evaporation meter were 3,460 mm (1962–1977) and 5,460 mm (1957–1977) respectively. The theoretical annual average potential evaporation was about 2,630 mm (1957–1977) [3].

There are no rivers or lakes, but small water collections (wadis), which are developed in the shallow depressions in the desert terrain. Surface run-off, sometimes, occurs in the large depressions during the rainy season from November to April. However, there is no permanent stream-gauging station, but flash floods are reported to last from few hours to several days. Due to the extremely high evaporation losses and the high deficit in soil moisture, only a small percentage of the precipitation infiltrates into the groundwater. The runoff ratio must be extremely small [3]. Therefore, precipitation is not considered as source of ground water recharge.

In the past, Kuwait relied on a scant number of wells to satisfy its fresh water needs [4]. In 1025, Kuwait stated to import fresh water from the Shatt Al-Arab in Iraq, about 100 km north-west from Kuwait to supplement the water obtained from wells. By 1946, the beginning of oil era, continuous transport of water from Shatt Al Arab at the rate of 80,000 gallons per day. Further exploitation of water resources was initiated by the rapid development of the oil industry and commerce in the 1950s, when water shortage became a constraint to economic development. The options at this time were

(i) importing water from Iraq or Turkey,
(ii) exploitation of ground water, and
(iii) desalting seawater.

As the first option was not politically sound, the second is limited but water was more exploited, and the third was applied.

In 1951, Kuwait Oil Company KOC installed 80,000 gallons/day seawater desalting plant in Al-Ahmadi and piped part of the desalted water to the town of Kuwait. In 1953 the first one MIGD desalting plant was commissioned in Shuwaikh using submerged tube multi-effect desalting system, in 1957 the first MSF desalting unit applied inland of 0.5 MIGD each (one million imperial gallons MIG is equal to 4546 m^3, and MIGD means on MIG per day) was built in Shuwaikh by Westinghouse Company in US, and in 1960 the first 2-MSF units by Weirs Company in UK based on Professor Silver design of one MIGD each were installed in Shuwaikh. In 2005, 317.1 MIGD capacity MSF units are operating in Kuwait, 432.5 MIGD capacity is expected by 2008, and 522.5 MIGD are planned to be installed by 2010 [4].

The 2007 statistical book of ministry of Electricity and Water MEW indicated that the fresh water consumption in Kuwait in 2006 in million imperial gallons MIGD (m^3/d) are 332.242 (1,416,500) average, 308.406 (1,402,000) minimum and 367.746 (1,671,770) maximum [5]. The average daily consumption in 2008 reached 1,600,000-m^3/d. These fresh water consists of almost 90% distilled water (from desalting plant), and the balance is ground water. The 2007 statistical book also indicated that in 2006 the average groundwater production was 92.78 MIGD (423.55-m^3/d), and its consumption was 67.1 MIGD (306,311-m^3/d). The difference was mainly added to the distilled water to produce the potable water.

Meanwhile, the capacity of Sulibya wastewater treatment and reclamation WWTP is 375,000-m^3/d. So, the total daily water consumption in 2006 was 2.15-million m^3/d, with 68.26% potable water, 14.27% brackish ground water, and 17.47% reclaimed water.

3. Water resources in Kuwait

The current local water resources for Kuwait are groundwater, desalted seawater, and reclaimed treated wastewater, as surface water can be neglected. By assuming 100 mm annual rainfall, the annual rainfall is 1780 million m^3, and with high evaporation loss, only 1% or only 17.8 million m^3 is runoff. A water balance was estimated by Al Otaibi et al. [6] with no reference given to its reported values as:

a) The fresh water production was 520-Mm^3/d (million cubic meters per day), and consist of 480 Mm^3/d desalted seawater blended with 40 Mm^3/d ground water to improve its palatability.

b) The fresh water was used as 500 Mm^3/d by domestic users, and 20 Mm^3/d by industrial users.
c) Fresh water withdrawal was 1 Mm^3/d from Al-Rawadatain and sold as bottled water.
d) Fresh water storage was estimated by 20 Mm^3/d.
e) Brackish water production is 80 Mm^3/y.
f) Potential aquifer storage recharge is estimated by 100 Mm^3/d.
g) Treated wastewater is 260 Mm^3/d.
h) Reused wastewater is 180 Mm^3/d.
i) Agriculture water usage is estimated by 250 Mm^3/d by abstraction from ground water.
j) Rainfall is estimated by 2600 Mm^3/d, with evaporation of 2440 Mm^3/d and 160 Mm^3/d recharge.

3.1. Brackish ground water (GW)

The only natural water resource in Kuwait is the brackish ground water GW located in the Kuwait group with salinity of 4,300 to 10,200 mg/L and the Dammam aquifers with salinity of 2,500 to 10,000 mg/L and limited fresh water in Al-Rawdatain and Umm Al-Aish fields with salinity range of 359–1737 mg/L in the upper part of Dibdibba formation of the Kuwait group aquifer. Location of ground water fields and their salinity are given in Figs. 1 and 2 [6].

In 2005, the extracted GW from wells in Sulaibiya, Al-Shagaya, Umm Ghudair, and Al Atraf, was 245.5×10^3 m^3 (120 MIGD) [4]. The daily consumption of GW in the 2005 summer reached 138.4 MIGD. The actual amounts of recharge or inflow to these wells are not exactly known. The estimated flow to the Kuwaiti group aquifers was 310 $\times 10^3$ m^3 (68.2 MIGD) in 1976 and 140×10^3 m^3 (30.8 MIGD) in 1988, with annual decrease of by 14×10^3 m^3 (3.08 MIGD). The estimated flow to the Dammam limestone aquifers in Umm Gudair field along the border with Saudi Arabia is 10×10^3 m^3 (2.2 MIGD), which is far below the extraction of 60×10^3 m^3 (13.2 MIGD), and a serious decline resulted in the GW level [7]. The simulated head is estimated to decrease from 1993 to 2003 by 9.14 m in the Kuwait group of Umm Gudair, and 3.05 m in the Dammam aquifers. It is unfortunate that there are more programs to increase in the extraction (in fact mining) of ground water from wells, causing depletion and deterioration of this water quality. The ground water is used in Kuwait for irrigation, landscaping, construction work, livestock watering, and about 10–12% of total ground water production is blended with distilled water from desalting plant to make it potable and to increase its capacity as fresh water.

1.2. Water desalination

Kuwait was the first country in the Gulf Co-operating Countries (GCC) to desalt seawater in large quantities and the first in the world to use Cogeneration Power Desalting Plants (CPDP) in 1953, and to apply the multistage flash MSF desalting system in 1957, and in 1960 in its present design. About 93% of potable water need was secured by desalting seawater in Kuwait in 2002. The installed capacity of desalting units and the consumed

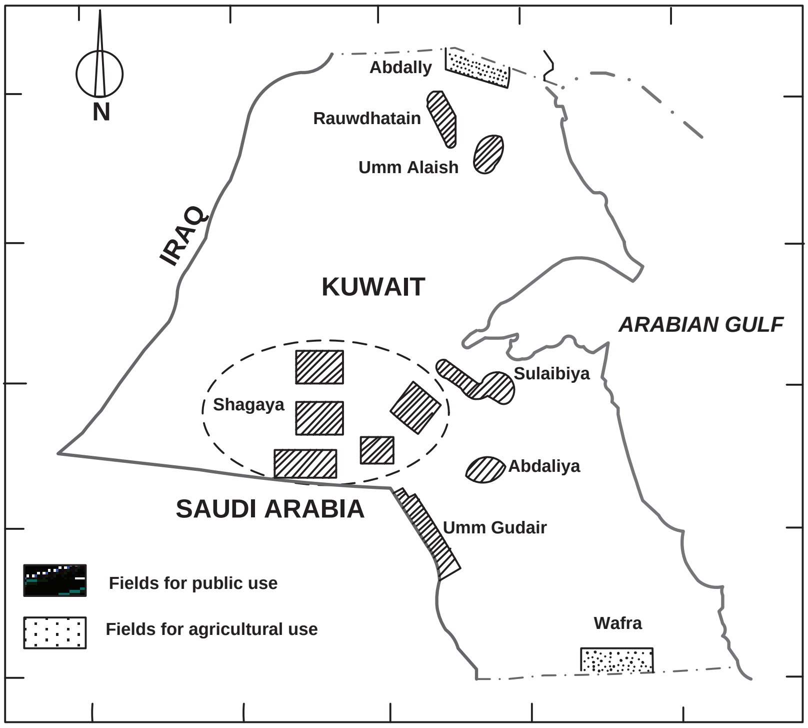


Fig. 1. Locations of ground water fields [6].

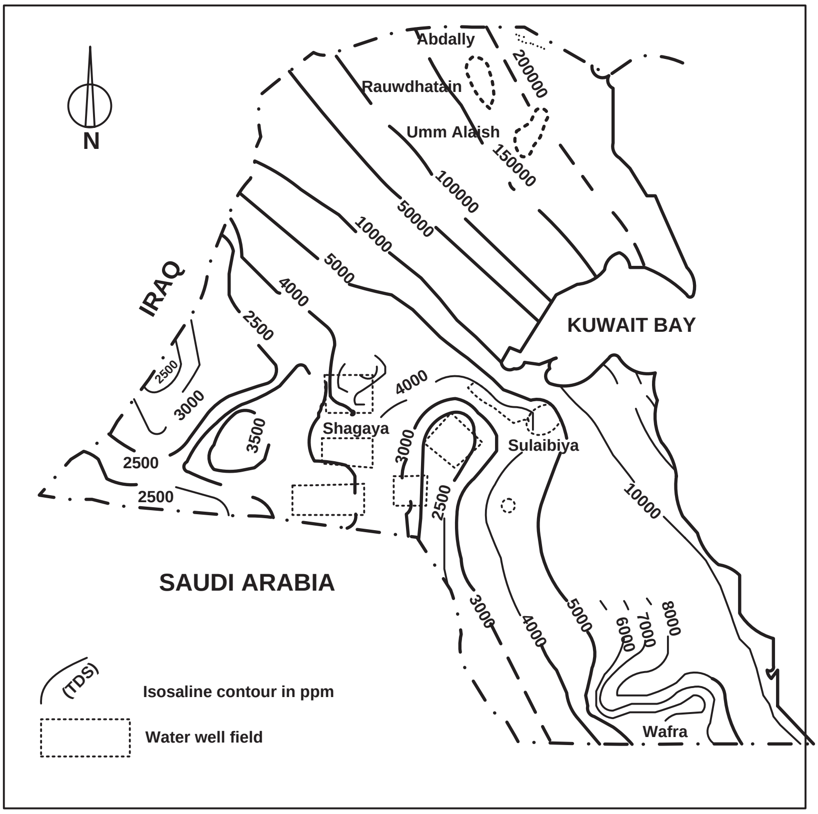


Fig. 2. TDS in groundwater of Kuwait.

Table 1
Kuwait installed desalting capacity and daily consumption in MIGD.

Year	Installed capacity (MIGD)	Daily average consumption (MIGD)	Daily per capita fresh water consumption in l/d (imp. g/d)
1963	6	5.5	82.8(18.2)
1973	52	25.5	137.4(30.2)
1983	136	86.2	245(53.8)
1993	216	136.3	403(88.6)
2003	313.5	279.1	497.3(109.3)
2006	369.1	313.2	(98.4)

desalted water in the last four decades in million imperial gallons (MIG) per day or MIGD are given in Table 1. The daily-consumed fresh water in liters per capita increased from 137 in 1973 to almost 500 in 2003 [4], and the population increased from 900,000 in 1983 to 3,051,000 in 2005.

These necessitate desalting huge amounts of seawater with huge amounts of consumed fuel, as desalting is energy-based process. Thermally operated desalting units usually obtain their heat input as steam supply; either extracted from steam turbines or from heat recovery steam generators HRSG combined with gas turbines. Thus, desalted water is produced generally in cogeneration power desalting plants CPDP. The percentage of fuel consumed in Kuwaiti CPDP in 2003 for desalting amounts to 22% of the total fuel used by the Ministry of Electricity and Water MEW for both power and desalted water. The fuel consumption depends on the used method, and the way energy is supplied to desalters. Burning fuel for desalting increases the environment pollution by producing carbon dioxide CO_2, nitrogen oxides NOx, and sulfuric oxides SOx, with quantities directly related to the amount of fuel consumed.

So, desalting contributes the environment pollution. Increasing the efficiency of both power and desalted water productions lowers the impact of fuel combustion on the environment.

The multi-stage flash MSF is the only seawater desalting method used in Kuwait. It is known by its high-consumed energy and its need to be combined with steam turbines in steam power plant; or heat recovery steam generators HRSG working by hot gases from gas turbines in gas turbine power plant, to secure its steam needs. Otherwise, steam is supplied from fuel-fired boiler at unacceptable high cost. Combining MSF units with steam turbines in CPDP imposes limited range of desalted water to power ratio. The CPDP are designed and built to produce constant water rate while power production changes according to load, from full to 25–30% of turbine rated capacity. All Kuwait power plants are CPDP, which cannot match the water demand increase due to their design limited water capacity. One of reasons the country did not match the increase of demand with increase of installing MSF desalting is the lack of steam turbine to combine the MSF units with.

Keeping business as usual in the way energy is consumed needs rethinking to sustain this energy. The power plants efficiency is less than 38%, while that of combined gas/steam turbine cycle is up to 55%; and the used multi stage flash MSF desalting system consumes energy in 20-kWh/m^3 range while that of reverse osmosis desalting system is in 4–6 kWh/m^3 range. Beside, dealing with water as free resource gives no incentives to utilize it efficiently and promotes un-sustainability.

3.3. Wastewater treatment and reclamation

Municipal wastewater (WW) comprises mainly more than 99% water with the balance 1% of relatively small concentrations of suspended and dissolved organic and inorganic solids. It is feasible to treat WW to quality high enough that it is a resource that can be used rather than wasted. It is more logic to do that in Kuwait where natural water resources almost do not exist, and cost of desalting seawater is very high. Treating WW for re-use becomes common practice worldwide. The WW treatment cost for re-use for non-potable purposes, even with potable quality is lower than the cost of desalting high salinity brackish or seawater. The volume of treated wastewater compared to the irrigation water resources is actually about 7% in Tunisia, 8% in Jordan, 24% in Israel, and 32% in Kuwait. Approximately 10% of the treated effluent is being reused in Kuwait, 20–30% in Tunisia, 85% in Jordan, and 92% in Israel. In California, where the largest number of water reuse facilities existing in the United States is found, there is around 434 million m^3 of municipal wastewater currently reused with, in 1999, water reuse for agricultural irrigation amounting to 68% of the total recycled water used [9]. In Japan, water reuse is mainly directed toward non-potable urban applications such as toilet flushing, urban environmental water, and industrial reuse. As a water source, the WW increases as the water consumption does and is located where the water demand exists. Water reuse requirements are

a) reliable treatment of wastewater to meet strict water quality requirements for the intended reuse application,
b) protecting public health, and
c) gaining public acceptance.

The WW includes organic substances such as carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries.

3.3.1. Wastewater polluted substances [11]

The wastewater polluted substances include:

(a) Pathogens in wastewaters

Pathogenic substances are diseases causing organisms, which represent great health fear from the in the use of WW. The contaminated water with pathogens is associated with diseases such as cholera, typhoid, bacterial dysentery.

(b) Oxygen-demanding substances

The amount of dissolved oxygen (DO) present in water is a measure of the water quality, as the DO is needed for the survival of aquatic plants and animals. The DO saturated value in water is in the order of 8–15 mg/L, depending on water temperature and salinity. Oxygen-demanding wastes in municipal and industrial wastewaters are usually biodegradable organic substances. Certain inorganic compounds may also be decomposed, thus contributing to DO depletion in water.

The oxygen amount needed to chemically oxidize all the oxygen-demanding substances is commonly measured as chemical oxygen demand (COD). The amount of oxygen required by micro-organisms to degrade the waste biologically is called the biochemical oxygen demand (BOD). BOD has traditionally been the most important measure of the strength of organic pollution of water.

(c) Nutrients

Nitrogen, phosphorus, carbon, sulfur, calcium, potassium, iron, manganese, boron, and cobalt are essential to the growth of living organisms, and are called chemical nutrients. Nutrients are considered as pollutants when their concentrations are high enough to allow the excessive growth of aquatic plants and other life forms.

(d) Non-toxic chemicals

The concentration of salts (non-toxic salts) is an indicator of the water usefulness for various application. The recommended maximum total dissolved solids (TDS) concentration for drinking water is of 500 mg/L. In the case of irrigation water the TDS exceeds 500 mg/L but has limits depending on the type of soil and crops.

(e) Toxic chemical compounds

Heavy metals, pesticides, organic compounds, etc are toxic chemical compounds which pollute water bodies. The term "heavy metal" is referred to metals with a specific gravity higher than 4 or 5. The most important heavy metals, based on environmental impact are: mercury (Hg), chromium (Cr), cadmium (Cd), and arsenic (As). They are totally non-degradable, (virtually indestructible in the environment). Higher doses of heavy metals can cause nervous disorders and kidney damage, creation of mutation and induction of tumors. Pesticides include a wide range of chemicals that are used to kill organisms that humans consider undesirable. Pesticides can be insecticides, herbicides, rodenticides, or fungicides. Pesticides, because of their persistent nature in the environment, accumulate in the fatty tissues of the body, causing harmful effects.

3.3.2. Wastewater treatment

The aim of WW treatment is to dispose this water in safe way, without danger to human health or damage to the natural environment. Wastewater treatment plants WWP are designed to reduce organic and suspended solids loads to limit environment pollution. Pathogen removal is a primary concern for reuse of effluents in agriculture. Removal of toxic elements and pathogens that may affect human health needs to be considered. Irrigation by treated WW serves as disposal and utilization. Some degree of treatment is required for raw municipal WW before its use for agricultural and landscape irrigation, aquaculture or other uses. The required quality of effluent depends on the proposed water uses, crops to be irrigated, soil conditions and the irrigation system.

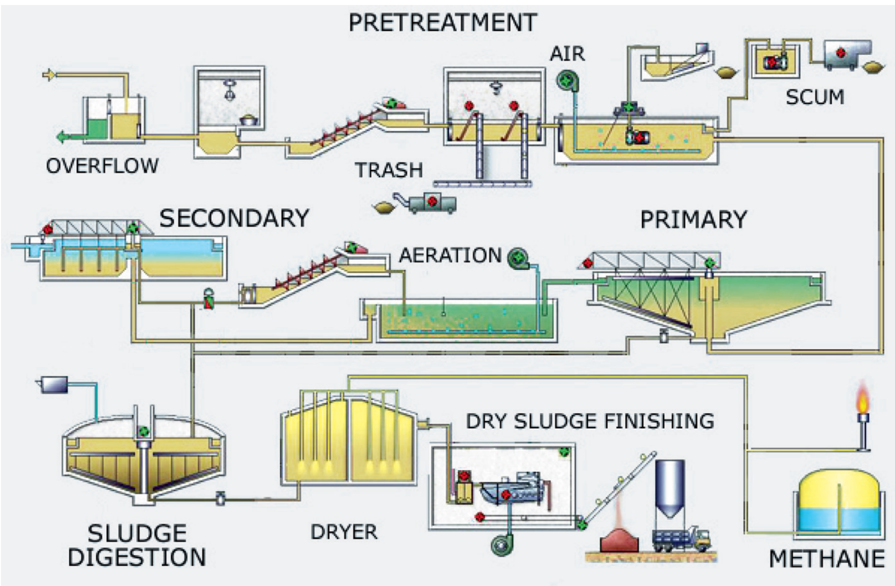
Conventional WW treatment consists of combined physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from WW. Different degrees of treatment are usually considered.

(a) Preliminary treatment

The objective of the preliminary treatment is the removal of coarse solids and other large materials from the raw WW. The operations include coarse screening, grit removal in most small treatment plants and, in some cases, grinding to reduce the size of large particles so as to remove them in the form of sludge in subsequent treatment processes.

(b) Primary treatment

The objective of the primary treatment is the removal of settable organic and inorganic solids by sedimentation, and the removal of materials that float by skimming. Large fractions of the biochemical oxygen



http://en.wikipedia.org/wiki/Sewage_treatment

Fig. 3. Process flow diagram for a typical large-scale treatment [10].

demand (BOD) substances, total suspended solids, oil and grease are then removed. Some organic nitrogen, organic phosphorous and heavy metals associated with those solids are also removed, but not colloidal and dissolved constituents. It may be considered sufficient treatment if the WW is to be used to irrigate crops that are not consumed by humans. Primary sedimentation tanks or clarifiers are used. The sludge of settled solids is removed from the bottom of tanks and floating solids are swept across the tank surface by water jets or mechanical means. In large sewage treatment plants, primary sludge is commonly processed biologically by anaerobic digestion.

(c) Secondary treatment

After the WW pass through *Primary Treatment* processes, it flows into the *Secondary treatment* process. This can remove up to 90% of the organic matter in WW by using biological processes. The two most common conventional methods used in the secondary biological treatment are: *attached growth* processes and *suspended growth* processes.

(d) Tertiary and/or advanced treatment

The tertiary treatment is used when specific undesirable wastewater constituents cannot be removed by secondary treatment. This may be the case for nitrogen, phosphorous, additional suspended solids, refractory organics, and heavy metals and dissolved solids. Where the risk of public exposure to the treated water is high, the intent of the advanced treatment is to minimize the probability of human exposure to enteric viruses and other pathogens. Because effective disinfection is believed to be inhibited by suspended and colloidal solids in the water, these solids must be removed by advanced treatment before the disinfection step. Therefore, the sequence of treatment often is secondary treatment followed by chemical coagulation, sedimentation, filtration, and disinfection. This level of treatment is assumed to produce an effluent free from detectable viruses.

(e) Disinfection

Disinfection normally involves the injection of a chlorine solution (5–15 mg/L) at the head end of a chlorine contact basin. Ozone and ultra violet irradiation can also be used to meet the required advanced WW treatment. A chlorine contact time as long as 120 min is sometimes required. In Near East countries adopting tertiary treatment, the tendency has been to introduce pre-chlorination before rapid-gravity sand filtration and post-chlorination afterwards.

3.4. Wastewater treatment in Kuwait

The city of Kuwait and its suburb has a modern sewer system collecting sewage for centralized treatment. It is served by three main WW treatment plants: Reqqa, Jahra and Sulaibiya. The Sulaibiya plant (built in 2004) plant replaced an old plant at Ardiya with added influent flow. Reqqa and Jahra plants provide conventional biological treatment (activated sludge) for secondary treatment and effluent filtration and chemical disinfection for tertiary treatment.

The dissolved organics and other contaminants present in the tertiary treated effluent are known or suspected to be detrimental to various reuse applications and still limit full utilization of this valuable resource. What is called Quaternary treatment is defined and used as the treatment producing potable water quality to meet unrestricted residential uses and industrial applications requiring ultra-pure water. Membranes of different pore sizes are usually used in this process such as microfiltration (MF), ultra-filtration (UF), nano-filtration (NF), and hyper-filtration reverse osmosis (RO) in descending pore diameter order, see Fig. 4. As a general rule, MF is suitable for the removal of suspended solids, including larger micro-organisms like protozoa and bacteria. UF is required for the removal of viruses and organic macromolecules down to a size of around 20 nm. Smaller organics and multivalent ions may be removed by NF while RO is even suitable for the removal of all dissolved species [12]. The RO removes dissolved salts and harmful contaminants, including bacteria, viruses and chemicals. The WWRP is the largest facility of its kind in the world to use RO and UF membrane-based water purification. The plant initial daily capacity is 375,000-m^3 and designed for extension to 600,000-m^3/d in the future. The plant output has potable quality, but is not used currently for this purpose, but non-potable uses as in agriculture, industry and is planned for aquifer recharge. The reasons for not using the output as potable water are psychological and probably religious.

Now the question to be asked: is the WW fully utilized as a water source? The three sewage treatment plants receive 375,000 m^3/d at Sulaybia, 102,000 m^3/d at Rigga, and 54,000 m^3/d at Jahra, a total of 513,000 m^3/d. The reported daily fresh water consumption in 2008, as reported in Al-Seyasah newspaper, according to an official in the MEW was 351 MIGD in 2008 (1.6-million m^3/d). More 0.6 million m^3/d of brackish ground water and reclaimed water are consumed. So, the wastewater collected is only 33.2% of the domestic water while it should be in the range of 70% of the domestic water supply (i.e. 245.7 MIGD or 1.12 million m^3/d). *So, more WW should be collected by connecting more houses to the sewage system.* The reclaimed water can be considered as a primary option

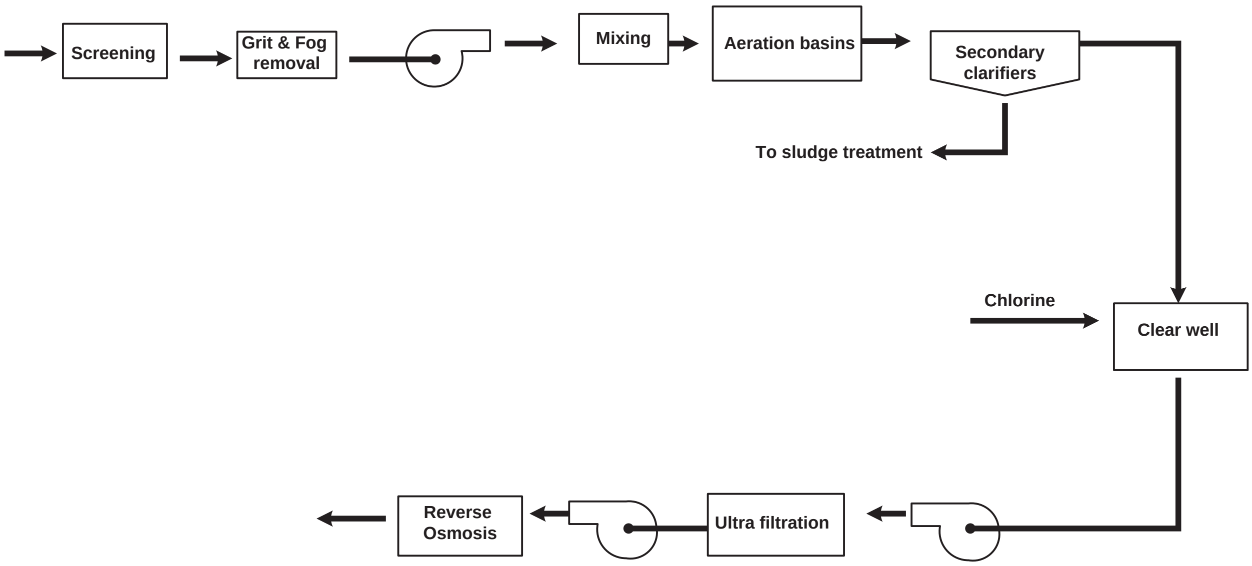


Fig. 4. Sulibya wastewater treatment and reclamation plant WWTRP in Kuwait.

for developing new water resources through water reuse in irrigation and landscaping. Significant reduction in chemical oxygen demand and biological oxygen demand were noticed in the filtrate and permeate of MF and RO, respectively from the Sulaibiya WWTRP. The capacity of the Sulaibiya WWTRP capacity is 375,000 m^3/d only and should be extended to 600,000 m^3/d). So the pioneering step towards utilization of treated wastewater effluent should be extended for full utilization of this resource.

The Ministry of Energy is financing research project to artificially recharge the Sulaibiya plant output potable quality water in ground water aquifers. The conventional treatment cost is \$0.36/m^3, which represents less than 10% of the cost of MSF distillate. Reuse is frequently practiced as a method of water resources management. For example, depleted aquifers may be "topped-up" by injection of highly treated water, thus restoring aquifer yields or preventing saltwater intrusion (in coastal zones).

4. Water management

4.1. General concern

Water is essential for all sectors in Kuwait and it is important to have proper coordination between different water agencies, choose the most efficient ways to develop non-conventional water resources since the natural resources are almost non existing. Then the use of the developed water sources should be in the most efficient ways. This requires putting a water demand management strategy. Therefore, it is important put forward an integrated water management plan IWMP, or at least study and evaluates the different options to develop this plan. The IWMP should include

a) Collecting data about all water resources in terms of quantity and quality, its efficient utilization and cost,
b) Collecting data on factors affecting the water resources such as population growth, agriculture and industrial activities.
c) Ensuring efficient piping system including leak detection.
d) Developing water demand management plan for efficient water utilization in residential, public sector, landscaping, and irrigation.
e) Use of water auditing, metering, pricing, low flow devices, and behavioral modification to reduce wasting of water.
f) Promoting education and public information to better water management, conserve water, training of engineers, technicians and workers in the field of water.

The IWMP are generally grouped under four major categories:

(1) Measures related with supply enhancement, introducing new structural interventions to increase water availability;
(2) Measures of Demand Management, aiming to control and limit water demands;
(3) Development measures, affecting the socio-economic preferences given to certain types of water use with respect to others and finally,
(4) Institutional policies, such as changing water pricing, economic incentives etc.

After outlining the water resources in Kuwait, some items or factors affecting the integrated water management plant will be discussed. It is beyond this preliminary report to give an integrated plan to be followed. These items include:

4.1.1. Managing ground water

It is important to point out here that exploiting the non-renewable, not only has to be stopped, but these aquifers should be recharged to work as strategic storage system. More research works are needed for:

a) Assessment of groundwater resources.
b) Examining legislative and management frameworks for better outcomes for groundwater,
c) Assessing wastewater sources and geological conditions for suitability for managed aquifer recharge.
d) Strategic aquifer characterization to quantify sustainable yields.
e) Managing risks to groundwater quality.

4.1.2. Managing desalination

The multi-stage flash (MSF) is the only seawater desalting method used in Kuwait. The MSF is known by high energy consumption, (22-kWh/m^3 if its steam supply is extracted from steam turbine ST and 40-kWh/m^3 if this steam comes directly from fuel fired boiler). Thus, almost all the MSF units in Kuwait are combined with ST in the steam power plants, which producing electricity and desalted water, and called cogeneration power desalting plants CPDP. This combining imposes limited range of desalted water W to power ratio P, or W/P. The CPDP are designed and built to produce constant water rate while power production changes according to load, from full to 25–30% of turbine rated capacity. All the Kuwaiti CPDP cannot match the rate of water demand increase due to their design limited water capacity. **So,** *the MEW should look for more energy efficient desalting system than the MSF system.* The MSF was designed when the fuel was at low cost, and thought to be abundant. The seawater reverse osmosis SWRO, the low temperature multi effect boiling LT MEB, and the mechanical vapor compression MVC desalting system are more energy efficient than the MSF system.

It is essential to look for energy efficient ways to produce power and desalted water to save the nation's income, non-renewable fuel resources, environment, and the life itself in Kuwait. The resulted almost ultra pure water from desalting seawater is mostly used for purposes, which do not need that high quality water, as flushing toilets, gardens, cleaning, washing, ... etc. Promotion of dual piping system, one for potable water, and the other for less quality (treated WW or gray, or brackish) water. In fact, it is more important to promote all conservation measures for both the water and power. The high fossil fuel consumption by desalting seawater and its negative impact on the environment call for studying the feasibility of other alternative energy sources such wind, solar, and nuclear. More research work should include:

a) Better water desalination practice in terms of final cost, energy used, and product quality,
b) Use alternative energy sources for desalination.
c) State-of-the-Science Review of Membrane Fouling: Organic, Inorganic and Biological.
d) Feasibility Study of Offshore Desalination Plants
e) Conceptualizing Next Generation Desalination Systems: Beyond Current Spiral Wound Membranes.
f) Considerations for the Co-sitting of Desalination Facilities with Municipal and Industrial Facilities.
g) Study of environmental issues for coastal desalination. Many environmental issues of cogeneration power desalting plant concentrate disposal, and energy costs need to be addressed.
h) The produced water by desalination from fossil energy production is almost pure water and very expensive, and should be used only for drinking and food preparations, but not for applications where grey water can be used.

4.1.3. Developing water treatment and reuse

Recycled water is a reliable source of water that must be taken into account in formulating a sustainable water policy. Water reuse is increasingly been integrated in the planning and development of water resources, particularly for agricultural and landscape irrigation. Regulations on wastewater recycling and reuse are essential to be established for Kuwait. These will help in protecting public health, increase water availability, prevent coastal pollution and enhance water resources. The status of wastewater recycling and reuse is not clear yet, although The Sulibya WWTRP was built few years ago. The treated quaternary treated municipal wastewater may be used in domestic water supply when separate distribution systems are available in some locations in Kuwait. It can be used for toilet flushing and outdoor washing. The treatments follow stringent standards to prevent infections by direct contact, since direct contact with the water is always possible. The costs associated with expanding the dual distribution piping system can be justified for Kuwait areas. So, it is essential for Kuwait to expand the Sulibya plant to its full design capacity of 660,000 m^3/d, expands its usage, put forward the necessary regulations and rules to use its output. It is also necessary to put regulation of reuse of treated wastewater with tertiary treatment and treated water output in general. More research project can be done such as:

a) Wastewater treatment and reuse systems to analyze and optimize any urban water system and provide suggestions and decision support for how a system should be designed or modified to improve its sustainability.
b) Modeling and Control of WWT Processes focusing on the activated sludge (AS) process and modeling the sedimentation.

4.1.4. Aquifer storage recharge

The Quaternary treated wastewater from Sulaibiya WWTRP can be used for aquifers storage recharge. The recharge process through the soil will act as extra natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses, and other microorganisms. Also, significant reductions in nitrogen, phosphorous, and heavy metal concentrations can also be achieved. When this water has reached the aquifer, it usually flows within it before it is collected. This movement through the aquifer can produce further purification. The soil and aquifer are then used as natural treatment systems, so they are often called soil-aquifer treatment systems (SAT systems). The water is not only well purified but is also stored for later use which is badly needed for Kuwait due to desalting system vulnerability.

4.1.5. Water conservation and pricing

Water conservation is the management of water resources to eliminate waste or maximize efficiency of use. Water conservation is the most reliable and the least expensive way of stretching the country's water resources. Water-saving measures should include fair pricing of water, with a penalty for exceeding certain limit beyond actual water needs. The consumption per capita in each country of the inversely proportional to the price charged for water. So, the very cheap price charged for water in Kuwait (about $\$0.2/m^3$) is the main contributor to the high water consumption. The actual desalting water production cost is more than $\$3.5/m^3$. Promoting conservation in the domestic sector includes the use of small toilet's tanks, installation of low flow taps and showers in households and hotels, use of pressure reducing devices, dual-flush toilets, taps with air devices, taps with sensors, taps for limited time flow and cisterns with double quantity dispensers. Increased public awareness and media campaigns play a significant role in reducing domestic water use.

Meanwhile, there are many water wasteful practices which should be stopped by law such as the use of hosepipes for washing cars and pavements and patios. Other bad practices include: not checking hidden leaks, using toilets as ash tray or waste basket and flush it throwing a cigarette butt or facial tissue, using large capacity flush tanks taking long showers, frequent use of dishwasher and cloth washer when not fully loaded, and watering lawn when not needed.

It is interesting to know that water consumption increases whenever metering is not used, consumers have high income, and water price is low, flat price rate for water is applied, weather is hot and dry, and consumers do not realize the value of water. It takes two sides to conserve water: the consumers and authorities, such as municipalities and ME. Authorities should have demand management measures such as:

- Inform, encourage, and teach consumers how to use water efficiently and enforce necessary measure to achieve that, regulate and restrict specific water uses, and develop public education program.
- Meter water at the source and points of use, detecting leakage to decrease unaccounted water (up to 50% of water loss is due to leakage in many countries), repair water lines, and charge fees according to amount used by consumers.
- Invest in appliances, processes, and technologies that reduce consumed

Meter water at the source and points of use, detecting leakage to decrease unaccounted water (up to 50% of water loss is due to leakage in many countries), repair water lines, and charge fees according to amount used by consumers.

- Invest in appliances, processes, and technologies that reduce consumed. Water has an economic value in all its competing uses and should be recognized as an economic good. Within this principle, it is vital to recognize first the basic right of all human beings to have access to affordable, clean water and sanitation. Economic incentives are instruments used to influence human behavior through economic means such as charges, subsidies, taxes, or the creation of markets. "Water pricing" is a general term for setting water prices for different users. Because water users in most parts of the world have traditionally been charged only part of the actual costs of water, "water pricing" is generally seen as synonymous with "increasing prices." It also refers to choosing more appropriate tariff structures. For example, an increased price per liter may be charged if total use exceeds a certain limit, or—at worst—instead of a fixed price per user irrespective of the total amount used.

It is interesting to know that the city of Los Angeles has grown by 1 million people since 1970, but still using the same amount of water [13]. The water consumption per capita in Kuwait is among the highest in the world, although it the poorest country in natural water resources. The per capita of fresh water in liters per day is more than 500, and of total water is more than 700. This is double the really needed water consumption.

5. Conclusion

The ground water, the only natural water resource available in Kuwait, is extremely limited, exhausted, and replenished. Its exploitation not only should be stopped, but it should be recharged to serve as strategic water storage. The main non-conventional water resource is desalting seawater and treated wastewater. The presently used MSF desalting system is inefficient, energy wise, and should be replaced with the most energy efficient system of seawater reverse osmosis SWRO system to save about ¾ of the fuel energy used for desalination and substantially reduces desalting water cost. The treated wastewater should be fully utilized as a water resource. It cost is much cheaper than desalting seawater or brackish water, and its amount increases with the increase of population and their consumption. The per capita water consumption in extremely high, and should be reduced through an effective water demand management program. The fresh water production in Kuwait can satisfy more than twice the water demand if the water is used wisely.

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