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Status and New Developments on the Use of Brackish Water for Agricultural Production in the Near East

Yemen Country Report

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Abbreviations

BCM	Billion cubic meter
GOY	Government of Yemen
MAI	Ministry of Agriculture
MCM	Million cubic meter
MWE	Ministry of Water and Environment
NASS	National Agricultural Sector Strategy
NWRA	National Water Resources Authority
NWSSIP	National Water Sector Strategy and Investment Program
WWTP	Wastewater Treatment Plant

Executive summary

Water resources and use

Yemen is regarded as one of the countries of scarce water due to its geographical location within the arid and semi-arid countries, where the average annual rainfall is between 500 – 1200 mm at the western highlands, and less than 50 mm at the coasts of the Red Sea and Gulf of Aden. The whole annual rainfall volume all over the country varies between 67 and 93 km^3.

The renewable resources from rainfall and groundwater were estimated as 2.5 BCM in year 2008 and the substantial need for the same year was estimated as 3.4 BCM. The deficit (0.9 BCM) was covered by more pumping from groundwater, resulting in a decrease of 2 – 6 m annually in the groundwater level. About 90% of the water resources is utilized in agriculture and the balance is used for domestic (8%) and industrial purposes.

The high rate of the population growth caused an increasing demand for water for agriculture and domestic water supply. This led to increase in the use of non-conventional water resources, which is divided into four categories: brackish water, treated wastewater, grey-water and desalinized water.

Brackish water appears naturally in both surface and groundwater. However, the extensive withdrawal of groundwater caused an increase in the salinity in many basins particularly in the coastal areas. The brackish water quantity has not been identified over all the country. However, the usable brackish water for agriculture in Yemen is about 300 MCM/year, mostly in the coastal areas and particularly in Tehama region.

Increasing urbanization and the provision of potable water supply and sanitation resulted in an increasing amount of treated effluent being produced. Thirteen WWTPs were constructed. The total treatment capacity for the WWTPs in Yemen is estimated at more than 200,000 m^3/day (about 74 million m^3/year). Due to the water deficit through over-abstraction from the groundwater aquifers, the option of the desalinating sea water or brackish groundwater is being debated among water managers in Yemen. The production of desalinated water reached 25.1 MCM in 2006.

Water quality

Regarding of the water quality, there are no monitoring for surface water quality except some measuring data for water salinity in limited sites. However, groundwater quality has not been studied extensively in all regions in Yemen. The groundwater quality has been assessed with respect to its suitability for intended use for irrigation or drinking water. This means that the main determinant of water quality was the degree of mineralization. Hence, many electrical conductivity measures have been taken all over the country.

Surface water is generally fresh, but the amount of total dissolved solids (TDS) tends to vary inversely with the discharge rate. The salinity for Wadi Bana in Abyan delta is 1500 – 1800 micromhos/cm for the periods of low flows, and 400 -500 micromhos/cm for flood periods.

The EC_{25} in the dams varies between 800 - 1200 micromhos/cm. However, the EC_{25} of the dams located downstream of the main cities is very high varying between 2000 – 2900 micromhos/cm, particularly the dams located in the downstream of the Sana'a Wastewater Treatment Plant.

Groundwater quality in Yemen has a complex nature. EC values ranging from 2,000 to 5,000 micromhos/cm are observed in some areas in the highland basins as well as in the lowlands, particularly the wells located nearby the Wadis. The salinity of the groundwater in the coastal areas increases from the water source towards the water divides between the Wadis, where EC values range between 8,000 to 14,000 micromhos/cm. This is highly indicative of seawater intrusion as a result of excessive pumping.

In year 2008, the total rain-fed cultivated area was 695,388 ha, while the area irrigated by spate irrigation was 136,335 ha and the area irrigated by water harvesting structures was 79,963 ha. However, the cereal cultivated area is about 760,189 ha, representing 58 % of the total cultivated area in the country, mostly depending on rainfall and spate irrigation. The irrigated area basically depends on groundwater. This area was increased from 120,000 ha in 1979 to 418,879 ha (almost 11 times) in 2008. Vegetables and fruits were the main irrigated crops, covering an area of 84,854 ha and 90,719 ha respectively.

Challenges facing irrigated agriculture

The challenges that face irrigated agriculture in Yemen are basically four: (i) sustainability of groundwater irrigation; (ii) low productivity of all irrigated agriculture; (iii) low irrigation efficiency; and (iv) need for institutional strengthening and enhancing the capacity building of the institutions connected with water use in the agriculture sector.

Locations of brackish water

There are many locations for brackish water in Yemen. In some locations, brackish water was naturally available, others as a result of over-pumping of groundwater and intensive use of irrigation water which led to increasing salinity.

NWRA's study for groundwater quality conducted in 2011, identified the locations of the groundwater with high level of salinity, where EC started from 3000 micromhos/cm reaching up to 17000 micromhos/cm in some locations close to the sea. The Electrical Conductivity (EC) maps indicated the distribution of EC, which led to identify the brackish water. Brackish water was mostly located in the coastal areas, except two areas located in the northern and western parts of Taiz city.

Brackish water use

Brackish water is mainly used for rock cutting industry in high lands, as well as for irrigating some tolerant crops mainly in coastal plains.

The usable brackish water for agriculture in Yemen is about 300 MCM/year, mostly in the coastal areas particularly in Tehama region. This amount of brackish water is used to irrigate about 38500 ha. However, brackish water with high salinity is used for water supply in Taiz city, by mixing with fresh water for domestic use without any desalination. Hence, Taiz city is the most critical city in water resources in Yemen.

Impacts of the use of brackish water

In irrigated areas, salinity problem often originates from salts in the applied water. Yield reductions often occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in water stress for a significant period of time. To avoid problems of using these poor-quality water supplies, there must be a sound water management system to ensure that the quality of available water is put to the best use. In addition, there is a need to improve the plant-soil-water availability by maintaining low salinity level in the root zone through frequent irrigation and leaching requirement applications.

In general, the problem of water in Yemen is not limited to diminishing water levels and scarcity, but extends to the quality of water, and a decline in its properties, and its becoming unfit for use in all areas, including human use, especially when over-exploitation of water is the case. There is a high need to use the non-conventional water resources such as brackish water, treated wastewater, and desalinated seawater.

The use of high salinity water for irrigation has negative environmental, economical and social impacts. The best on-farm water management practices using brackish water well decreased these impacts.

Opportunity for brackish water use

The rapid growth of population in Yemen is putting enormous pressure on the water availability, and consequently on the food security which is directly dependent on water. Yemen is facing a grave water crisis which, if left unattended, will threaten the survival of both urban and rural areas. The urgent action to pull the country back from the brink of disaster is imperative. Conservation of water, use of the non-conventional water, and improving agricultural productivity per drop of water are the only means of salvation for Yemen.

Results of the water quality studies, conducted by the Water Resources Authority in 2011, pointed out that the salinity of groundwater increased vastly in many basins particularly those in the coastal areas where the seawater intrusion renders the coastal areas in an extremely hazardous situation.

Due to water scarcity problems, there is a need to use brackish water in agriculture and water supply purposes.

Constraints facing brackish water use

Brackish water use in irrigation is facing many problems and constraints which can be summarized as follows:

- Increase in soil salinity.
- Yield reductions due to salt accumulation in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solutions resulting in water stress for a significant period of time.
- high cost of agricultural inputs due to the need for deeper plowing and more pumping costs to cover the additional water requirement for leaching.

To avoid the above constraints when using brackish water, it is necessary to have a sound water management system to ensure that the quality of available water is put to the best use. In addition, agricultural practices should be improved and extension services provided.

Major policies, strategies and regulations related to the use of brackish water

The GOY is aware of the challenges that the country's water problems pose for achieving food security, and has taken some significant institutional steps over the past years as follows:

- In 1996, the National Water Resources Authority (NWRA) was established to implement an integrated approach.
- In 2003, the Ministry of Water and Environment (MWE) was established. In 2005, MWE in cooperation with the Ministry of Agriculture and Irrigation (MAI) and related ministries, prepared the National Water Sector Strategy and Investment Program (NWSSIP).
- In 2008, NWSSIP was updated for the period 2008 – 2015. NWSSIP emphasized the importance of desalination of brackish water or seawater to be used for drinking. On the other hand, the poor farmers in the coastal areas currently use brackish water for irrigation of different crops without any guidance from the official institutions.
- In 2011, the Government also established a National Food Security Strategy, one of the major objectives of which was the sustainability of the water resources, as the water scarcity is the main challenge facing food security in Yemen. The strategy stressed on the importance of using of non-conventional water resources.
- The Ministry of Agriculture and Irrigation (MAI) in 2000, started the preparation of an agricultural sector strategy, the so-called Aden Agenda, followed by MAI agricultural policies and strategies in 2005 and 2009.
- In 2011, MAI updated the National Agricultural Sector Strategy (NASS). The strategy was approved in March 2012.

Major findings

Brackish water has become an important resource that could be used in agricultural purposes, particularly in the coastal areas. From the results of the groundwater quality studies conducted by NWRA for many Wadis in Tehama coastal areas, it is evident that the groundwater salinity increased in many regions in such a way as to affect the small farmers. In Tehama areas, the farmers used the highly saline brackish water to irrigate the field crops particularly sorghum (grain and fodder). The yield of all crops in Yemen are very low due to many reasons. The farmers are unaware of the leaching requirements for each crop, the irrigation scheduling, and the suitable interval time between irrigations for each crop. In addition, the increase in the prices of fuel will lead to increase in the water pumping costs.

Brackish water could be used for irrigation in different ways: a) the direct use of brackish water to irrigate low and medium salinity tolerant crops; b) the highly saline brackish water could be desalinated by low-cost desalination units and used in irrigation; and c) the highly saline brackish water could be mixed with treated wastewater, particularly in the highland basins, and used in irrigation of fodder crops and green belts.

Moreover, brackish water with high or low salinity could be desalinated and used for domestic purposes. The cost of desalination of brackish water is lower than the cost of desalination of seawater which needs additional cost for transportation.

Yemeni's "Standards for Treated Wastewater Use in Irrigation and Water Supply" were issued, yet these standards are still unapplied. The farmers are using wastewater available in the Wadis without any consideration to the standards. Evidently, brackish water use is the major challenge facing agriculture and food security.

The study is concluded with a set of recommendations for consideration by the responsible authorities.

1. Introduction

1.1 Water Resources in Yemen

The Republic of Yemen is located in the southwestern part of the Arabian Peninsula. It has a 400 km long coastline along the Red Sea and extends about 1200 km along the Arabian Sea. The country is regarded as one of the countries of scarce water due to its geographical location within the arid and semi-arid countries. Yemen depends on two main sources of water: surface water and groundwater. The water resources could be identified as follows:

1.1.1 Renewable water resources

- ***Surface water***

Surface water is considered to be an important source for irrigation in Yemen. High runoff speed and heavy rainfall cause deep wadis and form several water basins. Topographic patterns control the flow of rainwater leading it in two directions; the outer water basins (draining to the west in the Red Sea and to the south in the Gulf of Aden and the Arabian Sea) and the internal water basins (draining east or west towards the Rub Al-Khali desert, the Ramlat Al-Sabatain and Wadi Hadramout).

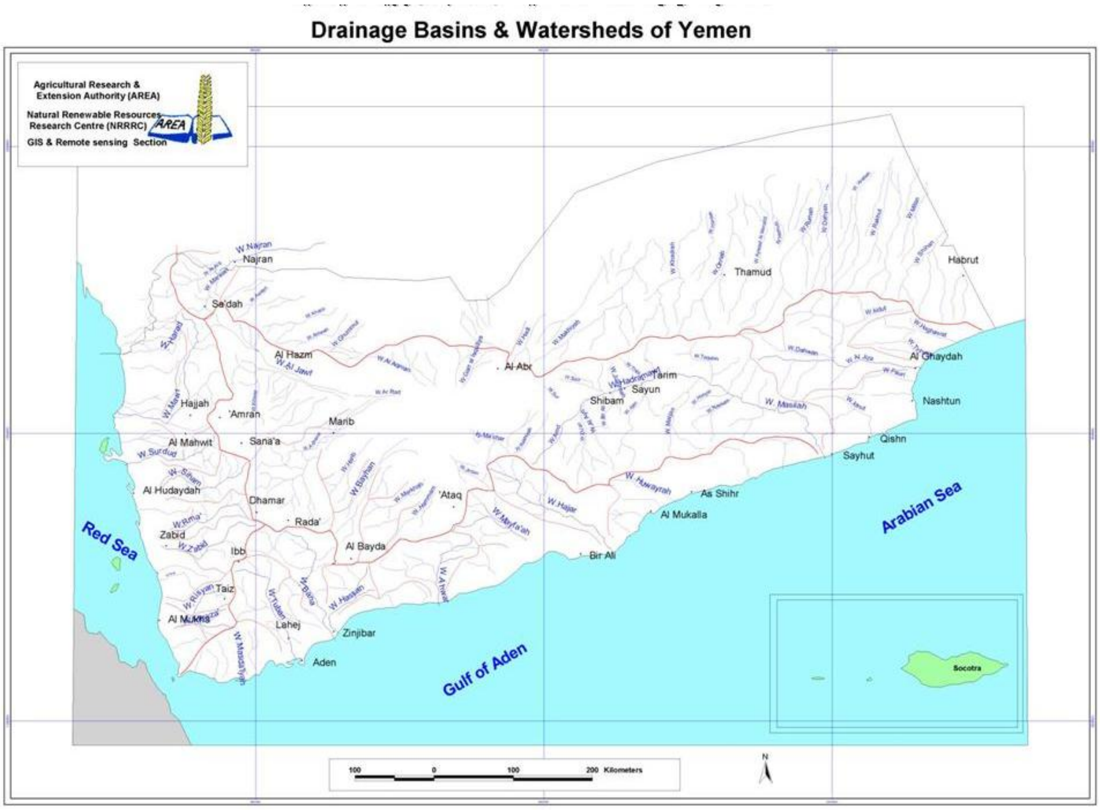

Figure 1. Drainage basins and wadis in Yemen

The annual precipitation average is about 500-1200 mm at the western highlands, and less than 50 mm at the coasts of the Red Sea and Gulf of Aden. However, the rainfall is more intensive on the western highlands, the southwest highlands and the upper plateaus. Then it gradually becomes less towards the east and northeast where the rainfall average reaches the desert climate. The whole annual rainfall volume all over the country varies between 67 and 93 km^3.

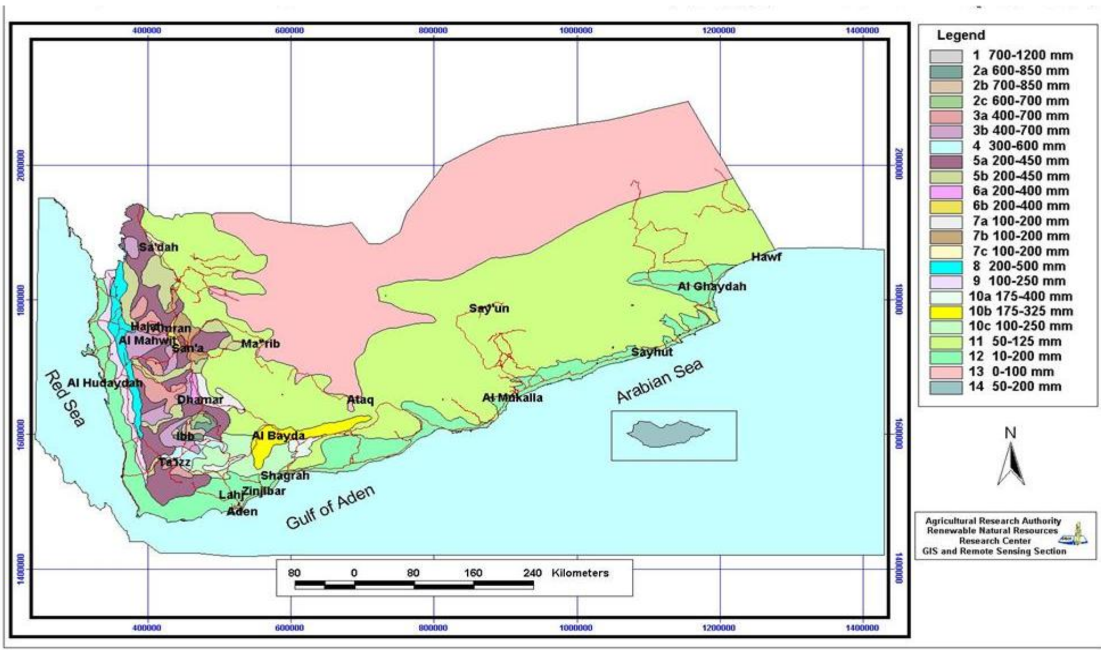

Figure 2. Precipitation range over all the agro-climatic zones in Yemen

Due to climate change, the precipitation had changed from year to year. The rain-fed areas decreased from 1.06 million hectares in year 1970 to 0.695 million hectares in 2008. Therefore, to increase the benefits from the surface water, the Government constructed many types of surface water structures. More than 42 diversion weirs and about 288 distribution canals have been built in many Wadis for the purpose of directing spate waters into branches of the Wadis to earth canal spate irrigation systems. Around 532 medium and small dams, and 1623 traditional pits, cisterns and reservoirs have been constructed for rainfall water harvesting. Storage total capacity of the water harvesting schemes is about 100 MCM, in addition to the famous dam in Yemen called Marib dam which has 400 MCM capacity. Areas irrigated by surface water in year 2008 were about 216000 ha, out of which 136000 ha were irrigated by spate irrigation structures, and about 80000 ha by dams and water harvesting schemes. Moreover, about 27000 ha were irrigated by natural springs. *(Ref.: Official JAR 2009 and MAI paper in the Water Forum, Jan. 2011)*

- ***Groundwater***

The quantity of groundwater reaches around 10 BCM, of which 1 BCM is in Al-Masila basin, 2.5 BCM in Tehama basin, and the remaining of the groundwater reservoir is distributed on the other regions. The quantity of pumping from these reservoirs reaches 1.5 BCM annually through more than 55,000 groundwater wells drawn from the mentioned reservoirs. The total water demand is estimated to be 3.4 BCM with 0.9 BCM deficit, which is covered from deep aquifers**.** The quantity of exploited water exceeds the average of groundwater recharge, resulting in a decrease of 2 – 6 meters annually in the groundwater level.

- ***Non-conventional water***

Non-conventional water is divided into four resources: brackish water, treated wastewater, grey-water and desalinized water.

- ***Brackish water***

Brackish water is water with a level of salinity between freshwater and seawater. In many places in the country, brackish water appears naturally either in surface water or in groundwater. However, the extensive withdrawal of groundwater caused to increase the salinity in many basins particularly in the coastal areas.

The actual brackish water quantity has not been identified over all the country. However, the usable brackish water for agriculture in Yemen is about 300 MCM/year and mostly in the coastal areas particularly in Tehama region. On the other hand, the amount of brackish water used in the water supply for Taiz city is about 3.1 MCM/year. This amount is expected to be about 4.9 MCM/year by pumping brackish water from new wells in Al-Hawban and Al-Hawgalah fields, located 5 km and 2.5 km north of Taiz city.

- ***Wastewater***

The current amount of available water per capita in Yemen is 137 m^3/y, which is the lowest rate in the world. However, increasing urbanization and the provision of potable water supply and sanitation is resulting in an increasing amount of treated effluent being produced. Thirteen WWTPs are constructed, while few of the oldest WWTPs are extended and upgraded. The total treatment capacity for the current and planned WWTPs in Yemen is estimated at more than 200,000 m^3/day (about 74 million m^3/year).

- ***Grey-water***

Grey-water is usually described as all sources of domestic water that have been used once, apart from toilet and bidet wastewater (which is known as blackwater). Grey-water is washing water, water coming from baths, showers, washing machines, and bathroom sinks. Grey-water has, by definition, relatively low levels of microbiological contamination which has led to its being reused as a source of non-potable water. It can be used to further sustainable development and resource conservation without compromising public health and environmental quality.

The amount of grey-water from mosques is about 2-3 m^3/day from the small and medium mosques, reaching about 5 m^3/day in the big mosques. However, the amount of grey-water in households ranges between 60 -80 liters / day per house. On the other hand, the amount of grey-water that could be used from hotels is not yet identified.

Grey-water was used in Yemen traditionally in either rural or urban areas by using mosque ablution water (WADOOW water) on crops grown in surrounding gardens.

Many projects funded by IDRC, UNDP, GIZ and SDF have been conducted in several main cities. The main goal of these projects was the reuse of grey-water from mosques to irrigate gardens or lands in the main streets.

- ***Desalinized water***

The country's water deficit is currently met through over-abstraction from the groundwater aquifers; hence, many aquifers are being depleted. The option of desalinating seawater or brackish groundwater is being debated among water managers in Yemen.

Up to now there are two desalination stations in Yemen, one of which is located in Aden called Al-Haswah Electricity Station. This station used to supply electricity mainly for Aden city through the heating of seawater, producing about 69000 m^3/day of freshwater. This amount of water is mixed with the network of Aden water supply. The second desalination station is under construction and is located in Al-Mokha area 100 km south of Taiz governorate. This station is constructed by private sector (Hail Saeed Group). In 2002, the total installed gross desalination capacity (design capacity) was 76 596 m^3/day or 28 million m^3/year *(Wangnick Consulting, 2002)*. The production of desalinated water reached 25.1 MCM in 2006.

For many cities, the cost of desalinating seawater and transport of the desalinated water to inland urban centers is not attractive. However, for the coastal cities, seawater desalination may become a viable option as the current aquifers are increasingly depleted and the technology development reduces the cost per cubic meter.

According to a study conducted by McKinsey consultant for the Cabinet in 2011, the cost of desalinated water from Hodiedah in the west coastal area to Sana'a city (capital of Yemen) with elevation of 2300 meters above mean sea level (amsl), and pipe length 230 km, is about 5-6 US \$/m^3. This cost will be half in the case of Taiz governorate, located 90 km from the Red Sea and with elevations between 1100 and 1600 amsl.

1.2 Water quality

1.2.1 Surface water quality

There are no networks monitoring surface water quality in Yemen, as far as known. However, various projects have measured surface water salinity, but only at a few sites; in most cases measurements of electrical conductivity were obtained during current metering. Water use and groundwater quality which have usually been studied in more detail give additional clues about the mineralization of water.

Surface water is fresh in general, but the construction of Total Dissolved Solids (TDS) tends to vary inversely with the discharge rate. WAR project has monitored Electrical Conductivity (EC) at its stream gauging stations in the Wadis of Surdud and Adhana, and in the Abyan delta. The resulting data show that the EC_{25} of Wadi Surdud water is relatively low: it typically varies between 500 – 600 micromhos/cm during base flows. It drops to 300 micromhos/cm or slightly more during floods. The corresponding figures for Wadi Bana in Abyan delta are 1500 – 1800 micromhos/cm for the periods of low flows, and 400 -500 micromhos/cm for floods.

The water quality in some dam reservoirs in Yemen has been monitored by the Central Water Monitoring Unit in the Ministry of Agriculture and Irrigation. The resulting data reflected that the EC_{25} in the dams varies between 800 - 1200 micromhos/cm, while the EC_{25} of the dams located in the downstream of the main cities are very high varying between 2000 – 2900 micromhos/cm, particularly the dams located in the downstream of Sana'a Wastewater Treatment Plant (Al-Musireqa and Al-Masham dams). *(Reference: Annual monitoring reports and the dams inventory report for Sana'a Basin, 2005).*

As yet, there have been no investigations or mapping of typical Surface Water Quality in Yemen, except some monitoring data in very limited Wadis.

1.2.2 Groundwater quality

Water quality refers to the water chemical, biological and physical characteristics. The use of water (drinking, irrigation, *etc*.) is the main factor in determining the required water quality. Water is said to be good or acceptable for a special use if its characteristics meet the standards for that use. A standard is the concentration of the constituent that does not result in significant risks (negative impact) to the health of the consumer or consuming system over the lifetime of consumption. Short-term deviations above the standard values do not necessarily mean that the water is unusable for consumption. The amount by which and the period for which any standard value can be exceeded without affecting public health depends upon the specific substances involved.

Groundwater quality has not been studied extensively in all regions over all Yemen. The groundwater quality has been assessed with respect to its suitability for intended use for irrigation or drinking water. This means that the main determinant of water quality was the degree of mineralization. Hence, many electrical conductivity measures have been taken all over the country. Therefore, there is a reasonable picture of the occurrence of fresh and brackish /saline water.

Groundwater aquifers decline with a rate of 2-6 meters annually with very rare recharge in most of the basins in Yemen, particularly in the Central Highlands and northern parts. This causes a deterioration of groundwater quality including sea (salt) water intrusion in the coastal plain areas.

Generally, groundwater quality in Yemen has a complex nature. EC ranging from 2,000 to 5,000 micromhos/cm is observed in some areas in the highland basins, as well as in the lowlands, particularly the wells located nearby the Wadis. The groundwater salinity in the lowlands and coastal areas is low in the upstream and increases in the direction of the downstream becoming very high near the coast. However, the salinity of the groundwater in the coastal areas increases from the water source towards the water divides between the Wadis. EC values ranging between 8,000 to 14,000 micromhos/cm are reported in some wells located near the coast and in the vicinity of water supply field wells. This is highly indicative of seawater intrusion as a result of excessive pumping.

Recently in 2011, groundwater quality studies have been conducted by NWRA for seven major Wadis producing maps and water quality analysis reports. The results of these studies could be summarized as follows:

Groundwater in Tehama basin is fresh to brackish in nature. The water type evolves from low TDS (earth alkaline water with increased portions of alkalis with prevailing bicarbonate in the recharge areas) to moderate and high TDS (alkaline water with prevailing sulfate and chloride along the Red Sea coast in the western parts).

Deterioration in groundwater quality from anthropogenic activities has resulted from saltwater intrusion along the coastal areas due to groundwater over-pumping and extensive use of fertilizers. Salinity and nitrate contamination are the two major problems in the coastal areas. The following provides a summary of the study analysis of the different parameters of groundwater quality for Tehama Wadis:

- **Electric Conductivity / Total Dissolved Solids (TDS):**

  EC varies between 747 micromhos/cm and 17790 micromhos/cm in Wadi Zabid with an average of 1558 micromhos/cm, while it varies between 634 and 10850 micromhos/cm in Wadi Rema'a with an average of 1287 micromhos/cm. This indicates that the salinity of the water in Wadi Zabid is higher than that in Wadi Rema'a. The average TDS over all Tehama Wadis varies between 452 and 8964 mg/l. This indicates that the water salinity has become an important issue, and the higher salinity in a Wadi than that in another is due to many reasons, the major two reasons of which are the amount of flood and the amout of groundwater abstraction. Generally, groundwater salinity in the Wadis is low in the upstream and increases in the direction of the downstream becoming very high near the coast.

- **Hydrogen - Ion Concentration (pH):**

  The measured pH is an important parameter in the geochemical equilibrium. The pH varies between 6.85 and 7.99, with an average of 7.46 in Tehama Wadis. The result of the study analysis clearly illustrated that the pH value is normal for all the area except in very limited zones that are closely located to the coasts.

- **Major cations in Tehama Wadis are summarized as follows:**

  Calcium (Ca^{+2}) **:** Calcium is one of the most common ions in groundwater. One of the main reasons for the abundance of calcium in water is the weathering and decomposition of some rocks such as calcite ($CaCO_3$), limestone and dolomite. Calcium content ranges between 30 – 390 mg/l in Tehama Wadis. Calcium in this concentration has no known effect on the health of humans or animals. Results of the analysis clearly illustrated that the distribution of calcium concentration is normal for all the area except a small part in the sout-west of Wadi Zabid.

  Magnesium (Mg^{+2}) **:** Magnesium content ranges between 11 – 360 mg/l in Tehama Wadis. Results of the analysis revealed that the distribution of magnesium concentration is normal for all the area except a small part in the south-west of the same area which has a high concentration of calcium**.**

  Sodium (Na^{+}) : The main source of sodium in groundwater is weathered and dissolved igneous and metamorphic rocks which contain feldspathic minerals. Sodium content ranges between 90 – 2721 mg/l in Tehama Wadis. The result of the analysis clearly illustrated increasing sodium element in the east-west of Wadi Rema'a extending in the coastline to south-west of Wadi Zabid. The increase of salinity in these areas may be caused by connate water of marine origin, recharge from coastal precipitation, or return flow from irrigation waters or from seawater intrusion to freshwater.

  Potassium (K+): Potassium content ranges between 1.2 – 47.11 mg/l in Tehama Wadis. Results of the analysis indicated that the distribution of potassium concentration is normal for most of the area. However, small areas along the coast have high concentration of sodium, which implies that the original for potassium is the marine water which usually contains about 400 ppm potassium.

- **Major anions in Tehama Wadis are summarized as follows:**

  Carbonate (CO_3^-) and Bicarbonate (HCO_3^-): The main sources of carbonate and bicarbonate is carbon dioxide (CO_2) from the atmosphere. Carbon dioxide is also released from the soil by organic decay and from plant respiration. Carbonate ranged between 7.5 to 75 mg/l, while only one sample in Wadi Rema'a was found to be 15 mg/l . The concentration of bicarbonate in Wadi Zabid and Wadi Rema'a ranges between 244 – 976 mg/l. Results of the analysis showed that four areas (north-east, north-west, west of the coast, and the central area near Zabid city) contain a high concentration of bicarbonate.

Sulphate (SO_4^-) **:** Sulphate is not a major constituent of the earth outer crust, but is widely distributed in reduced form both in igneous and sedimentary rocks of metallic sulphides. Sulphate content ranges between 24 – 432 mg/l in Wadi Zabid, while values range between 26 - 411 mg/l in Wadi Rema'a. Results of the analysis showed that the entire area is normal except a small part in the south-west of Wadi Zabid.

Chloride (Cl^-): Chloride is one of the most commonly occurring anions in the environment. In natural water, the main source of chloride is from feldspathoid sodalite in igneous rocks and halite in evaporates, which is washed from these rocks and subsequently ends up in water. In the Tehama area, the chloride contamination increases closer to the coast especially in the downstream. Results clearly illustrated that the general trend of chloride in Tehama area is rising steadily downstream. This trend extends along the entire Wadi from east to west. So, this figure implies that the increase in concentration of the chloride may be the result of salt water intrusion with freshwater (chloride is the main anion in seawater). Chloride content ranges between 53 mg/l – 3284 mg/l in Wadi Zabid, while it ranges between 53 - 2308 mg/l in Wadi Rema'a. Results of the analysis shows an increase in chloride contamination in the coastal area.

Nitrate (NO_3^-) : Nitrate ranges from 1.8 - 665 mg/l with an average of 30 mg/l. The high amount of nitrates detected is probably due to the use of nitrogenous fertilizers and to the crop watering practices based on irrigation by flooding. The nitrogen contained in the fertilizers is only partly absorbed by the crops. The remaining portion percolates as a solution into groundwater in the form of ammonium that oxidizes fast into nitrite and finally into nitrate. This remarkable spreading of nitrates in the groundwater of this area represents a major problem for drinking water supply.

Fluoride (F^-)**:** The presence of this element in drinkable water is of utmost importance, as it contributes to protect tooth enamel. Values were found to range from 0.07 - 1.55 mg/l in Wadi Zabid and from 0.15 - 6.175 mg/ l in Wadi Rema'a. Result of the analysis revealed that the distribution of fluoride concentration in the area is normal except for a small area in the north-west of Wadi Rema'a on the Red Sea.

1.2.3 Wastewater quality

Current effluent quality is generally poor as none of the existing WWTPs produce effluents that comply with the effluent quality regulations.

The low rates of per capita water consumption in Yemen cause an increased concentration of pollutants in the wastewater. Also the disposal of car oils into the network leads to weak efficiency of the wastewater treatment plants, which are not equipped to treat/separate oil. Effluent wastewater BOD in the mountainous cities ranges between 174 mg/l – 900 mg/l, while it ranges between 47 mg/l – 59 mg/l in the coastal areas. However, the EC of the effluent of WWTPs in the mountainous cities is low ranging between 1600 to 1900 micromhos/cm and TDS ranges between 1050 to 1200 mg/l, while the EC in the effluent of WWTPs in the coastal cities is very high ranging between 2850 - 2960 micromhos/cm, and TDS ranges between 1850 - 1900 mg/l.

1.2.4 Grey-water quality

Grey-water quality has not been extensively studied in Yemen. There are major constraints to the development of treated grey-water from households including plumbing at existing houses which does not separate grey-water from blackwater, and members of households lack expertise or commitment to treat and reuse grey-water. However, these constraints do not exist at most mosques, where a significant quantity of water is produced in ablution room with plumbing to separate it from blackwater.

1.3 Main issues for water

The total water consumption in Yemen is about 3.4 BCM, of which 90% is mostly exploited for agricultural activities, 8% for municipal water supply sector and 2% for industrial sector *(FAO AQUASTAT, 2008).*

Yemen is facing a water crisis due to rapid depletion of groundwater. In a number of basins, the groundwater mining is occurring at an alarming rate. Many towns are facing a serious water shortage. The situation in Sana'a and Taiz basins is no better. The groundwater drawdown of the order of 2 – 6 meters per year is recorded in some locations in these basins. Besides the quantitative aspect of groundwater use, the qualitative aspect is also facing serious setback. Untreated wastewater of towns and industries is allowed to percolate to groundwater causing serious threat to groundwater quality. Also in many coastal regions, seawater intrusion has rendered the groundwater salinity beyond recovery. In addition, the salinity increased in many basins even in the highland basins, particularly nearby the water supply wells. This situation puts the Government in a very critical position, rendering the water scarcity issue to be one of the ten priorities for the Government of Yemen.

1.3.1 Challenge facing water

Yemen is currently facing a big challenge related to water scarcity, however the non-conventional water resources such as brackish water or wastewater is an alternative. It has become imperative to establish a national strategy for non-conventional water comprising brackish water and treated wastewater use. The strategy should spell out ways and means of implementing policy directives. A national strategy should define the nature and mechanism of inter-institutional collaboration, allocation of funds, establishment of pilot brackish water and treated wastewater use in farms, demonstration of good management practices, and phasing the implementation of brackish water and wastewater programs. The strategy should integrate environmental management and use conditions, as well as coherent national policies for brackish water and treated wastewater use in agriculture.

1.3.2 Water use in agriculture

Yemen depends on two main sources of water: rainfall and groundwater. Rain-fed agriculture in Yemen is one of the traditional existing agricultural systems, on which most of the farmers depend for producing food grains. It represents about 54 % of the total cultivated area. However, the cropped area under rain-fed agriculture depends upon rainfall which widely varies from summer to spring seasons and from one year to another. On the other hand, rainfall constitutes the source of the spate flow water, which is used in irrigation of the Wadis lands. In addition, rainfall water is very important for water harvesting systems which are used as complementary irrigation for production of several crops.

In year 2008, the total rain-fed cultivated area was 695,388 ha, while the area irrigated by spate irrigation was 136,335 ha and the area irrigated by water harvesting structures was 79,963 ha. However, the cereal cultivated area is about 760,189 ha, representing 58% of the total cultivated area in the country, mostly depending on rainfall and spate irrigation. The irrigated area basically depends on groundwater. This area was increased from 120,000 ha in 1979 to 418,879 ha (almost 11 times) in 2008. Vegetables and fruits are the main irrigated crops, covering an area of 84,854 ha and 90,719 ha, respectively.

1.3.3 Challenges facing irrigated agriculture in Yemen

The challenges that face irrigated agriculture in Yemen are basically four: (i) sustainability of groundwater irrigation; (ii) low productivity of all irrigated agriculture; (iii) low irrigation efficiency; and (iv) need for institutional strengthening and enhancing capacity building of the institutions connected with water use in the agriculture sector.

The MAI has established measures to face the challenges of water demand, water scarcity, water sustainability and institutional coordination for better water management. These actions are concentrated in the two main water resources in Yemen as follows:

A- Concerning groundwater:

Enhancing irrigation efficiency through introduction of new irrigation technology to the farmers. This is the main focus of the MAI through many projects which aim at installing improved irrigation technologies with a view to conserve groundwater, improve efficiencies of water use, and reduce over-exploitation.

There are direct and indirect benefits which will accrue to farmers as a result of the installation of improved / localized on-farm irrigation systems. The direct benefits will accrue to farmers from the extractive use of groundwater for irrigation in the production process. On the other hand, the indirect benefits, which are not easy to quantify by farmers, include prolonging the operational life of the well, the engine and the pump.

Table 1 identifies the average of savings realized as a result of installation of the piped conveyance systems and the localized on-farm irrigation systems.

Table 1. Average savings and yield increase as a result of installation of piped conveyance systems and localized irrigation systems

Irrigation System	Saving (%)			Average Increase in Yield (%)
	Irrigation water	Fuel consumption	Irrigation labors	
Piped conveyance systems	15 - 20	15 – 17	14 - 16	12 - 13
Localized irrigation systems	35 - 40	29 – 33	30 - 34	14 - 16

The total area irrigated by groundwater in year 2008 was about 420,000 ha. However, the total area equiped with irrigation systems in 2008 was about 76400 ha, out of which 70000 ha were equiped with conveyance pipe systems and 6400 ha with localized irrigation systems (drip, bubbler and sprinkler irrigation systems). The total water saved as a result of introducing those different irrigation systems were 113 MCM. This means the remaining areas were still irrigated by farmers using traditional irrigation with low irrigation efficiency (40 – 45%).

B- Concerning surface water:

Yemen has practiced water harvesting techniques for centuries, and they represent the most efficient methods to improve the available moisture in the soil profile (both for agriculture and rangeland). In addition, water harvesting is a good way of involving and organizing communities, and good experience is now available in Yemen.

MAI has focused on water harvesting schemes (*i.e*. construction of dams, weirs and low-cost water harvesting structures). Water harvesting is a traditional and often skillfully applied method of water resources exploitation in many areas of Yemen. It is based on collecting and retaining overland flow in zones where soils permit agriculture.

The numerous management-made mountain terraces that cover considerable parts of the western and southern slopes collect and retain rains and overland flow. They are supported by walls of stones, not only to retain water but also to prevent the soils being washed away. As a result, there is large extent of agricultural lands on the mountain slopes during wet periods. Thus, under water harvesting, instead of the runoff being left to cause erosion in the uplands, it is harvested and utilized to become productive form of soil and water conservation. Both yields and production significantly improved with these methods.

However, many interventions have been taken to improve both groundwater and surface water but are still at the early stages. A lot of actions must be established, particulary in the enhancement of non-conventional water resources such as brackish water, treated wastewater and grey-water.

2. Status on the Use of Brackish Water for Agricultural Production

2.1 Brackish water

Brackish water is water with a level of salinity between freshwater and seawater. In many places in the country, brackish water appears naturally, and it forms an important water resource particularly for the poor farmers. However, it can cause environmental problems, since the salinity increased in some basins and the farmers have not adapted to it. It is also unpleasant to drink, and it may cause health problems.

Brackish water appears in both surface and groundwater naturally. However, the extensive withdrawal of groundwater has caused an increase in the salinity in many basins in Yemen. Identification of the brackish surface water and brackish groundwater is as follows:

2.1.1 Brackish surface water

Surface water is generally fresh, but the amount of total dissolved solids (TDS) tends to vary inversely with the discharge rate. WAR project has monitored Electrical Conductivity (EC) at its stream gauging stations in the Wadis of Surdud and Adhana, and in the Abyan delta. The resulting data showed that the EC_{25} of the water of Wadi Surdud is relatively low, typically varying between 500 – 600 micromhos/cm during base flows, dropping to 300 micromhos/cm or slightly more during floods. The corresponding figures for Wadi Bana in Abyan delta are 1500 – 1800 micromhos/cm for the periods of low flows, and 400 -500 micromhos/cm for flood periods.

The Central Water Monitoring Unit at the Ministry of Agriculture and Irrigation has monitored the water quality in some dam reservoirs in Yemen. The resulting data reflected that the EC_{25} in the dams varies between 800 - 1200 micromhos/cm. However, the EC_{25} of the dams located downstream of the main cities are very high varying between 2000 – 2900 micromhos/cm, particularly the dams located in the downstream of Sana'a Wastewater Treatment Plant (Al-Musireqa and Al-Masham dams). *(Ref: Annual monitoring reports and the dams inventory report for Sana'a Basin, 2005).*

2.1.2 Brackish groundwater

Numerous studies have been conducted in many regions in Yemen identifying the salinity values and could be summarized as follows:

Brackish water with EC values ranging from 2,000 to 5,000 micromhos/cm are observed in some areas in the highland basins as well as in the lowlands, particularly the wells located nearby the Wadis. The groundwater salinity in the lowlands and coastal areas is low in the upstream and increases in the direction of the downstream becoming very high near the coast. However, the salinity of the groundwater in the coastal areas increases from the water source towards the water divides between the Wadis. EC values ranging between 8,000 to 14000 micromhos/cm are reported in some wells located near the coast and in the vicinity of water supply field wells. This is highly indicative of seawater intrusion as a result of excessive pumping. However, salinity of brackish water in the water supply wells, situated north of Taiz city, ranges between 4550 – 6900 micromhos/cm and TDS ranges between 2730 – 4485 mg/l. This water with high salinity is used by mixing with freshwater for domestic use without any desalination. Hence, Taiz city receives water with very poor quality every 40 days. Therefore, studies were conducted to enhance the water supply through desalination of the renewable brackish water from Al-Hawban and Al-Hawgalah fields, situated 5 km and 2.5 km north to Taiz city respectively, or through desalination of seawater from Al-Mukha, a coastal area 100 km west to Taiz city. Private sector completed the station of seawater desalination in Al-Mukha area. The Government requests support from the donors to convey the desalination water to Taiz city. *(Ref. Study conducted by NWRA – Taiz Branch in 2011. Financed by UNDP and IDRC)*

2.2 Locations of brackish groundwater

There are many locations for brackish water in Yemen. In some locations, brackish water was naturally available, others as a result of over-pumping of groundwater and intensive use of irrigation water which led to increasing salinity.

NWRA's study for groundwater quality identified the locations of the groundwater with high level of salinity, where EC started from 3000 micromhos/cm reaching up to 17000 micromhos/cm in some locations close to the sea. The EC maps give an overview of the locations of brackish water in different areas in Yemen.

The maps indicated the distribution of Electrical Conductivity (EC) which led to identify the brackish water. Brackish water is mostly located in the coastal areas, except two areas located in the northern and western parts of Taiz city. The brackish water maps are identified as follows:

2.2.1 Wadi Harad and Al-Jar:

EC varies between 438 and 9990 micromhos/cm in Wadi Harad and Al-Jar with an average of 2018 micromhos/cm (Figure 3).

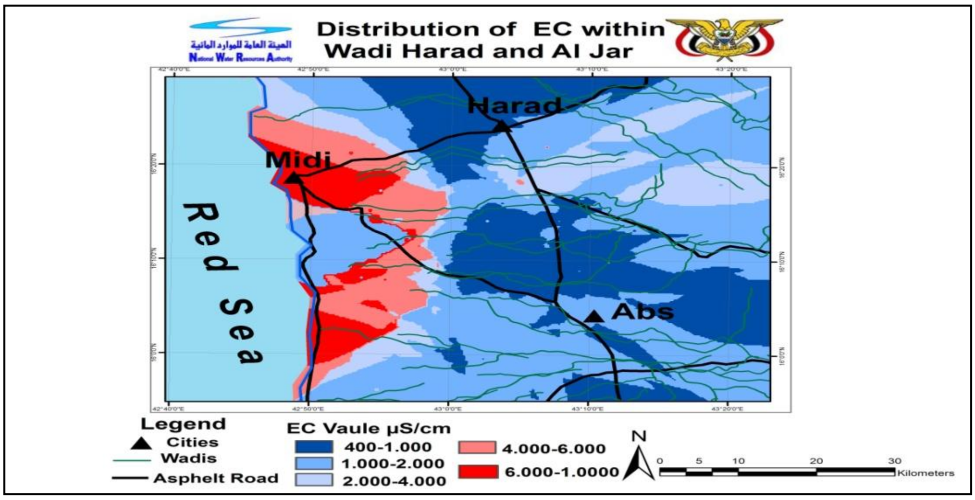

Figure 3. Distribution of electrical conductivity within Wadi Harad and Al-Jar

2.2.2 Wadi Mawr:

EC varies between 907 and 11,650 micromhos/cm in Wadi Mawr with an average of 3216 micromhos/cm. This indicates that the salinity of the water in Wadi Mawr is higher than that in Wadi Haradh and Al-Jar (Figure 4).

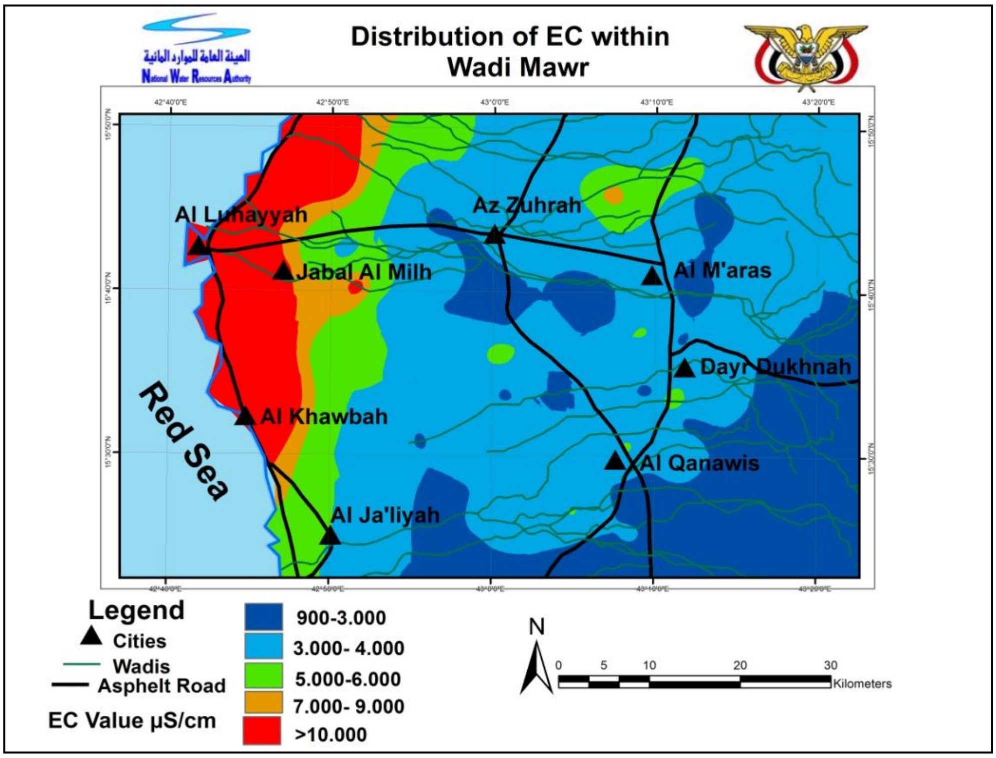

Figure 4. Distribution of electrical conductivity within Wadi Mawr

2.2.3 Wadi Surdoud:

EC varies between 813 and 9,750 micromhos/cm in Wadi Surdud with an average of 1947 micromhos/cm. The conductivity is normal in the upstream with some salinity anomalies in certain areas which have high EC reaching more than 4800 micromhos/cm due to presence of sebkha zone, where high salinity is related to evaporation. The EC increases in the downstream westward, reaching to more than 9700 micromhos/cm in the south (Figure 5).

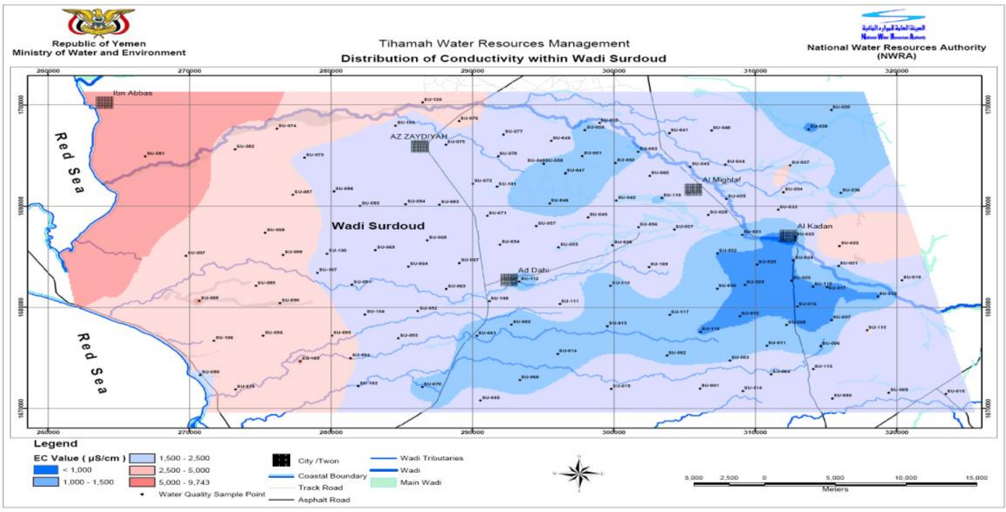

Figure 5. Electrical conductivity distribution in Wadi Surdoud – Tehama Plain

2.2.4 Wadi Siham:

Electrical Conductivity (EC) ranges between 571 and 15300 micromhos/cm with an average value of 2676 micromhos/cm. Results clearly illustrate that the high concentration tends to increase towards the west and south-west which is restricted to coastal areas (Figure 6)**.**

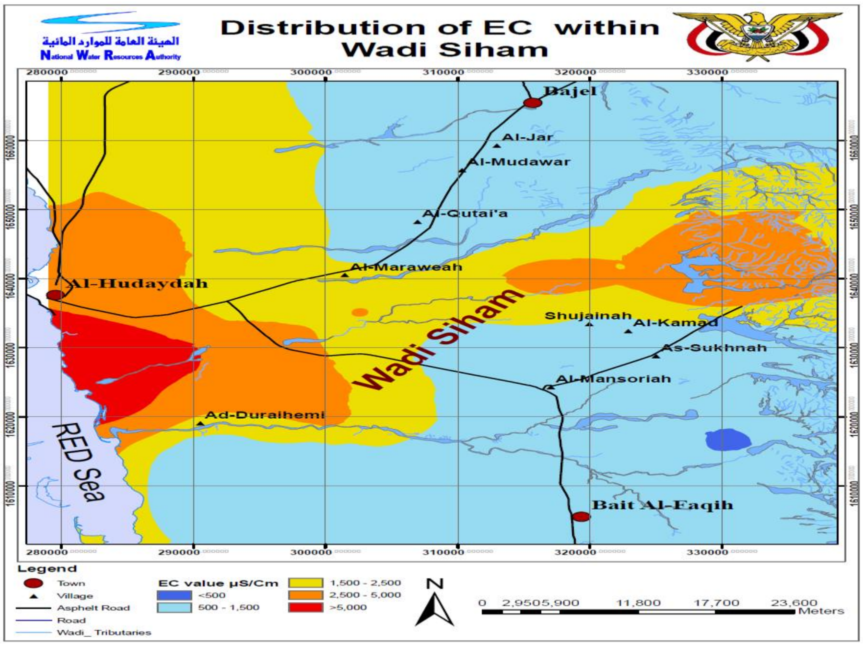

Figure 6. Distribution of electrical conductivity within Wadi Siham

2.2.5 Wadi Zabid and Rema'a:

EC varies between 747 and 17790 micromhos/cm in Wadi Zabid with an average of 1558 micromhos/cm, while it varies between 634 and 10850 micromhos/cm in Wadi Rema'a with an average of 1287 micromhos/cm. This indicates that the salinity of the water in Wadi Zabid is higher than that in Wadi Rema'a (Figure 7).

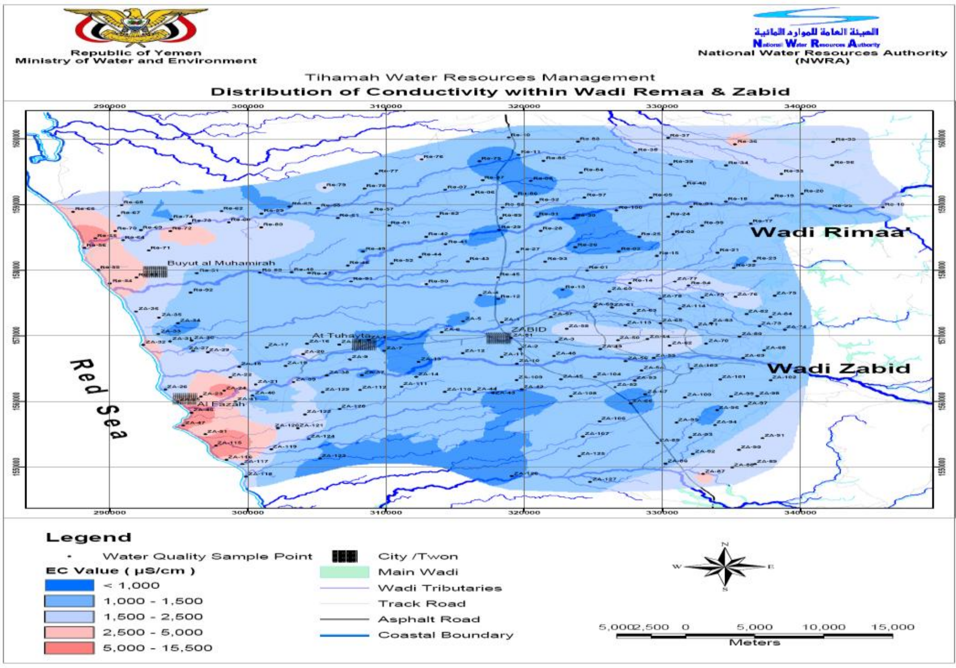

Figure 7. Distribution of electrical conductivity map of Wadi Zabid and Wadi Rema'a

2.2.6 Al-Dhabab area:

Al-Dhabab area is located in the western part of Taiz city. EC varies between 1160 and 9520 micromhos/cm, with an average of 2980 micromhos/cm (Figure 8).

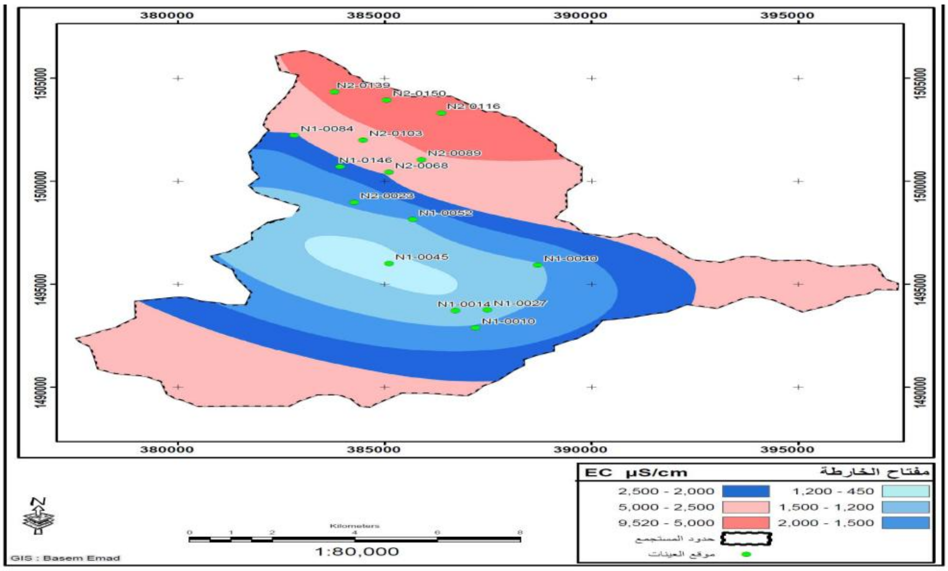

Figure 8. Distribution of electrical conductivity in Al-Dhabab area west of Taiz city

2.2.7 Abyan Delta:

Abyan Delta is one of the southern Wadis, draining in the Gulf of Aden. EC varies between 1200 and 10000 micromhos/cm (Figure 9).

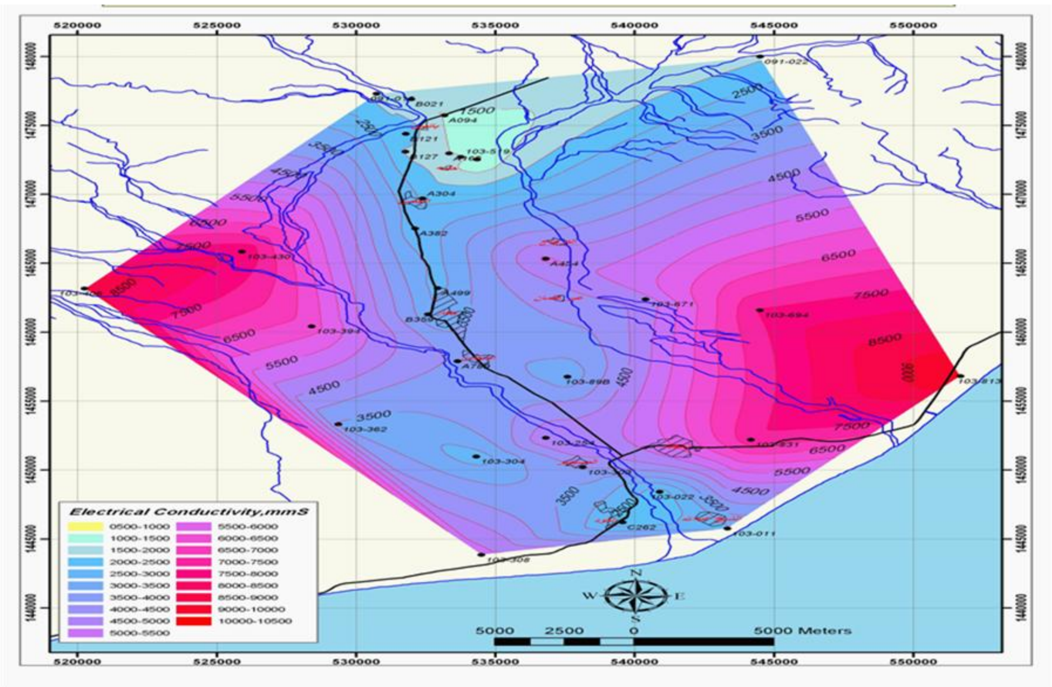

Figure 9. Distribution of electrical conductivity in Abyan Delta

2.2.8 Tuban Delta:

Tuban Delta is one of the southern Wadis, draining in the Gulf of Aden. EC varies between 1500 and 15000 micromhos/cm (Figure 10).

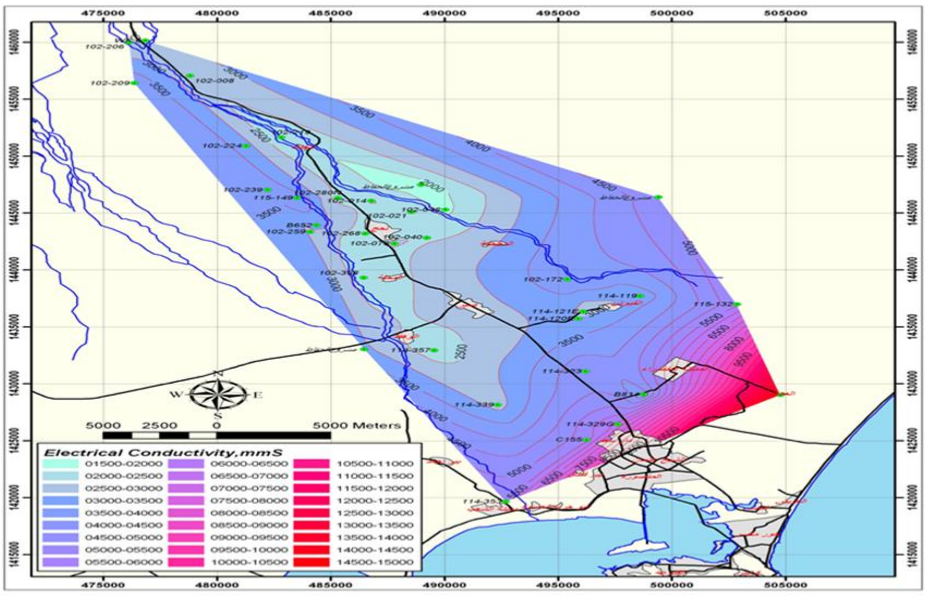

Figure 10. Distribution of electrical conductivity in Tuban Delta

2.3 Brackish water quantity

As mentioned above, the groundwater salinity is increased in many basins due to the high abstraction of the groundwater or due to seawater intrusion. In addition, there are areas which have brackish water naturally. However, the usable brackish water for agriculture in Yemen is about 300 MCM/year, mostly in the coastal areas particularly in Tehama region. This amount of brackish water irrigates about 38,500 ha. On the other hand, the amount of brackish water used in water supply for Taiz city is 3.1 MCM/year. This amount is expected to be 4.9 MCM/year by pumping brackish water from new wells in Al-Hawban and Al-Hawgalah fields, located 5 km and 2.5 km north of Taiz city respectively.
Ref.: Studies carried out by ICBA (2003), followed by Stenhouse and Kijne (2006).
Ref.: Study conducted by NWRA – Taiz Branch in 2011. Financed by UNDP and IDRC.

2.4 Treated wastewater

The current amount of available water per capita in Yemen is 137 m^3/y, which is the lowest rate in the world. However, increasing urbanization and the provision of potable water supply and sanitation results in an increased amount of treated effluent being produced. Thirteen WWTPs are constructed, while few of the oldest WWTPs are extended and upgraded. The locations and capacities of WWTPs in Yemen are summarized in Table 2. For the current and planned WWTPs, the total treatment capacity in Yemen is estimated at more than 200,000 m^3/day (about 74 million m^3/year).

The principal WWTPs that are currently operational or planned in Yemen are listed in the table below.

Table 2. Existing and planned WWTPs in Yemen

Location	Design capacity (m^3/d)	Actual flow rate (m^3/d)	Type of treatment	Date commissioned
Aden (Ash Shaab)	11,000	15,000	3 stage stabilization ponds	1970s, extended 1989
Ash Shaab (upgrade)	30,000		3 stage stabilization ponds	Designed
Aden (Al Arish)	70,000	17,000	3 stage stabilization ponds	2002
Al Hota/Lahej	1,300	11,350	stabilization ponds	1985
Amran	1,480	1100	3 stage stabilization ponds	2002
Bait El Faqih	2,544	500	3 stage stabilization ponds	2008
Bajil	4,151		3 stage stabilization ponds	Under construction
Dhamar	11,000	6,000	3 stage stabilization ponds	1991
Hajjah Main	2,428	1,200	Imhoff tank / 2 stage trickling filter	1998
Hodeidah (existing)	12,000	18,000	3 stage stabilization ponds	1983
Hodeidah (upgrade)	51,500		3 stage stabilization ponds	Under design
Ibb (current)	5,200	7,000	Activated sludge	1991
Ibb (upgrade)	10,000		Imhoff tanks / activated sludge	Designed

Mukalla	14,000		stabilization ponds	Under construction
Rada'a	1,880	1,500	2 stage stabilization ponds	1996
Sana'a	50,000	56,000	Activated sludge	2000
Taiz	9,000	8,000	3 stage stabilization ponds	1982
Tarim	16,000		3 stage stabilization ponds	Designed
Yarim	1,771	530	3 stage stabilization ponds	2005
Zabid	1,146		Imhoff tank / 2 stage stabilization ponds	Under construction
Al-Rugoom	500		Reactor / stage stabilization ponds	Under construction
Shibam	500		Reactor / stage stabilization ponds	Under construction
Al-Tawilah	500		Reactor / stage stabilization ponds	Under construction

This list shows that the predominant method of treatment is by stabilization ponds, which is considered the most appropriate for the warm climate conditions in Yemen, being mechanically simple and easy to maintain. However, a number of existing WWTPs are overloaded, and in some cases inadequately designed, with the consequence that effluent qualities are consistently below that necessary for safe reuse or discharge. Nevertheless, an indication of the robustness of stabilization ponds is Hodaidah, where the WWTP is over 20 years old and is currently treating more than twice its design flows.

2.4.1 Wastewater quality

Current effluent quality is generally poor as none of the existing WWTPs produce effluents that comply with the effluent quality regulations. The low rates of per capita water consumption in Yemen cause an increased concentration of pollutants in the wastewater, also the disposal of car oils into the network leads to weak efficiency of the wastewater treatment plants, which are not equipped to treat/separate oil. Effluent wastewater BOD in the mountainous cities ranges between 174 – 900 mg/l, while it ranges between 47 – 59 mg/l in coastal areas. However, the EC of the effluent of WWTPs in the mountainous cities is low ranging between 1600 - 1900 micromhos/cm and TDS ranges between 1050 - 1200 mg/l, while the EC in the effluent of WWTPs in the coastal cities is very high ranging between 2850 - 2960 micromhos/cm and TDS ranges between 1850 - 1900 mg/l.

Industries in the wastewater catchment area may discharge a wide range of heavy metals and organic contaminants, as well as contribute significant amounts of BOD, COD, salinity, etc., depending on the type of industrial processes involved. Since large industries are often significant point sources of pollution, sewage quality can be more easily controlled at the source by setting and enforcing effluent discharge standards. This is necessary to protect the fabric of the sewerage system from aggressive chemicals and to avoid excessive concentrations of pollutants in the effluent and sludge. This may require pre-treatment of industrial effluents before they can be accepted into the system.

Surface run-off from paved areas due to rainfall into combined sewerage system may introduce significant amounts of sand and pollutants. Uncontrolled industrial discharges may also enter the sewer in this manner, typically from small workshops and garages. The use of ventilated manholes allows some surface drainage to enter the system, although this is not intended but it adds to the sand load in the sewage. The quality of surface run-off also reflects aerial deposition of heavy metals and organic contaminants from, for instance, combustion products and other atmospheric discharges from cars, domestic fires, industries and power generation. Where leaded petrol is used, this can be a significant source of lead in sludge.

2.4.2 Wastewater reuse

Due to the water scarcity condition in Yemen, treated sewage effluent becomes very important, particularly in the mountain areas in which water scarcity is very critical and the cost of pumping groundwater is very high reaching 0.5 USD /m^3.

In case of the WWTPs located in the mountain cities, effluent discharge is to Wadis, and the flow continues by gravity along 5-10 km. The farmers located downstream of the WWTPs in both banks are using the effluent, whether treated or not. Farmers continue to irrigate a wide range of crops, including vegetables intended for the main markets. Although they realize that there are potential health risks to consumers, they do not care as the product is not for their own consumption.

In case of the WWTPs located in the coastal cities, effluent discharge is to small farms and to irrigate forestry trees in the wetlands. The rest of the effluent is discharged to seas. There is only limited agricultural land in the vicinity of the WWTP as the area is characterized by mobile sand dunes which encroach on the cities and the main roads. The farms in the coastal area that are supplied with the effluent grow forage crops.

The total area irrigated by effluent of WWTPs in Yemen is 1100 ha, including rangelands. There is no data on the number of farmers who reuse wastewater effluent and sludge. However, the effluent of Sana'a WWTP, treated or untreated, is used by about 600 farmers to irrigate about 300 ha of crops, including vegetables. This practice poses a high risk of aquifer contamination and endangers the health of both farmers and vegetable consumers. *(World Bank, 2006)*.

Different crops are also irrigated by the effluent such as sorghum, maize, wheat, barley, millet, potatoes, tomatoes, pulses. In addition, the effluent is used to irrigate the fodders (Para-grass and Elephant grass) and forestry trees.

Generally, the yields of rain-fed crops are low, limited by rainfall and the minimal use of fertilizer. For instance, the yields of cereals range from 0.9 t/ha in Aden and Hajjah, to about 1.5 t/ha in Ibb and Amran. The relative differences in productivity are explained by the amount of rainfall, the use of supplementary irrigation and the specific crops grown in the different areas. In general, the yields from land irrigated by effluent are 2 - 5 times greater than from rain-fed production. *(Ref.: Study conducted by Al-Kuawd Research Center)*

2.4.3 Sludge use

As far as known, there have been no specific studies or projects on sludge management and use in Yemen. However, the sludge produced by the existing WWTPs in Yemen is generally readily used by local farmers but without any control or monitoring. No chemical analyses are made on the sludge and no records are kept of the recipient farmers or where the sludge is used.

Farmers do not pay for the sludge (at least formally) and they usually collect the sludge at their own expense. However, at Ibb, liquid sludge is occasionally delivered to farmers using a tanker operated by the WWTP to ease sludge handling problems on the plant. For some WWTPs, there is apparently high demand from farmers from within and outside the area (e.g. farmers at Tehama take sludge from Hajjah). This may be due in part to the fact that conventional WWTPs such as Hajjah and Ibb produce sludge continuously, whereas most WWTPs in Yemen are stabilization ponds which produce sludge only periodically. The effluent-irrigated areas for each WWTP will generally be limited to that which can be reached by gravity flow as pumping should be avoided where possible, so as to minimize costs and reliability problems. In most circumstances, this will be land immediately downstream of the WWTP and alongside the Wadi into which the treated effluent is likely to be discharged. In some situations, effluent-irrigated land would be a narrow strip of land alongside the Wadi, stretching for several kilometres.

However, farmers may purchase portable pumps to lift effluent from the discharge to irrigate higher ground, but this is only likely to occur where the farmers have sufficient land to justify the costs, or can share equipment, and appreciate the benefits through higher crop production. Since effluent discharge will result in permanent Wadi flow, farmers will have access to a reliable source of water throughout the year. This not only provides opportunities for extended cropping in areas predominantly reliant on rain-fed cultivation, but also as a low-cost alternative to pumping groundwater from tube-wells. While the fertilizer benefits of raw sewage to crop production is recognized by farmers who use it (usually by blocking sewers to flood nearby land), treated effluent is likely to be considered as less beneficial and many farmers are concerned that the fertility of their land will be adversely affected. The limited experience of treated effluent reuse in Yemen shows that salinization of soil does occur in some areas, but this is more a function of poor irrigation practices rather than poor effluent quality. Farmers clearly need to be convinced of the benefits of effluent reuse and they need advice on appropriate changes to their irrigation practices to adapt to water of different quality.

In addition to the scarcity of water, agricultural production is restricted due to the low usage of fertilizer and the inherently low organic matter contents of soils. The quantities of sludge produced by WWTPs are generally not recorded or, if recorded, they are in inappropriate units.

For the current and proposed WWTPs, it is estimated that the total sludge production in Yemen may exceed 40,000 tons /year within ten years or so. Assuming that all of this sludge is used in agriculture and that the annual rate of application to land is 4 tons/ha, about 10,000 ha (0.9%) of total cultivable area would be required annually. While this area is small in relation to the overall cultivable area of Yemen, sludge is produced in only a few locations and so will require a significant proportion of the land locally. Unlike effluent reuse, where the area of reuse is usually constrained to land immediately downstream of the WWTP, the principal limitation for sludge reuse is transport distance (i.e. the cost of the farmer's collecting sludge from the WWTP). The main sludge reuse area would normally be expected to be around the WWTP within a few kilometers.

2.5 Overview of the large areas of salt-affected soils in Yemen

Soil in Yemen has not extensively been studied, as focus was merely set on soil classification and soil texture. Salinity hence occurred in the soil irrigated by brackish water due to evaporation of the water leaving the salt in the soil.

Soil in Tehama areas is generally poor in nitrogen, a fact that suggests reconsidering the fertilization programs and the possible use of organic fertilizers. Regarding soil phosphorus, some locations are over-fertilized with P; therefore, modified fertilization programs are to be considered. Soil salinity, as indicated by the EC, is generally suitable for almost all crops with very little yield reductions. The salinity and the harmful increase of chemicals in the upper layer of soil due to the use of flood irrigation instead of using a high-tech irrigation system, affect the crop yield (quantitatively and economically). In case of low permeability, it will increase the seriousness of salinity in the high degree of evaporation and this leads to low-quality agricultural production. However, in the case of a soil having high permeability, drainage will be effective becoming a very important factor for the growth of agricultural crops, even if salty water is used.

<u>The effect of water salinity at the soil of Al-Jar area (Tehama Plain):</u> Al-Jar area could be divided into three areas: North, Middle and South. The maximum altitude from the east is estimated to be between 100 and 300 m above sea level with an estimated slope of 0.5 % (from east to west). However, according to the concerned experts, and confirmed by the soil analysis performed in the Al-Jar area, texture may be considered as sandy loam, with soil available moisture (holding capacity) approximately 120 mm/m.

The soil analysis of samples taken from the area indicated that the acceptable salinity in general is neither saline nor sodic, hence the soil of the area is appropriate to grow different kinds of vegetable, field crops and fruit trees with supplement of the needed fertilizers and nutrients.

To deal with the situation of soil, water and yield deterioration, several measures have been suggested by the study. One of these measures is the suggested Crop Rotation which is actually guided by the Crop Pattern, in addition to the use of additional leaching requirement and decreasing the irrigation interval time.

2.6 Overview of the coastal aquifer systems

Yemen has a 400 km long coastline along the Red Sea and about 1200 km along the Arabian Sea. According to previous studies, water in the Tehama coastal area is categorised into three categories based on water electrical conductivity (EC) values to include freshwater (EC <3000 mS/cm), brackish water (3000>EC<6000 mS/cm), and saltwater (EC>6000 mS/cm). Freshwater is present at shallow depths in both the major Wadi areas and in the inter-wadi areas, but quality in the Wadi areas is better than the inter-wadi areas.

The distribution of the EC values is found to be changing from the east to the west with high values at the east where brackish and saltwater may be found at the shallow depths (as in the Sebkha zones). **Sebkha** is the local term for the land lying within about one kilometer of the coast which has been saturated with salt spray driven in land by onshore winds. The interface between seawater and freshwater gets its maximum depth within a distance less than 10 km from the coast.

2.7 Seawater intrusion

Deterioration in groundwater quality from anthropogenic activities has resulted from saltwater intrusion along the coastal areas due to groundwater over-pumping. Seawater intrusion is a major problem in many regions along the coastal areas. The study conducted by NWRA has identified the locations of seawater intrusion as follows:

2.7.1 In Tehama coastal plain

Due to the extensive abstraction of groundwater and the extension of the irrigated areas along the coastal Wadis, in addition to the fact that floods did not reach the coastal zones for many seasons, all this resulted in seawater intrusion in many areas along the coast. However, four locations are more critical in Tehama plain which are (Al-Jar, Midi) in Wadi Harad north Tehama, and (Al-Luhayyah, Al-Khawabah) in Wadi Mawr. Figures 11, 12 and 13 indicate the locations of seawater intrusion in Tehama plain.

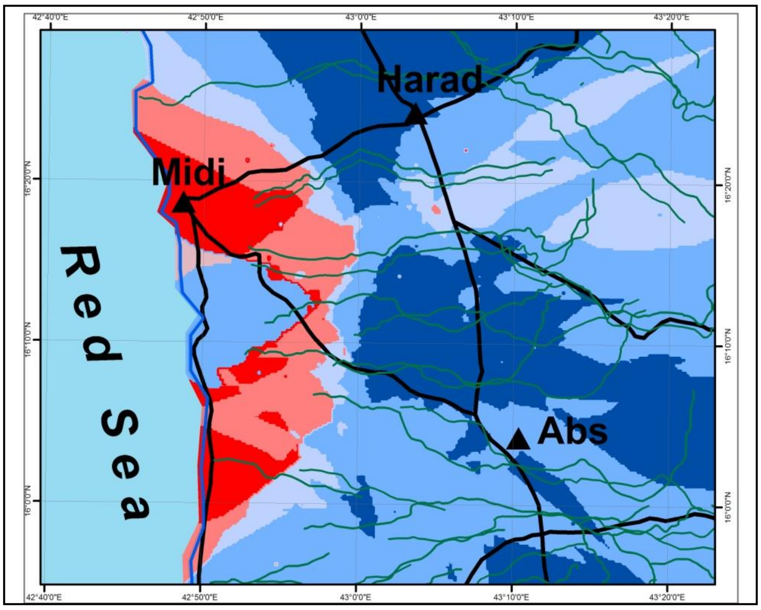

Figure 11. Red color shows the areas affected with seawater intrusion in Wadi Harad and Abss in Tehama Plain

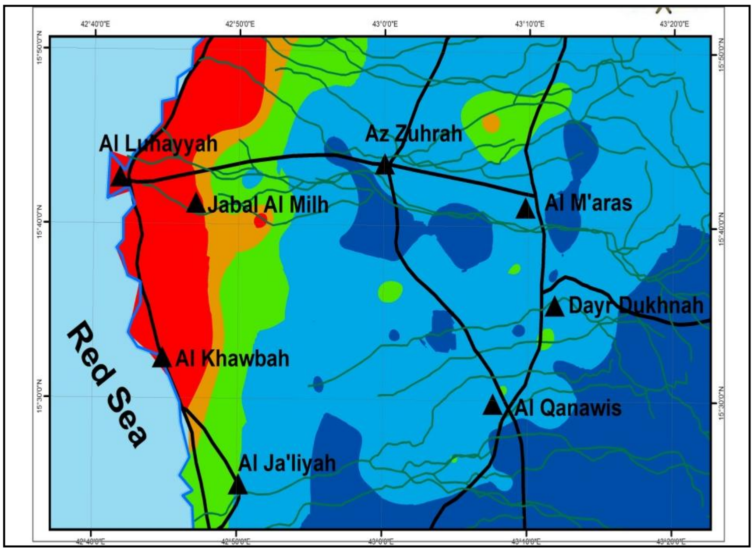

Figure 12. Red color shows the areas affected with seawater intrusion in Wadi Mawr (Al-Luhayyah and Al-Khawabah regions) in north Tehama plain

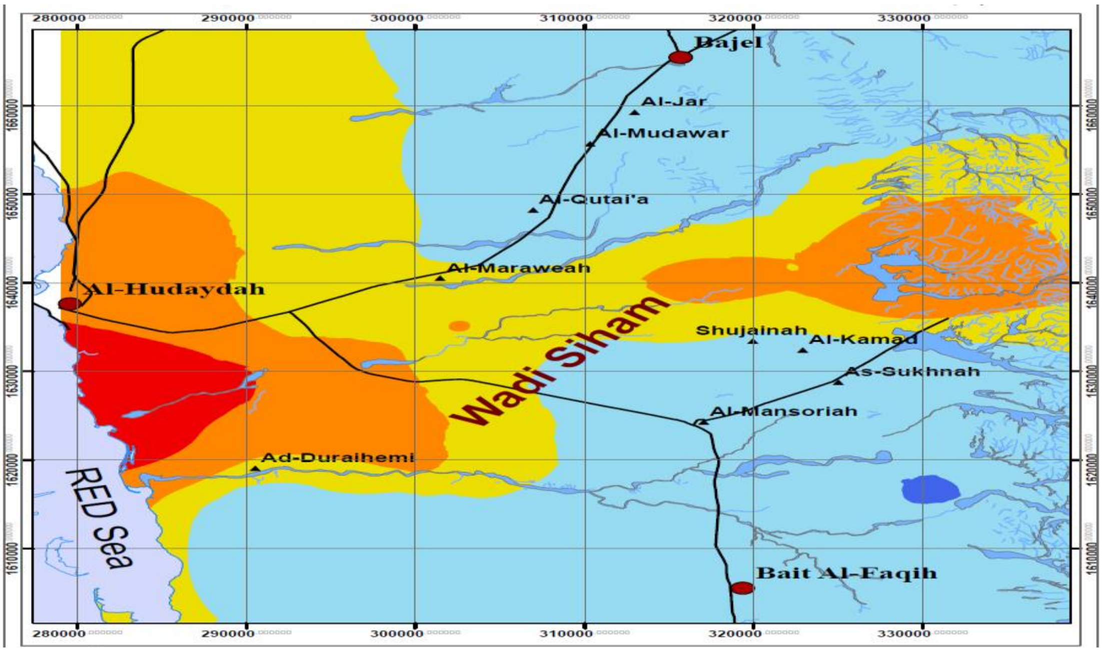

Figure 13. Red color shows the areas affected with seawater intrusion in Wadi Siham in Tehama Plain

2.7.2 In Al-Jar Area

Most of the agricultural investment is located in Tehama plain. Al-Jar area is the largest area in Tehama cultivated by fruit trees. The total area of Al-Jar is 12, 250 ha, out of which 9368 ha are actually cultivated. The cultivated areas consist of fruit trees such as mango 8782 ha, date palm 158 ha, fig 65 ha, in addition to 362 ha covered with vegetables, field crops, cereals and a very small area assigned for other fruits such as lemon and pomegranate. Due to the high amount of groundwater pumped in this area, the seawater intrusion increased the salinity in the freshwater in the area, hence the huge agricultural investment was facing a big problem. MAI hired an international consultant, the Scientific Council for Systems and Applied Science (SCSAS), to conduct a study on "Water Resources Assessment, Development and Utilization in Al-Jar Area" in December 2008. One the major recommendations was to desalinate brackish water and use it to irrigate different crops and fruit trees particularly mango trees. However, the long-term recommendation was to stop cultivating mango trees due to the scarcity of freshwater and mango is one of the low-salinity tolerant trees.

Figure 14. Al-Jar area highly affected with seawater intrusion north Tehama plain.

2.8 Data for brackish water use in agricultural production

Brackish water is mainly used for rock cutting industry in highlands, as well as for irrigating some tolerant crops mainly in coastal plains. However, brackish water with high salinity is used for water supply in Taiz city by mixing with freshwater for domestic use without any desalination. Hence, Taiz city is the most critical city in water resources in Yemen. Taiz city receives water with very poor quality every 40 days. Over-pumping of groundwater and intensive use of irrigation water have led to increase in saline water, hence farmers had to rely on lower quality and less desirable sources.

The usable brackish water for agriculture in Yemen is about 300 MCM/year, mostly in the coastal areas particularly in Tehama region. This amount of brackish water is used to irrigate about 38500 ha. [*Ref: Studies carried out by ICBA (2003), followed by Stenhouse and Kijne (2006)]*.

There are no data or investigations available for the yield of crops irrigated by brackish water, except one field trial conducted by the team of experts working in the Field Unit of the Land and Water Conservation Project (LWCP), piloted by Dr. Makki Omar from Tehama Environment Protection Project (TEPP).

The trial was conducted in 1999 at El-Zuafran extension center in Central Tehama plain. The farmer used a tube well as a source for irrigation water where salinity EC reaches 6000 micromhos/cm. Results are shown in Table 3.

Table 3. Results of the trial of brackish water in Tehama area

Crop	**Salinity Tolerance Rate**	**Treatment (A)**		**Treatment (B)**	
		Applied water including leaching water requirement (m^3/ha)	**Yield (ton/ha)**	**Applied water without leaching water requirement (m^3/ha)**	**Yield (ton/ha)**
Sorghum (grain)	Moderate salinity tolerance	7500	1.22	6323	0.52
Sorghum dry matter			8.52		5.21
Cotton	High salinity tolerance	12950	1.8	9713	1.11
Okra	low salinity tolerance	10237	0.75	8148	0.73

Comparing the crop yield in treatment (A) irrigated by brackish water with leaching water requirement and decreased irrigation interval time up to half, with that of the same crops under treatment (B) irrigated by brackish water without leaching requirement and no change in irrigation interval time, it was found that about 40% of the yield decreased. However, salinity ranged between 5000 - 6000 micromhos/cm for both treatments.

Moreover, when comparing the yield of crops irrigated by brackish water with salinity range between 5000 - 6000 micromhos/cm and the yield of the same crops in Tehama region irrigated with freshwater, the yield was found to increase by about 60% and 70% for the sorghum and cotton, respectively. Regarding the Okra, the yield was very low due to the high salinity.

Table 4 shows the productivity of crops irrigated by brackish water compared to the productivity of the same crops irrigated by fresh groundwater in Tehama region.

Table 4. Productivity of crops irrigated by brackish water compared to fresh groundwater in Tehama region

Crop	Yield for the crops irrigated by Brackish water (ton/ha)	Yield for the crops irrigated by fresh groundwater in Tehama (ton/ha)	A balance of the yield
Sorghum (grain)	1.22	0.8	+ 60%
Sorghum dry matter	8.52	12.8	- 60%
Cotton	1.8	1.3	+ 70%
Okra	0.75	6.1	The yield is only 13% of the normal

2.9 Management and practices related to the use of brackish water

In irrigated areas, salinity problem often originates from salts in the applied water. Yield reductions often occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in water stress for a significant period of time.

To avoid problems of using these poor-quality water supplies, there must be a sound water management system to ensure that the quality of water available is put to the best use. In addition, there is a need to improve the plant-soil-water availability by maintaining a low salinity in the root zone through frequent irrigation and leaching requirement applications.

In addition, the estimated brackish water requirement, including the leaching water requirements for different crops, is about 10000 –15000 m^3/ha. The current irrigation efficiency is about 40 % , which means that water saving technologies must be applied in order to save water and increase irrigation efficiency. From the experience of existing projects, 20 to 25 % could be saved by installing conveyance pipe systems to convey and distribute irrigation water from the wells to the cultivated fields, i.e. about 2000 – 2700 m^3/ha could be saved. The use of localized irrigation systems could also save about 3500 – 6000 m^3/ha.

Generally, the main crops irrigated by brackish water under various ranges of salinity all over the country are sorghum, millet, cotton, tobacco, sesame, elephant grass, date and tomato *(Ref. : Al-Jar study)*.

2.10 Main issues stemming from the brackish water use practices

Farmers do lack the experience in the use of brackish water due to the following reasons:

- Lack of efficient, sufficient and accurate data and information on the best practices or the suitable crop varieties
- Lack of extension services that should be provided to the farmers, particularly the irrigation advisory services
- Lack of researches on the use of brackish water requirement and the recommendations on the best practices, suitable crop varieties to be irrigated by brackish water.

3. Impacts, Opportunities and Constraints

3.1 Major impacts of brackish water use on agricultural production

The use of high salinity water for irrigation has negative environmental, economic and social impacts. The best on-farm water management practices for brackish water have considerably decreased those impacts. The major impacts of brackish water use for agriculture could be identified as follows:

3.1.1 Environmental impacts

The use of brackish water in agriculture in Yemen has become a reality as a result of over-depletion of groundwater resources, in addition to limited rainfall, which led to inadequate flood flow to the valleys, consequently resulting in the non-arrival of floods to the sea, thus aggravating the problem of seawater intrusion in the agricultural areas along the coastline. Moreover, the continuous use of saline water increased the salinity in the soil leading to decreased soil fertility and crop productivity.

3.1.2 Economic impacts

High salinity of groundwater in the coastal basin has significant economic impacts including:

The change in cropping patterns in the coastal areas includes the shift from cultivation of fruits (mango, banana) to cultivation of field crops (sorghum - millet - cotton) and limited types of vegetables (okra - tomato - onion), a fact that led to lowering the farmer's income because the average income return of (mango, banana) is higher (about 1-1.5 million/year hectare). In contrast, the average income return from cereals is very low (0.3 - 0.4 million/year/hectare). *(Ref.: Water savings study conducted by GSCP).* This is because most of the production of grain crops is mainly intended for production of animal feed, as cereal production requires large amount of water and due to low productivity in general. Therefore, the use of brackish water is accompanied by low crop productivity and low income level. This in addition to the high cost of agricultural inputs e.g. cost of seeds, irrigation, land preparation (plowing and grubbing) and harvesting. These costs increase as a result of increase in fuel prices leading to negative economic impacts on people, national income and gross domestic product.

In agricultural areas with water problems, there is a significant decline in the prices of agricultural lands where salinity is high with a possibility of salinity increase in future to the level of non-availability of drinking water. This may lead to the inability of farmers to sell their lands.

There is a clear example of this problem in Al-Jar area where there are huge investments in the large areas of mango farms exported to Gulf countries with high return benefit to the farmers there. Yet in 2009, when the problem of seawater intrusion started, the situation is now completely changed. The price of one hectare of agricultural land in the recent years has gradually decreased and the decline in the price of agricultural land is still continuing.

3.1.3 Social impacts

The social related impacts include the migration of labor to look for other works and a significant decline in the prices of agricultural land as the region has become of high salinity with possibility of future salinity increase. This created great fear among farmers that the water becomes unfit for drinking in the near future, leading to local migration of population to the cities.

3.2 Opportunities and constraints related to the use of brackish water

3.2.1 Opportunities created by brackish water use in Yemen

The rapid growth of population in Yemen is putting enormous pressure on the water availability, and consequently on the food security which is directly dependent on water. Yemen is facing a grave water crisis which, if left unattended, will threaten the survival of both urban and rural areas. The urgent action to pull the country back from the brink of disaster is imperative. Conservation of water, use of non- conventional water, and improving agricultural productivity per drop of water are the only means of salvation for Yemen.

Results of the water quality studies, conducted by the Water Resources Authority in 2011 pointed out that the salinity of groundwater increased vastly in many basins particularly those in the coastal areas where the seawater intrusion renders the coastal areas in an extremely hazardous situation. Due to water scarcity problems, there is a need to use brackish water in agriculture and water supply purposes as follows:

- ***Opportunity for brackish water use in agricultural purposes***

Agriculture is the major potential sector to use brackish water in Yemen. Most of the crops have a high resistance to salinity particularly cereals as well as the fodder crops, which are the milestone of food security.

A study was conducted by an international consultant in 2006, with the aim of assessing water resources, highlighting the groundwater current conditions including seawater intrusion, and proposing the possible solutions to protect the existing agricultural development in Al-Jar region (Tehama plain).

The study area was located in the northern part of Tehama plain, which is a flood plain covering more than (120 km^2) extending to the east of the Red Sea coast in the west and the highlands in the east.

The study indicated that the groundwater situation had reached a super critical condition in Al-Jar area, seriously threatening the existing agricultural activities in the area.

One of the study solutions to solve the problems of seawater intrusion was the use of brackish water by digging 35 wells and pumping about 31 MCM from the northeastern areas where brackish groundwater levels are within reachable pumping levels with reverse osmosis (RO) desalination compact units of capacities 2200 m^3/day to desalinate the brackish groundwater. At least 31 MCM of brackish water is needed to produce the required 20 MCM of freshwater.

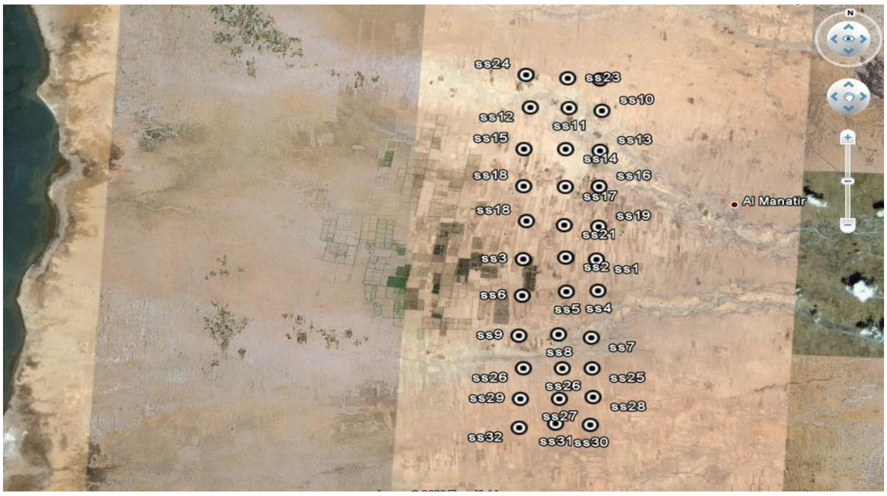

Figure 15. Site map of proposed brackish water wells

The study proposed cropping patterns according to the water requirement. About 3000 ha could be irrigated using the desalinated brackish water.

Three crop rotations were suggested with different crops to adapt the specific conditions of that area taking into consideration that levels of water salinity may rise within the next few years if the right measures were not taken.

As mentioned in this study, brackish water could be a practical solution not only in this area but all over the coastal areas, as well as in the highland areas. Moreover, brackish water could be used to irrigate different crops without any desalination, particularly in areas that have a low rate of salinity.

- ***Opportunity for brackish water use in water supply***

Due to the crisis of groundwater scarcity in Taiz Governorate, by which water supply comes to the houses every 40 days, the water demand in Taiz is currently met with the water wells spread within the city and around. Al-Hawjalah and Al-Hawban are two of the main water fields, but unfortunately the quality of those two water fields is brackish with EC ranging between 3350 - 6500 mmhos/cm. The city water field is also brackish with EC ranging between 800 - 3630 mmhos/cm. To solve the current water supply problems, Taiz Water Supply Corporation appointed Dar Al-Teqniya consultant in 2006 to conduct a feasibility study for desalination of brackish water from Al-Hawjalah and Al-Hawban aquifers, situated 5 km and 2.5 km north of Taiz city, respectively.

In this study, recommendations are made for ensuring sustainable development of Al-Hawjalah and Al-Hawban well fields through: maintaining the current wells, drilling extra wells, and desalinating the total quantity of brackish water envisaged to be extracted from the zone which is 16000 m^3/day (5.84 MCM/year) with average TDS of about 4000 mg/l, so as to meet Yemeni or WHO recommended standards.

Problems that may face the desalination of brackish water for drinking purposes are: the high cost of desalinated water compared to the cost of water from other sources, and the problems in disposal of Brine (salts and volatile organic compounds), However, in view of the recent drought conditions in many aquifers, desalination of brackish water or seawater are promoted.

3.2.2 Constraints affecting the scaling-up of brackish water use

Brackish water use in irrigation is facing many problems and constraints which can be summarized as follows:

- Increase in soil salinity.
- Yield reductions due to salt accumulation in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solutions resulting in water stress for a significant period of time.
- High cost of agricultural inputs due to the need for deeper plowing and more pumping costs to cover the additional water requirement for leaching.

To avoid the above constraints when using brackish water, it is necessary to have a sound water management system to ensure that the quality of available water is put to the best use. In addition, agricultural practices should be improved and extension services provided.

4. Policies, Regulations and Institutions

4.1 Major policies, strategies and regulations related to use of brackish water

The GOY is aware of the challenges that the country's water problems pose for achieving food security, and has taken some significant institutional steps over the past years. Strategic planning began in early 1990s. In 1996, the National Water Resources Authority (NWRA) was established to implement an integrated approach. In 2003, the Ministry of Water and Environment (MWE) was established. In 2005, MWE in cooperation with the Ministry of Agriculture and Irrigation (MAI) and related ministries, prepared a consolidated strategy, action plan, and an investment program for the water sector as a whole, namely the National Water Sector Strategy and Investment Program (NWSSIP). In 2008, NWSSIP was updated for the period 2008 – 2015. NWSSIP emphasized the importance of desalination of brackish water or seawater to be used for drinking. On the other hand, the poor farmers in the coastal areas currently use brackish water for irrigation of different crops without any guidance from the official institutions. In 2011, the Government also established a National Food Security Strategy, one of the major objectives of which was the sustainability of the water resources as the water scarcity is the main challenge facing food security in Yemen. The strategy stressed on the importance of using of non-conventional water resources.

The Ministry of Agriculture and Irrigation (MAI) in 2000 started the preparation of an agricultural sector strategy, the so-called Aden Agenda, followed by MAI agricultural policies and strategies in 2005 and 2009. In

2011, UNDP supported the Ministry to update the National Agricultural Sector Strategy (NASS). The strategy was approved in March 2012.

The main objectives of the Agricultural Sector Strategy is to contribute to national development through:

- Increasing the productivity of irrigated agriculture through promotion of improved irrigation technologies, comprehensive knowledge transfer, and research on agricultural water use efficiency and conservation.

- Promote usage of treated wastewater including brackish and grey water to support environmental preservation activities.

- Improve and maintain soil fertility through increased use of organic fertilizers, which will also assist in the control of soil erosion and other environmental degradation.

- Promotion of water resources sustainability through improvement of watershed management, wadi bank protection, tree planting in watersheds, and rehabilitation of agricultural terraces and existing water structures including construction of subsurface dams.

- Promote the production of rain-fed and drought-tolerant crops, and provide support to research to develop new varieties of drought-resistant crops or alternative crops.

Based on the above mentioned strategies, no specific policies, strategies or regulations concerning brackish water use were established in Yemen. It is highly recommended that technical assistance be provided to the Government to establishe an appropriate brackish water policy, strategy and regulations.

4.2 Institutions mandated with the development and management of brackish water

The Ministry of Water and Environment (MWE) and the Ministry of Agriculture and Irrigation (MAI) are the main ministries responsible for water resources management in Yemen. Different institutions and authorities are working under the umbrella of the two ministries as follows:

The Ministry of Agriculture and Irrigation (MAI): is responsible for formulating policies concerning irrigation, crops, livestock and forestry production, and for coordinating public investment and services in the agricultural sector. The Irrigation and Land Reclamation Sector (ILRS) is located within the Ministry, and carries out all the duties related to irrigation, particularly the construction of dams, water harvesting and spate irrigation structures. Most field services are provided to farmers through decentralized Regional Agriculture and Irrigation Offices (RAIO) at the different governorates of the country. Moreover, several projects working under the supervision of the MAI provide different services, particularly in the field of introducing water saving techniques and construction of water harvesting and spate structures, as well as wadi bank protection and abused terraces rehabilitation, in addition to rehabilitation and maintenance of the existing irrigation structures. There is one regional development Authority for the Tehama plain called Tehama Development Authority (TDA). In addition to the above, there is the Agriculture Research and Extension Authority (AREA) working under the umbrella of the Ministry. Also the Agricultural Cooperative Union (ACU) was established in August 1991 with 213 societies. The ACU main objective is the consolidation, integration and coordination aspects with Government effort in setting up of several common projects, the most important of which are the infrastructure projects such as agricultural marketing, water storage, regulation dams and weirs. This is in addition to irrigation supply networks, agricultural inputs and means of development of livestock.

Ministry of Water and Environment (MWE): Recently established (2003) to take over the formulation and development of the strategy and policy of the water sector in the Republic. There are many sub-sectors and authorities such as: National Water Resources Authority (NWRA), Environment Protection Authority (EPA), General Authority of Rural Water Supply and Sanitation Projects (GARWSSP's), Local Corporation of Urban Water Supply and Sanitation. All those institutions are working under the umbrella of the Ministry of Water and Environment.

Additionally, there are some dependent institutions like the Social Development Fund (SDF) and the Public Works projects, working in the water resources field.

4.3 Policy and institutional gaps and related recommendations

As mentioned, there is no specific policy for brackish water use. The initiative for brackish water use should be promoted, yet due to several reasons, brackish water as well as wastewater use policy and strategy are not yet established.

There has been a proposal for wastewater reuse strategy but not promoted due to the following reasons:

- Lack of coordination among related institutions is a key constraint at present for further development, efficient and safe use of treated wastewater.
- A particular institutional problem is the inadequacy of pollution control and other environmentally-oriented monitoring and absence of regulatory agencies.
- Considering the risks associated with treated wastewater use, there is no institutional framework to control, supervise and advize on reuse schemes**.**
- Lack of coordination between related authorities, implementation directorates and research centers.
- Inefficient regulations and legislation: Regulations and rules enforcing the application of research results are inefficient or absent. Many, if not all, concerned authorities neglect the various precise facets reported by researches, claiming that it may retain implementation or require additional costs.
- Lack of efficient, sufficient and accurate data and information.
- Research is an organized and long-term work and directly connected to the requirement of each country. Research should therefore be an integral part of the country's development programs of this resource and its use. This necessitates the setting up of master plans on which research programs and projects are depending. There are no clear plans for development of this resource and its reuse, which are a prerequisite in the modern research work.

Accordingly, it can be concluded that under such circumstances, the brackish water and the treated wastewater use cannot be used for any agricultural purposes unless all mentioned problems are solved. On the other hand, the current reuses and practices are of great danger to human health and environment and adversely affect the plant and soil productivity.

5. Research and Technological Knowledge on the Use of Brackish Water for Agricultural Production

There are no investigations or researches conducted for the use of brackish water in Yemen, except one field trial conducted by the team of experts working in the Field Unit of the Land and Water Conservation Project (LWCP), piloted by Dr. Makki Omar from Tehama Environment Protection Project (TEPP). The objectives of this trial were: i) to improve the plant-soil-water availability by maintaining a low salinity in the root zone through frequent irrigation and leaching requirement applications, and ii) to determine crop yield response to salinity. However, many researches were conducted on the use of treated wastewater and its impacts. All such researches were not disseminated or implemented. It is highly recommended to turn our interests and views to the better use of brackish water and treated wastewater as the country is presently in a real critical water situation.

5.1 Water and soil management practices

Over-pumping of groundwater and intensive use of irrigation water have led to increased saline water, hence farmers had to rely on lower quality and less desirable sources. In irrigated areas, salinity problem often originated from salts in the applied water. Yield reductions often occur when the salts accumulate in the root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution, resulting in water stress for a significant period of time.

To avoid problems of using these poor-quality water supplies, there must be a sound water management system to ensure that the quality of available water is put to the best use. In addition, there is a need to improve the plant-soil-water availability by maintaining low salinity level in the root zone through frequent irrigation and leaching requirement applications.

5.2 Salt-tolerant crop varieties or genotypes/cultivars

The main crops irrigated by brackish water under various ranges of salinity all over Yemen are sorghum, millet, cotton, tobacco, sesame, elephant grass, date and tomato *(Ref.: Al-Jar study)*

5.3 Crop husbandry practices

There is no documented information in this regard. However, the farmers irrigate using brackish water without any consideration for the best management practices for the water and soil.

5.4 Success stories and failures

There are no success stories as related to the use of brackish water in agriculture. However, brackish water is mostly used to irrigate sorghum or elephant grass for producing fodder for their animals because their income is dependent on animal production particularly in Tehama coastal areas.

6. Conclusion and Recommendations

Conclusion

Brackish water has become an important resource that could be used in agricultural purposes, particularly in the coastal areas. From the results of the groundwater quality studies conducted by NWRA for many wadis in Tehama coastal areas, it is evident that the groundwater salinity increased in many regions in such a way as to affect the small farmers. In Tehama areas, the farmers used the highly saline brackish water to irrigate the field crops particularly sorghum (grain and fodder). The yield of all crops in Yemen are very low due to many reasons. The farmers are unaware of the leaching requirements for each crop, the irrigation scheduling, and the suitable interval time between irrigations for each crop. In addition, the increase in the prices of fuel will lead to increase in the water pumping costs.

Brackish water could be used for irrigation in different ways: a) the direct use of brackish water to irrigate low and medium salinity tolerant crops; b) the highly saline brackish water could be desalinated by low-cost desalination units and used in irrigation; and c) the highly saline brackish water could be mixed with treated wastewater, particularly in the highland basins, and used in irrigation of fodder crops and green belts.

Moreover, brackish water with high or low salinity could be desalinated and used for domestic purposes. The cost of desalination of brackish water is lower than the cost of desalination of seawater which needs additional cost for transportation.

Yemeni's "Standards for Treated Wastewater Use in Irrigation and Water Supply" were issued, yet these standards are still unapplied. The farmers are using wastewater available in the Wadis without any consideration to the standards.

Brackish water use is the major challenge facing agriculture and food security. Several recommendations in different aspects are suggested as follows:

Recommendations

First: On the policies and regulations level

All water institutions, with the leadership of the two main ministries [Ministry of Agriculture and Irrigation (MAI) and Ministry of Water and Environment (MWE)], should coordinate with other related institutions and stackholders as well as the donors, to prepare a National non-conventional Water Resources Strategy and submit it to the cabinet for approval and endorsement. However, the strategy should include the investment program.

MAI should prepare a specific policy for brackish water use in agricultural purposes. Hence, brackish water would be recognized as a suitable and acceptable alternative to use in agricultural purposes.

Due to population increase in the urban areas, thirteen WWTPs have been constructed and about 10 WWTPs are under planning and design. However, the Wastewater Reuse Strategy was drafted, yet due to lack of coordination between the officials, the draft strategy was suspended. It is highly recommended that this draft strategy be updated as soon as possible.

MAI and MWE must enforce the wastewater standards, through public awareness programs in the areas located downstream of the WWTPs.

MAI and other partner institutions call for: incorporating brackish water in the current water policies and strategies, establishing non-conventional water resources policy and strategy that will comprise brackish water and treated wastewater, and preparing as soon as brackish water assessment studies for all basins.

Second: On the research and technological development level

- Establish brackish water research programs with the aim of increasing crop yield and identifying the leaching water requirements. All data and information on crop water requirements and related issues available must be provided to the farmers encouraging them to irrigate their crops accordingly.
- Introduce modern irrigation systems to the farmers who irrigate by brackish water, with a suitable subsidy for the poor farmers, and provide them with Irrigation Advisory Services (IAS) and comprehensive agricultural extension services to increase irrigation efficiencies and reduce irrigation losses.
- Provide farmers with the multiplication seeds recommended by the research authority, with comprehensive agricultural extension services to increase yield of the crops irrigated by brackish water.
- Establish "Water Users' Associations" to help the farmers and investors find the best ways to purchase, design, implement and maintain modern irrigation systems.
- Encourage the farmers to have more than one main crop in each farm and gradually replace the salt-sensitive crops with more tolerant once.
- Improve yield quantity and quality through the use of modern techniques and good farming inputs especially selected seeds, side by side with right farming operations.
- In order to save water, energy and money, the farmers have to learn how to get hold of the crop water requirement information to help them determine when and how much to irrigate. The extension office and agents may play an important role in this regard.
- Produce brackish water use guidelines including Crop Patterns and Crop Rotations and provide the farmers with the guidelines to be aware about crop rotations and how to save water, secure soil fertility and improve yield quality and quantity.
- Allocate a certain number of farms in different regions as demonstration farms cultivated with good and selected varieties of fruit trees and other crops with the adoption of modern irrigation and efficient farming methods. The farmer should participate with all the farming operations along with encouraging other farmers to visit, view and compare, provided that all the farm products go to the farmer or owner of this farm.
- Conduct awareness and extension campaigns on topics such as modern irrigation systems and its efficiency, fertilization and pesticides, improved seed varieties, etc.
- Allocate special extension programs to highlight and encourage the role of rural women in agriculture in addition to programs related to healthy house.
- Upgrade the capabilities of the existing extension and agricultural staff by nominating them to participate in on-job training programs, short and intensive (5 - 15 days) or long-term programs inside or outside Yemen.

- Conduct intensive monitoring programs to determine the trends in water quality, soil degradation, the effects of pollution and to analyze the origin and spatial distribution of brackish and saline groundwater.

Third: On the capacity development level

In terms of administrative and Institutional development:

- Establish a brackish Water Use Unit within the Ministry of Agriculture and Irrigation to take the responsibility of coordination between all concerned departments and authorities within the ministry, as well as with related water sectors, particularly NWRA and EPA. The unit should monitor and evaluate the implementation of such policies within a certain period of time (quarterly, semi-annual or annual).

- Provide a qualified administrative and technical staff along with the needed budget to implement the suggested plans and policies.

- Provide technical assistance to support MAI in the preparation of a master plan for brackish water use in agricultural purposes and producing GIS maps for the locations and boundaries of brackish water in Yemen.

- Provide training programs to the technical staff to implement and supervize proposed plans and policies.

- Provide the unit with the instruments and equipment required to carry out the field test and measurements.

Other activities could be recommended:

- Collect and review available reports, studies and hydro-geochemical data.

- Interpret water quality patterns on the basis of reviewed information and additional samples analyzed; mainly to identify where groundwater has limitations for certain water use categories.

- Prepare a groundwater quality baseline data.

- Prepare guidelines for all field activities and laboratory procedures required for groundwater quality measuring.

- Develop a water quality monitoring program including a regular basis monitoring activity for groundwater pollution in the main recharge zones.

- Provide guidance for measuring groundwater quality.

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