WATER AND SALINE AGRICULTURE IN CENTRAL-SOUTHERN IRAQ

A scoping study on the conditions, solutions, and actors in the field of saline farming.

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Executive summary

Insufficient natural water resources and salinity increasingly pose a challenge worldwide and certainly also Iraq. In the agricultural area of the Mesopotamian basin that covers central and southern Iraq – the focus of this report –, agricultural water resources are limited and overstressed, and soils predominantly saline. This situation impacts farming and livelihood to a great extent. Efforts to address and curb this are underway.

In central and southern Iraq, the combination of decreasing natural water supplies, a harsh arid climate, land degradation and salinization, and a growing water demand for its growing population, dictates the need for an integrated approach and involvement of a wide range of actors.

This report, commissioned by the Netherlands Agricultural Network for Iraq, aims to provide an overview of the prevailing water and salinity situation in central and southern Iraq and how this affects farmers and farming systems. It also seeks to highlight potential solutions. It is intended to support policy makers, farmers, researchers, and representatives in other sectors as a reference for future initiatives and endeavors.

This report does not intend to be an in-depth, exhaustive study, but aims at providing a helicopter view of the situation, while highlighting the priority measures and approaches that could make a difference for dealing with salinity and water use efficiency in agriculture. In parallel, other fields warrant equal attention, such as urban planning, water reuse, water allocation policies, training, and capacity building in all the above fields and raising water awareness.

At present, the natural inflow of water into Iraq, mainly from the transboundary rivers Euphrates and Tigris, just outweighs the total water use and evaporation loss. This balance is expected to shift in coming years, as population and water demand grows and because of increased water use in neighboring countries and continued use of inefficient irrigation methods and water treatment systems. Climate change further exacerbates the delicate water supply and quality situation. Reducing river flows and groundwater recharge, especially in the summer months, leads to saltwater intrusion from the Gulf.

Over the past thousands of years, salinity has been an issue for the Iraqi people and its agriculture. Despite this, much is still unknown on the development and distribution of salinity. Natural processes, water table levels and soil composition all have effects on salinization processes, as have farming practices and infrastructure developments.

A variety of short- and long-term solutions to salinity are available on-farm, ranging from water management and irrigation practices, water efficient crop choice, crop varieties offering better yields under salinity stress, to the design of more sustainable farms and use of agroforestry. A diagram of solutions is provided in Table 2, with actions for the various stakeholders.

Priority areas which need to be addressed are:

- The repair and maintenance of old drainage systems, introduction of new drainage options and field research on bio-drainage.

- Introduction of better on-farm management practices, including new farming systems based on sustainable principles, biodiversity, agroforestry, soil restoration, and irrigation water management, and a general shift towards more biological and biodiverse farming practices.

- The development of more insight into the extent of salinity, both on-farm, regional and seasonal, and the use of GIS-based decision support systems to plan and monitor supporting practices.

- Solving spot pollution sources and natural resource and river management.

A vital role in successful implementation of, or support for these measures lies government, who essentially manage the agri-water sector in Iraq. This management involves the supply and maintenance of the irrigation systems. In addition, capacity building and knowledge development on water and soil management and mitigation of the effects of salinity, and the development of sustainable, commercial farming systems. Finally,

policies are required that inform and protect farmers, and give them a fair and level playing field to sell their produce.

Private sector can improve its on farm practices to save and conserve water and develop water-sustainable food processing systems. Civil society organizations, international organizations and international donors can play a key role to promote sustainable water management and re-use in the agri-sector as well as on the development of knowledge for and with farmers. An important step in this process is the development of agro-hubs, practical and commercial farming locations where farmers, policy makers, researchers and the commercial sector can experiment and interact.

Development projects can contribute to more sustainable water use for agriculture and other purposes, and reduction of salinity, where done in harmony with the available natural resources. Equally so, further cooperation with neighboring countries on water distribution and improved maintenance in water treatment plants and irrigation infrastructure is also needed.

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1 Introduction

1.1 Assignment and goal

Insufficient natural water resources and salinity are an increasing issue worldwide and certainly also Iraq, where the dominant agricultural area of the Mesopotamian basin that covers central and southern Iraq (Figure 1) is currently dominated by saline soil (Sahib, 2014). This situation impacts farming and livelihood to a great extent in Iraq, and more and more efforts are going into finding solutions and approaches that help curb the situation.

To that affect, this report has been commissioned by the Dutch Embassy in Bagdad and provides an overview of the prevailing water and salinity situation affecting farmers and farming systems in this affected area – central and southern Iraq –, and highlights solutions and initiatives that can help to improve water productivity and water quality and can help reduce soil salinity and salinity effects. It is intended to support farmers, researchers, industry specialists and policy makers as a reference for future initiatives and endeavours.

This report does not intend to be an exclusive, full resume. The water (Chapter 2), agriculture and salinity (Chapter 3) conditions in Iraq have been assessed only in general, aiming to provide a helicopter view of the situation, and more detailed work may be warranted in various areas of concern and interest. Similarly, an overview has been provided on Iraq actors and initiatives dealing with water supply, agriculture, salinity, and the future of farming in Iraq. Further work with local stakeholders will uncover more details, but different solutions have been elaborated to a considerable extent.

Figure 1. Overview map showing the agricultural systems in Iraq. Reprinted from Sahib, 2014.

1.2 Data

This report is based on publicly available data sources. Best efforts have been made to identify, collect, and compare data, preferably recent data. However, experience learns that data or reports are not always published or shared. On occasion, considerable differences exist between referenced data, for instance on the amount of a certain river's discharge or an aquifer's yield. Sometimes this can be accounted to the timing or exact location of the data, but sometimes the reason is unknown, and seemingly lies in the quality of the underlying data and its analysis by the authors, or other considerations by the author when publishing findings. In cases where data is not uniform or apparently differs among publications, choices have been made which data to use and cite.

1.3 Reading guide

Chapter 2 provides a generalised overview of the (natural, artificial, waste and irrigation) water resources in central and southern Iraq, and its geographic and climatic background.

Chapter 3 provides reference information on agriculture and salinity in central-southern Iraq.

Chapter 4 provides an Iraqi actors in the agri-water sector, and highlights important policies, knowledge gaps and programmes that affect or deal with water and salinity in agriculture.

Chapter 5 provides an overview of potential project interventions and opportunities that are relevant to the situation in central-southern Iraq.

Chapter 6 provides a summary and recommendations for follow-up.

2 Water resources in central and southern Iraq

This Chapter provides a summary of the water resources in central and southern Iraq, and a reflection on water use and availability, and water quality.

More elaborate background information and literature references is found in Appendix A. Water resources in central and southern Iraq.

2.1 Water volume and availability

Although literature is consistent that Iraq experiences a decline in renewable water resources in the last 10-20 years and an increase in water use, the actual volume of decline, as well as the absolute amount of water, the water sources, and how its use is distributed among users, all varies across different sources and research. An additional problem in analysis of research is that the location – for instance upstream (north) or downstream (south) – makes a huge difference.

For this report, absolute figures are less of a focus than relative figures, i.e., it is more relevant to know the degree of water shortage, than the exact amount.

From reviewed literature the following can be said:

- The volume of available, renewable water in Iraq comes mostly from Euphrates and Tigris rivers and contributes to over 90% of the total. Groundwater contributes between 1-7% of the total, with 1-4% of the water coming from secondary rivers. This is based on review of various literature, see Appendix A.
- The total volume of water entering Iraq lies between 57 and 75 BCM annually (billion cubic meter) since 2013. This is based on review of various literature, see Appendix A.
- Water coming from unconventional sources is minimal. Reuse of wastewater and desalinated water is negligible, the amount of reused agricultural drainage water is < 2%.
- Iraq experiences a small water deficit, order < 2%, i.e., the amount of used water lies < 2% above the amount of renewable water. "*Iraq experiences a water shortage of 33 MCM/yr (2015) for all its needs (UN, 2013).*"
- Over the last 8-10 years, the total volume of available water has decreased with at least 0.25% per year. The main cause of this depletion is higher abstractions from Turkey and Syria.
- The amount of renewable water resources expressed per capita is on a stronger decline. This is due to population growth and deterioration of water quality.
- Actual evapotranspiration is lower than rainfall on an annual basis, the water surplus ranges from 25 to ~75 mm in the Mesopotamian basin (higher surplus in KRI) (Al-Sudani, 2019)

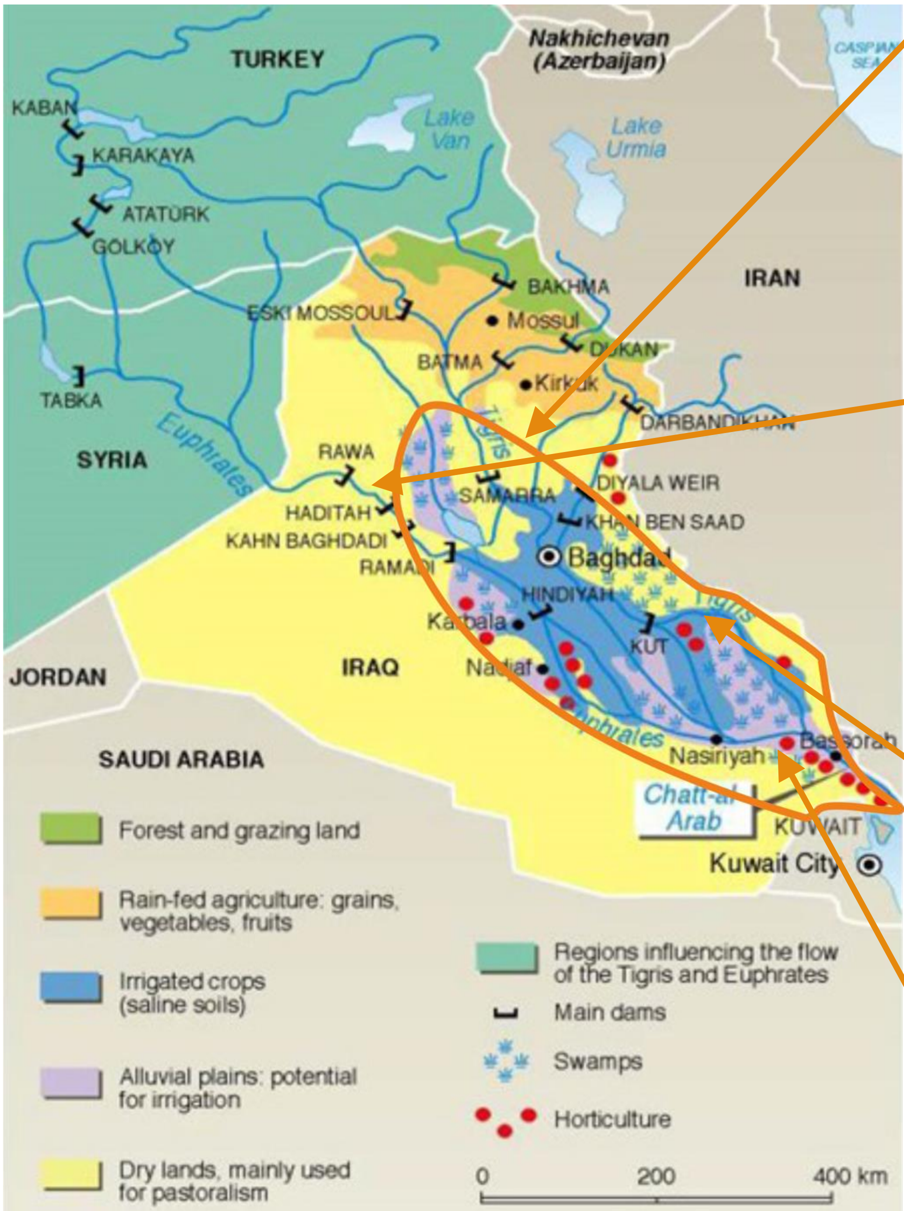
2.2 Water users

- Agriculture is the main water user and uses around 78-90%, followed by domestic (4-8%) and industry use (6-15%). This is based on review of various literature, see Appendix A.
- The total volume of all users lies between 50 and 70 BCM per year. This is based on review of various literature, see Appendix A.
- *"If left unaddressed, the constant decline of and rising pressure on the water supply will lead to increased vulnerability and insecurity. Such a scenario requires more sustainable management of water resources, a more effective domestic irrigation system as well as the introduction of the 'polluter pays principle', which entails improved water pricing policies and new regulatory measures." (UN, 2013)*

2.3 Surface water supply

- The Euphrates and Tigris rivers contribute to over 78% of the total water available. See Table 1 for the key statistics for the Mesopotamian basin, i.e. the study area.

Table 1. Summary of key statistics of Mesopotamian basin



Mesopotamian basin

- Focus of this report
- Historically fertile agriculture belt of Iraq
- Most major cities and population
- 50-200 mm rainfall
- Overstressed water resources
- Increasing salinity problems

Euphrates

- Origin Syria-Turkey, 2730 km
- Catchment 440,000 km2
- 25.5 km3/yr (2014) entering Iraq
- 0.25 km3/yr volume reduction since 2014
- Seasonal runoff, 7-42% of Iraq annual runoff
- Irrigated area 4.6 M ha

Tigris

- Origin Turkey-Iran, 1800 km
- Catchment 221,000 km2
  25 km3/yr discharge
- Irrigated area 2.3 M ha
- Seasonal runoff

Marshes

- 10% remains (~1,500 km2) due to human drainage, land recovery, climate change, less surface water supply
- UNESCO heritage site

2.4 Groundwater

- Groundwater plays a small role in agriculture in the Mesopotamian basin, and mostly in the southern basin in the unconfined to semi-confined Dibdibba aquifer. Groundwater salinity ranges from 1,000 (shallow) to 15,000 (deep) mg/l TDS (ICA 2016).
- Total annual groundwater use was 3.117 billion m3 in 2016 (MWRI, 2016) for all of Iraq. For the Mesopotamian basin, groundwater contributes < 1%.

2.5 Artificial water storage

- Iraq has a network of several reservoirs (dams) to manage its water resources. Flood peaks are managed using the storage capacity of on-stream dams and barrages as well as some off-stream topographic depressions (See Appendix A).
- Dams have an impact on downstream regions. The Tigris and its tributaries are an economic lifeline, followed by the Euphrates, and play a huge role in irrigation and power supply (See Appendix A).
- Most dams in Iraq within the Tigris and Euphrates catchments are built mainly for irrigation, power supply and flood control purposes. These dams have an impact on the water discharge and volumes in the rivers, so they play a major role not only in nearby areas but also in downstream areas. (See Appendix A).
- Poor maintenance, poor water management and the impact of several conflicts and wars have led to Iraq being ranked as having one of the poorest water infrastructures worldwide (UNEP, 2017).
- Maintenance in the lower reach of Tigris and Euphrates are not sufficient, thus updated operation and maintenance manuals are needed to increase their efficiency (Abdullah et al., 2019).

2.6 Wastewater

- Most sewage disposal stations are draining wastewater directly to the nearby rivers, without sufficient chemical treatment. Generated sewage water in Baghdad amounts to 1.200.000 m^3/day, partly drained by a sewage network. Annual treated wastewater is around 580 million m^3.
- Water demand exceeds the total capacity of sewage treatment, but using treatment units more efficiently could tackle part of the water shortage problem and could control the spreading of infectious diseases (Al-Mossawai, 2014)

2.7 Irrigation and water management

- 25% of Iraq's landmass is suitable for agriculture (around 11.11 million ha). To complement the rainfall 70% of Iraq's cultivated area is under irrigation. In the northern part of Iraq, 30% of the cultivated area is under rain fed cultivation. 62.8% of the irrigated area in all of Iraq (incl. KRI) receives irrigation water through gravity irrigation projects, 36% of the area receives water that is pumped from rivers and major channels and 1.2% comes from ground water aquifers and springs (AQUASTAT, 2017).
- Much of Iraq's irrigation infrastructure relies on ancient and inefficient methods of flood irrigation, furrow irrigation or merely digging a channel on the riverbanks or installing a series of barrages and weirs. Most of these methods are inefficient, because more water than is needed by the plant is applied to the field, and water evaporates, seeps into the ground and percolates down to the groundwater, where it can be out of reach of the plant's roots. In 2008, only 8000 ha was used for localized irrigation, such as drip irrigation or bubbler irrigation (FAO, 2008).
- Existing governmental irrigation projects are extremely important in the centre and southern Iraq. Most of the irrigated lands fall under 142 government led projects – half of which are found in the retaken governorates of Anbar (12 projects – 80 000 ha), Diyala (15 projects – 152 000 ha), Kirkuk (six projects – 76 900 ha), Ninewa (18 projects – 113 900 ha) and Salah al-Din (22 projects – 138 100 ha (FAO, 2018). It is vital that adequate water supplies are ensured through regular maintenance of the existing irrigation infrastructure, but also repair of irrigation facilities damaged during wars (Bishay, 2003).

2.8 Water quality

Figure 2 presents an inter annual prediction of Tigris and Euphrates rivers, their tributaries and water quality (TDS) between the present and 2035. Decrease of river flow of the Tigris and Euphrates rivers are especially prominent at their upstream areas.

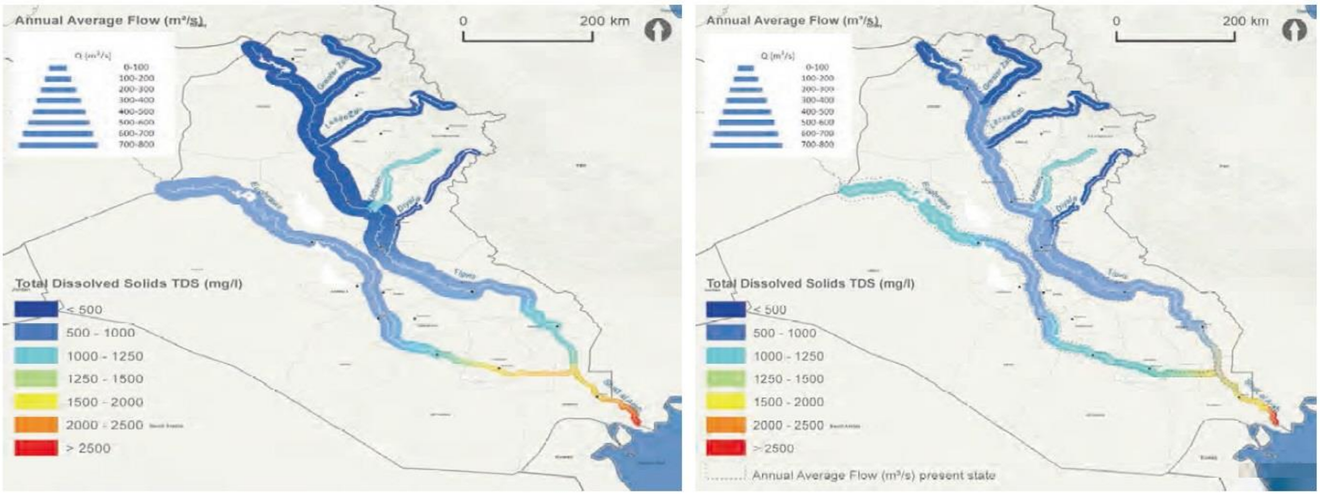


Figure 2. River discharge and water quality in 2015 and projected in 2035. Reprinted from JICA, 2016.

In the field of domestic water use, access to safe water varies from 77 to 98% of the population, depending on the location (Figure 30). Water quality for domestic and agricultural use does not meet the national and WHO standards by a factor 3 for organic contamination. Salinity is also an issue, with the Euphrates seeing an increase from ~450 ppm (1980s) to ~1200 ppm (2009). In 85% of households the chloride levels are too high. In 2018, according to Human Rights Watch, 118,000 people in Basra were hospitalised due to symptoms related to water quality (Human Rights Watch, 2019).

Citing the UN (UN, 2013) "*The deterioration in water quality and the associated growing number of waterborne diseases calls for the development of a national water quality management strategy aimed at strengthening the coordination and collaboration among the various stakeholders, enforcement of monitoring standards, and reporting of water quality information.*"

With water tariffing extremely limited compared to other countries, combined with low awareness of water conservation and water losses in the supply chain, the daily water use lies at ~392 litres. By comparison, in the Netherlands this value lies at around 130 litres/day. "*A substantial rise in water tariffs should be applied immediately, together with a proper tariff system for irrigation water* (UN, 2013)."

2.9 Projected future developments

- Waterflow from the Euphrates and Tigris are expected to reduce significantly before 2030. As mentioned in previous paragraphs, the overall water supply and energy production in Iraq will be heavily affected (Clingendael, 2018).
- Shatt Al-Arab River will reach freshwater deficit due to the decrease of water inflow for its tributaries and receives now only fresh water from the Tigris River. However, it is expected that this freshwater inflow from Tigris will discontinue somewhere in the 2040's. The main rivers will also see an increase in seawater intrusion from the south (Clingendael, 2018).
- Proper water access rights are needed with neighbouring countries and modern irrigation techniques need to be funded and supplied. During recent years, more and more development programs have started in Iraq. In 2019, the United Nations World Food Programme was launched to rehabilitate irrigation canals and provide water where needed (See Appendix A).
- In 2017, the International Fund for Agricultural Development (IFAD) invested in a post-war agricultural investment project in Iraq. Goal is to enhance resilience to climate change as well as improve productivity of small-scale crop and livestock producers in 20000 households by providing access to finance, technologies, and remunerative markets.
- Between 2011 and 2014, the SWLRI (Strategy for Water and Land Resources in Iraq) project was implemented, after realizing that Iraq's water demand was surpassing its supply in 2015. Goal is to achieve efficient and sustainable water and land use between 2015 to 2035 (See Appendix A).

- According to UNAMI (2021), there are no indications that water scarcity will be reduced in the near nor long run. All signs are pointing to more frequent problems such as increase in temperature and desertification, in addition to of course societal developments that increase water scarcity.

3 Agriculture and salinity in Iraq

Mesopotamia is known worldwide to be the place where agriculture developed. The oldest written document on agriculture is a 3,000-year-old clay tablet with cuneiform script found at Nippur (Jacobson, 1951) that gives instructions on sowing and irrigation (Burough, 1960).

"Salinity has always been a major issue in both old Mesopotamia and modern-day Iraq and it was already recorded as a cause of crop yield reductions some 3,800 years ago. By 1,700 BC, salt levels in soils throughout southern Mesopotamia were so high that no wheat was grown. In Iraq, the shift from wheat to barley was accompanied by a serious decline in fertility (attributed to salinization). In Girsu, yields were 253.7 m3 /km2 (~1.6 ton/ha) in 2400 BC; 146. m 3 /km2 (0,9 ton/ha) by 2100 BC, and 89.7 m3 /km2 in 1700 BC. (0,56 ton/ha) In southern Iraq, about 3500 BC, wheat and barley were nearly equal in area. In 2500 BC, however, the less-salt-tolerant wheat accounted for 1/6 of the cropped area, and by 2100 BC it accounted for 2% of the cropped area in the Girsu region. By 1700 BC, wheat had been abandoned completely in the southern part of the alluvium plains (Jaradat, 2002) ".

From this narrative, a trend can already be observed of a shift towards more salt tolerant crops (wheat to barley) and a gradual decline in productivity starting 4 decennia ago. On top of this trend, a large increase in salinity started in the mid-20th century with the introduction of large-scale dry season irrigation, as further explained in section 3.1.

The salinity in Iraq is an ancient problem and comes from a few main sources:

- Natural salinity as result of dissolving salts from the marine deposits.
- High natural evaporation and low precipitation due to the prevailing climate conditions.
- Long term poor irrigation and drainage techniques.
- Intrusion of seawater in the south of Iraq.
- Chemical mineral fertilizer (a relative recent addition of salt).
- Pollution from saline water discharged in the rivers (mostly near cities).

Buringh in 1960, commented on the Iraq salinity situation:

"*Almost all soils are saline, most of them even strongly saline and large areas are out of production. The process of salinization still continues, and it will even increase when floods are controlled."*

What Buringh predicted has happened: with the construction of dams in the upper basin of the twin rivers, salts no longer flushed out during floods.

3.1 Intensified salinization as result of irrigation

The large increase in salinization in the mid-20th century with the introduction of large-scale dry season irrigation, and possible future developments, is important to explain further: large amounts of salts are naturally present in both soil and groundwater of the Mesopotamian plain due to the composition of the subsurface, which include many layers containing salt, such as anhydrites. These layers are widespread in all the Arabian Peninsula, and this was a factor even before humans started to apply artificial irrigation. Shallow water tables are also widespread across the Mesopotamian plain. These water tables enhance soil salinization by avoiding adequate leaching from occurring and allowing capillary up-flow of saline water to the surface (Figure 3). As the saline water evaporates the salts are left in the topsoil. This phenomenon is amplified when the soils are irrigated during the dry season when evaporation is at its peak. During continuous irrigation, as is common in Iraq, the relative fresh irrigation water mixes with saline groundwater. In addition, continuous evaporation 'pulls' the salts up (capillary rise) and when the water evaporates, the salts settle and accumulate in the topsoil.

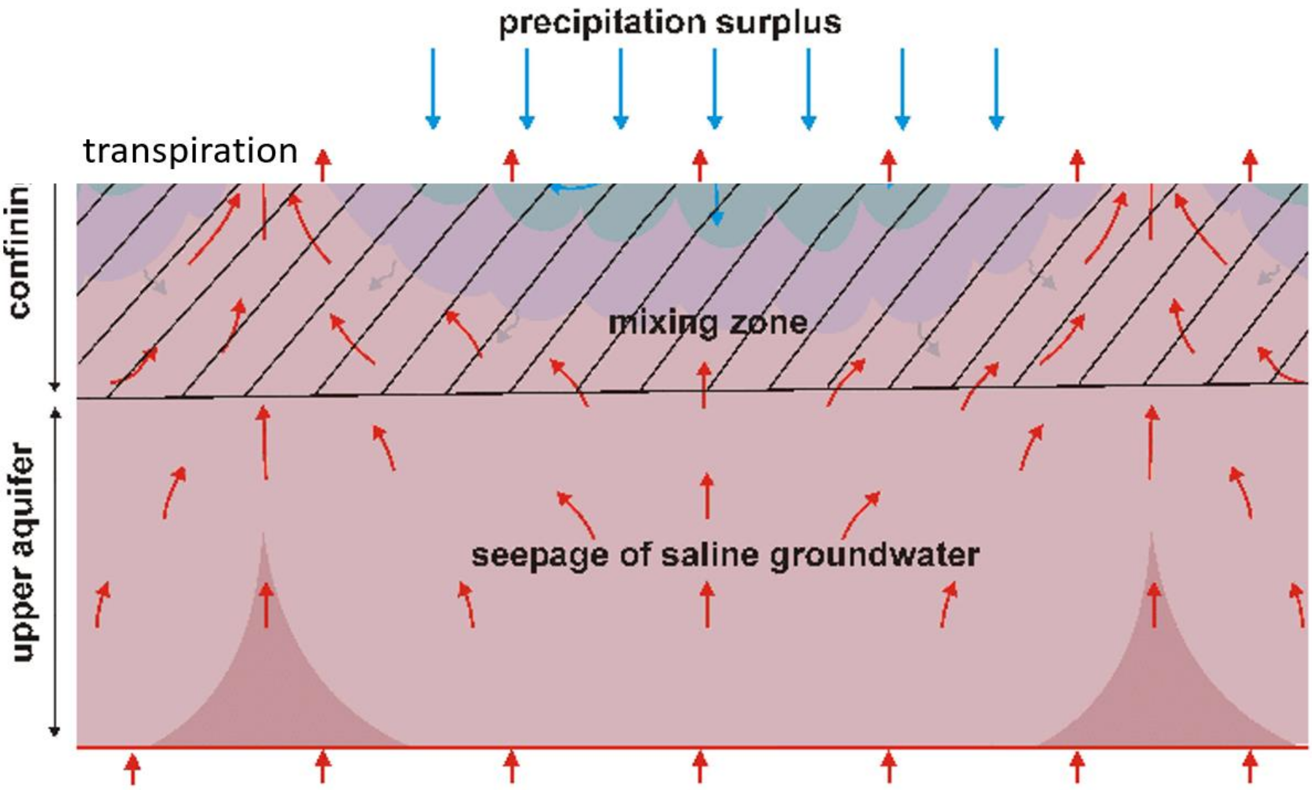


Figure 3. Visual representation of the salinity problem in most locations in the Mesopotamian basin in the absence of drainage. Reprinted from de Louw et al. 2011.

Another consequence of shallow water tables is the increase of waterlogging risk. Waterlogging reduces the amount of oxygen in the soil, which negatively affects plant growth and thus their ability to tolerate salt. Sufficient leaching and drainage processes are necessary to remove salt accumulated in the root zone after the crop has taken up irrigation water (Figure 4). Unfortunately, the natural drainage capacity of both soil and the groundwater systems in irrigated areas is usually insufficient to achieve this. As a result, the water table (including salts) rises (Moutaz, 2013).

These processes are typical for the Mesopotamian plane. In those regions outside the Mesopotamian plane where the groundwater is either deep or not saline, the situation is different.

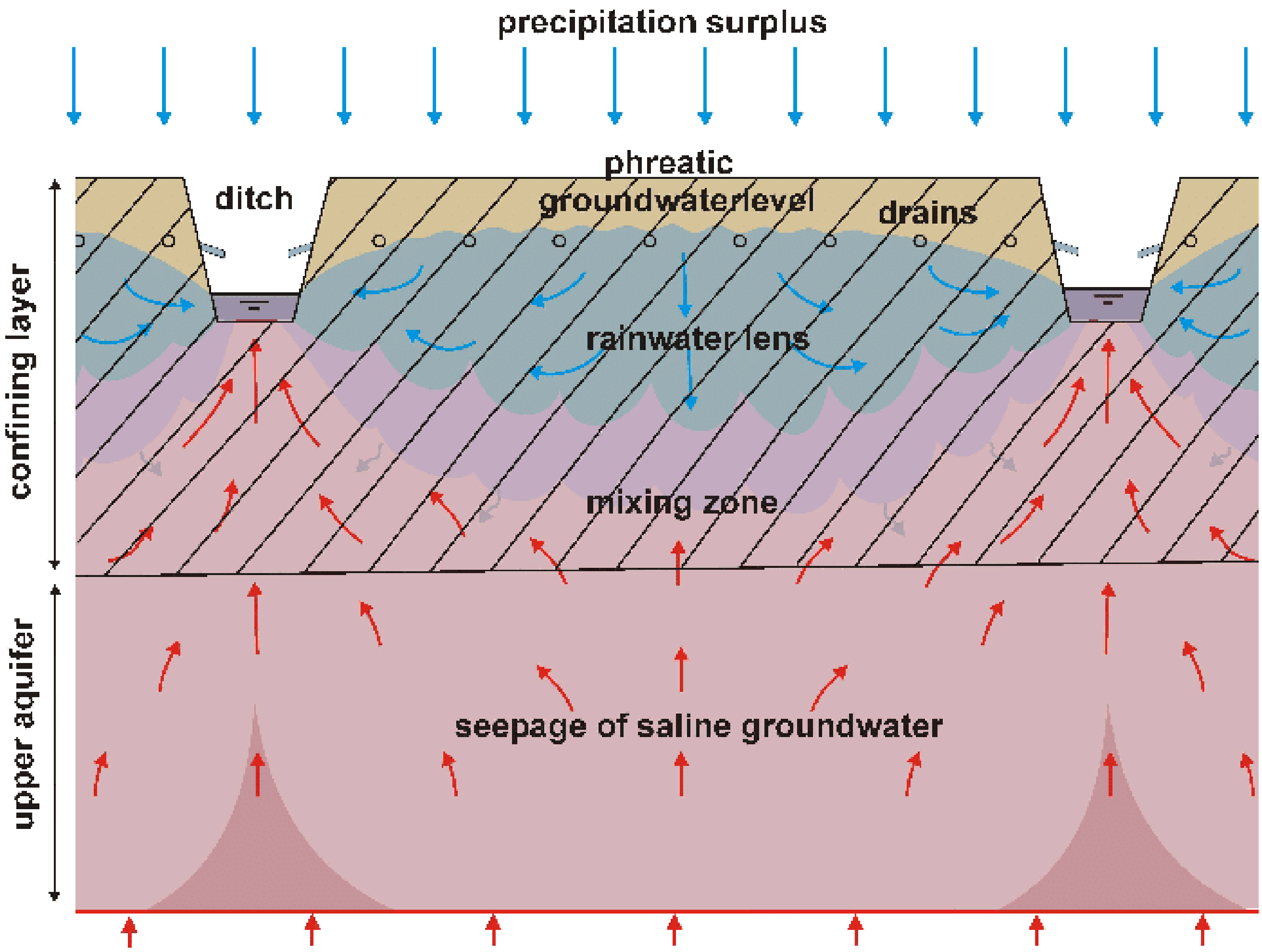


Figure 4. Ideal situation of farm management with shallow saline groundwater (In this case 'precipitation surpluses, for the Iraqi situation the precipitation should be read as irrigation water). Reprinted from de Louw et al. 2011

In summary the Mesopotamian plain faces the following situation:

- Slightly to heavy saline soils
- Saline water and spot pollution
- Drainage systems in poor state
- Outdated irrigation methods
- Traditional farming practices

3.2 Field scale

Several different actions can be undertaken to address salinity at field scale. Moutaz (2013) summarizes his vision on addressing salinity in Iraq at field level:

"In Iraq these problems can be addressed by both improving irrigation practice and using drains to remove water from the soil profile and allow leaching of salts from the crop root zone. Soil salinity can be controlled by a combination of improved drainage and better irrigation practices. However, existing drainage systems were installed 40/50 years ago. Since than not much maintenance work has been done to repair and maintain the operational capacity of these drainage systems."

Matching water requirements to crop use and groundwater depth provides a win-win solution to enhance productivity, water use efficiency (WUE), decrease salinity and environmental degradation (Moutaz, 2013).

Agronomic practices

During irrigation, different patches of low and high infiltration rate can be observed due to poor land levelling, which cause an uneven distribution of water on the surface. This can also lead to increased salinization in certain areas where low infiltration rates are found (in combination with other factors). Improved cultural practices (precision land-levelling, zero tillage, and bed and furrow methods of planting) could save up to 40% of the water applied, without negatively affecting crop yields (Moutaz, 2013).

Soil moisture management

Maintaining soil moisture at a level that can reduce the salt stress, which needs to be calculated, is another way of coping with salinity. This can be achieved by modifying the planting methods (e.g., shifting the production of maize from basin to furrow irrigation, figure 5). In addition, some literature sources, and own conclusions, give the impression that increasing the canopy density is essential in reducing surface evaporation and accumulation of salts at the soil surface.

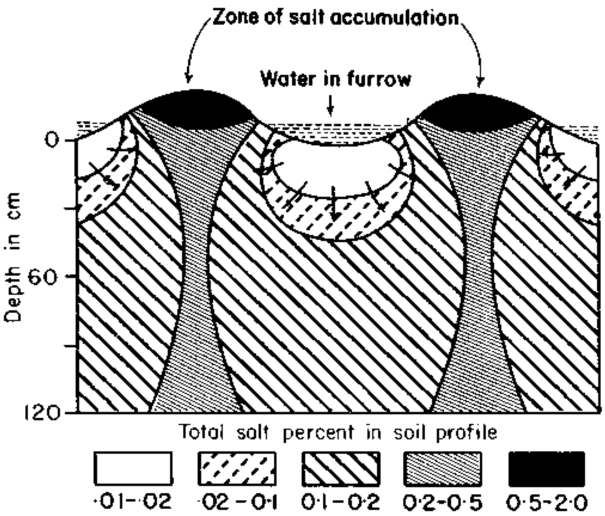


Figure 5. Furrow irrigation in saline conditions can push the salt to the beds (www.fao.org). The opposite can be achieved when drip irrigation is applied on the beds. The advised method depends on local soil and water salinity.

Salt-tolerant crops/Halophytes

Different crop production systems of productive halophyte crops and forages are needed to match farming systems in mildly, moderately, and highly saline areas. A productive system method should also use plants with lower water requirements and ability to use groundwater as an alternative resource. All plants need to be examined: benefits may not necessarily relate directly to the amount of crops produced, but also their timing. (e.g. fodder plants fill feed gaps) and how much other resources (water, fertilizer etc.) can be saved (Moutaz, 2013).

There are different halophytes species that can be used in Iraqi farming systems, including trees such as Tamarix, Prosopis, Acacia, and Atripex spp (Salth bush) which are known to be saline tolerant (F. Al-Farrajii, M. R. Al-Hilli, 1994; Marcar, N.E, 1999; Iman S. S., 2014). Other plants such as *Haloxylon spp* and *Petropyrum euphratica* are also recommended for this purpose (Moutaz, 2013). Regarding crops, local varieties such as alfalfa, triticale, barseem, and purmuda grass are always preferential, or for fodder (Iman S.S. (2014) varieties such as sporobolus arabicus, panicum turgidum, passpalum vaginatum, and pennisetum clandestinum (kikuyu).

Forage production from rainfed old man saltbush under optimal management was reported to be about 2-4 tons/ha per year in the Maghreb and Middle East. Under irrigation with water at 10-15 dS/m, forage yield was about 10-16 tons DM (dry matter)/ha (Le Houérou, 1992). Halophytic grasses can present similar differences in annual production: 0.2 to 1.0 t DM/ha under condition of dryland salinity; 40 t DM/ha when irrigated with water of 9.5 dS/m (Norman et al. 2013).

Halophytic grasses and forage can also support solving another problem. They can offer a chance to provide a protein and mineral supplement to animals grazing cereal stubbles in summer. Ruminant production, primarily sheep, is already a component of farming systems in the irrigated zone of Iraq. For this reason, changing production from crops and forages to halophytic forages will not require as much change in type of farming systems as it would be required to develop an entirely new farming system (Moutaz, 2013). Two groups of plants fit the situation: halophytic grasses and forages, and halophytic chenopods. The first group may be highly productive but require high inputs to optimise growth and nutritive value. The second group are less productive but constitute an inexpensive risk-management strategy. Farming systems which incorporate halophytes, need to focus on livestock performance rather than biomass production alone.

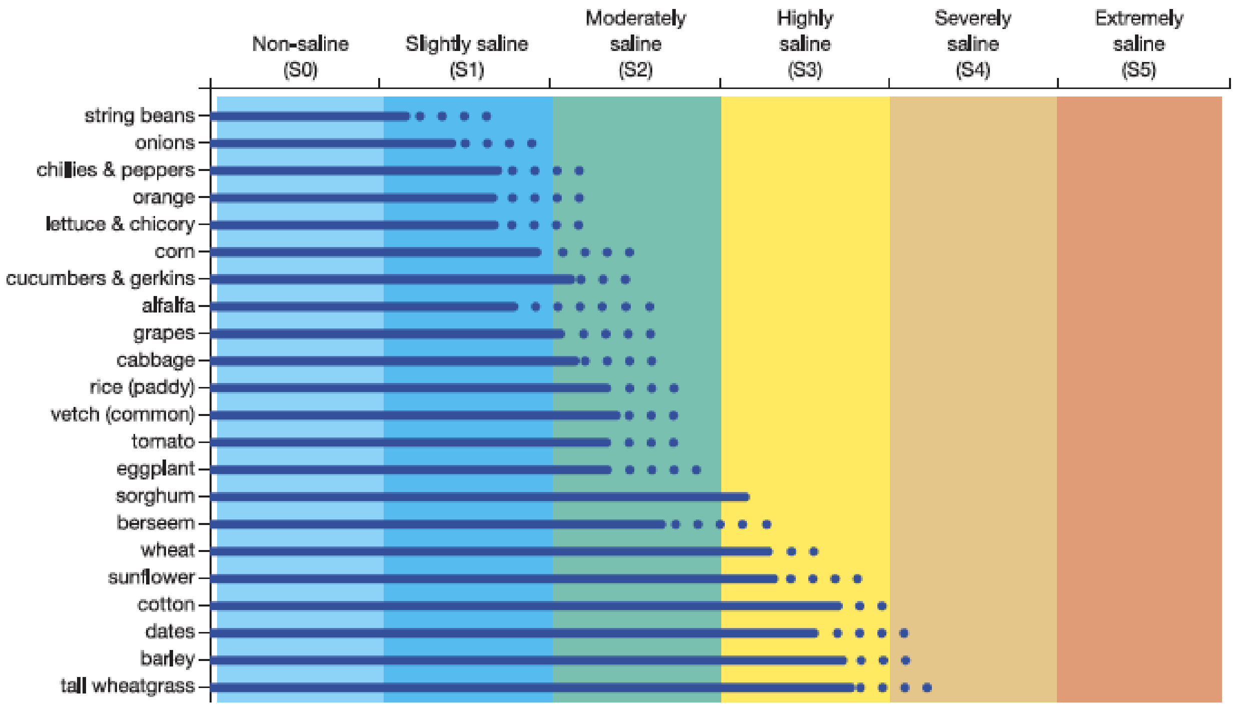


Figure 6. Ability of typical Iraqi crops to grow at different salt pressures. Solid lines indicate yields of 75-100% max yield; dotted lines indicate yields of 50-75% max yield (Moutaz et al., 2013)

Table 2. Soil salinity classification and crop responses

Saline Quality	Ec (dS/m)	Ec TDS (mg/l)	Crop responses
non saline	0 -- 4	0 -- 2560	salinity affects only sensitive crops
slightly saline	4 -- 8	2560 -- 6400	yield of non tolerant crop is reduced
moderate saline	8 -- 12	6400 -- 9600	yield of non tolerant crop is severely reduced
saline	12 --17	9600 -- 13600	halphytes loses 25% of their yield
highly saline	17 -- 25	13600 -- 20000	halphytes loses 50% of their yield
severely saline	25 --40	20000 -- 32000	halphytes loses about 75% of their yield
extremely saline	> 40	> 32000	only shrubs

- Maintenance of drainage system

If a well-designed and maintained drainage system is present, it will avoid the rise of the water table and waterlogging (water table rises to within 10-30 cm of the soil surface, see Figure 4). The interaction salinity-waterlogging causes additional harmful effects: as waterlogging causes soils to become oxygen deficient, roots become restricted in burning sugars to produce the energy required to exclude salt from their tissues (Barrett-Lennard, 2003). For arid regions such as Iraq, drain depths between 150 and 250 cm are widely suggested, with a consensus merging towards 200 cm (Moutaz, 2013)

Greenhouses

Greenhouses are another potential option to explore as solution to deal with salinity. However, they can't be introduced as the silver bullet. Greenhouses are superior in water efficiency per crop (most crop per drop) compared to open field farming, but due to the intensive production of vegetables throughout the year greenhouses still require large amounts of water per surface area. This water is not always available. However, a large benefit of greenhouses is the possibility to grow without soil, which cancels the problems of soil salinity, leaving only the water salinity to address.

There are a range of greenhouse options that can be introduced in Iraq. These range from simple net houses up to closed greenhouses. But greenhouses, no matter the type and the amount of technology that you put into them, are a significant investment for farmers. And using saline water in a greenhouse can hamper the production of the crop as can be seen in figure 6. Reversed osmosis (RO) or other water treatment may be required to reach the production that is required to make the greenhouses financially viable. In addition, the use of RO causes further damage downstream of the greenhouses. This aspect and many others like the supporting infrastructure need to be well planned before any greenhouse is constructed.

Crucial to point out is that a thorough cost-benefit analysis and market analysis must be executed to study and assess the viability of greenhouses in Iraq. Discussions with farmers in Basra has already indicated that the type of tomato (bush tomato, not the climbing variety) and the price on the market throughout the season (down to $ 0,10/kg in peak season) makes greenhouses an unviable option for most farmers in Basra. In addition, economic factors prevent that many important crops (e.g. wheat, rice) are not grown in greenhouses.

Farmer's perspective

According to farmers there are four main sources of salinity: water shortage, absence of a drainage system, high-water table levels, and long fallow. Water policies of Iran, Turkey and Syria coupled with the shortage of rainfall have reduced the supply of water to the farmers who are obligated to use water of higher salinity for irrigation. Sometimes also a drainage system is present but left without maintenance. Long fallow, due to the shortage of water, forces the farmer to leave lands with no cultivation for years (Fig. 7).

Moreover, farmers face more constraints and limitations regarding farming such as the unavailability of fuel in adequate quantities or at suitable prices; inflexible irrigation delivery system (timing and volume); shortage of machinery (mainly seeders and combine-harvesters); reduction in subsidies on inputs and low output (production) prices; seed, fertilizer and machinery services are subject to delay; lack of teaching or informative programmes; transportation facilities need rehabilitation; and lack of legislation, regulations and policies.

The process of salinization in rivers is highly dynamic and has various causes. Determining these causes is data-intensive and case-specific. Monitoring past and current field conditions of salinity and a delta's hydrology and water use is to be done to develop understanding of the causes. Irrigation water in Iraq is not being used to its full potential because of the poor state of the country's irrigation infrastructure and soil salinity (Abdullah Ali, 2016).

Salinity assessment through digital map

In recent decades, an increasing amount of evidence has shown the problem of salinity in many Iraqi regions. However, a clear overview of the whole problem has not yet been mapped (yet). There is an urgent need to fill this knowledge gap to take the best possible measures. To develop a complete idea of the scope of the problem, the first action is to collect and summarize, in digital form, all available data on salinity distribution in each Iraqi province. The creation of a database will allow further action, such as the creation of a digitized map of the current situation (see example Figure 7).

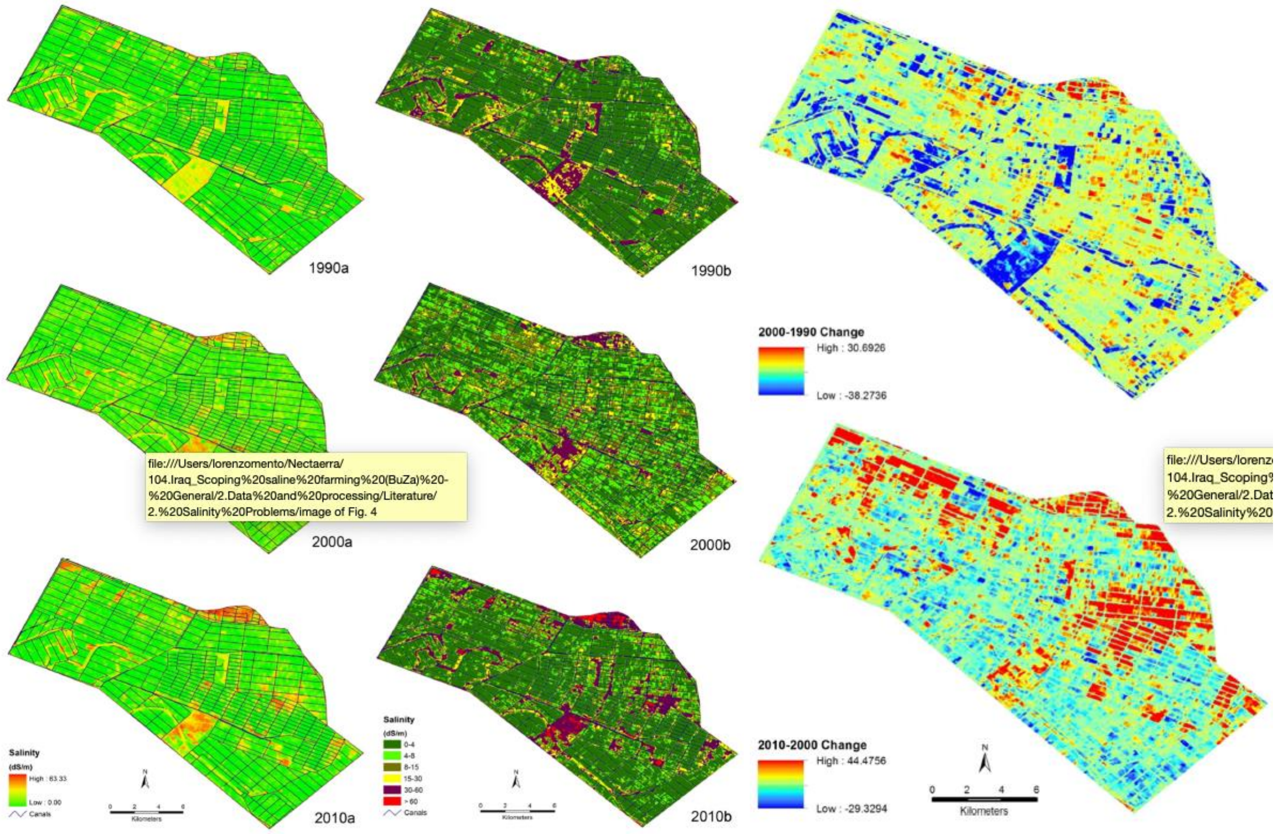


Figure 7. Multitemporal salinity maps of the Dujaila pilot site. Left: (a) maps are expressed in hue-saturation, Middle: (b) maps are shown in salinity level as required by land users and managers, right: salinity change trends. Red indicates an increase in salinity levels, blue indicate a decrease in salinity levels (Wu et al, 2014).

It is important to detect the concentration of salt, especially in the upper part of the soil, which strongly affects plant growth. However, this is not so easy to map. Many studies have explained the increase in salinity levels using digital soil maps. Salt concentration in soil is not as easy to detect for several reasons: salt concentration in top/subsoil is not easily detected by optical remote sensing, especially if it is less than 10-15%; soil moisture can decrease reflectance in the mid- and near-infrared bands which can easily lead to misinterpretation of salinity if based on reflectance or vegetation indices alone; halophytic vegetation and salt-tolerant crops can alter the overall spectral response pattern, in the green and red bands, of saline soils (W. Wu et al.,2014). Regardless, according to W. Wu et al. (2014), remote sensing is still a promising tool, especially for large-scale salinity assessment.

There are some limitations to creating multi-year salinity maps. The main difficulty in this area is related to cropland. Models for analysing cropland data normally involve the choice of vegetation indices, however, farmers normally perform crop rotation/ fallow strategies, which make a significant change in soil reflectance intensity. Considering a short time span with the same indicators, the presence of these fallow years can indicate sudden salinity peaks due to the higher reflectance of the soil. To avoid this inconvenience in cultivated soils, a better approach would be to first divide the entire monitoring period into a lower time scale (fallow lasts for 4 years maximum in Iraq, unless the land is left to desertification). Then, in these 4 years, only the data related to the lowest level of reflectance would be considered, which would correspond to the highest value of the vegetation index, to minimize the incidence of fallow years on the change of salinity levels in each area. For soils that are not vegetated throughout the time frame, another type of model must be chosen (W. Wu et al.,2014).

According to W. Wu et al. (2014) the best models to consider for data analysis and thus to determine soil salinity status are EC-GDVI for vegetative area and EMV-LST/NDII for non-vegetative area. EC (electrical conductivity), GDVI (Generalized Difference Vegetation Index) (WU 2014), EMV (vertical EM38 (electromagnetic instrument to measure soil electrical conductivity)), LST (land surface temperature), and NDII (moisture/water content index) must thus all be determined.

3.3 Thematic mapping

Thematic maps are a valuable way to visualise various data findings or visualise a situation, and more mapping could be valuable to help identify and understand certain problems and opportunities and help to design future solutions for specific areas. Thematic maps are commonly used for a range of issues, such as displaying biophysical characteristics (e.g. available water resources), water harvesting potential, vulnerable areas, (future) agricultural development, etc.

Befitting the goal of this short study, two basic thematic maps were prepared. The availability of water for agriculture in the study area is shown in Figure 8. The suitability of the soil for agriculture is shown in Figure 9.

Availability of water for agriculture

This map (Figure 8) is based on an evapotranspiration map from Flint et al. (2010), combined with local data of river discharges at different cities and barrages taken from various sources and from two groundwater quality maps from Al-Jiburi and Al-Basrawi (2015) and Al-Jawad et al. (2018). These maps were overlain on top of each other and were then delineated to generate this map. Therefore, this map should be seen as a general sketch of possibilities for agriculture from a basic hydrological perspective. Including more data and selection parameters in the future should greatly help improve and expand the map.

Due to relatively low annual evapotranspiration and surface water quality, the surface water in the northern region (north of Baghdad) is considered (slightly) high suitable for agriculture. Further downstream, through the Mesopotamian Plain, evapotranspiration increases and quality of (surface and ground) water near cities deteriorates significantly. Due to high saline water from the lower Euphrates and Tigris and saline intrusion from the Gulf, available water in the lower region is less unsuitable for agriculture. However, in the middle of the Marshes fresh water is sufficient, at present conditions, giving it a relatively neutral suitability for agricultural purposes.

Data comes from various articles (Al Ansari et al. (2019); Al Ansari (2018); Issa et al. (2014), Sisakian et al. (2014); Al Yaman (2008); Flint et al. (2010), Al-Jiburi and Al-Basrawi (2015) and AL-Jawad et al. (2018). **Note**: Used data are inconsistent and were therefore roughly generalized. Consistent measurements and controlled monitoring would give an improved overview and a more accurate suitability map, and help delineate specific areas.

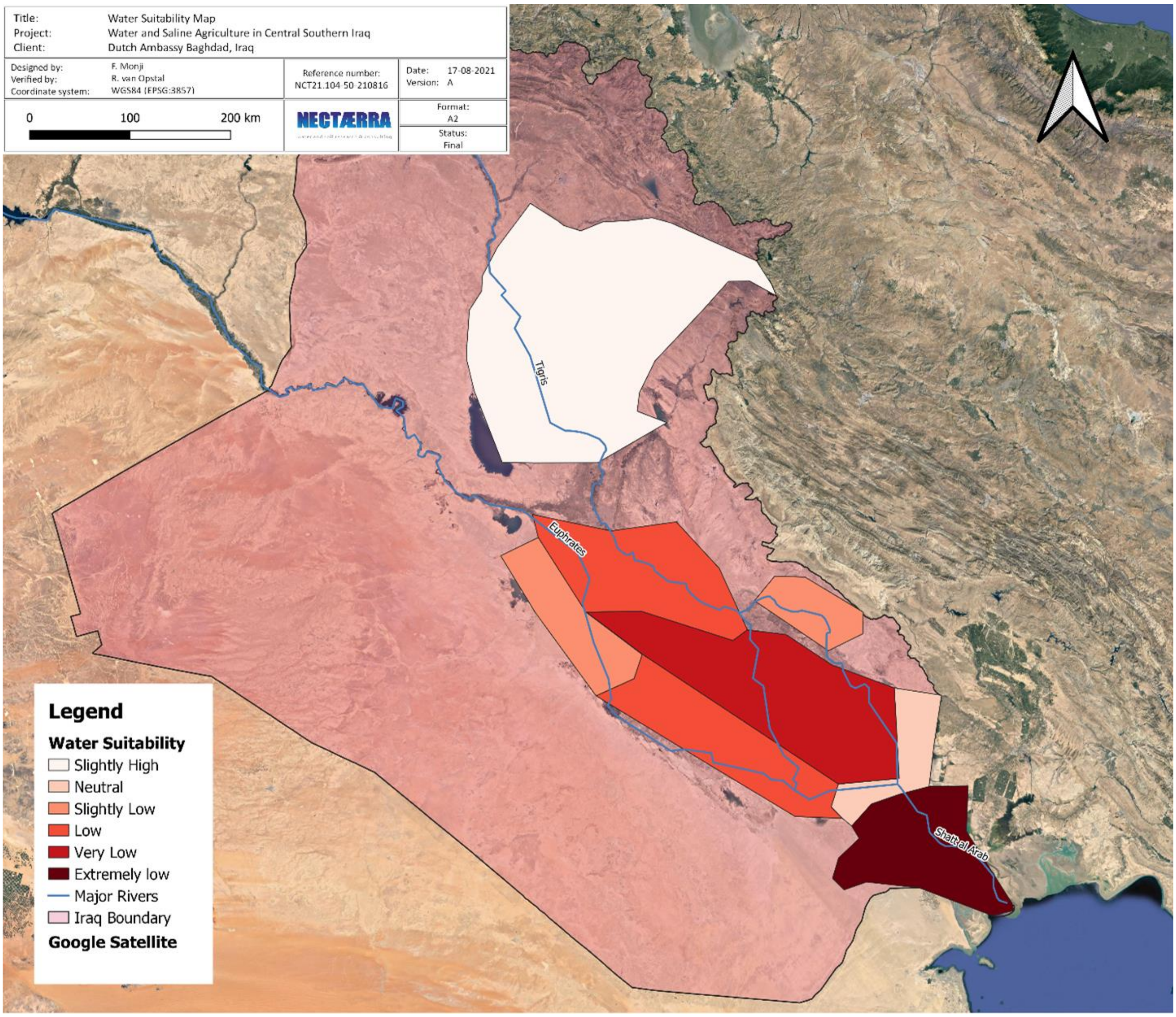


Figure 8. Water resources potentially available for agriculture

Soil suitability or agriculture

This map (Figure 9) is based on data from different sources (Buringh, 1960; Gatiea, H. H, 2011; Quereshi, A. S., & Al-Falahi, 2015), which was analysed and processed to create a soil salinity suitability map. Different regions, with different salinity levels, are highlighted in the Mesopotamian basin map. Three main Iraqi rivers are also shown. The shape of the zones is derived from combining multiple Iraqi salinity maps. An average was made between the collected data and our prediction. Based on this new data, the zones were drawn manually.

Salinity ranges presented are slightly saline (8-12 dS/m), moderately saline (12-17 dS/m), highly saline (17-25 dS/m), very high saline (25-40 dS/m), extremely high saline (> 40 dS/m). Due to high water tables, poor management of agricultural land and infrastructure, and increased salt intrusion from the Gulf, soil salinity increase in the direction of the Shatt Al-Arab. However, very high levels of salinity are also found in the region south of Baghdad and in the westernmost part of the plain. In the first case, associated with the reasons presented above, high pollution from the city's drains is added; in the second case, on the other hand, there is a significant drop in the flow of the Euphrates River and an increase in soil evapotranspiration. At present, only a few regions are considered acceptable for an efficient agricultural production.

More data and input parameters are needed to design a more accurate soil salinity map which covers a broader part of Iraqi territories.

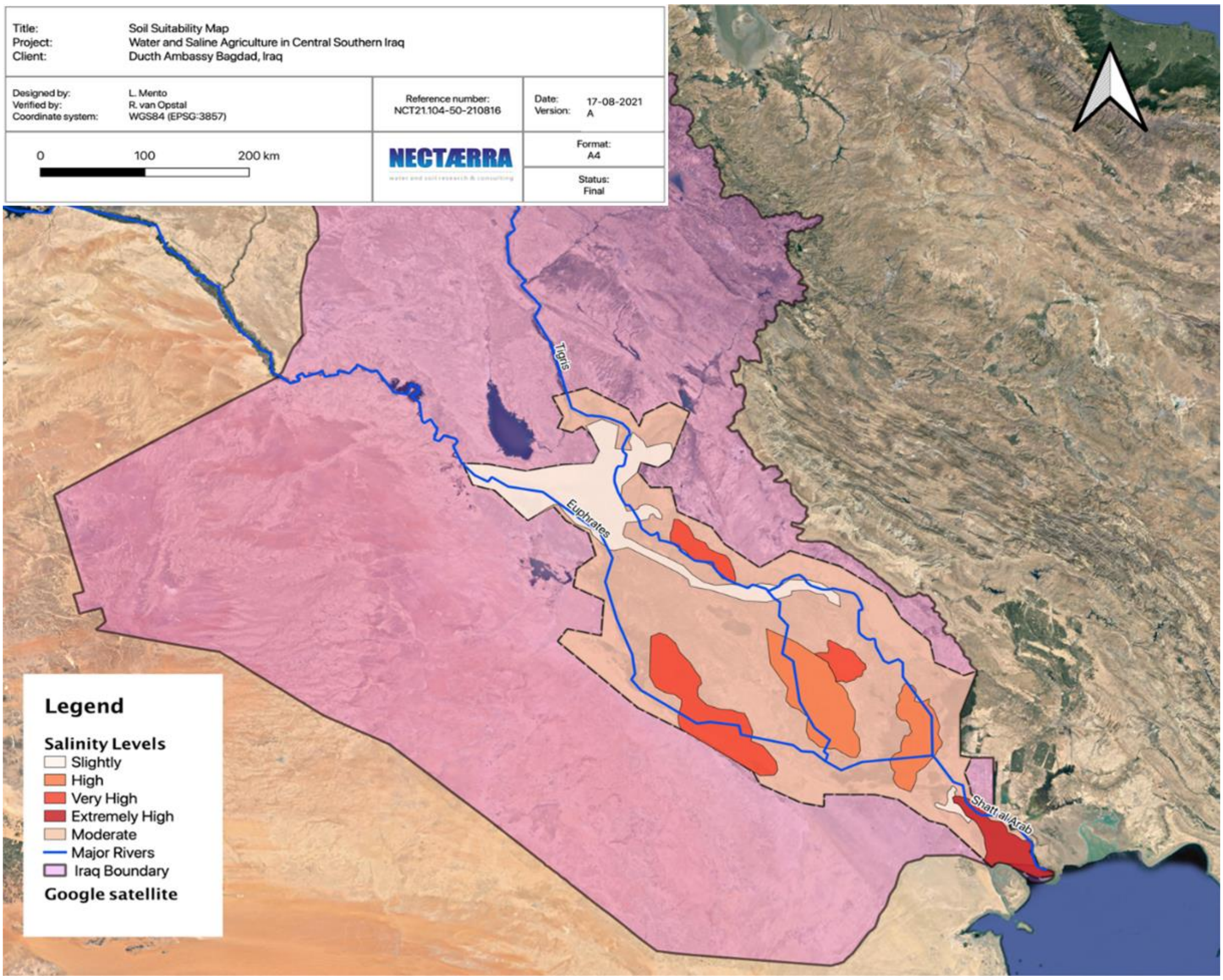


Figure 9. Soil suitability for agriculture

4 Iraqi agriwater market and actors

4.1 Introduction

The management of water is the sole responsibility of the ministry of water resources, except that on-farm level which is the responsibility of the MoA and the farmers themselves. Iraq has an old history of soil management, land reclamation and control of soil salinity. The irrigation system, since long time, used to be introduced without a drainage system, which resulted in salt accumulation due to excessive irrigation without leaching. Serval laws govern the operation and maintenance of the irrigation projects especially law No 9 for 20029, as will be detailed further on. The legislative framework for combating water shortage is the responsibility of the MoWR but it extends to other ministries and organisations. In general, rules and regulations are in place, but the enforcement of these regulations is a main problem in combating water shortage.

4.2 Government institutions

The main GOI's (Government of Iraq) institutions are the MoWR, MoA, the ministry of Health and Environment, but it goes to other main users such as the ministry of Industry and the ministry of municipality and public work. These institutions should be enforced to work together to ensure that they can play their role in water management in one national community. The most important GOI institutions that deal with Agri/water are listed below.

A. The Ministry of Water (MoWR) resources is responsible for water management, including maintenance and maintenance of the irrigation canals and dams and other related tasks. Their mission is to provide an integrated management of water resources in Iraq. Being responsible for this vital resource, the MoWR strives to balance the competing requirements for water for irrigation, drinking, industry, hydropower generation, flood control and meeting environmental requirements, including marshes restoration. The MoWR aims include an optimal operation and maintenance for water control facilities and pumping stations and effective water management through protection, optimization and comprehensive research for projects that consider environmental impacts, competing requirements and general needs.

B. Iraq Water Users Association (IWUA). The IWUA is a non-profit association established by the beneficiaries of the shared water source, and based on the collective work of its members to manage and operate the water source. The IWUA is considered among the modern water management systems in an efficient and fair manner, to rationalize the use of agricultural water and adopt modern methods of water management to reduce waste to achieve optimal use of water. The IWUA was initiated in 2009 by GOI as part of the "Agricultural Initiative" in all governorates of Iraq, the WUAs are sponsored by Ministry of Water Resources.

C. Ministry of Agriculture (MoA) in Iraq also has role in Increasing the production of agricultural crops in terms of quantity and quality, in order achieve agricultural development and carry out agricultural research to develop the production process, provide services in the fields of plant and animal production, spread modern farming methods, provide agricultural requirements, develop work in the areas of prevention, guidance, cooperation, training and livestock services, and work on implementing agricultural legislation for the purpose of achieving self-sufficiency and achieving food security.

Interaction and feedback between the various governance levels are critical. Laws, policies, guidelines, plans and large infrastructural works that are developed at the national level have implications for the decisions made at the regional (river basins) level. Decisions on water allocation, licencing, etc. can be made by regional Water Management Authorities (WMAs), but they will have direct repercussions for dam operators, farmers' communities, water user associations, etc, and eventually the end-users.

Problems and knowledge gaps

Due to wars and sanctions in Iraq in the last 30 years, the Iraq Agri-water sector need to be re-connected with new, advanced and sustainable technologies. To develop the institutions and human resources, from the central level down to the local level, capacity building is a continuous concern. This refers to regular academic programmes, mid-career training, train-the-trainers programmes, workshops, and refresher courses. Topics may include technical and managerial subjects, but in vocational levels this may require more attention. Farmers in Iraq have a level of literacy and are often not capable to innovate. It is also critical to establish relations with knowledge institutes and international knowledge networks and to become involved in collaborative research. Therefore, Iraq and the international donors should work together to ensure strong water management institutions at all levels, in terms of performance, institutional robustness and flexibility. Water management organizations should have proper development- and business plans, and a sound financial structure to ensure that the costs for water management are recovered through for example taxes, licences, water use or wastewater discharge permits, and services to third parties. Several (but not limited to) trainings that are needed to improve water management and Agriculture sector in Iraq:

- Using the new water management techniques like rainwater harvesting.
- Decrease water losses in irrigation and drainage.
- Entrepreneurship and private Sector development in Agri-Water sectors.
- Development capabilities skills in the modern agricultural extensions.
- Modern technologies for monitoring water resources.
- Decrease post-harvest losses (e.g., storing, cooling, processing, and marketing), which are currently estimated at 40% in Iraq.
- How to increase the water production e.g., precision agriculture, integrated farming systems, adequate crop selection and breeding.

4.3 Private sectors (farmers, suppliers, consultants, input/seed companies)

Iraq inherited the social system in managing all economic sectors, including agri-water sectors, hence the private sector has a minimal role.

The control of water resources via main dams, reservoirs and barrages are all government controlled. The distribution of water from the main rivers to the streams and to the irrigation projects are all the responsibility of the MOWR. The diversion of water through the water courses are also controlled by the MoWR. Beyond that, when it comes to the farm level, it is controlled by the farmers and private sector.

On the level of salinity control and land reclamation, any project subjected to land reclamation has to be first given approval of water availability by the MoWR based on the entire water budget of the country prior to any actual work on land reclamation and salinity control. There is a limited role of the private sector, but some of the work within the project can be awarded to the contracting/private sector companies such as construction of irrigation and drainage network, land levelling, concrete structures, and installation of the pumping stations.

Having the above work completed, then again it is the government responsibility to do the leaching of salts from the project down to the drainage system and then either to the main outfall drain or depressions.

In the recent years, some agencies such as JICA tried to introduce the concept of water use association (WUA) on a limited scale.

Relevant policies and regulations

Agriculture in Iraq is the 3rd major employing sector after the public sector and oil-related industries, contributing greatly to the economy. However, the water and agricultural policies keep this sector in hand of the government which limited investments. It also led to isolation from the international economy and resulted in considerably diminish of the agricultural sector in the last 20 to 30 years. As a result, Iraq is dependent on imports of food. On the other hand, to meet the domestic demand as well as to escape from excessive dependence on imported goods, the GOI is aiming to modernise agribusiness and market development.

The relation between water management organizations and governments

In Iraq administrative boundaries, provinces, do not coincide with hydrological boundaries, basins. This conflict between governance structures has been a barrier to perform strategic decisions in a basin level. The legal framework, including a financial framework, should ensure that decisions by provinces on the one hand, and basin water management organizations on the other hand are harmonized.

Important laws that regulate water and agriculture in Iraq

- Law no. 50/2008 for MoWR: according to this law, MoWR, is responsible for i) exploitation of water resources (surface and ground water) in Iraq to achieve optimal use; ii) developing water resources, identifying their sources and use them; iii) ensuring fair agreements are reached to divide the quantity and quality of water entering Iraq from the neighbouring countries and iv) preserving water resources from pollution, giving priority to the environmental aspect, and reviving and maintaining marshes and other water bodies.

- Law no. 7/1993 for MoA, according to this law, MoA is responsible for achieving agricultural development through i) conducting agricultural research to develop the production process, ii) modify services in the fields of plant and animal production, iii) spread modern agriculture and provide the agricultural requirements than are needed to develop work in areas of prevention, guidance, cooperation and agricultural training, and iv) implement agricultural reform laws and other agricultural legislation.

- Specific sectorial strategic objectives as given in the Iraqi NDP (2018-2022):

A. Water Sector:

- Increase the rate of coverage and decrease the waste of water use.
- Decrease the differences between the governorates in the provided services and minimize the differences between the urban and rural areas.
- Involvement of the private sector in the sector.
- Improve the water use efficiency.
- Secure the supply of potable water according to the international standards and increase the quantity to coincide with the population growth to reach 250 l/p/d in Baghdad and the centres of the governorates and 200 l/p/d in the other cities and towns.
- Reduce the misuse and wastewater by 10% calculated on the base year.

B. Water resources and agriculture sector:

- Increase the rate of participation of the agriculture sector in the GDP from 4.5% in 2015 to 5.2% in 2022 and achieve growth in the agriculture sector during the targeted year to reach up to 8.4%.
- Achieve sustainable food security.
- Secure the annual requirement on water resources for agriculture, industrial and municipal uses at a rate comparable to the water balance and reduce the requirement by 500 million m3 annually.
- Act on the bases to achieve sustainable water resources.

In general, Iraq needs to reform the water and agricultural system including the policies to achieve the national goals of the efficient agricultural production and allocation of irrigation water through improvement of farmers' farming techniques are essential for realizing more yields with less water.

The successful response to challenges in water management and agriculture requires good cooperation between policy and science. New scientific paradigms and scientific developments should find their way to the policy and executive levels, and knowledge institutions should (sufficiently) address the needs of society. Dedicated research and training institutes can promote the development of relevant knowledge and data, and the uptake of research results by water managers.

It can also be considered to create a formal advisory structure to support decision makers in policy development and implementation, for example for specific complex issues.

4.4 NGO's, farmer cooperatives

The main association in this respect is the General Union for Iraqi farmers. There is also the IWUS at very limited scale. IWURs were initiated in the aim to manage agricultural water. IWUAs instructions came into force in Iraq in 2014. Until 2018, about 140 IWUAs have been established in Iraq (JICA website, 2018).

In addition to that, the local farmers need to improve their skills and get more information about new and innovative farming methods. Moreover, farmers do not have the capacity to manage irrigation facilities as they are not fully aware about the how to deal with limited water resources. In general, modern irrigation techniques such as sprinkler and drip irrigation, which improve the irrigation efficiency, are less utilized in Iraq. This is because farmers cannot apply modern agricultural techniques since they do not have enough funds and are lacking in entrepreneurships. Most of famers have little knowledge about farming systems focusing on economic efficiency planned by the Government. In particular, they do not have access to the information about agricultural markets i.e., quality and prices of agricultural products. Therefore, there are urgent needs for MoA (with support of the international agencies and NGOs) to change education system so that farmers can adjust themselves to new technology and to impart agricultural guidance to farmers.

4.5 Dutch and international programmes

The contribution of the Dutch programmes is very well known in the water sector in Iraq and the academia as well as the ministry staff have very high opinion to the Dutch programs. There are several training and capacity building programmes that are funded by the Netherlands to support the Agri/water sector in Iraq. In addition to the Netherlands, many international actors have been supporting the Agri-Water sectors in Iraq can be summarised in the table below (Jaika, 2016).

(Gross expenditure, Unit: million US$)

Year	1st		2nd		3rd		4th		5th		Japan	Total
2008	EU	38.01	IDA	12.28	UNDP	4.19	GFATM	3.17	UNICEF	2.13	3.94	63.72
2009	EU	57.31	IDA	31.93	Isl. Bank	8.66	UNDP	4.09	UNICEF	2.03	3.71	107.73
2010	IDA	59.76	EU	54.10	UNHCR	10.84	GFATM	10.39	UNICEF	2.95	5.61	143.65
2011	IDA	42.11	EU	13.00	GFATM	4.09	UNDP	3.01	UNICEF	2.44	3.68	68.68
2012	EU	91.58	IDA	59.10	UNDP	2.81	GFATM	2.62	UNICEF	2.52	3.74	162.37

Source: OECD/DAC

Notes: Ranking reflects the major international organizations

4.6 Types of projects and possible partnerships

The implementation of the partnership should be such that there is a possibility to be flexible, to make use of all available opportunities, in terms of taking up activities as well as funding. Such flexibility enables Iraq to make use of various possibilities to reach synergy with other stakeholders in the cooperation with Iraq, both at the national level (National Commission for Investment, National Commission for Scholarships, etc.) and at international level (WB, UNDP, FAO, etc.). The partnership plan must be based on the idea of concerted actions that link private sector/business cooperation and capacity development to the various actions Water/Agri projects e.g., value chain development (including market issues), horticulture, dairy, poultry, fruit. Also, a national irrigated land capability understanding should guide decisions on reclamation and rehabilitation to ensure the efficient use of Iraq's land and water resources. To achieve this understanding, it is suggested to develop land and crop suitability maps based on soil, water, land drainage, water table depth, groundwater quality, and the other agro-hydrological conditions prevailing in different areas. Development or selection of suitable farming systems for different areas based on water availability and climate conditions in different regions of Iraq.

All these suggested innovations can be implemented by a partnership between the Dutch Universities and companies, and the Iraqi MoWR and MoA and selected other NGOs and private partners.

The possible set-up of the partnership

Iraq and the Netherlands could formulate a high-and-technical-level partnership committee to on two levels a policy level and an implementation level to gather the main Agri/water actors with representatives of both Iraq and The Netherlands. The activities of the Committee can include but are not limited to:

- Advise on quick 'no-regret' activities & ‘low hanging’ fruit.
- Advise how to follow-up on the various proposals that (will) come from Iraqi and Dutch companies and institutions.
- Advise interested parties on making use of the various Dutch tools (including PSD Apps, SDGP, DGGF, Shiraka and NUFFIC training and education possibilities).
- Identify possible synergy to be reached by teaming up with national (National Commission for Investment, etc.) and international partners (WB, FAO) in Iraq.

5 Range of potential project interventions and opportunities

5.1 Background

As the population of Iraq is rapidly increasing (e.g., 2000 23.5 million people and 2019 39 million people), the demand of food is also rapidly increasing. Goal for any country is to feed all the people with locally produced food and with imported food to reach food security. Salinity and water supply issues make this more challenging, and it is therefore important to understand how to tackle salinity in a faster and more efficient way.

There are different approaches that must be taken if the result is to be achieved, or four steps:

- First step is to divide the interventions along target scales and end goals (farms, irrigation districts, and interventions at a regional/national level).
- Second step is to consider the role of knowledge in the whole picture. Farmers and operators, at each scale, need good knowledge of the best practices to tackle salinity, need to be knowledge independent, and also be ready to notice and avoid future critical situations.
- The third step is to have a solid approach: plan- act- monitor- evaluate- react. Only with a simple and well-structured acting plan can salinity be tackled in the long term.
- Fourth step is to have a Food System Approach (FSA). This conceptual framework is a systems approach, and it structures an integral reflection on food security. It helps to guide the thinking on the cause-effect relations within the food system.

All four points will be further and extensively explained in the next paragraphs.

5.2 Interventions at farm level

When working in saline conditions, a few crucial components can always be identified as on-farm measures:

- Short term interventions such as improved parent material (more salt tolerant varieties of common crops), agro-chemicals, agro-minerals and/or different physical soil tillage operations.
- Reduction of water consumption of the farm:
    - Reduce consumption (Transpiration)
    - Reduce evaporation
- Optimization of on-farm drainage
- Monitoring of salinity

As proposed by Pinero et al (2020), to battle the salinity effectively it is recommended to implement a range of interventions which all provide minor or major contributions to address the issue. Simply relying on salt tolerant varieties, if already available and up to the task, will not solve anything on the long term, because problems will continue to grow. A solid background of techniques and practices needs to be taught to the farmers. Under this prospective, a large set of interventions should be presented at a demonstration location.

Physical

When farming in a salt affected soil, minimum (preferably no) tillage and deep subsoiling are the two main physical components to address. During every tillage activity soil life is killed, organic matter burned, and internal soil structure destroyed; all crucial parameters which need to be optimized in salt affected soils. However, subsoiling is required in compacted soils like clay soils or those soils which have a plough pan or have impermeable of mineral deposits; subsoiling does not turn the soil, it leaves the soil in place.

Chemical

Adding the right chemicals or minerals to a soil depends on structure, salinity, pH, and other soil parameters. Taking a soil sample is *always* required to assess the nutrient status of the soil. The most used inputs in saline soil are gypsum, magnesium sulphate, ammonium sulphate and elemental sulphur. The commercial fertilisers needed in the future agriculture of Iraq should not contain chloride and magnesium, as these add to salinisation. Lime fertilisers will never be required (Buringh, 1960). New products are entering the market which are more advanced and often based on humic or fulvic acids, also ingredients which have a positive impact against soil salinity, and which can occur naturally if the farm is managed correctly. Testing and showcasing fertilizers which have proven benefits in the Iraqi setting and new promising organic products at demonstration locations is recommended.

Biological

Improving soil properties is vital when addressing salinity in the soil, since a better soil quality has several different benefits in solving or mitigating soil salinity:

- Better water holding capacity
- Higher CEC values
- Better soil fertility
- Lower soil bulk density
- Better internal drainage

All these parameters are positively affected if soil organic matter (SOM) levels increase. A healthy soil has SOM in 3 phases: the living (roots, microorganisms), the dead (dead plant material and microorganisms) and the very dead (humus, and humic acid). All 3 are important and play a different role in managing/mitigating soil salinity. However, they can only occur in these fractions when the soil contains a healthy population of microorganisms. And soil microorganisms in their turn needs SOM as housing space and food source.

In summary, a SOM building strategy for each farming system needs to be developed as a long-term solution against soil salinity. This is a considerable challenge as Buringh has already observed 60 years ago: *“in arid and hot regions the organic manure disappears in a short time, due to rapid oxidation, and therefore the soils obtain no benefit from it. This is particularly true if the soils are saline…. Even after a few years of pasture, or leguminous fodder crops, the apparently increased organic matter content drops rapidly to the former low level, which is adapted to environmental conditions.”* In conclusion, besides focusing on the soil, we also have to address the environmental conditions and farming practices to maintain improved soil conditions.

Salt tolerant varieties

Before any of the above-described measures can be implemented, food still needs to be produced in the existing saline conditions. Unfortunately, some farms are in locations where salinity can’t be fixed in a short time frame since the water source contains salt. All proposed measured may be implemented by the farmer, but in many cases the farmer still faces salinity. Therefore, it will be important to promote the use of the right seeds/parent material in these situations. Halophytes and crop varieties with a higher salt tolerance are an important and relatively simple first step in the ‘farmers first aid kit’, although this may be limited due to cost and availability, and the limits of “salt tolerant crops” to tolerate salt.

Mixed farming systems & Aquaculture

Stenhouse and Kijne (2006) have shown technical feasibility of using saline water and land for irrigated agricultural production into the mixed farming systems of West Asia and North Africa (WANA) region. They have brought forward several practical examples from Egypt, Syria, and Tunisia and have shown the effectiveness of using saline and drainage water for conventional crops (Qadir and Oster, 2004). Reflecting on the Iraq situation, the agro-climatic conditions are quite like these countries. Therefore, there is a good potential for adopting these practices (Qureshi and Al-Falahi 2015).

Aquaculture can provide an interesting opportunity, especially for the use of disposal of saline drainage effluent. This will be especially useful for the areas that are already too saline for traditional aquaculture. In Iraq many areas exist where people could benefit from diversification of the farm income this way by using unutilized saline resources. This approach can also contribute to solving waterlogging problems, and this practice has already been adopted in many other developing regions, especially in the Nile Delta Valley (Stenhouse and Kijne, 2006) (Qureshi and Al-Falahi, 2015).

5.3 Interventions at policy level (Irrigation district)

It is obvious that all these potential on-farm interventions are challenging for a farmer to address. Institutional support is one of the aspects required to accommodate the farmer to adopt some of these interventions. Besides training and commercial inputs, the institutional framework needs be aligned to the need of the farmers.

WUA established and equipped

The mutual need of water requires institutional collaboration and the means to undertake the actions as required. A top-down approach to force the farmers in WUA's (water use association**s**) should be avoided. The urgency to cooperate must come from the farmers and their initiatives should be supported. Newly established WUA's or similar institutions should be supported and equipped.

5.4 Interventions at policy level (regional / national level)

Supporting (social/economical/physical) infrastructure should be made available to facilitate the farmer in implementing the mitigating measures. In the following section, several support measures are highlighted:

GIS-environment

Every salt-affected region has different soils, climate conditions, infrastructure, farmers, and markets. So, the solutions to be developed are different for every region as well. This in line with what several authors like Moutaz (2013) conclude: *"it is of extreme importance that cropping choices are based on land capability."*

A common way to provide insight in agricultural planning is a crop suitability map or something similar, which is commonly a result of climate and soil combined. As one of our recommendations is to diversify production systems, this crop suitability map must contain more than just the recommended crops for these conditions. Far more favourable would be the development of an application or dashboard containing advise for different farming *systems in different regions*, which also address the underlying infrastructure for crop production and the availability of certain agro-equipment.

Connections can be made to existing projects like GIS or Remote Sensing projects like WaPOR. FAO has developed a publicly accessible near real-time database using satellite data. It allows to monitor the status of agricultural water productivity, identifying water productivity gaps, proposing solutions to reduce these gaps, and enhancing a sustainable growth of the agricultural sector. Moreover, with its different functions, it allows for direct data queries, time series analyses, area statistics and data download of key variables associated to water and land productivity assessments. With its 3 different levels (continental level - 250 m ground resolution; national and sub-national level - 100 m ground resolution; irrigation scheme and sub-basin - 30 m ground resolution) water and land productivity can be assessed at different scales.

In Iraq WaPOR could mainly be used to modernise the irrigation schemes. Using WaPOR to evaluate farming is systems will prove more difficult given the resolution limitations.

Drainage systems

While all chemical, physical, and biological measures will have a positive effect, these might be sufficient at some places. Drainage is then an extra crucial component in managing salinity on farm or to reduce too high salt levels. This drainage can mean rehabilitation of existing systems, or installations of new systems. There are several different options compared to the conventional open field drainage channels, and all have their pros and cons. Depending on local conditions the best option should be chosen, preferably decided and managed in a GIS-environment. Further research also needs to be undertaken in Iraq to assess the pros and cons of different systems.

There is one drainage method that we wish to highlight as potentially very promising for Iraq: bio-drainage. Bio-drainage is defined as the process of removing the excess soil water through transpiration using bioenergy of the plant and radiation energy of the sun. Water use of plants varies with age, geometry, soil properties, water table, salinity, and climatic conditions, and generally varies between around 6,500 to 28,000 m3 ha/yr. Under ideal conditions, a tree canopy may lower water tables by 1–2 m over a time of 3–5 years (Singh and Lal, 2005). Large advantage of bio-drainage is the independence of neighbours to implement it and the relative short time frame required to see the result. Farmers become less dependent on institutions and reap the additional benefit of planting trees in an Agroforestry system.

Figure 10. Bio-drainage with Eucalyptus in an AF-system in India (Singh and Lal, 2005)

Tree planting

When looking to the Iraqi landscape, the absence of trees in most areas is disheartening. Trees could have a positive effect on nearly everything that is related to soil salinity. Some of the points include:

- Trees lower the temperature of the environment
- Trees produce shade to reduce soil temperature
- Trees produce biomass
- Trees provide shelter for beneficial life
- Trees can provide timber products and fruits/nuts.
- Trees prevent erosion
- Trees can be used for bio-drainage
- Trees reduce the wind speed
- Trees host microorganisms on their roots

(Belsky et al., 1989)

From agricultural perspective, trees are commonly cut or burned during war and replanting them takes long after the war. In Iraq, this was not different. Therefore, priority should be given to tree planting initiatives on-farm and off-farm in this post war period. However, tree planting policies should be carefully developed as reforested areas with monocrops of pine plantation can potentially do more damage than good. Brancalion and Hall (2020) have developed a set of interesting guidelines which can be helpful when looking at implementing tree planting projects:

1) Address the underlying drivers of environmental degradation

2) Integrate decision-making across scales
3) Tailor tree planting strategies to clearly stated project goals and plan, adaptively manage, and evaluate success over a sufficiently long timeframe
4) Focus on the forest, not the trees (on the Iraqi case: focus on the AF-system, not the trees).
5) Coordinate different land uses across the landscape
6) Involve all stakeholders throughout the process

These have been developed for reforestation projects, and on-farm tree planting requires a slightly different approach. Lessons on agroforestry are somewhat limited around the world, as only in the coffee and cocoa sectors it is common practice to plant trees for production support. For most of the other crops or livestock (except tree crops) the trees are often regarded as a nuisance. However, a very small minority of farmers will always be open minded to try something new like AF. These so called ‘innovators’ are the ones who need to be targeted by any future project. Second important aspect is ‘seeing = believing.’ Farmers are unlikely to experiment with their livelihood if there is not a reasonably high chance that new technologies will help in the farm operation. Implementing an AF farm as proof and demonstration is pivotal to make any AF project a success.

5.5 Interventions at knowledge level

As described in previous chapters, several actions need to be undertaken to effectively address the salinity issue in Iraq. The different stakeholders who need to undertake action in their different fields of operations, adds to the complexity. To safeguard an acceptable implementation of the different tasks, knowledge, support, and training is required. The fragmentation of the different knowledge levels and subjects makes the role out of knowledge transfer a complex task. All subjects and levels, however, have one thing in common and that is that the effect of the measures should all be reflected in the field of the farmer.

Therefore, it is recommended to initiate one (or more) practical field locations where all stakeholders can learn about different farming systems that are representative for their own location. This includes underlying infrastructure and commercial inputs.

5.6 Interventions at commercial level

Motivating farmers to adopt changes in their farming operations is the first step, but the farmers must implement them as well and this often requires new inputs, skills, knowledge and/or services. From experience it is of *crucial* importance to create an enabling environment for the farmers to adopt anything. Besides institutional support to develop this enabling environment, market development will help the farmers get access to these inputs required for no-till farming, deep sub-soiling, and AF.

5.7 Monitoring

Qureshi and Al-Falahi (2015) point to the important fact that data is limited and scattered on the topic of salinization of salt affected soils. Developing more understanding on this is it important to keep track of the progress and monitor where the situation is improving or worsening. This will help in understanding drivers for change and guide policy interventions.

5.8 Food System Approach (FSA)

After presenting individual practices to counter salinity on different fronts, it is important to understand how they can work together and what effect one practice can have on the entire system. To reach this goal a conceptual framework is needed. Moreover, it is important to understand how salinity is impacting food security.

Looking more in-depth to the approach, several components are visible. There are the drivers, the food system activities and food system outcomes. The drivers have a "driving" force on the food system. The drivers are socio-economic and environmental. Both types of drivers have their own interaction with the food system. Using this approach in a systematic way, the current challenges and relations concerning saline agriculture can be assessed. In this way it will become apparent which challenges and relations exist and what changes will do to the food system.

As we reflect on salinity, this could be placed under the environmental "water " driver (the salinity could also be placed in other drivers, depending on your goal). From here onwards, the research of the influence of salinity can start. As every component is connected to the water driver, either direct or indirect, the changes can be defined and described. In this way a change in the food system can be reflected in an integral way.

By researching the drivers and the FSA and incorporating expert knowledge, first insights how salinity is influencing the food system can be reflected on. As a result (displayed in Annex 4), the topic of salinity is now connected to the food system approach, ensuring that the food system drivers (environmental and socio-economic) are related to the salinity.

The takeaway message from this approach is that all components are related, and every intervention influences the whole system. Reviewing interventions from the FSA perspective helps to ensure an integral and sustainable food system (Snethlage et al. 2021).

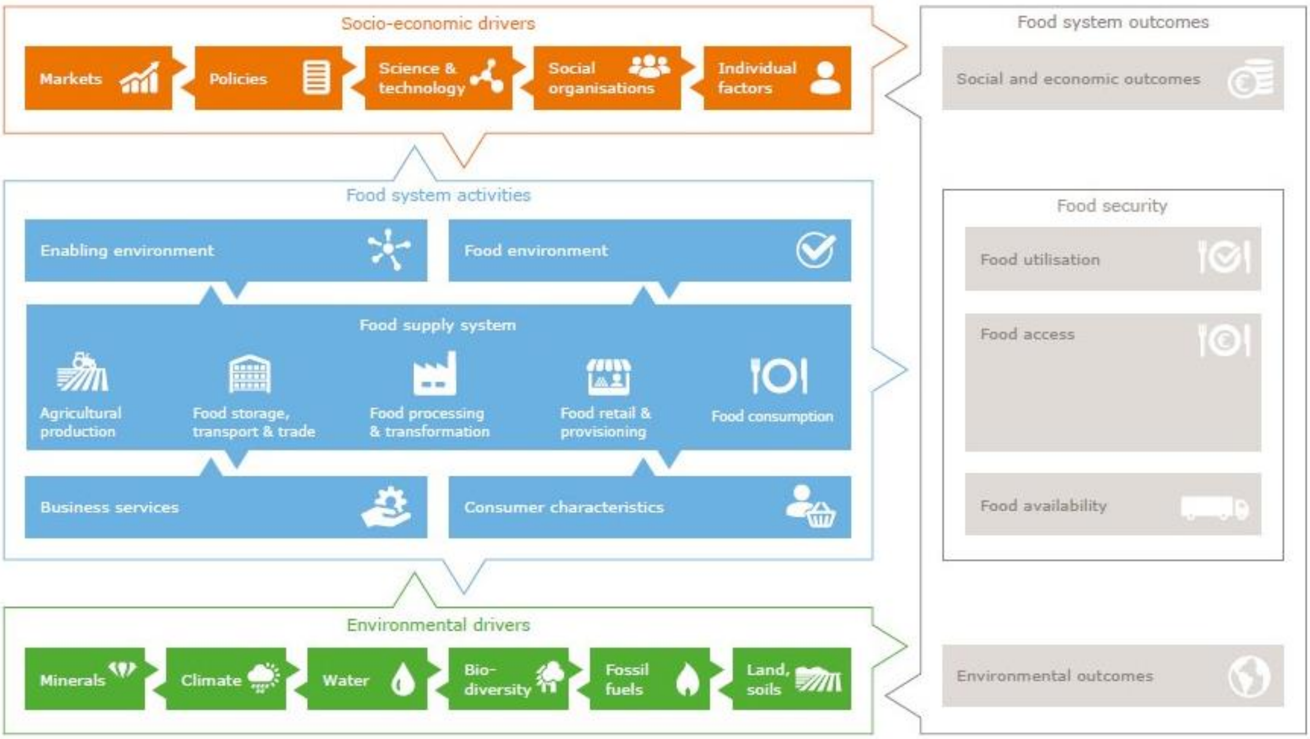


Figure 11. The Food System Approach (FSA): a way of mapping the relationships of the food system to its drivers (van Berkum et al, 2018).

Besides reviewing interventions from the FSA perspective to ensure an integral and sustainable food system, it is important to keep a few guidelines in mind to sustainably motivate the adoption of these interventions as proposed by Pineiro et al. (2020) who defined a set of tested guidelines to follow when designing interventions or policy instruments.

- ***Balance the incentives and outcomes***. *Incentives must be high enough to motivate a change in production practices. This is because productivity and profitability gains can be insufficient to compensate for the total cost of the initial capital requirements and any unexpected costs of the proposed agricultural interventions.*
- ***Know your farmers.*** *The likelihood of farmers adopting sustainable agricultural practices will vary depending on their experience, education, access to information and level of risk-aversion. Policymakers*

must be familiar with the farmers, and tailor the incentive programmes for them by incorporating the range of personal, political, institutional, and biophysical factors into the design of the programme.

- ***Keep it simple.*** *Instruments should be simple to understand and communicate given that farmers dislike instruments that are too complex (such as some legal regulations) and are therefore less likely to adopt them. Besides, complexity makes instruments harder to communicate and more expensive to adopt or enforce.*
- ***Complement.*** *Single interventions are less likely to succeed, hence the need to use a combination of policy instruments. For example, the provision of technical assistance and extension services contributes to the understanding of farmers and helps them adopt proposed practices.*
- ***Behavioural preferences matter****. Given that people tend to follow the behaviour of others, farmers' preferences should be considered when designing incentives, acknowledging that they vary depending on the target population.*
- ***Be prepared for a long-time horizon.*** *The time horizon depends on the agricultural practice, the production system, and the biological cycle. This means the opportunity cost of time must be considered and financial tools must be put in place so that cash flow problems do not jeopardize the intervention.*
- ***Create an enabling environment.*** *Incentives that make the adoption of sustainable practices attractive depend heavily on an enabling economic and financial environment. Beyond incentives, it is necessary to improve the general conditions that influence agricultural systems. There are many factors that influence the capacity and willingness of farmers to invest in land, water and forest conservation and to pursue sustainable practices such as agricultural institutions, policies and regulations, social protection, infrastructure and markets, prices, off-farm employment opportunities and structural poverty."*

In summary, we aim for long term, affordable, and simple sets of combined interventions that are understood and supported by farms, policy makers and are placed in an enabling environment.

The perfect setting would be a demo farm, agro-hub, or farmer field school setting where the 3 main stakeholders can interact and be educated on addressing salinity. This should be supported by researchers to keep improving on the solutions.

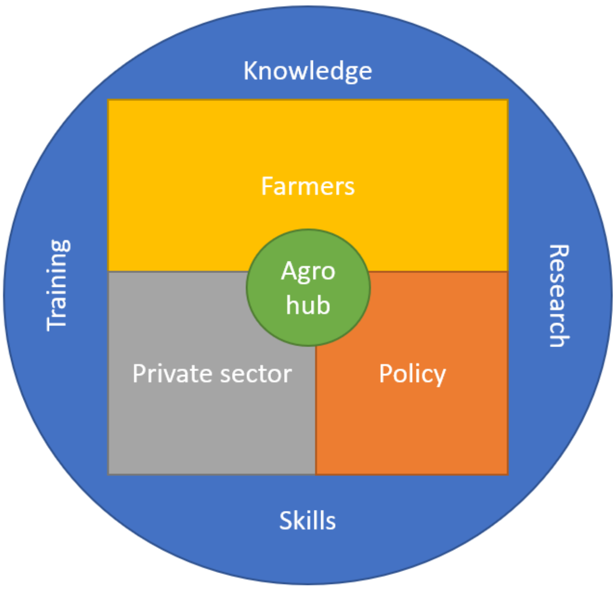


Figure 12. Figure 12. A physical location where different stakeholders interact with each other, and synergies are established, and new solutions are being found and spread.

6 Recommendations for next steps, projects, and partners

6.1 Summary of potential project interventions

The complexity of a decreasing natural water supply, harsh climate, land degradation and salinization, in combination with a growing population, demand for water and self-sufficiency in agriculture, demands an integrated approach in many different fields by the Iraqi stakeholders.

This report only highlights those measures and approaches that could make a difference directly in agriculture and in irrigation water supply and demand. However, other fields warrant equal attention, such as (the future of) urban and rural design and planning, water technology (for instance water treatment and water distribution), training and capacity building in all the above fields and raising water awareness.

In general, two main problems affecting agriculture in Iraq, namely lack of water and water quality (salinisation), have been gradually increasing for years, and will continue to do so unless extensive measures are taken. Elaborating here on, as explained, only the agriculture and water solutions, it is fundamental to preserve irrigation water through more efficient irrigation systems, irrigation schemes, drainage, and water harvesting, i.e., to improve on-farm water management practices. This prevents and slows the onset of salinisation.

Furthermore, regular maintenance of existing irrigation infrastructures, construction of new irrigation schemes and emergency repair to any irrigation facilities should all be catered for in a short-term plan. On the medium and long-term, it is essential for Iraq to complete the storage dams currently under construction, and well as all land reclamation projects. Iraq also needs to work hard on minimizing water losses of conveyance network channels, which involves proper cleaning of irrigation and drainage networks from weeds and sediments, routine cleaning of sub-surface tile drains, and concrete lining of selected earth canals.

The efficiencies of water diversion and conveyance must be achieved, and on-farm irrigation water applications must be implemented. This could be achieved through expansion in land reclamation suitable for surface irrigation as well as the introduction of modern overhead sprinkler irrigation and localized drip irrigation systems at farming fields.

Existing effects of salinisation can also be mitigated. To enhance the irrigation and soil quality, Iraq needs to develop sustainable and economical solutions for restoration of saline-affected lands, including leaching for flushing out accumulated salts, the construction of buried field drains, and open collector drains, and outfall drains to bring salinity levels down.

There is also an urgent need to manage salinity by better assessment of landscape capability and vulnerability when making decisions on new locations for irrigation development or farming plot suitability. In extension of this, Iraq should, like elsewhere in the world, introduce new farming systems that are based on sustainable, commercial farming and water management, and less on conventional farming. Practices to generate a better microclimate and biodiversity on-farm are possible, also in arid regions, and this helps generate more sustainable and robust income for farmers.

Using remote sensing and geographic information systems (GIS) offers an excellent option in addition to more traditional techniques in monitoring and evaluation of waterlogged and saline areas, and to guide decisions.

On the cultivation side, the selection of water efficient crops and use of better salt tolerant crop varieties can be stimulated. The success of these measures has more to do with breaking through traditional practices among farmers, and sharing of new experiences, than of new technology or knowledge. Many seeds already exist that do well under the local Iraqi conditions (incl. salinity, sunlight, and heat), and much can be learned from farmers and knowledge institutes in neighbouring countries.

Finally, Iraq should be using new techniques for forecasting consumer demands of an irrigation area using on-farm water-use information systems and methods like hybrid methodology and genetic algorithms.

6.2 Action diagram

We have differentiated measures and approaches in agriculture and agricultural water management in 4 main categories, and 4 different actor categories, as follows:

- Actions: Short-term actions / Long-term actions / Water management related actions / Monitoring
- Actors: Farmers / Policy makers / Knowledge and research / Commercial sector

Table 2 provides an overview of relevant actions to address.

Table 2. Proposed short, medium, and long-term actions by different stakeholder groups in Iraq

Measures to address salinity	**Farmers – Field demonstrations**	**Knowledge (consultants, R&D)**	**Institutional - policy**	**Private sector**
Short term action	Immediate on-field actions to deal with existing saline conditions: • Chemical: ammonium sulphate, superphosphate, etc. • Physical soil manipulation: subsoiling • Soil biology: humic, fulvic acid and microorganisms • Saline crops, halophytes • Use saline water for aquaculture	• On farm training on mitigating on-farm activities to offer immediate pain relief (avoid long fallow, choose best crops based on soil, water, and environmental conditions)	• Plan to address spot pollution regarding water sources • Raising awareness of the field problems and assist in developing supporting (social/economical/physical) infrastructure that should be made available to facilitate the farmer in implementing the mitigating measures • Development of an efficient and local market supply chain for farmers material	• Agri inputs • Salt tolerant crop seeds, halophytes • Microorganisms / Micro element fertilizers. • Tractor implements • beneficial insects
Water management	• Drip irrigation • Switching from basin to furrow • Mulching, • No or Minimum tillage • Increase plant cover • Improve soil properties • Drainage • Bio-drainage	• On-farm training with soil moisture measuring, crophealth and irrigation equipment. • On farm training on CSA farming practices (understand plant water requirements, change in tillage strategy, change in management strategy)	• Modernize irrigation infrastructure • WUA's, universities, Extension officers have access to these materials. No need to supply all farmers with a soil moisture probe. They can be brought in custody of the EO's or WUA • WUA's, universities, Extension officers have access to specialized no-till equipment 2) Vision developed on products best produced (also in quantities) in the region • Local drainage systems rehabilitated • Minimum tillage promoted by policy	• Soil moistures measuring material • Irrigation and drainage material • Specialty agri-equipment • No-till and minimum till equipment • Organic fertilizers • Subsurface drainage materials • Aquaculture (mixed farming)

Long term solutions	• Agroforestry • Climate smart agriculture • Polyculture	• On farm training on CSA farming practices. • Local adjusted AF-systems developed and improved • Development of local salt tolerant varieties • Research on bio-drainage • Minimum tillage equipment making	• Tree planting policies initiated • Tree planting integrated in urban development • GIS-environment for decision support and farm system integration	• Nurseries • Wood related products • Tree/Niche market products
Monitoring	• Measure soil salinity • Measure water salinity	• Development of new and cheaper monitoring systems • Learn to recognize differences between salt damage and drought damage and report	• Study current extent of salinity • Monitoring the state of infrastructure	-

6.3 Studies

- Study the extent of salinity (e.g. WUR)
- Plan of action developed to address spot pollution for water sources (Arcadis, Royal Haskoning DHV, IV-water, Witteveen & Bos, Sweco, Tauw etc.)
- Agroforestry and tree planting initiatives aligned with new and existing policies (e.g. WUR) → policy vision developed for irrigation and drainage, ensuring connection to the field level farmers.

6.4 Agro hub

- Agrohub (2-10 years & 5M€ +)

To facilitate the farmers in Iraq to make the changes on their farm we must align the other actors to develop an enabling environment in which the farmers are able to act as required. For example, zero-tillage is an important element for farmers to adopt as one of the measures, but if there is no zero-tillage equipment available (commercial sector, policy) and the farmer doesn't know how to use it (knowledge) it makes no sense to tell the farmer to change to zero-tillage.

Logically we can't expect that all elements from the table can and will be addressed. We can however take steps which help in improving the adoptions of a large range of the elements. This builds on the concepts of co-creation when people come together and improve on whatever they are doing *together.* Where better to bring farmers, policy makers, researchers, and entrepreneurs together than on a farm?

In this report we call this farm an 'agro-hub'; a location where farmers are exposed to new farming systems; Researchers can explore new solutions and improve old ones; Entrepreneurs can sell their products which help the farmers; and policy makers understand why and how they must develop the enabling environment for the farmers and entrepreneurs to make their business future proof.

The Agro-hub should address the following aspects:

- Physical, chemical, and biological farming interventions are shown (WUR + innovative partners)
- New farming systems are being developed and finetuned (WUR + innovative partners)
- Research on promising farming systems undertaken (WUR + local universities)
- Research and development on halophytes and salt tolerant varieties (seed companies + local universities + farmers)
- Commercial inputs made available to famers
    - Subsoilers, zero/minimum-tillage equipment
    - Agro-minerals
    - Soil microorganisms
    - Tree management equipment
    - Salt tolerant seed and seedlings
    - Irrigation equipment, drainage equipment
    - Other inputs (Nano clay, bio fertilizers, beneficial insects)
- Training for all stakeholders:
    - Farming systems
    - Irrigation and drainage
    - Water user associations
    - Institutional development
    - TVET practical training
- Farming implements available for rent
- Development of workable policies/measures based on farmer-policy maker on field discussions, these should align with existing or future policies.
- Farm systems + protocol development for different regions (0,5 - 5 years, 0,1-10M€)
    - Development of supply chain for required farming materials (connected to GIS environment).

6.5 GIS environment developed for agricultural planning

Starting with a combination of soil/crop suitability map which elaborates on the extend of salinization and mitigating measures or solutions per region. All relevant parameters for policy makers and farmers should be reflected in the GIS environment. The development of an GIS application or dashboard containing advise for different farming *systems in different regions*, which also address e.g. the underlying infrastructure for crop production and the availability of certain agro-equipment.

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Appendix A. Water resources in central and southern Iraq

This appendix provides a generalised overview of the water resources in central and southern Iraq (natural, artificial, wastewater and irrigation water), and its geographic and climatic background.

A. Geography and climate of Central-Southern Iraq

Geography

Iraq, formally the Republic of Iraq and literally meaning "deeply rooted, well-watered, fertile", is in the heart of the Middle East, with a short (58 km) coastline on the Gulf. The country has borders with Turkey, Iran, Kuwait, Saudi Arabia, Jordan and Syria. It has a long history and is often referred to as the cradle of civilisation, with successive civilisations since the 6th century BC that gave rise to for instance reading, writing, the wheel, and the first forms of government. Historically, these lands were also identified by some as 'Mesopotamia".

Its natural history is equally impressive, as the region was formed under the collision of the Arabian and Euro-Asian tectonic plates (Baltzer, 1990), giving rise to mountains, basins, and a somewhat complex geology that is strongly fractured and folded (generally two strong pre-requisites for formation of hydrocarbon reserves for which Iraq is also known). The subsurface consists of overwhelmingly of carbonate sediments, although aeolian and fluviatile clastic sediments exist locally. Moving towards the coast, extensive marshlands and swamps are present, which remain an important buffer for water resources, although their biological productivity has been rapidly disappearing over the years (Malinowski, 2002).

The natural evolution has resulted in a mountainous border region with Turkey and Iran – the highest point is the Cheekha Dar at 3611 m along the Iranian border (Malinowski, 2002) – and the origin of the main rivers of Iraq. Higher (and sparsely inhabited) elevations also exist to the west, northwest and southwest of Iraq in the form of stony deserts.

Iraq is otherwise dominated by the Mesopotamian Plain, or basin (light green area in Figure 13), occasionally also referred in literature under the name Alluvial Plain, across which the Tigris and Euphrates rivers run in a roughly NW-SE direction. These rivers confluence into the Shatt Al-Arab River 100 km north of Basra at Qurnah, which then continues its flow in the same direction until the Gulf. The Mesopotamian basin is the most populous area of Iraq, with most of its large cities, and most of the Iraq's agriculture.

Its importance in agriculture, society and prevailing water and salinity problems, has made the Mesopotamian basin of central and southern Iraq the focus of this report.

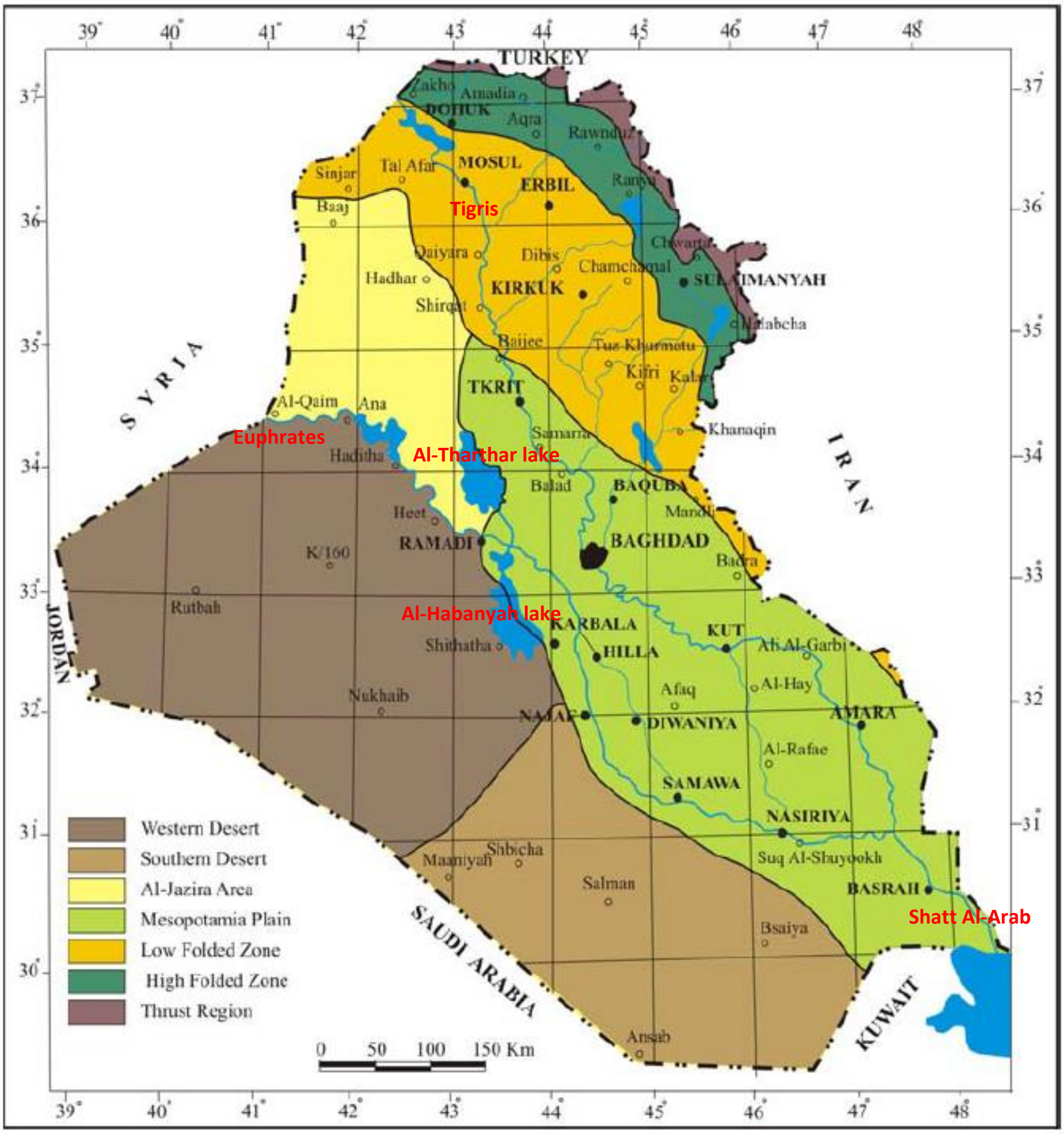

Figure 13. Location map of the Mesopotamia Plain. Modified from Yaacoub (2012)

Climate

The Mesopotamian plain is characterized as an (semi-)arid climate, known for extreme heat during the summers, with daytime temperatures sometimes exceeding 50 degrees Celsius and usually dropping to around 22 degrees Celsius at night. Rainfall occurs in the winter from December to February. Average annual rainfall varies locally in the Mesopotamian plain, ranging from 50 mm in the western part of the plain to a maximum of 250 mm in the eastern part of the plain (Figure 14). Near the rivers heavy showers may occur during the winter months, but rainfall usually does not exceed an average of 200 mm per year (FAO, 2008; Flint et al, 2010; Al-Ansari, 2018). The amount of rainfall is, however, expected to drop with 25-50% in the coming decade due to climate change (Immerzeel et al. 2011).

Relative humidity varies seasonally, ranging from 50% to 75% in the winter and to below 30% in the summer. Evapotranspiration can reach up to 3000 mm/year, especially from the irrigated croplands, and this impacts the (ground)water levels of the rivers and marsh lands (Rzoska, 1980; Flint et al, 2010).

Due to long dry periods, low humidity (min. 15%) and wind gusts, the plain experiences dust storms throughout the year. These storms consist of mostly clay and silt. This mix of dust usually originates from dunes formed by abandoned irrigation fields and parched marshlands between the two rivers (Lloyd et al, 2006; Sissakian, 2013).

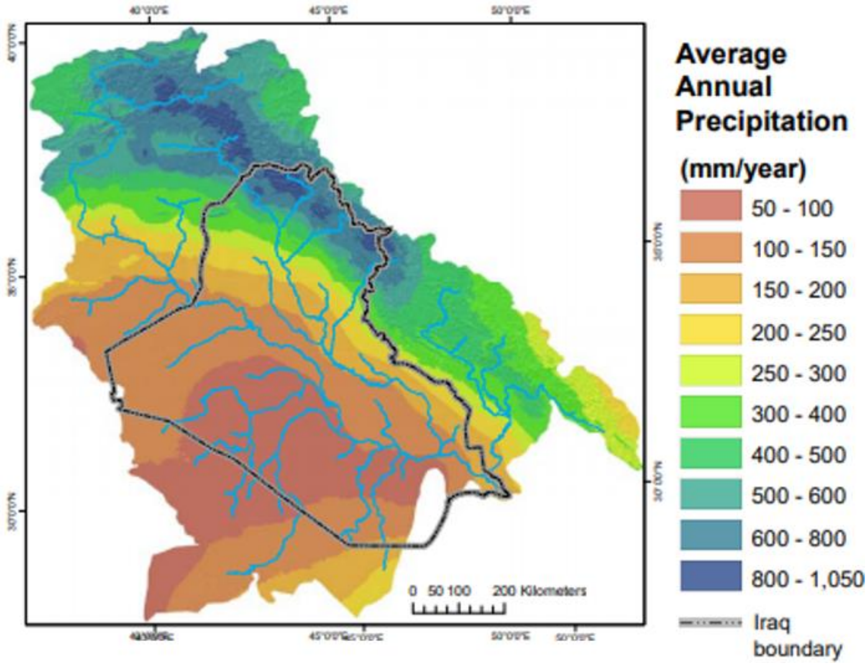

Figure 14. Average annual precipitation in mm per year. Reprinted from Flint et al (2010)

B. Water volume and availability

It is well known that there is a high demand on water resources from different sectors (See Figure 15, Figure 16, Table 3, Table 4). In 1990 water withdrawals were 42.8 km³ in 1990, ten years later this has increased to 66 km³. However, back then the amount of water used was lower than the availability of renewable water resources to Iraq each year (75 BCM) (World Bank, 2007). Nevertheless, the demand has currently exceeded the supply and will continue to exceed in the near future.

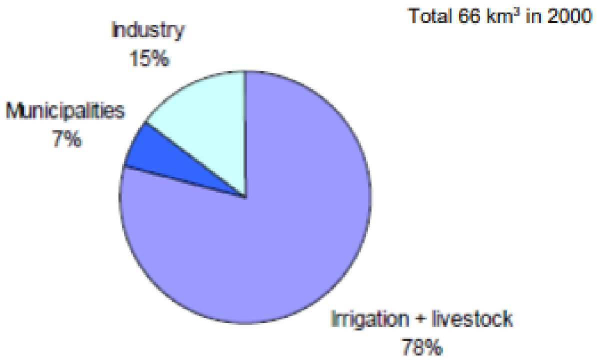

Figure 15: Water withdrawal by sector in 2000. Reprinted from Bishay (2008)

Table 3: Water withdrawals by sector and water sources. Reprinted from Bishay (2008)

Water withdrawal			
Total water withdrawal	2000	66 000	10^6 m³/yr
- irrigation + livestock	2000	52 000	10^6 m³/yr
- municipalities	2000	4 300	10^6 m³/yr
- industry	2000	9 700	10^6 m³/yr
• per inhabitant	2000	2 632	m³/yr
Surface water and groundwater withdrawal	2000	65 992.6	10^6 m³/yr
• as % of total actual renewable water resources	2000	87.3	%
Non-conventional sources of water			
Produced wastewater		-	10^6 m³/yr
Treated wastewater		-	10^6 m³/yr
Reused treated wastewater		-	10^6 m³/yr
Desalinated water produced	1997	7.4	10^6 m³/yr
Reused agricultural drainage water	1997	1500	10^6 m³/yr

Table 4. 2010 water demand by sector. Reprinted from Dunia Frontier Consultants, 2013).

2010 Water Demand by Sector[xv]	
Sector	Demand cubic meters/year
Drinking water	3,780,000,000
Industrial Usage	2,720,000,000
Agricultural/irrigation	42,000,000,000
Marsh renewal	19,600,000,000
Evaporation	8,400,000,000
Total	76,500,000,000

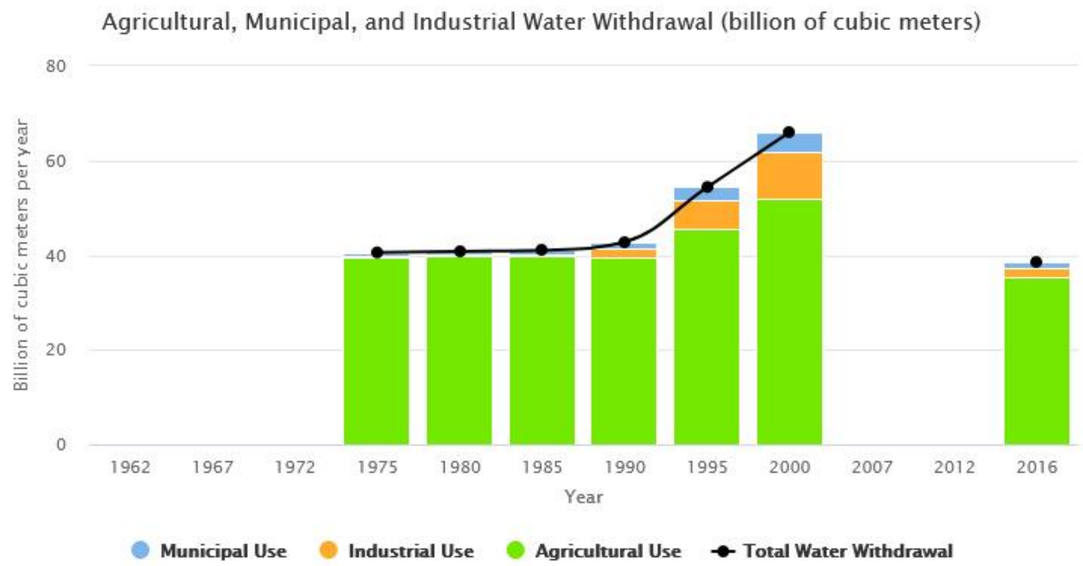

Figure 16. Water users and volume according to Worldometer, based on Aquastat, UN and World bank data. Reprinted from https://www.worldometers.info/water/iraq-water/

Distribution network in Iraq has deteriorated after 1991 due to political unrest and decrease in water availability. Before 1991 100% of safe water was supplied in the urban areas and 54% in the rural areas, but afterwards this decreased to almost 73% for urban areas and 45% to rural areas. For 17% of all households, it takes an average of 21 minutes by foot (urban areas) and 42 minutes (rural areas) to access safe water. Table 5 shows three water usage scenarios in relation to water availability (Al-Ansari, 2013). According to Abd-El-Mooty et al. (2016)

domestic water used per capita per day was calculated to be 251.42 litre and he advises that this amount should be reduced to 150 litre/capita/day.

Table 5. Scenarios of domestic water availability and demand. Reprinted from Al-Ansari (2013)

Water Usage (liters/capita/day)	Population (millions)	Water Demand/Day (million cubic meters)	Water Supply/Day (million cubic meters)	Balance (million cubic meters/Day)
350	24	8.5	6.8	−1.7
250	24	6	6.8	0.8
200	24	3.6	6.8	3.2

Increase of demands for freshwater is due to population growth as well as increase of contamination events from untreated wastewater and agricultural return flows. Research was conducted on the estimation of freshwater availability in the Shatt Al-Arab River.

According to Al-Asadi (2017), in 2010 following a census estimation it showed that the Iraqi population present in the Shatt AL-Arab River Basin was 28.60 million people, of which 18.40 million (64.33%) lived along Tigris River and 10.20 million (35.67%) along Euphrates River. Considering a population growth of 2.7% per year between 2000 and 2005. Using this population growth factor, the following prognoses on water balance in Shatt Al-Arab was calculated (Table 6).

Table 6: Water balance (km³/year) of whole river basin. Reprinted from Al-Asadi (2017)

Year	Total water available	Total conception	Water balance
2000	106.02	51.29	+54.73
2010	100.83	60.36	+40.47
2020	95.91	67.54	+28.37
2030	91.21	78.65	+12.56
2040	86.77	94.64	-7.87

C. Available water resources

Natural water resources

The major water sources of Iraqi irrigation system are the Tigris and Euphrates rivers, which feed a system of 25 dams and reservoirs, 275 pump stations, and an irrigation canal network of 27,000 km length. These basins constitute around 50% of the cultivated land in Iraq. The extensive use of groundwater for agricultural purposes is also common (Saleh et al., 2020).

The following section provides more information on the main natural water sources:

- The main rivers: Euphrates, Tigris, Diyala, Karkeh, Karun
- Marshland
- Groundwater

Figure 17 and Figure 18 show the natural water system and their catchments in central-southern Iraq.

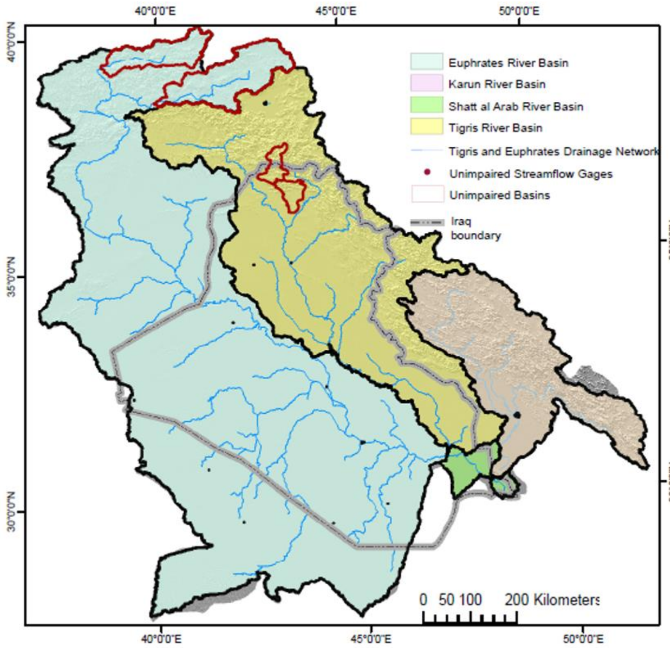

Figure 17. Map of Tigris Euphrates River System and major river basins. Adapted from Flint et al. (2010)

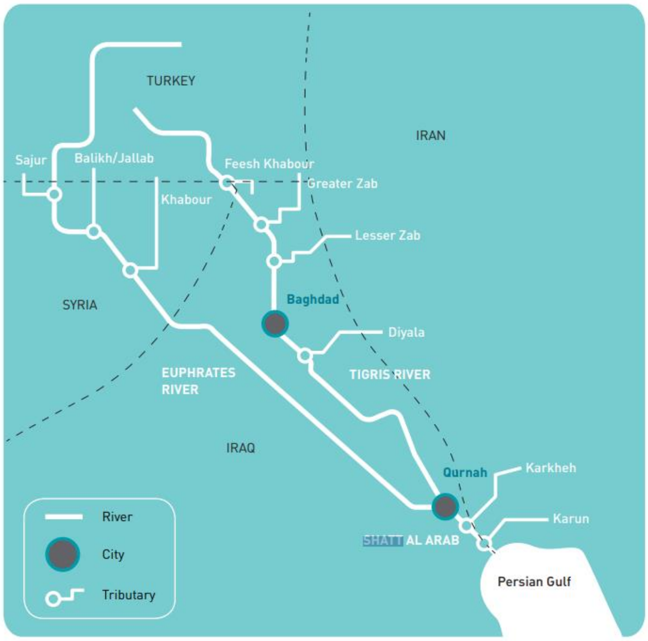

Figure 18. Schematisation of the Mesopotamian River system. Reprinted from UN-ESCWA and BGR (2013)

Euphrates

The Euphrates River (~ 2730 km long) originates in the Armenian Highlands, flowing south and joining the Tigris at Qurnah into the Shatt al Arab River discharging into the Gulf. Before reaching the Mesopotamian plain the Haditha Dam restricts the flow of the river and creates Lake Qadisiya. The river widens below the city Hit as it enters the alluvial plain with a width of 250 m (Al-Ansari, 2020). Its basin covers a total area of 673,000 km².

The maximum discharge period for the Euphrates is shorter and later than that of the Tigris and is usually confined to April and May. Within these two months, discharge accounts for 42% of the annual total. From August through October minimum flow occurs, contributing only 8.5% of the total. Discharge lied around 33 km³ per year before 1970s. Peak flows in the Tigris also occurs between April and May. Minimum flow conditions are from August through October and make up 7% of the annual total (Murakami, 1995).

By the end of 1980, while dams were built upstream in Turkey and Iran, discharge decreased to 8 km³ per year. During the nineteenth century the rehabilitation of several ancient canals led to the Tigris-Euphrates lowlands recovery (Murakami, 1995; Al-Ansari, 2020). According to Issa et al. (2014), in 2014 Iraq received 25.52 km³ from the Euphrates. The annual decrease of the water inflow was estimated at 0.245 km³ per year from 2014. In 2018 the annual flow in Hit was about 4 km³ (Al-Ansari, 2018).

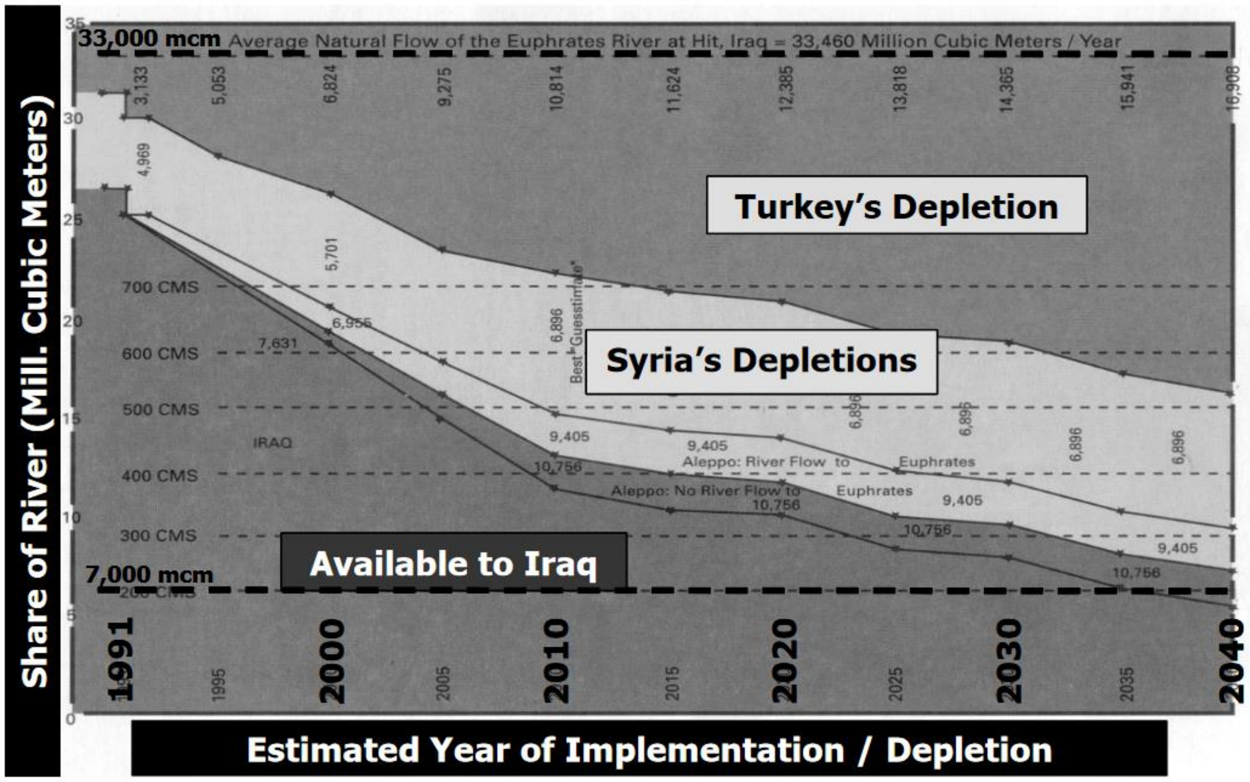

Figure 19. Euphrates water availability 1991-2040 in Turkey, Syria, and Iraq

Tigris

As the second-longest river in southwest Asia after the Euphrates River, the Tigris (around 1800 km) originates from the southern slope of Toros Mountains located in southwest Turkey. The river flows approximately 1430 km in the Iraq before its confluence with the Euphrates. Its basin covers a total area of 221,000 km² and 56.1% of it lies in Iraq. Flowing through tributaries and dams, the river has a mean annual discharge of ~25 km³ and an average discharge at Bagdad of 1,140 m³/sec.

Unfortunately, flow of the Tigris varies annually, causing damaging floods and, during drought periods, severe impairment of irrigation and agriculture (Flint et al., 2010).

Table 7 and Table 8 provide further quantitative information about both rivers.

Table 7. Tigris-Euphrates Basin Facts 2013. Reprinted from Bachman et al. (2019)

Basin Facts	Tigris River	Euphrates River
Riparian Countries	Iran, Iraq Syria, Turkey	Iraq, Syria, Turkey
Basin Area Shares	Iran 19%, Iraq 56.1%, Syria 0.4%, Turkey 24.5%	Iraq 47%, Jordan 0.03%, Saudi Arabia 2.97%, Syria 22%, Turkey 28%
Basin Area	221000 km2	440,000 km2
River Length	1,800 km	2,786 km
Mean Annual Flow Volume	20 BCM (Mosul, Iraq Station), 25.7 BCM (Kut, Iraq Station)	26.6 BCM (Jarablus, Syria Station) 27.1 BCM (Hit, Iraq Station); ~30 BCM (Before damming: 1930-73);
Riparian contribution to annual discharge	Turkey: 40-65% Iraq: 10-40% Iran 5-25%	Turkey: 89% Syria 11%
Projected Irrigated Areas (in Basin)	~4.6 million ha	~2.3 million ha
Basin Population	23.4 million	23 million
Main tributaries	9 (Batman, Botan, Feesh Khabour, Greater Zab, Lesser Zab, Adhaim, Diyala, Tib, Dwairej)	5 (Karasu, Murat, Sajur, Balikh/Jallab, Khabour)

Table 8. Tigris and Euphrates water volumes entering Iraq in 2003 (World bank, 2014)

	Current Mean flow (BCM)	Mean flow from outside Iraq (BCM)	% from outside
Euphrates	19	19	100 %
Tigris	48	32	67 %
Groundwater	1		-
Total	**68**	**51**	**75%**

Diyala

Most main tributaries in Iraq lie in the north, except for the Diyala River. The Diyala River originates in the Zagros Mountains in Iran, has a length of 445 km and a draining area of 32,600 km², and feeds the Tigris about 31 km south of Baghdad. It contributes around 182 m³/sec to the Tigris discharge (Al-Ansari et al., 2019; Chabuk et al., 2020). Diyala discharge is also strongly seasonal. High peak flow occurs in April and low seasonal flow occurs from July to December. 23% of the Diyala basin is used for agricultural activities (Abbas et al, 2016).

The Diyala River basin suffers from water scarcity and contamination, posing an increasing problem for Diyala City, which relies on the river as its main source of water. According to Abbas et al. (2016), Diyala water resources will further deteriorate in the future.

Karkeh, Karun, Shatt-Al-Arab

The Karkeh River forms the border between Iran and Iraq. Even though most of this river basin is in Iran, its influence provides important freshwater inputs to the Mesopotamian marshlands and the estuary (UN-ESCWA and BGR, 2013).

Just like the Karkeh River, the Karun River is not considered a tributary in Iraq and does not cross any political boundary, but has a primary impact on the salinity intrusion along the Shatt al-Arab river and forms an important part of the transboundary river system. With a catchment of about 67000 km³ this river is considered the most significant downstream tributary. The river originated in the Zagros Mountain and flows into the Euphrates joining the Shatt al-Arab river depositing large amounts of silt (Sadeghian et al, 2003; UN-ESCWA and BGR, 2013)

Historically, the Euphrates and the Tigris used to both reach the Gulf separately, but the growth of their deltas eventually created a large marshland area that eventually formed one river, the Shatt al-Arab (Kornfeld, 2009). At Qurnah city the Tigris and Euphrates join and form the Shatt al-Arab river, which flows south around 190 km before joining the Gulf. With a drainage area of 80,800 km², its annual discharge is about 35.2 km³ at Al Faw along the Gulf (Issa et al., 2014; Ansari, 2019). Figure 20 shows the water contribution to the Shatt al-Arab river.

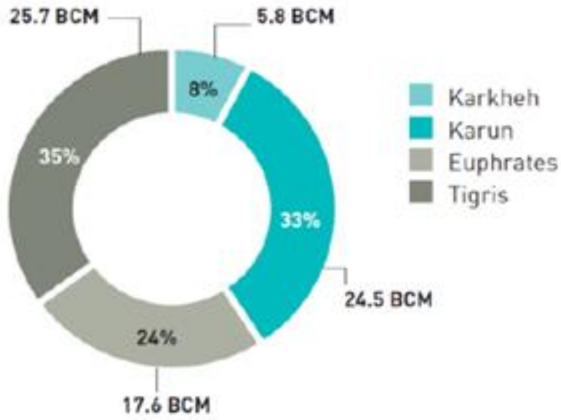

Figure 20. Water contribution to the Shatt al-Arab. Reprinted from Ansari (2019)

Marshlands

The marshes of Iraq (Figure 21) lie in the southern part of Mesopotamia and are considered one of the most important wetlands in the world due to their richness and diversity in flora and fauna (Clingendeal and BGR, 2018; Al-Zaidy et al., 2019).

Figure 21. Historic and current marshland area in southern Iraq (Fitzpatrick, 2004)

According to Al-Zaidy et al. (2019) their chemical and ecological properties provide four key functions:

1. Production function – suitable environment for harbouring fish resources.
2. Regulation function – contributing to flood control, water supply, water storage, water quality and erosion control.
3. Biological function – freshwater marshes associated with rivers are highly productive ecosystems and regulate carbon sequestration from the atmosphere.

4. Information function – source of information about aquatic species and natural processes and provides data on cultural heritage.

The marshlands once covered more than 15,000 km², but currently only around 10% remains. Since the 1950's the marshes have been drained to recover land for agriculture and hydrocarbon exploitation, with a strong surge in drainage during the 1980's and 1990's for political reasons. Since 2000 it has restored somewhat, to around 10% of the original area in 2003, and the marshes are currently a UNESCO Heritage site. However, climate change, characterized by rising temperature and droughts, now pose the greatest risk (Albarakat et al., 2018; Hashim et al., 2019), along with decreasing river discharge from the Mesopotamian basin.

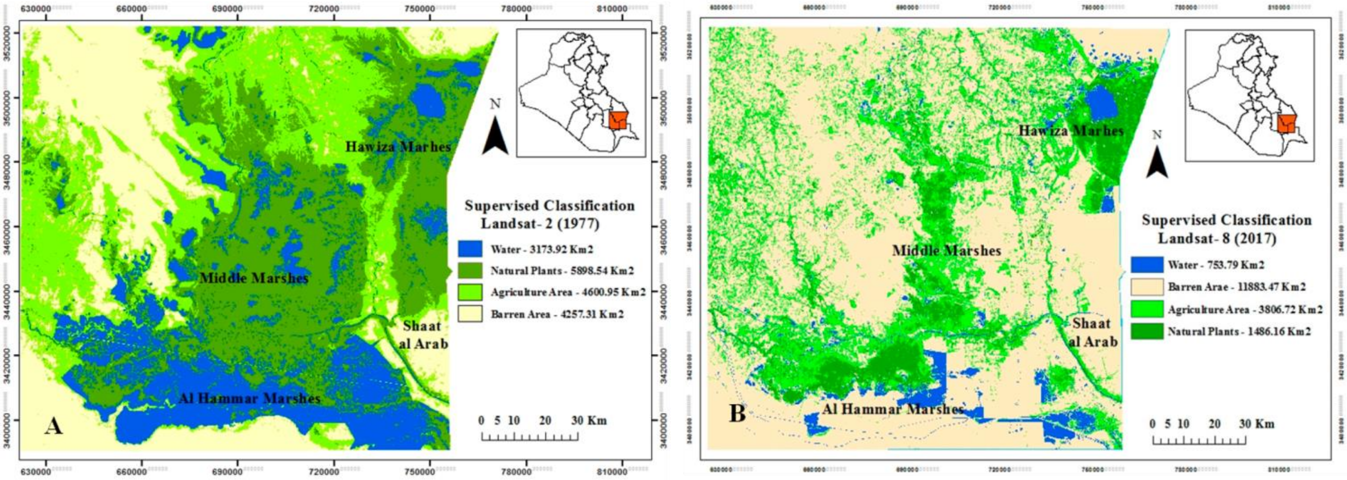

Figure 22. Landsat satellite imagery showing decreasing marshland in SE Iraq between 1977 (left) and 2017 (right). Adapted from Hasim et al. (2019)

Natural lakes

Al-Tharthar lake (see Figure 13) lies in the centre of Iraq around 120 km northwest of Baghdad and is known as the largest natural lake in Iraq. Although the lake is nutrient poor, it is one of the most important sources for irrigation in the surrounding area. Its size varies seasonally, and an annual decrease in size has been documented from around 2358 km² in 2001 to around 1688 km² in 2012 (Dawood et al., 2018).

Al-Habanyah lake is the second largest lake and lies near the Ramadi city. Its function is to store floodwater from the Euphrates and partly provide water for irrigation (Britannica, 2012; Dawood et al., 2018). Against the trend of reducing water volumes, this lake has grown from 2018 and 2020. See Figure 23. It seems to be caused by exceptional wet years during winter in 2018/2019 and 2019/2020 where most dams were filled up quickly (Patel, 2020). However, after 2020 the dry trend continued.

Figure 23: Satellite images of the Al-Habanyah Lake from 2018 (left) and 2020 (right). Reprinted from Patel (2020)

D. Groundwater (Aquifers)

Groundwater, depending on storage condition and underground flow, can be classified into 5 physiographic categories: mountains, highlands, Al-Jazeera (Upper Mesopotamia), the desert area and alluvial plain (Lower Mesopotamia). Total annual groundwater use in Iraq has reached 3.117 billion m3, with the following usages (MWR, 2016).

Most aquifers in Iraq are non-renewable. Due to extensive use over the past 30 years aquifers have been depleted and their hydrogeological conditions have changed. As a result, sustainability of groundwater use is being threatened, while there is no monitoring of high consumption. Moreover, due to climate change, extreme droughts and decreasing rainfall have led to groundwater abstraction exceeding recharge (UN-ESCWA and BGR, 2013).

The aquifer systems in Iraq range between the age of Quaternary and Palaeozoic time and are mostly made by sedimentary rocks formed around the Tertiary. Terrains with high groundwater content can be found in river terraces and alluvial fans which were deposited during the Pleistocene era. However, their reach is limited to the river courses and down the ridges. Most of the groundwater here is fed by the rivers. These aquifers also contribute to the development of marshlands (Al-Jawad et al., 2018). Most recent deposited aquifers are majorly present in the Mesopotamian Plain and Al-Jazeera zone (Al-Jawad et al., 2018).

In the south, the Dibdibba formation extends at the surface over the southern part of Iraq (Figure 24), where it forms an unconfined, or locally semi-confined aquifer. Groundwater salinity ranges from 1,000 (shallow) to 15,000 (deep) mg/l TDS.

The Dibdibba formation is characterized by medium coarse sand and sandstones with calcareous cement. Near Basra, the Jojab layer (clay stone layers) separates the aquifer layer creating aquifer layers with different hydraulic conductivity values (Al-Sudani, 2019). Water type of the upper layer is generally of calcium or sodium carbonate, deeper groundwater is sodium chloride dominant. The concentration of Boron was found to be relatively high ranging between 0.9 and 2.5 mg/l (Sadeq et al, 2018).

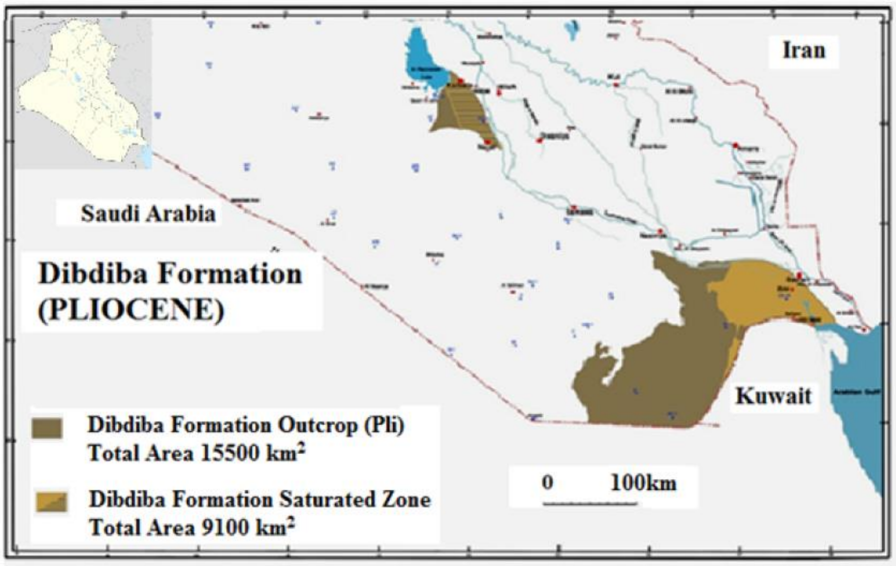

Figure 24. Extension of Dibdibba outcrop, corresponding to the margins of the Dibdibba aquifer (JICA, 2016).

Although agricultural activities are relatively marginal here, in southern Iraq outside the Mesopotamian basin, groundwater is used for irrigation. A salinity map is shown in Figure 25.

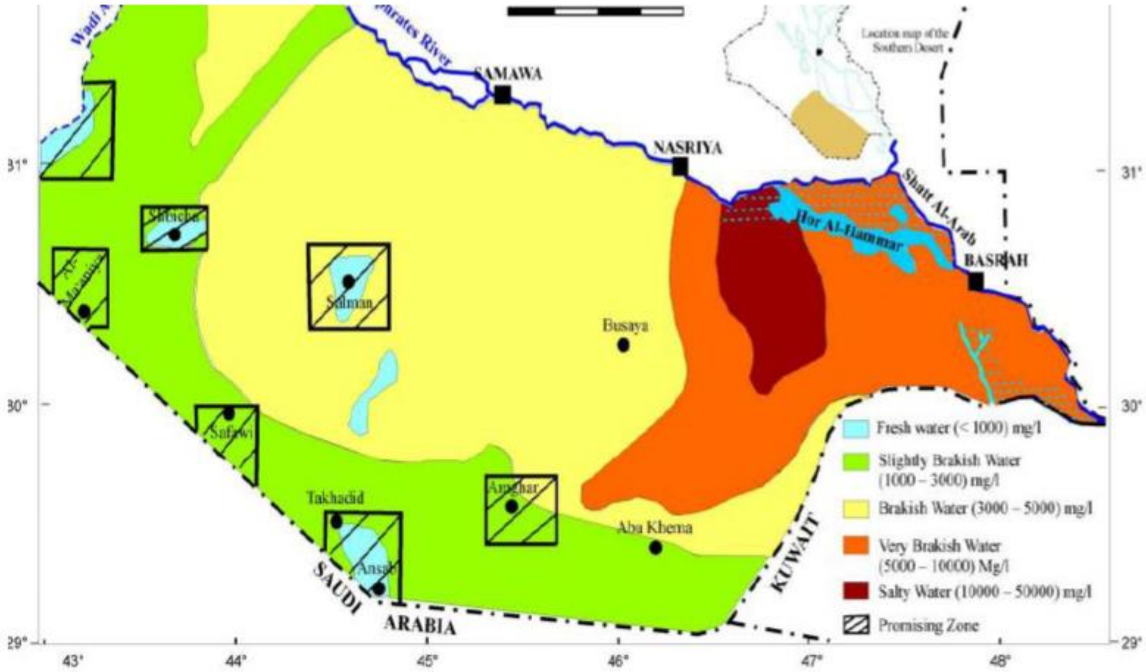

Figure 25. Hydrochemical map of groundwater salinity in the southern desert (2013). Reprinted from Salih et al, 2020.

Groundwater in the marshes is nowadays mainly fed by rainwater and floods. Here, the underground water storage is semi-open, and thus not confined. Depending on the topography of the region, groundwater flows according to the hydraulic gradient from high-pressure zones to low-pressure zones (Al-Zaidy et al., 2019). Recharge occurs mainly in the winter season and through infiltration from the Euphrates and Tigris. During the summer, groundwater is discharging to the rivers, but this discharge has decreased severely over the years due to over abstraction and decreasing recharge levels (UN-ESCWA and BGR, 2013).

At the center of the marshlands, groundwater levels are shallow and do not exceed one meter above sea level in some areas. Around 400 to 900 m³/day can be extracted from the wells in this area (Al-Zaidy et al., 2019). On average, the depths of groundwater between the Euphrates and Tigris go from less than 10 meters in the south of Baghdad and decreases towards the south reaching around one meter in certain areas of Basra (Saleh et al., 2019).

Along the western margins of the Mesopotamian basin, the Damman aquifer lies at the surface, with varying salinities. This ranges from 3,000-5,000 (shallow, generally in north) to order 80,000 mg/l TDS (south, deeper). Abstraction from the aquifer is in a practical sense not relevant to agriculture.

E. Artificial Water Storage

Iraq has a network for several reservoirs (dams) to manage its water resources. Flood peaks are managed using the storage capacity of on-stream dams and barrages as well as some off-stream topographic depressions. The Tigris is regulated by Mosul Dam and Dokan Dam on the Lesser Zab (a tributary to the Tigris) and Samarra Barrage. In case of extreme events where the Mosul and Dokan dams are not able to reduce flood peaks to acceptable values for the Baghdad reach, Samarra Barrage is the next point downstream that can manage flows coming from the upstream reservoirs (in addition to flows entering from the Greater Zab) and can divert water to Tharthar Lake. Haditha Dam and Ramadi Barrage regulate flows on the Euphrates. Ramadi Barrage can divert flows from the Euphrates to Habbaniyah Lake, and Al-Majarra canal conveys flows from Habbaniyah Lake to Razzazza Lake in the event of large flood events.

Iraq started building dams in the first half of the twentieth century to protect Baghdad, the capital, and other major cities from floods. The first large scale dam called “Dokan” was constructed in 1959 on the Lesser Zab River. Later, dams were constructed for irrigation and power generation purposes. Now, each of the dams are operated to manage the water distribution to municipal, industrial, agricultural, and environmental users and to provide downstream flood hazard protection. None of these dams were filled to their maximum storage capacities during the twenty first century. This is due to the depletion of flow in the Euphrates and Tigris Rivers by the Turkish and Syrian dams (Al-Ansari, 2013).

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A schematic diagram of the main water control structures is provided in Figure 26.

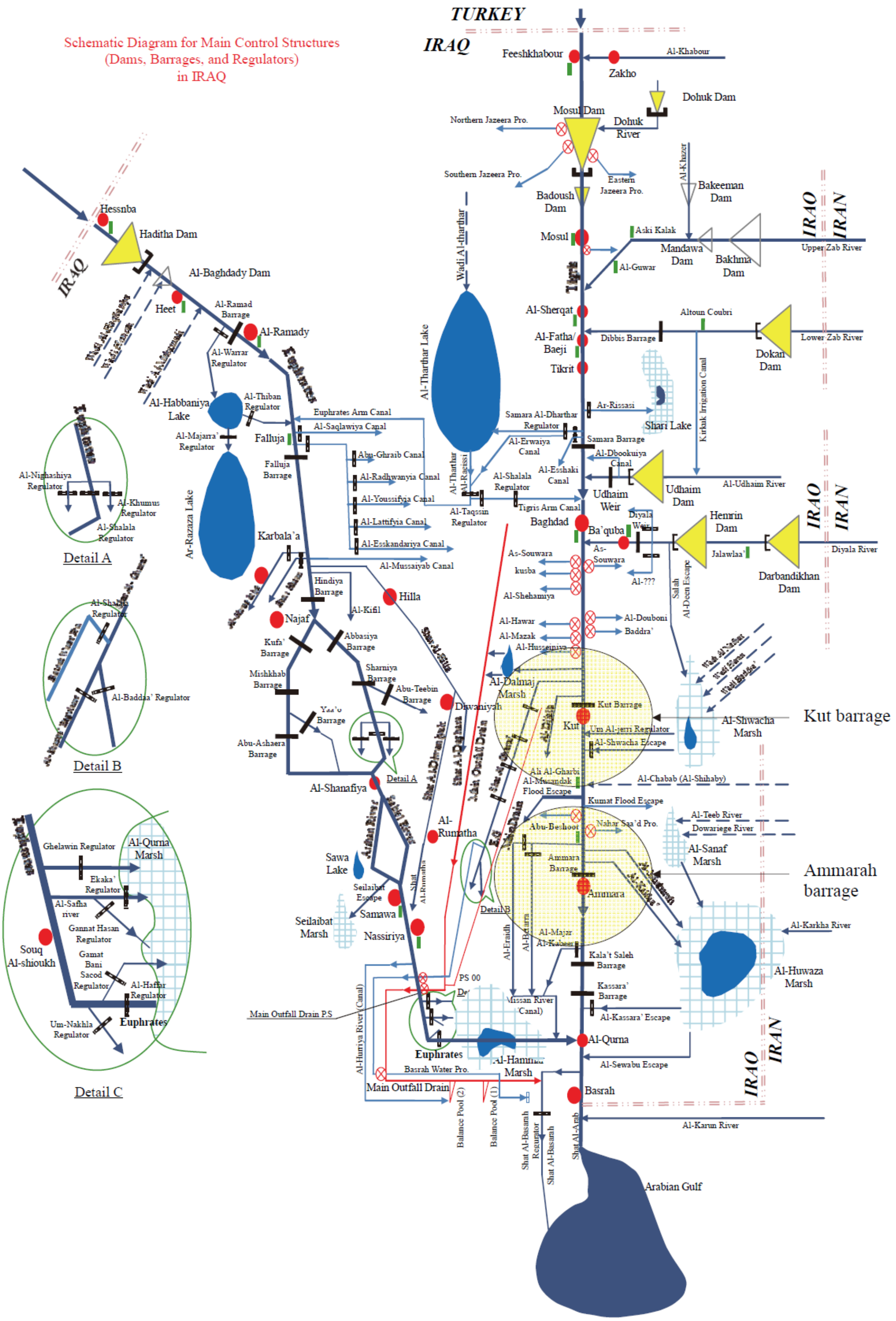
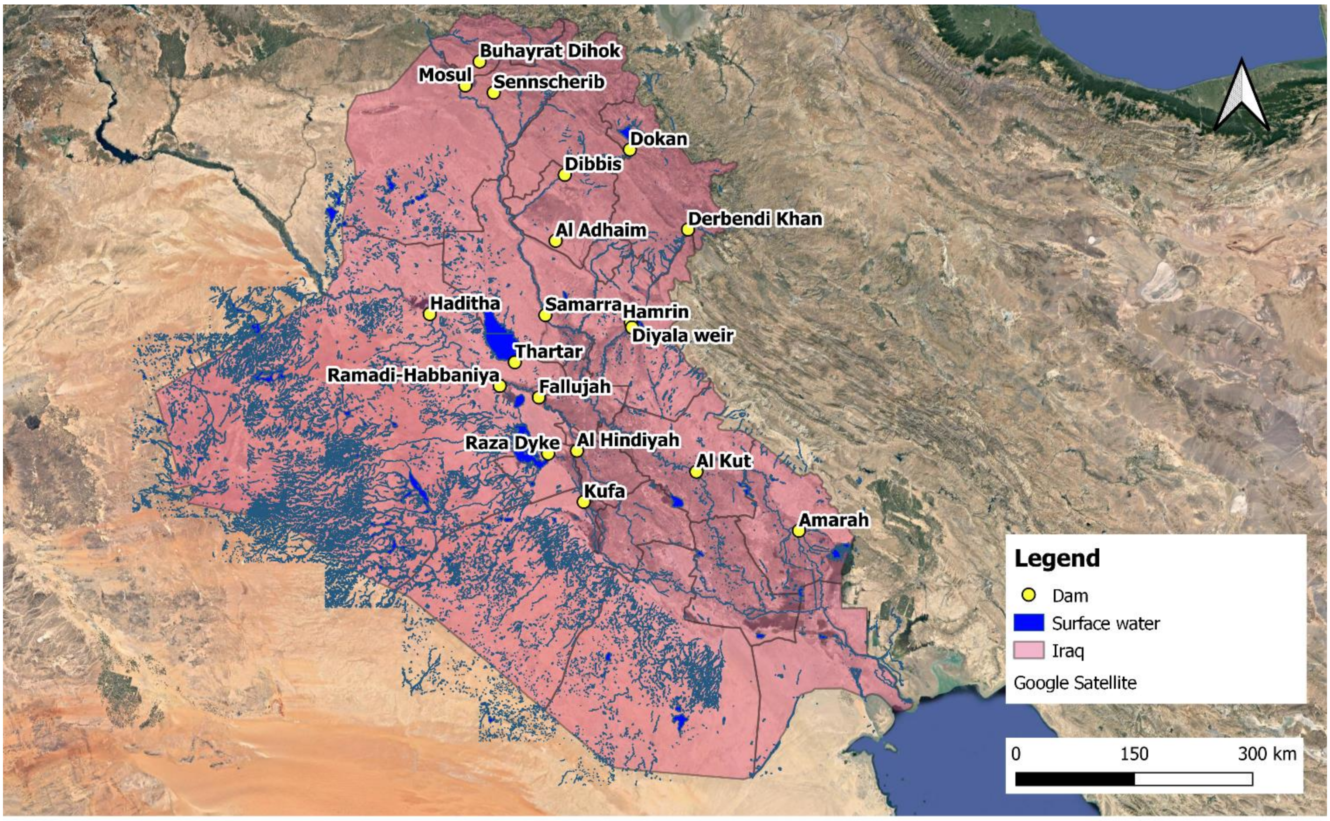


Figure 26. Schematic diagram for main control structures (dams, barrages, and regulators). Reprinted from Jica, 2016.

In Figure 27 an overview of dams is shown with details for each dam. The Senncherib dams were built on the spillways of the Khosr River around B.C. 694 by the Assyrian King Sennacherib. The dams were to supply water to the then Assyrian capital city Nineveh. Remains of the dams still exists, but no longer in use (Chanson, 1994). While the Haditha Dam was formed the old town of Anah and other settlements were submerged, as well as a large part of the agricultural base of the middle Euphrates (Loyd et al., 2016).



Name of dam	Administrative Unit	River	Dam height (m)	Reservoir capacity (million m3)	Reservoir area (km2)	Irrigation	Water supply	Flood control	Hydroelectricity (MW)
Ramadi-Habbaniya	Anbar	Euphrates	0	3300	0	x		x	
Samarra	Salaheldin	Tigris	0	0	0			x	
Sennscherib	Ninevah	Tigris	0	0	0				
Tharthar	Salaheldin	Euphrates	0	85000	1698.8	x			
Buhayrat Dihok	Dahuk	Euphrates	0	0	0				
Al Adhaim	Salaheldin	Adhaim	76.5	0	0	x		x	x
Al Kut	Wasit	Tigris	0	0	0				
Dokan	As Sulaymaniyah	Lesser Zab	116	6800	270	x			
Derbendi Khan	As Sulaymaniyah	Diyala	128	3000	121	x			
Dibbis	Ta'meem	Lesser Zab	15	3000	32	x			
Raza Dyke	Kerbala	Euphrates	18	26000	1330.3				
Hamrin	Diala	Diyala	40	4000	440				
Mosul	Ninevah	Tigris	131	12500	326	x			
Haditha	Anbar	Euphrates	57	8200	500	x			x
Fallujah	Anbar	Euphrates	0	0	0	x			
Al Hindiyah	Babil	Euphrates	0	0	0			x	
Kufa	Al-Najaf	Euphrates	0	0	0				x
Amarah	Maysan	Tigris	0	0	0	x			
Diyala Weir	Diyala	DIyala	0	0	0			x	

Figure 27. Overview of existing dams in Iraq and their details. The value zero indicates that there is no information available, or the dam is no longer in use. An "x" here denotes the dam is used for this purpose. Source: Open data from AQUASTAT (2008)

In the Diyala River within Iraq three dams have been built (Derbendi Khan, Hamrin, Diyala weir) for multiple uses. However, no significant influence on flow volumes and flow regime has been detected (Abbas et al., 2016). The Hamrin Lake is about 50 km northeast of Baguba and it functions as a source for fisheries and provides water to nearby palm groves and other agricultural areas. However, due to the Iranian dam of the Lund River the lake has lost about 80% of its capacity (Dawood et al., 2018)

Ramadi Dam was constructed in 1948 to supply water to the Warrar channel for flood control. Excess waters are supplied to Habbaniya. This channel was designed to discharge 2800 m^3/s of water over a length of 8.5 km. Storage water in the Habaniyah Lake returns to the Euphrates River through the Dhiban Channel located around 42 km south of Ramadi City. Habaniyah Lake does not have the capacity to store excess water during high floods. Which is why this lake was connected to Razazah Lake and then to Abudibis marsh (Al-Ansari et al., 2018).

The Kut Barrage was constructed to secure water levels for Gharraf Channel and currently functions for navigational purposes as well. Construction started in 1936 by a company named Balfour Beatty from England. It contains a discharge capacity of 6000 m^3/s. A fish ladder is constructed at the right side of the dam. In 1991 the barrage was partly destroyed by an air attack but was later renovated by the Iraqi government. (Abdullah et al., 2019).

In 1989 the Chinese Engineering Company constructed the Al Hindiya Dam, consisting of 6 openings with a maximum discharge of 2,500 m^3/s. Its purpose is to manage high floods and produce energy. Eastern part of the dam a 600-meter navigation channel links Hillan Canal and Euphrates River. It contains a project a residential complex for workers and a railway bridge for Musayab-Karbala railway (Abdullah et al., 2019).

Teheran has built several dams at three tributaries (Little Zab, Diyala and Karkeh) in the past 10 years. These tributaries account for 9 to 13% of the Tigris River. This has resulted in reduction of river flow for the central and southern part of Iraq. Land and environmental degradation accelerates, particularly in the Marshes. Discussion for a better cooperation with Teheran did not result in any concessions for Iraq (Aboulenein et al., 2018).

Between 2014 and 2016, ISIS controlled over the Mosul Dam, Samarra Dam, Ramadi Dam and Fallujah Dam to weaponize themselves for offensive purposes. In April 2014 they closed the Fallujah Dam to prevent Iraqi militaries from advancing against them (Mazlum, 2018). The condition of Iraq's water infrastructure has become worse and worse over the last 10 years. Poor maintenance, poor water managements and the impact of several conflicts and wars ranked the country as one of the poorest water infrastructures worldwide (UNEP, 2017).

The available capacities for hydropower are not used intensively due to water shortage and most navigation infrastructures are not fully used as planned. In the lower reach of Tigris and Euphrates maintenance are not sufficient. Survey, and updated operation and maintenance manuals are needed to increase their efficiency (Abdullah et al., 2019).

F. Wastewater

According to the Iraqi Ministry of Environment report in 2013, the number of sewage disposal stations for the whole of Iraq is 314 stations. Most of these stations are draining the wastewater, without sufficient chemical treatment, directly to the nearby rivers. This because the amount of water entering the WWTP is greater than its design capacity, and to the lack of maintenance operations.

The amount of sewage water generated in Baghdad alone is estimated at 1,200,000 m^3/day (equivalent to 438 million cubic meters annually), part of which is drained to sewage networks, and the bulk of it is discharged to water sources such as Tigris River, drains, and other water bodies without treatment. In total, the annual amount of treated wastewater is about 580 million cubic meters in recent years for all of Iraq. Treatment is carried out in different ways (primary, secondary, biological, activated sludge, aerobic and anaerobic oxidation ponds).

In general, the total capacity for sewage treatment is very weak in Iraq compared to the quantity of drinking water currently produced – the amount of net water production in 2013 amounted to 4,866 billion cubic meters – and required in the future considering the expected increase in the population and the improvement of the health situation. It is expected that the amount of wastewater generated in the future will reach (6.4) billion cubic meters, which is a large amount that should be utilized.

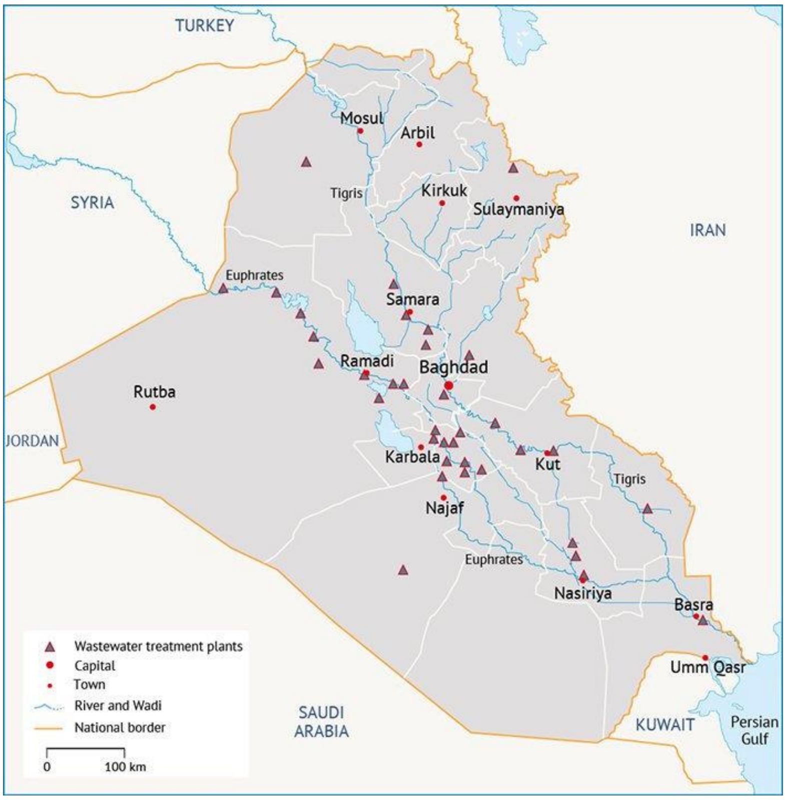


Figure 28. Locations of wastewater treatment plants in Iraq (Strategy for Water and Land Resources in Iraq; Iraqi Ministry of Water Resources: Baghdad, Iraq, 2014.)

It is necessary to pay attention to increasing the number of treatment plants to include all areas of population centres and to develop the existing ones to treat all quantities of sewage water reaching them, and not to throw water directly into rivers without treatment. Wastewater should be treated in accordance with national environmental regulations and legislation. The treated sewage water can be used for industrial purposes, especially oil ones, as well as for feeding the marshes and municipal purposes (irrigating gardens, landscaping) and irrigating forest trees and green belts around cities. Therefore, the improving the wastewater treatment in Iraq will result of filling part of the national water security using the treated wastewater and demands and help the country to get rid of pollution in water.

There are stations to drain rainwater directly into the river, without any treatments or partial treatment (Al-Ansari et al., 2018). Therefore, using treatment units fully will tackle part of the water shortage problem. It could also be the best control method to stop spreading infectious diseases caused by contaminated waters (Al-Mossawai, 2014).

G. Irrigation and water management

The oldest hydraulic civilization of the world started in Mesopotamia. Agricultural systems were developed that were strongly related to the presence of water. Around 7500 years ago Sumerians built a canal to irrigate wheat and barley. Irrigation was then already important, because the Tigris and Euphrates carried several times more silt per unit volume of water, resulting in rising rivers and meandering courses. Records show that even during this time people fought over water rights (Adams, 1965).

Now, almost 70% of the country's cultivated area is under irrigation to compliment the lack of rainfall, while mostly in the northern part of Iraq the remaining 30% are under rain fed cultivation. Of the areas under irrigation, 62.8% receives water through gravity irrigation projects, 36% are pumped from rivers and major channels and 1.2% from ground water aquifers and springs. Total irrigated area ranged between 3.055 to 3.404 million ha in the 1990’s (Table 9). However, in 2017 the area that was irrigated was 1.564 million ha, in which 73% accounts for medium-to-high suitable land. In 1990 63% of the irrigated land was in the Tigris basin, 35% in the Euphrates an 2% in Shatt Al-Arab basin. Through the Saddam River drainage water from irrigation were drained to the Shat Al-Arab River using a network of sub-surface tile drains and surface drainage canals. This way, agricultural fields were kept free from salinization and water logging issues. Moreover, pumping station are used to elevate effluent water when necessary, draining towards the Gulf (AQUASTAT, 2017; Bishay, 2003).

Iraq invested in the irrigation system since the first half of the twentieth century. Irrigation was developed either by merely digging a channel on the riverbanks or by a series of barrages and weirs for raising water levels to facilitate off-take. From 1920 onwards, large landholders along the margins of the rivers also developed pump irrigation. The total land that suitable for agriculture in Iraq is about 11.11 million hectares (which is about 25% of Iraq's landmass), whereas land technically and economically suitable for irrigation is about 5.72 million hectares. The main irrigated crops are wheat, barley, rice, maize, vegetables, and dates. About 70% of the country's cultivated area is now under irrigation while the remaining 30% are under rain-fed cultivation. In some areas supplementary irrigation is used to complement rainfall, the entire natural rangeland relies solely on rainfall.

Table 9: Overview on potential irrigation. Adapted from FAO (2008)

Irrigation and drainage

Irrigation potential	2007	5 554 000	ha
Irrigation			
1. Full or partial control irrigation: equipped area	1990	3 525 000	ha
- surface irrigation		-	ha
- sprinkler irrigation		-	ha
- localized irrigation	1994	8 000	ha
• % of area irrigated from surface water	1990	93.8	%
• % of area irrigated from groundwater	1990	6.2	%
• % of area irrigated from mixed surface water and groundwater		-	%
• % of area irrigated from non-conventional sources of water		-	%
• area equipped for full or partial control irrigation actually irrigated	1997	3 404 000	ha
- as % of full/partial control area equipped		-	%
2. Equipped lowlands (wetland, ivb, flood plains, mangroves)		-	ha
3. Spate irrigation		-	ha
Total area equipped for irrigation (1+2+3)	**1990**	**3 525 000**	**ha**
• as % of cultivated area	1990	59	%
• % of total area equipped for irrigation actually irrigated		-	%
• average increase per year over the last ... years		-	%
• power irrigated area as % of total area equipped		-	%
4. Non-equipped cultivated wetlands and inland valley bottoms		-	ha
5. Non-equipped flood recession cropping area		-	ha
Total water-managed area (1+2+3+4+5)	**1990**	**3 525 000**	**ha**
• as % of cultivated area	1990	59	%

According to AQAUASTAT from over 2017, not much is known on irrigation methods over the irrigated area except that 8000 ha was used for localized irrigation. Here the water is distributed under low pressure through a piped network in a pattern, where small amount of water is discharged to each plant. This can be done by drip irrigation, spray or micro-sprinkler irrigation and bubbler irrigation.

Two ministries are responsible for irrigated agriculture in the Centre and South of the country, Ministry of Irrigation and Ministry of Agriculture. Ministry of Irrigation focuses mainly on water resources development, construction, maintenance, and operating irrigation infrastructures. Ministry of Agriculture is responsible for on-farm irrigation. In 1995, 1.5 billion US$ of equipment were supplied to Iraq through a UN programme called "UN Oil-for-Food Programme". This meant for example that worn-out components of pumping station and irrigation systems had to be replaced, irrigation machines for 40.000 ha, 50.000 irrigation pumps and 10.000 irrigation systems (centre pivot and sprinkler) were provided (Bishay, 2003).

Existing governmental irrigation projects are extremely important in the centre and southern Iraq. It is vital that adequate water supplies are ensured, through regular maintenance of the existing irrigation infrastructure, but also to any irrigation facility that might be damaged during the war (Bishay, 2003).

Maintenance

There are a set of challenges associated with irrigation in Iraq that need to be addressed. The first one is related to outdated and damaged irrigation infrastructure. Headworks have operated for a long time without maintenance or proper management plans. Most pumping stations were built in early 1970's and although many worn-out components have been replaced, hundreds of large irrigation and drainage pumping stations are still in poor state. Most are severely run down, and some can no longer be repaired. The primary, secondary and tertiary canal networks are also degraded due to lack of maintenance. Deterioration of canal linings, the outgrowth of weeds and sedimentation has reduced conveyance capacity significantly. With drainage system incomplete, FAO estimated that less than one-quarter of Iraq's area developed for irrigation is equipped for drainage. Many drains are blocked and many of the drainage pumps used for lifting effluents into the outfalls have broken down (SHWAN MOHAMMED 2018).

H. Water quality

The most prevalent water quality issues in the region are salinity and nutrient pollution from agricultural return flows and sewage. The drainage water from agriculture flows back to the rivers which carries fertilizers, pesticides and salts that are washed out of the soils. This results in rivers becoming saltier and more harmful (Bachmann et al, 2019). The salinity in some areas in the Alluvial plain is so high that it is no longer possible to use the water for irrigation purposes. Therefore, agricultural activities and food production have been declining over the last 10 years, especially in the provinces of Basra, Dhi Qar and Maysan (Clingendael, 2018).

According to UN-ESCWA & BGR (2013) the Euphrates River has reached alarmingly high levels of salinity as the river progresses to the Alluvial Plain and by the time the Tigris River reaches Baghdad its waters have become too salty as well. Research made by Chabuk et al. (2020) was conducted along the Tigris River on water quality. In this research, quality of the Tigris decreased more and more downstream (see Table 10) with a TDS level from 764 in Tarmiyah station to 1394 in Qurnah, surpassing more than 50% of the WHO standard value. The results also showed that the measured concentration values during dry season were higher than during wet season.

Table 10: Parameters concentrations along Tigris River in the wet season. Adapted from Chabuk et al. (2020)

Station	Distance (km)	X	Y	Ca	Mg	Na	K	Cl	SO_4	HCO_3	TH	TDS	BOD_5	NO_3	EC
Tarmiyah	650.5	438,111	3,700,862	93	66	77	6.8	105	450	187	908	764	4.1	8.9	1175
Muthanna Bridge	652.6	439,145	3,699,016	94	70	88	6.9	120	464	183	941	800	4.3	9.5	1231
Shuhada Bridge	701.4	453,880	3,675,739	95	74	94	6.9	145	468	180	972	850	4.5	10.2	1308
Aziziyah	828.1	506,020	3,640,265	96	77	100	7.1	180	474	176	1014	900	4.8	11.1	1385
Kut	976.7	573,481	3,599,129	98	88	110	7.4	220	478	176	1072	960	5.1	12.1	1477
Ali Garbi	1105.3	658,264	3,593,945	104	90	132	7.9	270	484	174	1136	1160	5.5	14.1	1785
Amarah	1236.0	702,802	3,526,406	109	92	150	8.2	326	496	172	1211	1356	5.9	15.9	2086
Qurnah	1374.9	732,823	3,433,509	110	95	170	8.4	360	517	168	1267	1394	6.9	17.1	2145
Standard value (WHO 2006)				200	200	200	10	250	250	126	200	500	5	10	1000

The situation is quite the same in the Euphrates. Where the salinity is quite acceptable in the Qaim city with a value of 600 mg/l, this increases significantly downstream with more than 1300 mg/l in Samawa (Elaiwi et al., 2020). During the 1970s Iraq started to connect the water from the Tigris to the Euphrates through Al Tharthar Lake. However, this lake is known for its high salinity levels surpassing even the salinity levels of the two rivers. Currently, a TDS of around 1500 ppm was measured, while that of Habania Lake is about 1000 ppm. Moreover, the Euphrates is used as a drain carrying the irrigation return from agricultural areas near the city Al Kufa. TDS levels of 1000 ppm were measured near Al Kufa, but increased to 4000 ppm at Al Samawa and 5000 ppm at Al Nassiriah. This may explain the increase in concentration of TDS along the reach (Rahi and Halilhan, 2010).

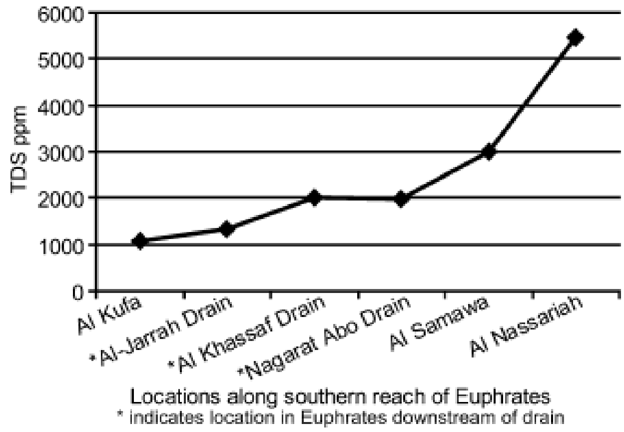


Figure 29. TDS in Euphrates in 2002. Reprinted from Rahi and Halihan (2010)

The water quality causes an increasing concern in the tributaries as well such as the lower part of the Karun River, especially during the summer season (Sadeghian, 2013). The water quality in the Diyala River contains high metal concentrations. The mean heavy pollution index is around 2097, which is far above the crucial value of 100. This indicates that the Diyala River is critically polluted, due to anthropogenic causes from agricultural, industrial, and urban sectors (Abbas et al., 2016). Around 40 years ago freshwater of Shatt Al-Arab in the lower basin were brackish, now levels of over 18,000 ppm have been recorded (Bachmann, 2019).

A groundwater quality assessment was done in 830 locations within the alluvial deposits. According to Al-Jawad (2018) a TDS equal to less than 1,000 mg/l was measured in the groundwater. The mean value ranges between 1160 and 2800 mg/l. However, in certain cracks a groundwater salinity level of 60000 mg/l or even higher can be reached (Al-Jawad et al., 2018). Unconfined aquifers that contribute to recharging rivers and contain high groundwater salinity may cause increase of salinity in the surface waters as well (Rahi and Halihan, 2010). In general, within the Mesopotamian Plain fresh water of around 600 mg/l are measured in wells drilled near surface water, freshwater bodies, or irrigation canals (Al-Jawad, 2018). According to Al-Sudani (2019), groundwater in Dibdibba aquifer is not recommended to be used for human and irrigation purposes, but even so farmers are using this resource for agricultural events.

The decline in water quality has also reached the Marshes. Marshes are at risk of drying up and salinity increase, due to reduced water discharge. Moreover, due to this reduction of water inflow seawater from the Gulf seeps in. This seawater intrusion pushes inlands up to around 73 km upriver and even higher at high tides reaching Basra, causing water and land degradation (Clingendael, 2018). Also, the use of motorboats to deeper areas of the marshes have caused increase in oil pollution along the waterways between main villages, where the total petroleum hydrocarbons (TPH) vary between 0.6 and 46.6 µg/l (Salman et al., 2021).

The average salinity level in Al-Hawizeh Marsh, a major marsh in the south of Iraq, reaches around 746 mg/l during winter season and 1956 mg/l during autumn season. This seasonal increase in average values is also seen for Sulphate (SO_4) and $CaCO_3$. SO_4 reaches an average value of 121 mg/l during winter and 202 mg/l during autumn. $CaCO_3$ reaches an average value of 84 mg/l during winter and 172 mg/l during autumn (Hasab et al., 2020).

High levels of Dissolved Oxygen (DO) are found in the southern marshes ranging from 5mg/l to 12.25 mg/l. During high water levels water becomes more aerated causing higher DO levels, whilst during low water levels and degradation or organic matter causes lower DO levels. Most marshes such as the Al-Hawizeh Marsh are well oxygenated, but some confined areas contain high organic matter production (Salman et al., 2021).

If the irrigated agriculture expands and untreated sewage are dumped into the rivers and their tributaries, water quality will continue to decrease (Bachmann et al., 2019). Maintaining a minimum instream flow (MIF), where freshwater flow that is controlled and not allowed for any anthropogenic use to maintain the health and biodiversity of a particular water entity (groundwater, rivers, marshes), is a concept that has been discussed in many studies and is considered a main option available to mitigate the salinity and pollution levels (Rahi and Halihan, 2010).

In the field of domestic water use, access to safe water from 77 to 98% of the population, depending on the location (Figure 30). Water quality for domestic and agricultural use does not meet the national and WHO standards by a factor 3 for organic contamination. Salinity is also an issue, with the Euphrates seeing an increase from ~450 ppm (1980s) to ~1200 ppm (2009). In 85% of households the chloride levels are too high. In 2018, 118,000 people in Basra were hospitalised due to symptoms related to water quality (Human Rights Watch, 2019).

Citing the UN (UN, 2013) "*The deterioration in water quality and the associated growing number of waterborne diseases calls for the development of a national water quality management strategy aimed at strengthening the coordination and collaboration among the various stakeholders, enforcement of monitoring standards, and reporting of water quality information.*"

With water tariffing extremely low compared to other countries, low awareness of water conservation and water losses in the supply chain, the daily water use lies at ~392 litres. "*A substantial rise in water tariffs should be applied immediately, together with a proper tariff system for irrigation water* (UN, 2013)."

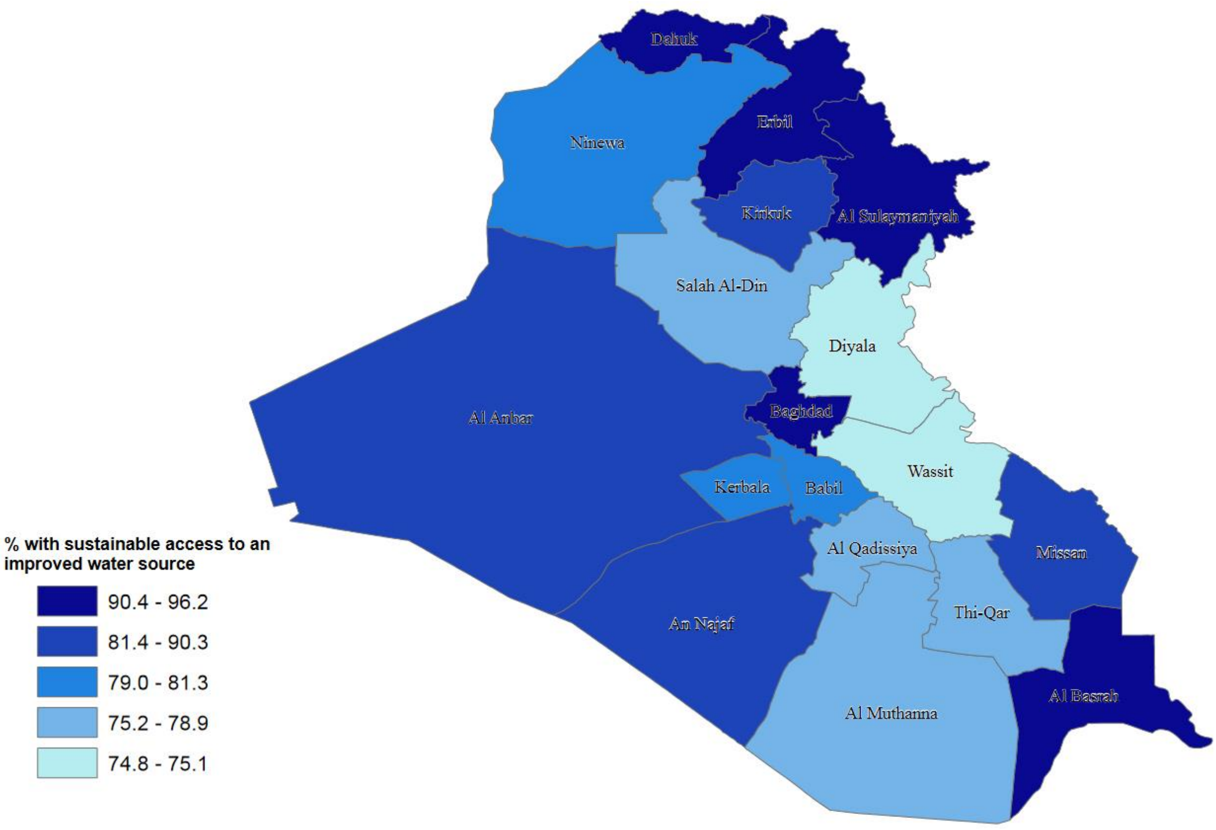


Figure 30. Population with access to safe water (UN, 2013)

Another central issue in water resources management is the protection of water quality. Iraq's irrigation water is not naturally saline. The problem has arisen from the combination of over-irrigation, poor drainage, and high evaporation rates. The increasing salinity of irrigation water is exacerbating many problems. The level of salinity in the Euphrates River is high and is expected to increase with the development of irrigation in the basin, particularly in the dry season. Consequently, irrigated cropping areas were diminished and productivity severely affected. Salinization and waterlogging have reportedly contributed to the abandonment of about 1.5 million hectares, which is 40% of the area developed for irrigation. Furthermore, the lack of a strategic policy for water in the region in addition to the absence of education that helps farmers to avoid abusing water.

I. Projected future developments

Waterflow from the rivers has reduced significantly since 1980 and is expected to further shrink by up to 50% before 2030. It has been estimated that the overall water supply will be reduced to 60% between 2015 and 2025. Consequently, energy production in Iraq will be heavily affected since Iraqi's large dams account for more than 75% of the country's electricity supplies (Clingendael, 2018).

Rivers will be facing big challenges in the future. The Shatt Al-Arab for example will reach freshwater deficit due to the decrease of water inflow for its tributaries. Now, the river receives only freshwater from the Tigris River, because of dam construction projects on its tributaries. It is expected that freshwater from the Tigris will not be able to Shatt Al-Arab in 2040. This leads to seawater intrusion increase into the river, which will lead to a significant change in water quality transforming from fresh to saline water. If this process continues, the seawater will progress further upstream reaching other tributaries. TDS concentration is expected to record highest levels in 2040 in the Shatt Al-Arab River and its progress will reach up north to Basrah city (Safaa and Al-Asadi, 2017).

Increase of salinity, droughts and fluctuating water levels in groundwater systems, Tigris, Euphrates rivers and their tributaries and continue to negatively impact agricultural development, unless more proper water access rights are agreed with neighbouring countries and modern irrigation techniques are more widely adopted to reduce wastage.

In 2019 the United Nations World Food Programme (WFP) started a project together with the Samaritan's Purse International Disaster Relief (SP) to rehabilitate irrigation canals. This project stimulates farmers who have been affected by IS to slowly return to their villages and farm fields and restore their vital irrigation canals. Providing farmers with much-needed water from the canals, farmers can plant their crops. Some even receive 2,000 US dollars to buy seeds and other agricultural equipment's (Xuxin, 2019).

After 2015 Iraq's water need has already surpassed its supply (Figure 31). From 2011 to 2014, Iraq started a project named "Strategy for Water and Land Resources in Iraq" (SWLRI). Figure 31 was a wakeup call to initiate this project. The gap between water demand and water supply only widens with time. SWLRI details a strategy to achieve efficient and sustainable water and land use for at least 20 years (2015 – 2035) and includes three main components:

1. Preparation of National Strategy for water and land resources management.
2. Preparing negotiation strategy on water for Iraq to achieve water sharing agreements with other neighbouring countries successfully.
3. Create and design institutionalization and training of a Project Management Unit to support the implementation of the SWLRI program.
   (Bachmann et al., 2019; Hussain and Qathan, 2021)

Their following actions are:

- Rehabilitate irrigation system infrastructure and to increase its operation levels and discharges.
- Rehabilitation of flood control systems such as expanding the Tigris – Thartar regulator to accommodate a flood of 135000 m^3/s instead of 9000 m^3/s.
- Rehabilitation of the drainage system to complete the drainage system from 45 large irrigation projects to Main Outfall Drain and to revive the mases.
- Water supply for municipal and industrial purposes to reduce water by rehabilitating existing water distribution networks and achieve a steady reduction in water losses in the network.
- Expanding sewage treatment plants so that the amount of municipal and industrial water treated increases from 0.55 to 2.08 billion m^3.
- Planting new crop composition that consume less water.

- Raiding total irrigation efficiency from 30 – 40% to 60% using modern irrigation methods and canal lining.
- Adopting operating policy where all municipal and industrial needs are secured, but accepting the possibility of a deficit in irrigation requirements.
- Regarding the management of water resources, coordination between the Federal Government and Kurdistan Regional Government is not seen as an option but a necessity.
  (Hussain and Qathan, 2021)

SWLRI is the first project where the Iraq government has officially allocated a minimum water amount to the Mesopotamian Marshes (Bachmann et al., 2019). However, Iraq will have to deal with some major challenges:

- Turkey continues with their development project called South-eastern Anatolia Region (GAP). 45% of this project focuses on construction of dams and other irrigation projects which are concentrated in the Euphrates basin. The rest are focused on controlling 80% of the water from both the Tigris and the Euphrates Rivers, resulting in an increased water import into Iraq.
- Iraq will continue to suffer from disputes between and with the upstream countries over securing its water share.
- Iran continues to implement dams and irrigation projects and divert courses of some important rivers such as the Karkha River. This river is the main source for the Hawizeh Marsh shared between Iraq and Iran. This will result in decrease of the marsh area.
- Iran diverted the course of Karun River. A source for desalination of the Shatt Al-Arab River. A catastrophic salty water intrusion from the Gulf can be expected.
  (Hussain and Qathan, 2021)

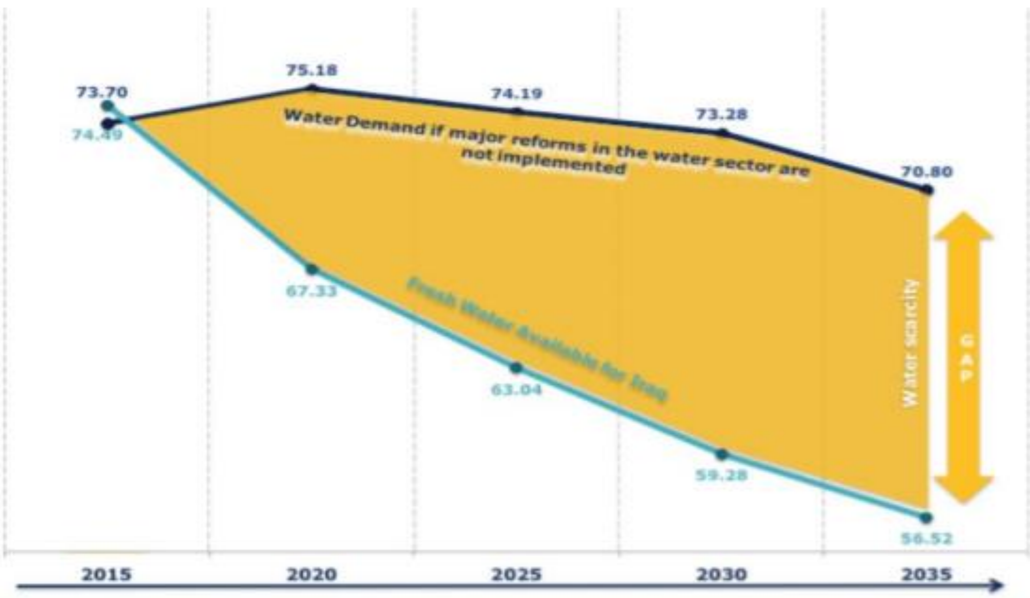


Figure 31. Iraq water supply and demand (million m³) without major water sector reforms. Black line represents the demand, green line the supply. Reprinted from Bachmann (2019)

Appendix B. Background information agriculture and salinity Iraq

This appendix highlights farming and agricultural practices in Iraq, and the issue of salinity in agriculture.

J. Agriculture in Iraq

Since the beginning of recorded time, agriculture has been the primary economic activity of the people of old Mesopotamia and modern-day Iraq. Mesopotamia is the ancient land of the “twin rivers” (the Tigris and Euphrates), with its bountiful land, fresh waters, and varying climates, contributed to the human civilization in many ways. The eastern limb of the Fertile Crescent was the cradle of the earliest known civilizations and served as the cultural heart from which the first ideas of sedentary agriculture, domestication of animals, the wheel, writing, and urban development are believed to have diffused westward to the Nile Valley and eastward to the Indus Valley.

Agriculture was the country’s major economic activity in the 1920’s; however, its contribution to the gross domestic product (GDP) dropped to 42% in 1981 and 18% in 1990. Even so, 13% of the labour force continues to be engaged in agriculture, more than in any other sector except services[1].

Figure 32. The Fertile Crescent

The agricultural sector in Iraq is the main source of the Iraqi economy after oil, but it has been in regression and hence the country became dependent on importing agricultural commodities of all kinds. This impacted the national budget of Iraq and reduced the number of employments in this important sector, e.g., in 2009, the country imported some $2.1 billion-worth of crops that could be grown in Iraq, including $342 million- worth of fruit and vegetables that could be grown under irrigation (Table 11) (Al-Dabbas 2013).

In the post 2001 war, the agriculture sector was unable to provide necessities for the production process, such as seeds, improved seeds, and fertilizers. Currently, Iraq officially imports between $2.8 and $2.2 billion worth of food and agriculture products from the Turkey and Iran respectively (WFP 2020).

[1] Jaradat 2002

In general, Iraqi natural resources have been facing serious challenges due to decrease in the quantities and degradation in the qualities of the water reaching its borders with the two rivers Tigris and Euphrates, land cover change, climate change, land degradation, impacts of anthropogenic activities, which aggravated due to population growth, and the remnants of historical wars and its negative environmental consequences (Al-Dabbas 2013).

Table 11. Value of agricultural products imported into Iraq that could have been produced in the absence of soil salinity and with an efficient and optimal irrigation regime for each crop, 2000 and 2009 (Al-Dabbas 2013)

	Imported value (US$ million)	
Product	**2000**	**2009**
Cereals	1,177	1,541
Rice	305	415
Sugar	116	375
Vegetable oils	229	359
Fruit and vegetables	334	342
Pulses	23	58
Total	2,184	2,715

Iraq horticulture and fruit production are important sectors for the country. Date palms are the most important tree crop farmed in Iraq and have traditionally been Iraq's main export after petroleum. Vegetable production and fruit orchards are most occurring in the high-rainfall (700-1,100 mm/y) zone in the north. In the medium-rainfall (400-700 mm/y) zone wheat dominates the agricultural areas. For the low rainfall (under 400 mm/y) zone barley is the main crop. Winter wheat and barley are planted in the fall (October) and harvested in the late spring (April-June). The northern region is rain fed, the plains along the rivers north-south are irrigated (Jongerden et al. 2018).

In the rain fed areas in the north farmers cultivate one crop per year, while farmers in the irrigated areas in central and south Iraq often grow a second crop. In the rain-fed areas, primarily in the north, the main crops are wheat and barley, which are planted in fall and harvested in spring, in the irrigated central and south.

The most of Iraq's agricultural harvest can be attributed to small-scale farmers (Beer 2016: 301). The most occurring farm type are smallholders' farms (less than 10 ha), and these plots are often scattered. The rainfed farmers in the north tend to be between 10-30 ha large while the irrigated centre-south farms are varying between 1-2.5 ha. Sharecropping is widespread and so are struggles over land rights.

With earlier described reduction in water quantities, it is not uncommon that disputes on water rights are occurring (Jongerden et al. 2018).

K. Historical situation of soil and water salinity

Soil classifications

Since the second half of the 90' there wasn't any specialized office responsible for arrangement of soil survey work in Iraq. Only after 1965, most of soil survey works had been done. However, the survey mapped only around 35% of the total area and it wasn't entrusted by Iraqi experts, but by foreigner staff (K. M. Hassan, 2018). Most of the works has been done to understand specific criteria (salinity, soil texture, nutrient levels, etc.), but no fully comprehensive work has been done so far. During the analyses an old USA system of soils classification has been chosen (A. S. Muhaimeed, 2014).

After 1965, a special commission, the state board for land reclamation, was established to be responsible for soil analysis works. The state board for land reclamation report focused on the type and properties of soils present in Iraq, land utilisation, and status of the soil. From this report came out that Iraqi soils are represented by a wide variation in the degree of development. Moreover, there are multiple dominant factors controlling soil formation in Iraq. The most important are parent materials (recent alluvium, calcareous or gypsiferous) and physiographic ranges. Secondary factors were the different climatic conditions (dry (less than 100 mm) to sub humid (more than 1000 mm)) affecting soil formation processes, and low density of natural vegetation.

Three years later, 1968, F. H., Al-Tie conducted a study on different (60) soil profiles belonging to all physiographic regions of Iraq. These 60 pedons were than classified in three soil orders, according to the U.S. taxonomy: Aridisols, Entisols, Vertisols. In 1986, M.S. Hussain added two other soil pedons: Mollisols and Inceptisols. Only in 2014, with the work of A. S. Muhaimeed, 2014 it was discovered that there are 300 pedons representing dominant climate and physiographic regions across Iraq (Tab.12).

Table 12. Classification of main Iraqi soils from A.S. Muhaimeed, 2014

Aridisols	Entisols	Inceptisols	Mollisols	Vertisols
Aquisalids	Psammaquents	Haplaquepts	Calciaquolls	Calcixererts
Haplosalids	Xerarent	Calcixerpts	Calcixerolls	Haploxererts
Petrogypsids	Xerofluvents	Haploxerepts	Argiaquolls	Gypsitorrerts
Calcigypsids	Fluvaquents		Argixerolls	Calcitorrerts
Haplogypsids	Torriarents		Haploxerolls	Haplotorrerts
Paleargids	Torrifluvents			
Gypsiargids	Torripsamments			
Calciargids	Xeropsamments			
Haplargids	Torriorthents			
Petrocalcids	Xerorthents			
Halocalcids				
Haplocambids				

The main five soil pedons were recognised as follow: Aridisols (62.2%), Entisols (16.2%), Inceptisols (12.6%), Mollisols (3.6%), Vertisols (1.2%) (K. M. Hassan, 2018). The soils of the Mesopotamian Plain are rich in calcium carbonate, moderate in lime (25–30% lime is quite common and less than 20% is rare) and low in organic matter (Buringh, 1960).

Land subdivision

According to the report of 1965 the Total Iraqi Area was 438 317 sq. km, of which about one fifth was Agricultural land (94 500 sq.km) (Fig.33). The newest data available (2018, worldbank.org) shows that the percentage of agricultural soil raised from 20.39% (1965) to 21.307% (2018).

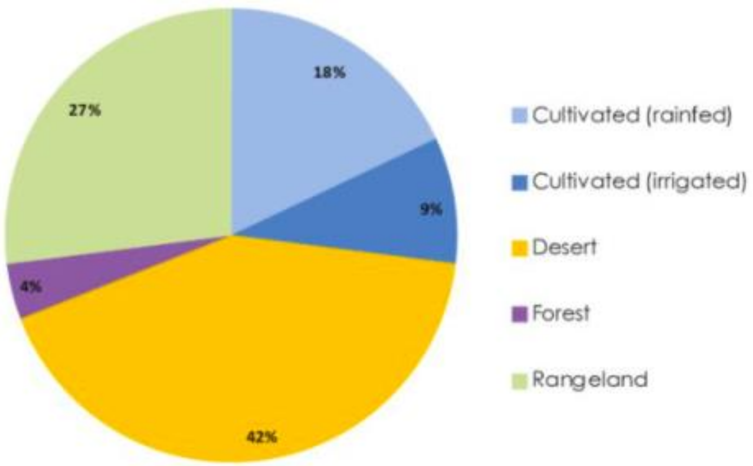


Figure 33. Land use in Iraq (Moutaz, 2013)

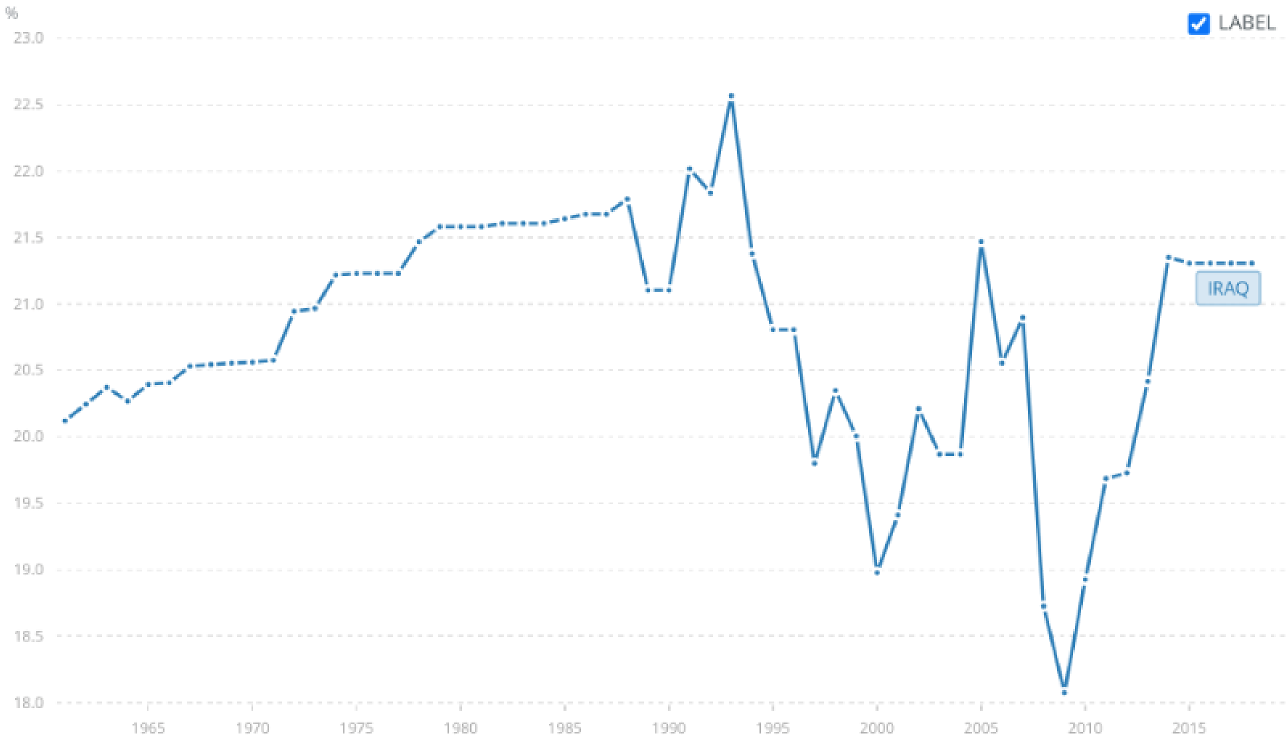


Figure 34. Agricultural land% from 1961 to 2018 (worldbank.org)

Regarding the production, the most irrigated agriculture is conducted in the central-southern part, as shown in Fig. 35. However, Figure 36 highlights the low content of dry matter (Kg/m^2) present in that area which is a flat and alluvial plain, poorly drained and which contains much salt both in soil and groundwater. Nevertheless, the area located between the Tigris and Euphrates rivers, is the most productive part of Iraq. There, more than 70% of the total Iraqi cereal production takes place (Moutaz, 2013).

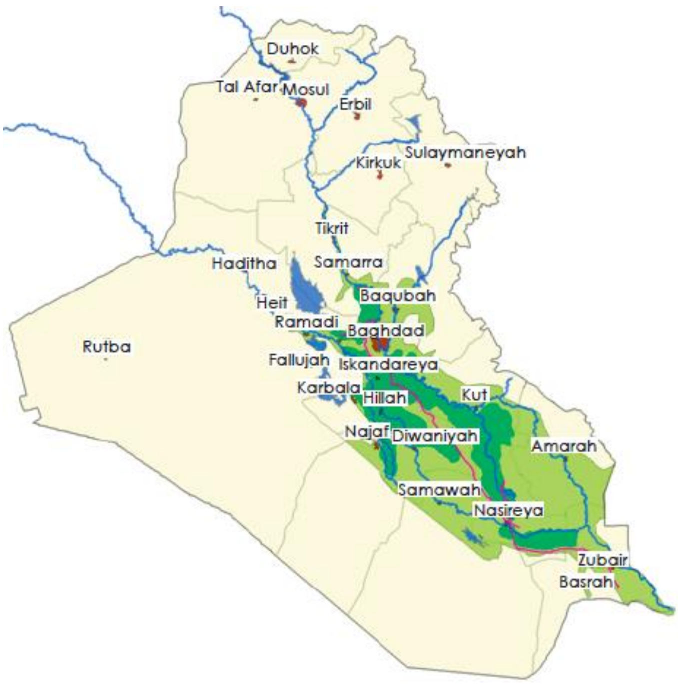


Figure 35. Map of Iraq where most irrigated agriculture is conducted. Dark green areas are main irrigated areas (Moutaz, 2013)

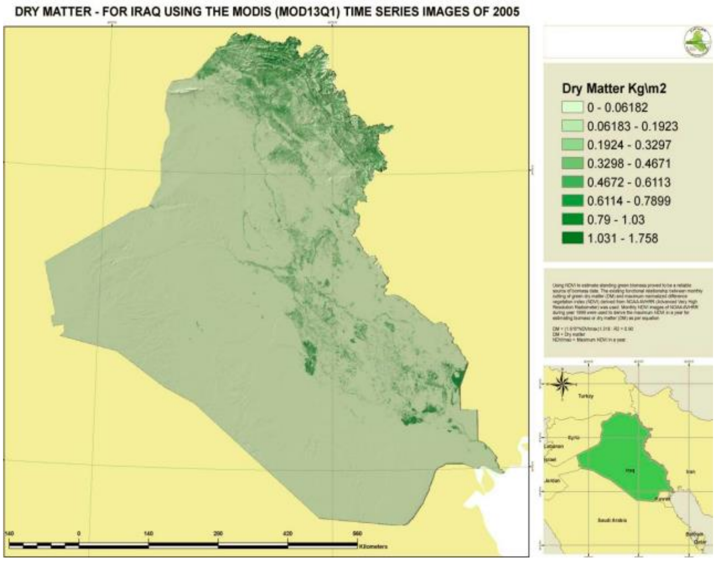


Figure 36. Dry matter presence (Kg/m^2) under Iraqi soils (A. S. Muhaimeed, 2014)

The salinity problem

Globally salinization can be differentiated in 3 main processes (Rengasami, 2006):

- Groundwater associated salinity (GAS) where fluctuation in shallow groundwater levels lead to salt discharge into root zone layers. This process happens particularly in areas with shallow groundwater levels (<4 meters) when natural (deep-rooted) vegetation and agricultural practices disturb the natural equilibrium of water levels causing salt movements to the root zone. Locations where this happens include valleys and foot slopes (Mesopotamian Plane).
- Non-groundwater associated salinity (NAS) which occurs in regions with deeper groundwater levels (>4 meters). The process is driven by evapotranspiration in combination with insufficient fresh water leaching into the soils which causes accumulation of salts. This may happen in areas where changes in hydrologic situation (e.g. urbanization) reduce the amount of fresh water leaching and may vary from location to location.
- Irrigation associated salinity (IAS) which is due to the input of salts in soils through the application of irrigation water and the accumulation in the root zone. This particularly happens at sites where irrigated land are insufficiently drained. Examples can be found in (semi)arid regions such as the MENA region where pivot irrigated lands became unsuitable for agriculture due to salt accumulation in soils. This can reduce yields by as much as 30%. (European Commission, 2019) (outside Mesopotamian plane, e.g. West of Basra).

Another form of salinization of aquifers is related to industrial and mining activities that discharge saltwater in surface- and/or groundwater. With respect to mining, the distraction of groundwater may also cause movement of more saline or even brine water from deep groundwater layers towards the upward aquifers (Snethlage et al. 2021).

Increasing salinity is a major water quality problem in many rivers around the world, especially in arid and semi-arid regions (Thomas and Jakeman, 1985; Roos and Pieterse, 1995). At salinity levels > 1 ppt water becomes undrinkable (WHO, 1996). Above 3 ppt, water is no longer suitable for most agricultural uses. Irrigation with high saline water causes yield reduction dependent on the crop tolerance to salinity (FAO, 1985; Abdullah Ali, 2016).

Iraqi salinity situation

The salinity in Iraq is an ancient problem and comes from a few main sources:

- Natural salinity as result of dissolving salts from the marine deposits.
- High natural evaporation and low precipitation due to the prevailing climate conditions.

- Long term poor irrigation and drainage techniques.
- Intrusion of sea water in the Southern part of Iraq
- Chemical mineral fertilizer is recent addition of salts.

Buringh, 1960, commenting Iraq salinity situation:

"*Almost all soils are saline, most of them even strongly saline and large areas are out of production. The process of salinization still continues, and it will even increase when floods are controlled."*

A large quantity of salts is already naturally present in both soil and groundwater of the Mesopotamian plain due to the subsoil conformation. This was even before humans started to apply artificial irrigation. Shallow water tables are commonly widespread across the Mesopotamian plain. They enhance soil salinization by avoiding adequate leaching from occurring and allowing capillary up-flow of saline water to the surface. As the saline water evaporates the salts are left in the topsoil. Another consequence of shallow water tables is the increase of waterlogging risk. Waterlogging reduces the amount of oxygen in the soil, which negatively affects plant growth and thus their ability to tolerate salt. Sufficient leaching and drainage processes are necessary to remove salt accumulated in the root zone after the crop has taken up irrigation water. Unfortunately, the natural drainage capacity of both soil and the groundwater systems in irrigated areas is usually insufficient to achieve this. As a result, the water table (including salts) rises (Moutaz, 2013).

According to the FAO estimates, salinity has robbed the production potential of 70% of the total irrigated area of Iraq with up to 30% gone completely out of production. It is estimated that 4% of the irrigated areas is severely saline (>16 dS/m), 50% moderately saline (>4 dS/m) and 20% slightly saline (>2 dS/m). Fig. 5 indicates the level of salinity present in different areas of Iraq in 1980. Overall, salinity appears to increase towards the south part of Mesopotamian plain (Moutaz, 2013).

Buringh 1960, in his survey explains that even if all salts could be leached from the topsoil and the below few meters, only 20% of the Mesopotamian plain's soils would be highly productive. Regarding the remaining 80%, 40% would be moderately productive, while 40% will remain marginal land, because the physical properties of these soils will not permit intensive agriculture. Whether this can be changed will depend on future research.

Figure 37. Location of projects with indication of saline areas in the Mesopotamian plain (Moutaz, 2013)

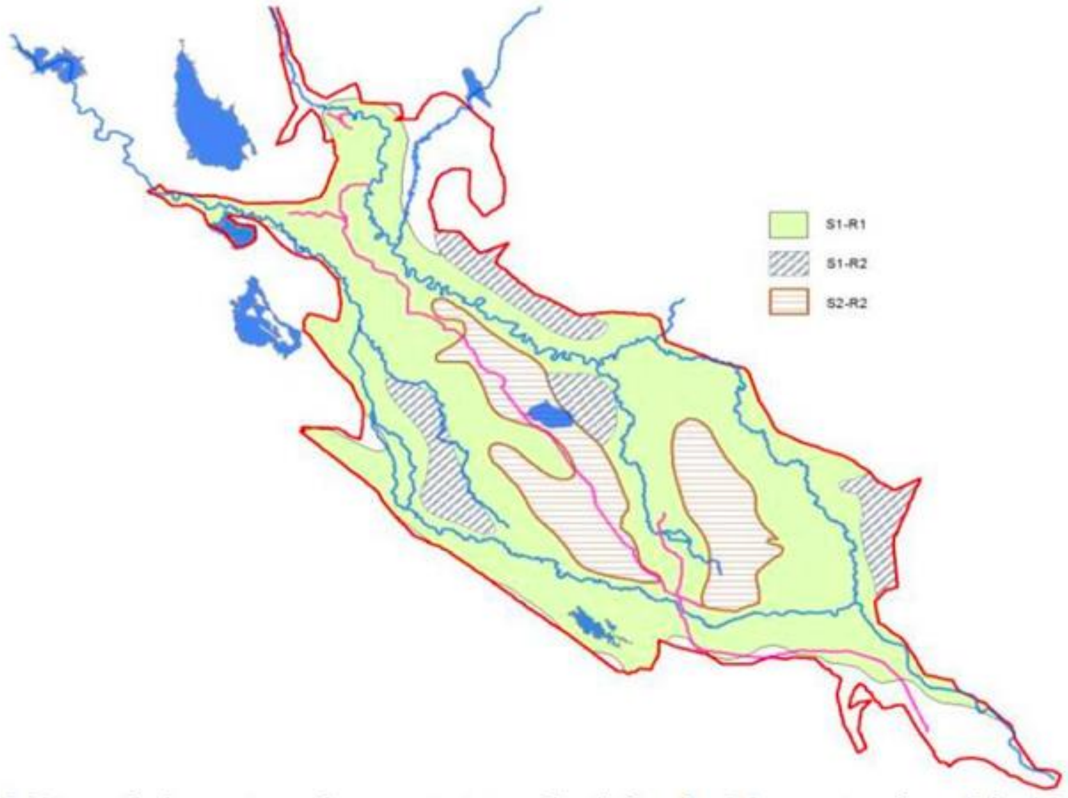


Figure 38. Degradation rate and current state of Mesopotamian soils. S1 indicates where soil salinity levels were 4-15 dS/m; S2 indicates where soil is greater than 15 dS/m; R1 indicates where soil salinity was increasing by 2-3 dS m^{-1}/yr; R2 indicates where soil salinity was increasing by 3-5 dS m^{-1}/yr (Qureshi, A. S., & Al-Falahi, A. A., 2015)

L. Current situation of soil and water salinity

Current challenges in the agricultural context of Iraq

According to farmers there are four main sources of salinity: water shortage, no drainage system, high-water table levels, and long fallow. Water policies of Iran, Turkey and Syria coupled with the shortage of rainfall in the last 15 years have reduced the supply of water to the farmers who are obligated to use drainage water of substantially higher salinity for irrigation. The drainage system is present but left without maintenance. Long fallow, due to the shortage of water, forces the farmer to leave lands with no cultivation for years (Fig. 37).

Moreover, farmers face more constraints and limitations regarding farming, such as: unavailability of fuel in adequate quantities or at suitable prices; inflexible irrigation delivery system (timing and volume); shortage of machinery (mainly seeders and combine-harvesters); reduction in subsidies on inputs and low output (production) prices; seed, fertilizer and machinery services are subject to delay; lack of teaching or informative programmes; transportation facilities need rehabilitation; lack of legislation, regulations and policies.

The process of salinization in rivers is highly dynamic and is and causes diverse (Fig. 39). Determining these factors is data-intensive and case-specific and should therefore be tailor-made to past and current field conditions of salinity and a delta's hydrology and water use. Irrigation water in Iraq is not being used to its full potential because of the poor state of the country's irrigation infrastructure and soil salinity (Abdullah Ali, 2016).

New predictions demonstrate that the situation in some water bodies, SAR for example, is quickly approaching a situation where intervention will be either ineffective or much harder and costly (Abdullah Ali, 2016).

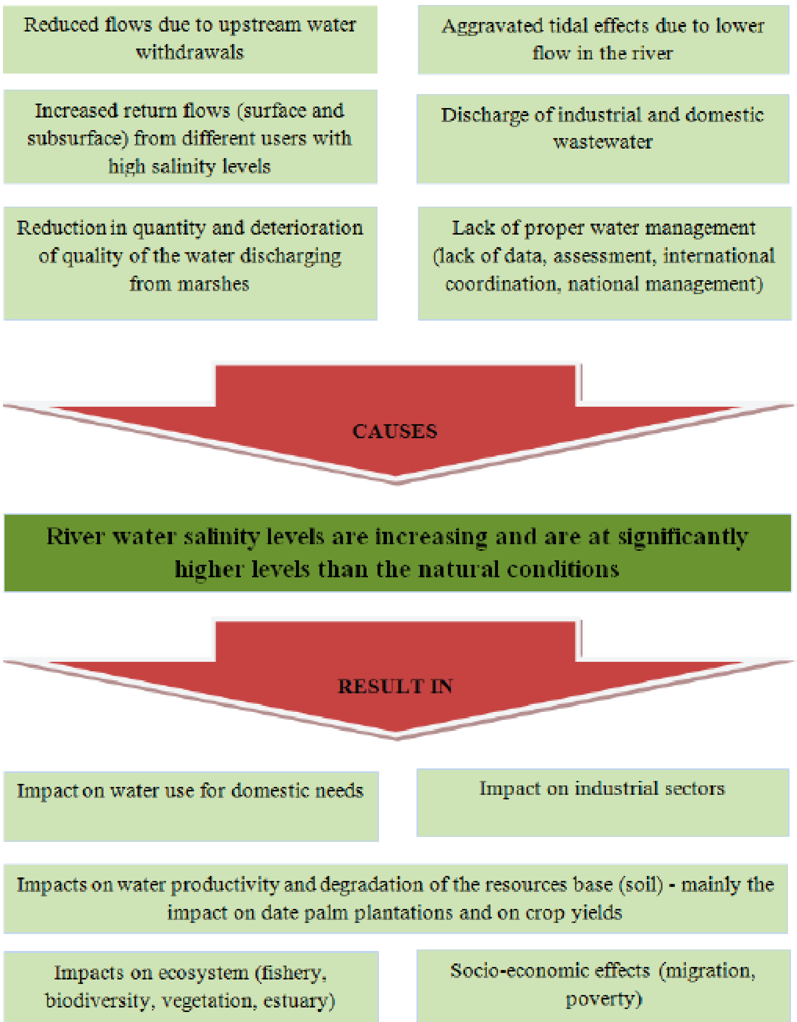


Figure 39. Factors affecting salinity changes of SAR and amin impacts on human and natural assets (Iman S. S., 2014)

Despite studies have constantly been carried on, there is no clear understanding on the magnitude of the salinization problem. Little is known about salinity management when there is a combination of different salinity sources in a tidal river. There is lack of studies which clarify the effect of factors (irrigation practices, industrial effluents, urban discharges, quality and quantity of upstream river inflow, seawater intrusion, and return flows) that determine the salinity of the tidal river (Abdullah Ali, 2016). Without understanding the baseline costs associated with salinity and the current agricultural problems, it is very difficult to understand the proportion of benefits that might accrue from the implementation of changed agricultural practices.

Abdullah, 2016 explains that different ions were found after the confluence of the Tigris and Euphrates (Shat al-Arab River (SAR)) (Fig. 40). The measurements were taken from Qurna to Faw, close to the river mouth. Their concentration increased critically during the period 1978-2014. The direct consequence is an increase in salinity.

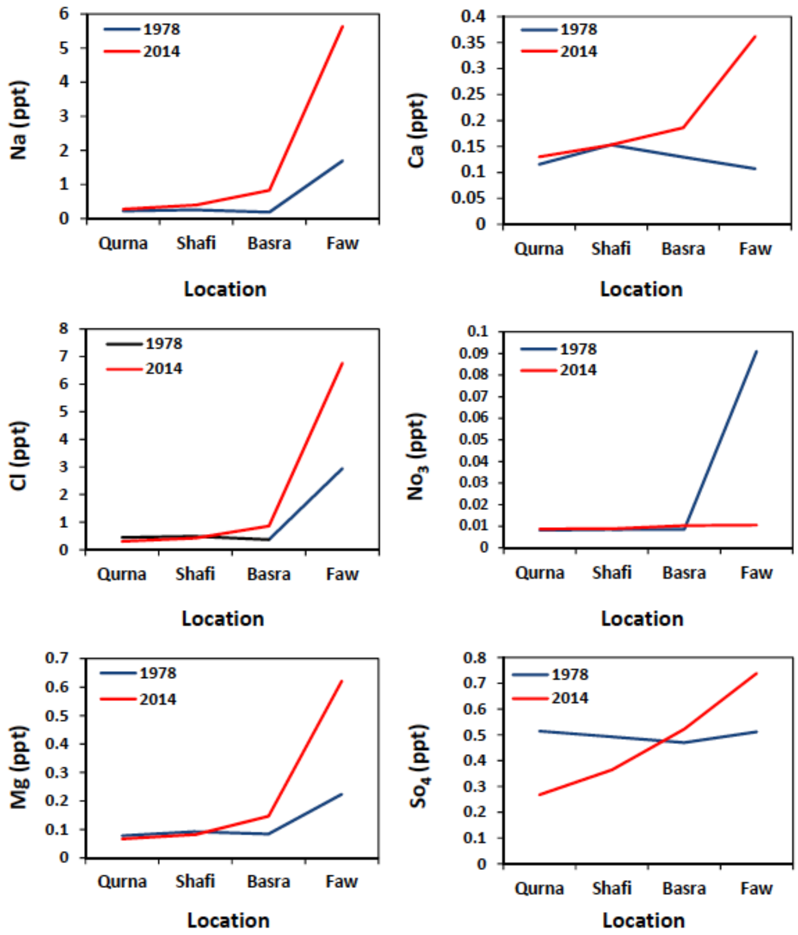


Figure 40. Main ions present in the SAR river (Abdullah Ali, 2016)

M. Projected situation

How to manage salinity

As reported by Abdullah Ali, 2016, improving the quantity and quality of the upstream water sources could reduce salinity concentrations. The crisis can only be averted through the collaborative water management initiatives taken by all the riparian countries, which require a drastic shift from the unilateral water management planning to international cooperation of the shared water resources. Support from the regional and international community can contribute to this paradigm shift. These actions must be supported by solid scientific proves and information's. There is lack of studies which clarify the effect of factors:

- Irrigation practices,
- Industrial effluents,
- Urban discharges,

- Quality and quantity of upstream river inflow,
- Seawater intrusion and return flows,
- Natural salinity

Mitigation strategies should focus on increasing inflows from the upstream source rivers and improving their water quality. Contemporary, local actions must be taken to avoid drainage of poor quality domestic, industrial effluents, and highly saline water (Abdullah Ali, 2016). No single approach alone can achieve successful results. Optimal salinity management can only be gained by a combination of different measures. It is important to emphasize the need to develop a framework for rehabilitation and reclamation of irrigated saline areas based on the highest return on investment in terms of benefits to the national good.

In general, there are two different approaches to deal with salinity: manage and reduce it or accept it. The first one (managing) is - from production perspective - the best option because it allows the farmer to work at full potential and have the maximum production, but this is not always a feasible solution. The development of a stable agricultural sector is dependent on the extent of the availability of sufficient quantities of fresh water as well as reclaimed lands (Iman S. S., 2014). As presented by Iman S. S., 2014 effective solutions should take into consideration changes in land-use practices and adoption of halophytes varieties, to efficiently cope with the desertification (Fig. 41). These topics will be explained in the following paragraph.

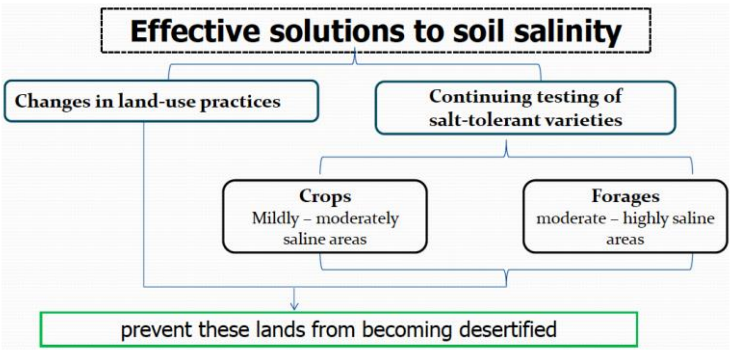


Figure 41. Solutions for an efficient management of salinity (Iman S. S., 2014)

Other solutions presented in most irrigation-based system divide salinity management into three areas of intervention: field, irrigation district and watershed scales.

- The main objective at the field level is to maintain or increase agricultural production and income for the farmer (producer)
- The main objective at irrigation command level is to reduce the impact of salinity on the farm providing acceptable quality, quantity, and regularity of water supply
- The main objective at watershed/river catchment scale is to provide the water command areas with the highest quality and quantity of water

Field scale

Several different actions can be undertaken to address salinity at field scale. Moutaz (2013) summarizes the vision on addressing salinity in Iraq at field level:

"In Iraq these problems can be addressed by both improving irrigation practice and using drains to remove water from the soil profile and allow leaching of salts from the crop root zone. Soil salinity can be controlled by a combination of improved drainage and better irrigation practices. However, existing drainage systems were installed 40/50 years ago. Since than not much maintenance work has been done to repair and maintain the operational capacity of these drainage systems."

- Managing salinity through irrigation water application

Matching water requirements to crop use and groundwater depth provides a win-win solution to enhance productivity, water use efficiency (WUE), decrease salinity and environmental degradation (Moutaz, 2013).

- Agronomic practices

During the irrigation, different patches of low and high infiltration rate can be observed due to poor land levelling, which cause an uneven distribution of water on the surface.

Improved cultural practices (precision land-levelling, zero tillage, and bed and furrow bed methods of planting) could save up to 40% of the water applied, without negatively affecting crop yields (Moutaz, 2013).

Maintaining soil moisture at a level that can reduce the salt stress, which needs to be calculated, is another way of coping with salinity. This can be achieved by modifying the planting methods (e.g. shifting the production of maize from basin to furrow irrigation) Moreover, increasing the canopy density is essential in reducing surface evaporation and accumulation of salts at the soil surface.

- Salt-tolerant/ Halophytes

Different crop production systems of productive halophyte crops, and forages are needed to match farming systems in mildly, moderately, and highly saline areas. Productive system method should integrate plants with lower water requirements and ability to use groundwater as an alternative resource. All plants need to be examined: benefits may not necessarily relate directly to the amount produced, but also important is when it is produced (fodder plants fill feed gaps) or how much other resource (water, fertilizer, etc.) can be saved (Moutaz, 2013). There are different halophytes species that can be used in Iraqi farming systems:

among trees, Tamarix (*Tamarix aphylla*), Prosopis, Acacia, and Atripex spp (Salth bush) are known to be saline tolerant (F. Al-Farrajii, M. R. Al-Hilli, 1994; Marcar, N.E, 1999; Iman S. S., 2014). Other plants such as *Haloxylon aphyllum*, *Haloxylon persicum* and *Petropyrum euphratica* are also recommended for this purpose (Moutaz, 2013).

Regarding crops, local varieties such as Alfalfa, Triticale, Barseem, and purmuda grass are always preferential. Despite they are still under testing conditions, regarding fodder species, Iman S.S. (2014) advice to consider Sporobolus arabicus, Panicum turgidum, Passpalum vaginatum, and Pennisetum clandestinum (kikuyu). Forage production from rainfed old man saltbush under optimal management was reported to be about 2-4 tons/ha per year in Maghreb and the Middle East. Under irrigation with water at 10-15 dS/m, forage yield was about 10-16 tons DM/ha (Le Houérou, 1992).
Furthermore, halophytic grasses can present similar differences in annual production: 0.2 to 1.0 t DM/ha under condition of dryland salinity; 40 t DM/ha when irrigated with water of 9.5 dS/m (Norman et al. 2013).

Halophytic grasses and forage can also solve another problem. They can offer a chance to provide a protein and mineral supplement to animals grazing cereal stubbles in summer. Ruminant production, primarily sheep, is already a component of farming systems in the irrigated zone of Iraq. For this reason, changing production from crops and forages to halophytic forages will not require as much farming systems change as it would be required to develop an entirely new farming system (Moutaz, 2013). Two groups of plants fit the situation: halophytic grasses and forages, and halophytic chenopods. The first group may be highly productive but require high inputs to optimise growth and nutritive value. The second group are less productive but constitute an inexpensive risk-management strategy. Farming systems which incorporate halophytes, need to focus on livestock performance rather than biomass production alone.

- Maintenance of drainage system

If the drainage system is in good conditions, it will avoid the rise of the water table and the waterlogging phenomenon (water table rises to within 10-30 cm of the soil surface) to occur. The interaction salinity-waterlogging causes even more severe effects on plant growth than those presented above. Waterlogging causes soils to become oxygen deficient, thus roots can't use it to burn sugars to produce the energy required by plants to exclude salt from their tissues (Barrett-Lennard, 2003). For arid regions such as Iraq, drain depths between 150 and 250m are widely suggested, with a consensus merging towards 200 cm (Moutaz,2013)

Irrigation district

- Managing salinity through irrigation water application

In Iraqi agriculture irrigation efficiency is low. The distribution of the water is not correlated with any type and necessities of cultivated crops, and usually it results in over-irrigation of some crops and under irrigation of others, with a negative effect for crop yields. First, is important to provide accurate information on irrigation requirement of different crops considering different agro-climatological conditions.

With the cooperation of the Ministry of Water Resources (MoWR), local water authority offices should increase changes on water allocation based on the needs of specific areas. These increases should be proportional to the minimum consumption in each area, so that scarce water resources can be used at maximum efficiency. If farmer's productive pattern in an area don't fit with the new redistribution of water flow, adjustments in the pattern should be made to maximize farmers profits (Moutaz, 2013).

- Modernize irrigation infrastructure

To achieve maximum crop yields an efficient drainage system is needed.

Currently, the management and maintenance responsibilities of irrigation and drainage projects are shared between MoWR and farmers. Roles and responsibilities for the drainage network are complex and farmers especially cannot maintain their side of the drainage agreements (Moutaz, 2013). Low efficiency of infrastructures (e.g. regulatory structures at Dujaila is 50-60%; drainage network at Mussaib is 70-80%) need urgent rehabilitation and modernization. The whole water delivery systems including canals/channels, pump lifts, farm intakes and weirs, and regulator structures needs maintenance too. However, during this process of rehabilitation it is important to create a design which best fits how the irrigation system should operate in the future, considering possible weak points, water availability of the areas and continuous monitoring activity. Furthermore, is important to report that rehabilitation of existing drainage systems is a todays and tomorrow's challenge primarily due to the large investments required.

Regional level

- Focus of maintenance

Iraq needs to take a strategic approach to the rehabilitation and reclamation of saline irrigated land, based on the knowledge that available funds need to be spent to maximizes the benefit per unit cost invested (Moutaz, 2013). There are many territories that needs to be brought back in production, but among them is important to start from the land with the highest potential. Some areas will benefit stronger than others from an investment and is there that Iraqi government needs to focus. Moreover, the focus of maintenance should also be on the selection of suitable crops. They are currently selected based on farmers' experience, and the availability of labour and other needed inputs, but it is of extreme importance that cropping choices are based on land capability (Moutaz, 2013)

- Assessing the extent of irrigation-induced salinity (also valid for chapter 3.2.)

A clear vision on the scale of the problem and its spatial and temporal variation are required to achieve a successfully control of the problem. So far, no exhaustive work has been undertaken to comprehend the extent of irrigation-induced salinity. There is a lack of any monitoring network to detect and register spatial and temporal changes and characterization of salt-affected soils in different parts of Iraq.

Geographic Information Systems (GIS) would be a precious tool to achieve this important result.

- Lack of solid policy and legislative environment

The first action must be taken by policymakers who, through targeted and well-structured policy actions, will create order and clarity in the Iraqi agronomic landscape. This will make it easier for individual districts and farmers to understand what needs to be done to effectively address this problem. In addition, responsibilities need to be delegated and there needs to be clarity on who should oversee what part of the project. Responsibilities must be divided and clear to all components of the three scenarios (field scale, Irrigation district, and regional level). Only through this approach an effective change can be achieved.

Managing salinity with knowledge

- Disclosure farmers' system

To improve administration at different scales, it is important to increase the efficiency of disclosure systems and increase farmer participation through robust extension delivery. The agricultural disclosure network has been inefficient in motivating farmers to adopt improved techniques, including adoption of saline agriculture practices (R. Soppe et al, 2012, Moutaz, 2013). Through a process of demonstration, training, and communication is possible to empower and educate farmers.

There are interventions, derived from the failure to educate farmers, that negatively affect the production system. Some of them are the non-use of climate smart agriculture (CSA), the non-respect of the rotation, the non-covering of the soil to limit temperature changes and high levels of evaporation, an inefficient and non-targeted irrigation plan. All these aspects are not implemented because there is no solid knowledge base to support them. Specific courses and practical examples, aimed at solving these problems, must be included in a program of rehabilitation of Iraqi agriculture.

In addition, a specific program on sustainable water management under salinity conditions should be launched. The goal is to educate farmers on the precise irrigation requirements of different crops under salinity conditions and water table depth, to make the best use of scarce water availability.

Long term action

Is important to remember again that the future of Iraqi agriculture is dependent on the available fresh water and reclaimed land.

- Adopt a continuous improvement (adaptive management) approach

Managing the salinity problem in Iraq requires a well-structured process of plan–act–monitoring-review–plan at all levels. Is important that actions are evaluated and reviewed frequently enough to detect improvements and failures (R. Soppe, et al 2012).

There is the need of an implementation of a national program for salinity management, based on specified review processes and checkpoints. There is a need for a culture that puts the national good first and rewards innovation and efficiency at that level, rather than just the interests of local communities.

- Authorities should explore an approach that establishes a National Program for Salinity

This program should start with a development of a comprehensive and detailed digital map on Iraqi soil (A. S. Muhaimeed, 2014). This would facilitate government-wide coordination of efforts and ensure high-level integration among the water, agriculture, and environmental sectors. This new program could be based in part on the experiences, information, and results of other projects already implemented in other parts of the world (Australian and Italian project) (R. Soppe et al, 2012, Moutaz, 2013).

MoWR's Commissions, companies, and research centres

1. The Public Authority for the Operation of Irrigation and Drainage Projects. The Commission undertakes the following main tasks: Coordination with the relevant authorities (within MoA), preparing the financial budget for projects, announcing the tenders for the implementation of the projects after approval of the plan, analysing the tenders and expressing opinions about them, contracting with the implementing agencies after the approval of the ministry and according to the financial, administrative and technical powers, the daily supervision of all projects and developing work implementation programs in coordination with the implementing agencies.

2. General Authority for the maintenance of irrigation and drainage projects. The Commission undertakes the maintenance of irrigation and drainage networks, through the sediments and unwanted plants removal works from streams and sewers by the mechanisms affiliated with the commission. An annual cleaning/removal plan is prepared in coordination with the General Authority for the Operation of Irrigation and Drainage Projects.

3. General Authority for Dams and Reservoirs. The Commission undertakes supervision of the implementation, operation, evaluation, and maintenance works of Dams and Barrages projects. Also, responsible for regulation

the storage and release water (in coordination with national Centre of Water Management). And reporting the water quality in different rivers and basin of dams through frequent chemical analyses

4. General Survey Authority. The Commission undertakes many tasks e.g., produce and supply updated maps to official agencies, Installation and rehabilitation of the geodetic networks, Geodetic and engineering survey works including topographic survey, Precise monitoring for significant structures such as dams, provide identification, drawing, and pillars installation of the official Iraqi's boundary with adjacent countries based on the approved coordinates and protocols and provide advanced training for engineers from different ministries

5. The General Authority for Ground Water. It is responsible for drilling, maintaining, and monitoring the public wells, provide hydrological consultancy, prepare the wells data base, grant the licenses for private companies who undertake well drilling, and R&D.

6. The General Authority for Irrigation and Reclamation Projects. It is responsible preparing the budget for the projects, announce the tenders and contracting procedures.

7. The Iraqi Marshlands and Wetlands Recovery Centre. The centre is conducting surveys and implement the measurements, and collecting analysing the necessary information to assess the water resources (daily follow-up) received from the main river basins and their tributaries and from groundwater sources.

9. Downstream project department (The general estuary or the third river). The downstream project is considered one of the major development projects in Iraq due to its importance in transferring the saline water resulting from irrigating agricultural lands in central and southern Iraq through an interconnected network of secondary and main sewage drains that eventually flow into the public estuary that transports sewage water and the chemicals residues from agriculture to the Gulf.

10. The implementation department of the river dredging works.

11. Al-Rafidain General Company for the implementation of dams

12. Al-Faw State Company for the implementation of irrigation and drainage projects

13. Engineering Studies and Design Centre

14. Water Resources Studies Centre for the Northern Region.