IOM IRAQ

WATER QUANTITY AND WATER QUALITY IN CENTRAL AND SOUTH IRAQ:
A PRELIMINARY ASSESSMENT IN THE CONTEXT OF DISPLACEMENT RISK

Deltares

IOM UN MIGRATION

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EXECUTIVE SUMMARY

Iraq faces a complex water crisis that is expected to persist and might have implications at the humanitarian, economic, security and social levels, including population movements. This report focuses on understanding variations in water quantity and water quality in central and south Iraq in the last two decades, providing insight for the coming decades, and key recommendations to mitigate the water crisis, based on an exploratory model-based analysis.

In Iraq, public water supply is assumed to be prioritized over other water uses. As a result, demand for public water is met most of the time. Although shortages are minor, model results indicate that periods with shortages occur in several governorates.

Al-Najaf Governorate has the highest prevalence of unmet water public supply, with 16 per cent of the months in the modelled period 1998–2018 experiencing water shortages (meaning water public demand in Al-Najaf was unmet in 16% of the months included in the modelled period of 1998 to 2018). Babil, Kerbala, Al-Qaddisiya, Thi-Qar and Al-Muthanna also face frequent (almost every other year) shortages in public water supply.

Irrigation uses the largest volume of fresh water and may quickly experience supply gaps in years that are relatively dry, partly because irrigation has a lower supply priority compared to public water supply. Missan experiences almost continuous irrigation shortages, with demand unmet 99 per cent of the time,[1] while Thi-Qar and Al-Muthanna experience shortages in relatively dry years, based on the model results.

The study found that extending irrigation areas by 30 per cent with the same irrigation techniques and cropping patterns would result in large supply gaps for both public and irrigation water supply. Doubling irrigation efficiency (from the assumed 30% at present to 60%) would lead to a dramatic decrease in the volume of water withdrawn from the water resources system, and to a situation with nearly no supply gaps in central and south Iraq for both public water supply and irrigation.

Therefore, increasing irrigation efficiency seems to be the most effective measure to reduce water shortages.

Three water-quality parameters were explored in the analysis: salinity level (TDS), bacteriological contamination (F.Coli) and biological oxygen demand (BOD5). Thi-Qar presented the highest TDS levels, which make the water unfit for irrigated agriculture according to the model. It is followed by Babil, Al-Muthanna and Basra, for which the model presents high levels of TDS, but their levels do not rule out the use of water for irrigation. Lake Tharthar is an important source of salt contamination for both the Euphrates and Tigris rivers. However, it is not possible to stop using the lake as intermediate storage unless other measures are taken to ensure water supply to irrigated agriculture.

Generally, the modelled F.Coli levels do not seem to be a major water quality issue. The governorates of Missan, Thi-Qar and Wassit have relatively high values, yet the water would still be suitable to be used for personal hygiene.

With respect to BOD5, the highest levels are found in Missan, Thi-Qar and Wassit, followed by Basra and Babil. Lower values, but still beyond the acceptable range, are found in Al-Muthanna and Al-Qadissiya. High levels can be a concern for river ecosystems.

Since Thi-Qar presents high pollution levels of TDS and BOD5 according to the model, its water supply poses the highest risk to irrigated agriculture and public water systems.

Improving water treatment of public wastewater may be an effective way to reach drinking water standards. If primary treatment were implemented by temporarily holding the sewage in a quiescent basin, it would result in reducing the F.Coli concentration by 10 per cent, and that of BOD by 25 per cent. This would lower the average F.Coli levels in all governorates; F.Coli values would remain in the same categorization, that is, drinking water quality in Kerbala and excellent bathing water quality in all other governorates. Primary treatment would bring average BOD5 levels to acceptable conditions (below 10 gO_2/m^3) in all governorates.

If secondary treatment were to be added to primary treatment by removing dissolved and suspended biological matter by microorganisms in a managed habitat, F.Coli concentration would decrease by 25 per cent and that of BOD by 80 per cent. F.Coli values would again remain in the same class and average BOD5 levels would be brought to good conditions (at or below 3 gO_2/m^3) in all governorates. Furthermore, the model results show that all water quality indicators deteriorate in years with low river discharge.

Additionally, Iraq is dependent on the transboundary water flows. Intake from the Tigris and the Euphrates rivers – the country's primary sources of water – are decreasing at an unprecedented rate because of high buildup of the hydraulic

1 Meaning water irrigation demand in Missan was unmet in 99% of the months included in the modelled period of 1998 to 2018.

infrastructure upstream, outside of Iraq's borders.

A reduction of 20 per cent in transboundary water would result in frequent shortages of public water supply (more than 20% of the months in the period 1998–2018 in Al-Najaf, Al-Muthanna, and Al-Qaddisiya) and irrigation (more than 35% of the time in the period 1998–2018 in Al-Muthanna Thi Qar and Missan). TDS levels would increase, with high values specifically in Thi-Qar, as well as F.Coli and BOD5 values in Basra, Wassit, Missan and Thi-Qar.

An increase of 20 per cent in transboundary water would result in large reductions of the period with public water supply or irrigation shortages, except in Missan where irrigation remains largely unserved. Water quality would improve for all indicators in all governorates.

CONTEXT

Iraq faces a multifaceted water crisis that might have implications at the humanitarian, economic, security and social levels, including population movements. Iraq's water crisis is expected to persist. Intake from the Tigris and the Euphrates rivers – the country's primary sources of water – is decreasing at an unprecedented rate because of high buildup of hydraulic infrastructure upstream, outside of Iraq's borders. Increasing average temperatures and decreasing annual rainfall due to climate change further challenge the entire region. Therefore, risk of water shortage-induced displacement of populations in Iraq remains high due to degrading water availability in both quantity and quality.

In 2012, an estimated 20,000 individuals, particularly from agricultural communities, displaced because of the drought that affected Iraq. In July 2019, the International Organization of Migration (IOM) in Iraq identified 21,314 internally displaced persons (IDPs) from the southern and central governorates who displaced due to the lack of water associated with high salinity content and / or waterborne disease outbreaks in both urban and rural communities, with approximately 5,300 families displaced from the southern governorates of Missan, Muthanna, Thi-Qar and Basra; and 1,700 from the central governorates of Qadissiya, Wassit, Najaf, Babylon and Kerbala. Environmental challenges such as water scarcity, pollution and reduced ecosystem services can affect people's income generation possibilities and their health and physical well-being, and can therefore be a factor in the decision to leave one's place of residence. Environmental factors are among the drivers of displacement and migration, along with political, demographic, economic and social factors.

This report focuses on understanding variations in water quantity and water quality in central and south Iraq in the last two decades and on providing insight for the future. The report also suggests key recommendations to mitigate the water crisis.

To further this understanding, an exploratory modelling system including hydrological, water resource and water quality models was developed for the Euphrates and Tigris rivers basin. The main water problems identified are mainly linked to water shortages for irrigated agriculture and poor water quality due to excessively high total dissolved solids (TDS), that is, salinity levels.

Further research on the reasons why some people displace from the most affected areas while others remain would be required to better understand the link between water issues and displacement.

METHODOLOGY AND APPROACH

This study assessed the role of water management and climate change in the water quantity and water quality in Iraq.[2] To carry out the analyses, this study developed and applied a set of models that simulate water availability and quality of the Tigris and Euphrates rivers. The suite of connected computer models[3] was used to:

1. Translate precipitation into river discharge (Wflow model);
2. Account for river regulation and water use (RIBASIM model);
3. Account for emissions and processes of pollutant transport and degradation (DWAQ model).

These models feed into each other: Wflow provides river discharge information at selected locations, which forms the input for RIBASIM. RIBASIM computes remaining water availability after storage in dams and water withdrawals for various types of use, which form the input for DWAQ. DWAQ combines information on emissions of pollutants with river flows to assess concentrations of pollutants through space and time. All models simulate the period of 1998–2018.

A set of indicators was used to quantify the effects of changes in water quantity and quality (Table 1).

Table 1. Overview of Indicators

CATEGORY	INDICATORS	UNIT
Water availability and shortage	Water shortage for domestic water use	Percentage of time steps during which demand is not met
	Water shortage for irrigation water use	Percentage of time steps during which demand is not met
	Falkenmark indicator[4]	m^3/cap per year
Water quality	Total dissolved solids (TDS)	mgTDS/L
	Faecal colioforms (FColi)	MPN/m^3
	Biochemical oxygen demand (BOD5)	gO_2/m^3

The results for the period between 1998 to 2018 were first analysed to observe the variation in water availability and water quality of the past two decades and better understand what may have caused the water crisis in 2012 and 2018. Once the major causes of the recent water crisis were pinpointed, the extent to which the water crisis and its effects could further worsen or be reduced, if specific measures were taken, was investigated. Three types of scenarios that might develop in the future were examined: 1) an increase in irrigation areas, 2) climate change, and 3) reduced inflows from regional tributaries that feed the Tigris and Euphrates catchments. Furthermore, three types of possible mitigation measures were analysed: 1) an increase in irrigation efficiency, 2) a reduction in water stored in the Lake Tharthar, and 3) applying two types of wastewater treatment (Table 2).

2 Because of the short duration of the study, global data is used as a basis for the modelling, supplemented with information from literature.

3 Annex A provides a more detailed explanation of the three models. References to these models can be found on the Deltares website Further references to these models can be found on the Deltares website *www.deltares.nl/en/software.*

4 Falkenmark, et al. (1989)

Table 2. List of Scenarios Analysed During This Study

SCENARIO	TYPE	CHANGE	ASSUMPTION
Changes in irrigation water demand	Exacerbating factor	Increase of irrigation demand with 30%	Irrigated agriculture uses most water of the Tigris-Euphrates catchment. In this scenario, it is assumed that all irrigated areas in Iraq, Turkey, Syria and Iran will increase by 30%
	Mitigation measure	Increase of irrigation efficiency by 30%	This scenario assumes a drastic increase in efficiency, by 30 percentage points, meaning that efficiency goes from the current 30% to a hypothetical 60% in the future
Climate change	Exacerbating factor	Changes in precipitation and evaporation according to the GFDL-ESM2 model and the RCP 8.5 climate change scenario for the period 2040–2060	The impact of climate change, which affects both water availability and the demand for irrigation water when precipitation volume and temperatures change, is investigated according to standard models of climate change prediction Two models were investigated:
	Exacerbating factor	Changes in precipitation and evaporation according to the HadGEM2-ES model and the RCP 8.5 climate change scenario for the period 2040–2060	The GFDL-ESM2M Global Circulation Model estimates an increase in temperature between 2020 and 2050 of 1 degree Celsius, and annual precipitation fluctuations between 200 and 500 mm, with some higher peaks The HadGEM2-ES Global Circulation Model estimates an increase in temperature between 2020 and 2050 of 1.5 degrees Celsius, and annual precipitation fluctuations between 250 and 400 mm, with some higher peaks
Change in inflow from regional tributaries	Exacerbating factor	Decrease of inflows from upstream countries with 20%	A 20% increase or decrease is assumed in changes in inflows from upstream countries Changes in inflow may be the result of climate change or upstream water regulation and abstraction, or of a combination of both
	Mitigation measure	Increase of inflows from upstream countries with 20%	
Improvements in water quality	Mitigation measure	Not using Lake Tharthar for water storage to reduce the salt load in the rivers	This scenario examines the impact of the choice to discontinue the use of Lake Tharthar The use of Lake Tharthar as an intermediate storage device to provide water to both the Euphrates and the Tigris rivers in the dry season has a major drawback: the gypsum subsoil leads to a large increase in the TDS of the water flowing out of the lake, thus contributing significantly to the salt load in the Euphrates and Tigris rivers
	Mitigation measure	Primary treatment of wastewater flows	The primary treatment scenario consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom, while oil, grease and lighter solids float to the surface The secondary treatment scenario consists of removing dissolved and suspended biological matter by microorganisms in a managed habitat The impact of primary treatment and secondary treatment is investigated for all locations where return flows from public water supply is released into surface water
	Mitigation measure	Secondary treatment of wastewater flows	

WATER SHORTAGES AND WATER QUALITY IN RECENT DECADES

This section analyses water shortages in public water supply and irrigation water supply, followed by an analysis of water quality, focusing on temporal variations in TDS, F.Coli and BOD5. The analysis is for the period 1998 to 2018, and contributes to identifying geographical areas prone to be affected by water quantity and quality issues in the future. All findings discussed here are based on the developed models. The models were tested and calibrated for water quantity and TDS. The model results for BOD5 and F.Coli are not calibrated/validated and results should thus be considered with care.

Water Shortages in Public Water Supply

In Iraq, it is assumed that public water supply is prioritized over other uses. As a result, the demand for public water is met most of the time. Although the shortages are minor, in a number of governorates periods with shortages did occur.

Based on the model's results, Babil, Kerbala, Al-Najaf, Al-Qaddisiya, Thi-Qar and Al-Muthanna all faced frequent (almost every other year) shortages in public water supply. Al-Najaf was the governorate with the highest unmet water public supply. In this governorate, demands were not met 16 per cent of the months during the period 1998–2018 (calculated as the situation in which total monthly water demand exceeded total monthly water availability, producing an average of monthly water demand) and this occurred in 18 of the 21 years analysed from 1998 to 2018.[5]

Al-Muthanna and Al-Qaddisiya were also significantly affected. In both governorates, public water supply was unmet 12 per cent of the months during the period 1998–2018. Shortages occurred in 12 of the 21 years analysed; followed by Babylon (10% of time, 10 years). Kerbala (8% of time, in 10 years) and Thi-Qar (6% of time, 12 years).

On average, these water shortages lasted slightly less than two months. However, in very dry years, public water supply shortages lasted three to four months, as was the case in the years 2000, 2001, 2008, 2009, 2012, 2014 and 2018.

Wassit, Missan and Basra did not face shortages in public water supply because of the availability of water from the main rivers. However, even in cases in which sufficient water is theoretically available, users may still experience supply problems due to possible failures in the water supply system. Therefore, these results should be understood as an indication of the areas that can be considered most prone to public water supply shortages that are not due to the malfunctioning of the supply network.

Table 3. Summary of Public Water Supply Results (RIBASIM Modelling Results Over Simulation Period)

Governorate	Lowest Supply/ Demand Ratio	Average Supply/ Demand Ratio	Percentage of Time During Which Demand Is Not Met	Number of Years with at Least One Time Step During Which Demand Is Not Met (Max 21 Years)
Basra	100	100	0%	0
Al-Muthanna	80	98	12%	12
Al-Najaf	80	97	16%	18
Al-Qaddisiya	80	98	12%	12
Babil	80	98	10%	10
Kerbala	80	99	8%	10
Missan	100	100	0%	0
Thi-Qar	80	99	6%	12
Wassit	100	100	0	0

5 Despite the large coverage of water supply for public use, it is possible that shortages of less than one month occurred as the values presented in this analysis are averaged by month, even in those areas that apparently have no shortages or in parts of a governorate that depend on smaller tributaries instead of on the main stream rivers.

Water Shortages for Irrigation Water Supply

Irrigation is often the largest user of fresh water and may quickly experience supply gaps in years that are relatively dry, partly because it has a lower supply priority compared to the public water supply.

Based on the model results, Missan experienced irrigation shortages almost continuously, and the demand was unmet 99 per cent of the time (in the period 1998–2018), while Thi-Qar and Al-Muthanna experienced shortages only in relatively dry years (1999, 2000, 2001, 2008, 2009, 2012, 2014, 2017 and 2018). During these dry years, shortages could be considerable, as the low supply/demand ratios show.

Babil and Wassit, the other two governorates of Iraq with a significant percentage of irrigation land, did not experience irrigation water shortages.

Table 4. Summary of Irrigation Water Supply Results*

Governorate	Lowest Supply/ Demand Ratio	Average Supply/ Demand Ratio	Percentage of Time During Which Demand Is Not Met	Number of Years with at Least One Time Step During Which Demand Is Not Met (Max 21 Years)
Babil	99	100	0	1
Wassit	100	100	0	0
Missan	0	7	99	21
Thi-Qar	8	92	19	13
Al-Muthanna	12	94	14	11

* Only governorates with a significant extent of irrigation land.

Water Quality

This section presents the results of the spatial and temporal variations for three water-quality parameters: TDS,[6] F.Coli[7] and BOD5.[8] These parameters are chosen because they have a direct negative impact on whether water can be used for public water systems or irrigated agriculture. High TDS values make water unfit for human consumption and detrimental for agriculture as many crops have low salt tolerance – and the high salt content leads to salinization of the soil. An elevated level of F.Coli bacteria is dangerous to human health when water is used for drinking or personal hygiene. A high BOD5 level may result in highly contaminated surface water and might kill the fish population.

For Thi-Qar, the model presented the highest TDS levels, with an average of 1985 mg/l and peaks of 8019 mg/l, making the water unfit for irrigated agriculture. Thi-Qar is followed by Babil, Al-Muthanna and Basra, for which the model also presents high levels of TDS, but their average values of just above 1000 mg/l do not rule out the use of water for irrigation.[9]

The governorates Missan, Thi Qar and Wassit have relatively high values of F.Coli, yet water would still be suitable to be used for personal hygiene. Only in Kerbala the average values fall within the category of water suitable for consumption, but peak values are still outside this range. Generally, the modelled F.Coli levels do not seem to pose a major water quality issue.

As for BOD5, most pollution is found in Missan, Thi-Qar and Wassit, followed by Basra and Babil. Lower values, but still beyond the acceptable range, are found in Al-Muthanna and Al-Qadissiya, which might be a concern for river ecosystems.

Thi-Qar's water supply poses the highest risk to irrigated

6 Total Dissolved Solids (TDS) is a water quality indicator that can be directly related to salinity. A high salinity of freshwater resources impacts directly the quality of the water for drinking or agricultural uses.

7 Faecal coli (F. coli) are a group of organisms found in the intestines of animals and humans. The presence of the bacteria indicates that human or animal faeces may be present in water and contain potentially harmful organisms that may cause illness.

8 Biological oxygen demand (BOD5) is a measure of total organic pollution that could result in low oxygen concentration.

9 Although there are peaks in high salinity levels in Wassit and Maysan, this only applies to the maximum recorded values, which slightly increases the average values.

agriculture and public water systems, according to the model's high pollution levels of TDS and BOD5. The three types of pollution show peak levels in the same years; however, these years vary for locations along the Euphrates (pollution peaks in 2000, 2008, 2012, 2014 and 2017) and along the Tigris (pollution peaks in 1999, 2002, 2005, 2007, 2010, 2012, 2014 and 2017). These years all correspond with low flow conditions in the rivers.

Table 5. Summary of Water Quality Model Results*

Governorate	TDS (mg/l)		F.Coli (MPN/m³)		BOD5 (gO_2/m^3)	
	Average	Maximum	Average	Maximum	Average	Maximum
Basra	1148	2064	93362	415902	9	36
Al-Muthanna	1165	3092	44092	187924	4	15
Al-Najaf	913	1323	13070	48619	1	4
Al-Qaddisiya	944	1453	24430	150718	2	12
Babil	1067	2325	68248	338767	6	27
Kerbala	895	1258	7609	25615	1	3
Missan	954	2765	98349	804257	9	71
Thi-Qar	1985	8019	113676	778428	10	64
Wassit	875	2959	89874	965171	8	82

*Model results for BOD5 and F.Coli are only proof of concept and results should be considered with care.[10]

Thresholds used for colour coding		
TDS	F.Coli	BOD5
Fair drinking water quality (600–900 mg/L)	Drinking water quality (<10000 MPN/m³)	Good quality (<3 gO_2/m^3)
Poor drinking water quality (900–1200 mg/L)	Excellent bathing usage quality (10000-5000000 MPN/m³)	Acceptable (3-10 gO_2/m^3)
Unacceptable drinking water quality (1200–2000 mg/L)		Poor (>10 gO_2/m^3)
Harmful for agriculture (2000–4000 mg/L)		

A Link with Displacement?

Annex B shows the number of IDPs by subdistrict during the period April 2018 to January 2019, together with water quantity and quality indicators at governorate level. In all subdistricts with reported displacement, one or more water indicators point at water issues. However, these same water problems are present for other subdistricts that did not report water-related displacement.

As the spatial resolution of the water resources model chosen for this study does not allow breaking down the water quantity and quality results at the subdistrict level, the modelling results do not allow to establish a clear link between water and displacement. Probably, this link is not straightforward. Various intervening factors, for example economic, social or institutional, can play a role, which together determine whether a worsened water situation induces displacement or not. Further research would be needed to explore the link between water factors and displacement.

10 TDS thresholds for domestic water are based on WHO guidelines (WHO, 2017). As there is no international standard on water salinization for irrigation or drinking water for animal consumption the thresholds for agricultural productivity and suitability for animal consumption were taken from the water quality guideline of the Mary river catchment coordinating committee, Australia (MRCCC, 2013). F.Coli thresholds are based on WHO and EU standards (Basin Water Directive). BOD5 thresholds are based on expert judgment.

WHO (2017), Guidelines for drinking-water quality, 4th edition, incorporating the 1st addendum, WHO, *https://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/* Accessed on 15/07 2019.

MRCCC (2013), Water quality standards, Mary River Catchment Coordinating Committee, Australia, *http://mrccc.org.au/wp-content/uploads/2013/10/Water-Quality-Salinity-Standards.pdf* Accessed on15/07 2019

EU Basin Water directive: *https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32006L0007&from=EN*

WHAT-IF SCENARIOS: SENSITIVITY ANALYSIS OF THE WATER RESOURCES SYSTEM

In this section, the water resource system's response to changes in the Euphrates and Tigris rivers basin is examined, through several what-if scenarios on water management and on climate change. The summary results for all scenarios are included in Annex C.

Water Management Scenarios

Water Management Scenario measures alternative levels of water availability and water quality between 1999 to 2018 by modeling hypothetical modifications to existing irrigation levels, water treatment infrastructure and transboundary water levels in upstream countries.

Irrigation Scenarios

The irrigation scenarios display a change in the amount of water needed for irrigation purposes, due either to an increase in the number of crops or to water-saving improvements of irrigation systems.

What if irrigation areas were extended by 30 per cent with the same current irrigation techniques?

Irrigation is already the largest user of fresh water in Iraq. Extending irrigation areas by 30 per cent with the same irrigation techniques and cropping patterns would result in an increase in irrigation demand of 30 per cent, leading to large supply gaps for both public (roughly doubling the time of shortages compared to the present) and irrigation water supplies (irrigated agriculture areas that witness shortages now would see a two- to three-fold increase in shortages).

What if irrigation efficiency was increased from 30 to 60 per cent?

Doubling the irrigation efficiency (from the assumed current 30% to 60%) would lead to a dramatic decrease in the volume of water withdrawn from the water resources system, and to a situation with nearly zero supply gaps in central and south Iraq for both public and irrigation water supplies. An example of how this irrigation efficiency could be achieved is lining canals to avoid the losses that happen between the point of intake from the river and the point where the water is channelled to the crops.

Infrastructure Scenarios

The infrastructure scenarios test two potential infrastructure-related solutions to improve water quality, such as the construction of wastewater treatment plants and treatment efficiency. A scenario in which Lake Tharthar, a large source of salt, is no longer used for water inputs into the Euphrates River is also tested.

What if treatment of public wastewater was improved?

Improving water treatment of public wastewater may be an effective way to reach drinking water standards, as shown by the simulations of two scenarios, which vary in intensity.[11]

The primary treatment scenario consists of temporarily holding the sewage in a quiescent basin where heavy solids can settle to the bottom, while oil, grease and lighter solids float to the surface.

If primary treatment were implemented, it would result in removing 10 per cent of the F.Coli concentration and 25 per cent of the BOD concentration of all waste water that re-enter the system. This would lower the average F.Coli levels in all governorates. However, F.Coli values would remain in the same class (drinking water quality in Kerbala and excellent bathing water quality in all other governorates). Primary treatment would bring average BOD5 levels to acceptable conditions (below 10 gO_2/m^3) in all governorates.

The secondary treatment adds treatment to the primary treatment process, and consists of removing dissolved and suspended biological matter by micro-organisms in a managed habitat. In the model, this treatment is simulated by removing 25 per cent of the F.Coli concentration and 80 per cent of the BOD concentration of all waste water that re-enter the system. If secondary treatment were implemented, this would further lower the average F.Coli levels in all governorates. However, F.Coli values would remain in the same class (drinking water quality in Kerbala and excellent bathing water quality in all other governorates,

11 Both scenarios assumed to treat 100% of all wastewater that results from household water use.

with Al-Najaf at the upper threshold level of drinking water quality). Secondary treatment would bring average BOD5 levels to good conditions (at or below 3 gO_2/m^3) in all governorates.

What if Lake Tharthar was no longer used to store water?

Lake Tharthar is an important source of salt contamination for both the Euphrates and Tigris rivers. Temporarily storing excess water in this lake, therefore, results in higher salinity of the river water downstream. Although a logical step would be to stop the use of Lake Tharthar as an intermediate reservoir, the model's results showed that this would have a very negative impact on water availability for both public water supply and irrigated agriculture in central and southern Iraq. The results show the importance of transferring water from the Tigris to the Euphrates River, with Lake Tharthar as intermediate storage, especially for the irrigated agriculture downstream along the Euphrates River, which suffers from shortages.

Transboundary Inflow Scenarios

The transboundary scenarios explore the impact of a change in water inflow from the three major rivers upstream of Iraq: the Euphrates, Tigris, and Karoun.

What if inflows from transboundary tributaries change?

The transboundary inflow scenarios represent the changes that could occur as a result of a significant decrease or increase of the water availability coming from tributaries to the Tigris and Euphrates rivers in Turkey, Syria and Iran.

Although changes are not linear – because of the regulation by reservoirs and because a large part of the additional water in the 'increase' scenario would be used by upstream users before it can reach the central and southern governorates – changes in inflow result in large changes in water quantity and water quality parameters. For almost all indicators, the negative impact of reduced flows is larger than the positive impact of increased flows.

A reduction of 20 per cent would result in frequent shortages of public water supply (more than 20% of the time in Al-Najaf, Al-Muthanna, and Al-Qaddisiya) and irrigation (more than 35% of the time in Al-Muthanna, Thi-Qar and Missan). TDS levels increase, with high values specifically in Thi-Qar. F.Coli and BOD5 values in Basra, Wassit, Missan and Thi-Qar.

An increase of 20 per cent would result in large reductions of the period with public or irrigation water supply shortages, except in Missan where irrigation remains largely unserved. Water quality would improve for all indicators in all governorates.

Climate Change Scenarios

What if climate change results in higher temperatures and rainfall extremes?

Climate change scenarios estimate future levels of water availability and water quality for the year 2050 in two different plausible scenarios of climate change. Both scenarios are based on the same increase in greenhouse effect (RCP 8.5) but, since they are based on two different Global Climate Models (GCM), each scenario leads to a different temperature and precipitation trend.

The first scenario, called 'high variability,'[12] results in an increase in temperature of approximatively 1°C by 2050 and shows high variability in rainfall. The 'high variability' scenario would result in negative effects on both water availability and water quality indicators in all governorates.

The second scenario, called 'low variability,'[13] results in an increase in temperature of approximatively 1.5°C by 2050 and no significant change in rainfall variability. The 'low variability' scenario would result in slight improvements of shortages for public water supply in the governorates of Al-Qadissiya, Babil, Kerbala and Thi-Qar. Salinity concentrations would increase in all governorates, and F.Coli and BOD 5 would worsen in most governorates, except for Kerbala (no change) and Thi-Qar (slight improvement).

12 Based on the GCM called GFDL-ESM2M

13 Based on the GCM called HadGEM2-ES

CONCLUSION

- The governorates along the Euphrates have similar levels of water shortages, while pollution levels increase downstream. Shortages of irrigation water occur in both Al-Muthanna and Thi-Qar. Salinity and BOD5 levels are particularly high in Thi-Qar, although short-duration salinity peaks occur in all governorates, and BOD5 peaks in all other governorates except for Al-Najaf and Kerbala. F.Coli levels remain within levels that allow use of water for bathing, but except for Kerbala, exceed the levels for drinking water.
- The two governorates along the Tigris, Wassit and Missan, do not face public water supply shortages. Wassit has no irrigation water shortages, whereas Missan experiences shortages for irrigation water frequently. Higher pollution levels are observed for Wassit than for the more downstream Missan. F.Coli levels remain within levels that allow use of water for bathing.
- Low flow conditions result both in shortages of public water supply and irrigation and in poor water quality conditions. Modelled indicators for water quality show clear peaks in years with low river discharge.
- Increasing irrigation efficiency seems to be the most effective measure to reduce water shortages.
- The largest negative impact among the various model scenarios on water resources would be caused by a 20 per cent decrease in inflow from the Turkish, Syrian and Iranian tributaries. The two climate scenarios that were tested also resulted in a worsening of both water quantity and water quality indicators.
- Lake Tharthar plays a major role in the water resources of both rivers and, despite its negative impact on salinity levels, it is not possible to stop using the lake as intermediate storage unless other measures are taken to ensure water supply to irrigated agriculture.
- Water quality strongly depends on variations in water quantity. Improved treatment would help to bring F.Coli and BOD5 levels down. However, commonly applied wastewater treatment methods will not reduce salinity. Reducing salinity levels requires measures related to water quantity and finding a solution to limit the use of Lake Tharthar as intermediate storage.
- Increasing discharge is key to reducing both water shortages and water quality problems. Increased irrigation efficiency and increased transboundary water inflows would both contribute towards this goal.

RECOMMENDATIONS ON WATER GOVERNANCE POLICY

At the Governorate Level:

- Renovate failing water treatment plants and install new treatment plants at the most critical wastewater locations in terms of pollution level and distance from the main drain.
- Establish alternative public water supply sources, such as tanked water, to ensure a safe water supply when local surface water-based sources are unfit for consumption or hygienic use.
- Clean and maintain irrigation drainage canals, until the tertiary level, to prevent low irrigation efficiency.

At the National Level:

- Focus on the overall improvement of efficiency of irrigated agriculture, the sector with the highest demand in water, by renovating and maintaining irrigation systems.
- Maximize the return flow from irrigated agriculture and public water supply towards the main drain to avoid return flow reaching the Tigris and Euphrates rivers.
- Assess the possibility to transfer water directly from the Tigris to the Euphrates rivers, without relying on Lake Tharthar, by managing the storage of the upper Tigris River with Lake Mosul.

- Assess the possibility to limit the use of Lake Tharthar as an intermediate storage device and instead focus on flood prevention and/or bypasses in the region of Bagdad.
- Assess the possibility to divert saline outflow from Lake Tharthar to the main drain or other salt lakes in the western desert, for example during low flow situations in the main rivers.

At the Transboundary Level:

- Assess whether there are any options for a combined management of the reservoirs that would lead to a higher average yearly flow in the Tigris and Euphrates rivers, with a similar or improved local situation in the system.
- Assess whether improvements are possible in the irrigation efficiency of the various major irrigation systems that would lead to lower withdrawals from, or a higher return flow towards, the rivers.

ANNEX A: MODEL DEVELOPMENT WFLOW – RIBASIM – DWAQ

For the assessment of the water resources situation in the Tigris-Euphrates basin under various scenarios of water availability and regional developments, a system of models was developed, based on the Deltares software packages Wflow, RIBASIM and DWAQ. These packages form an integrated set that can be summarized as follows:

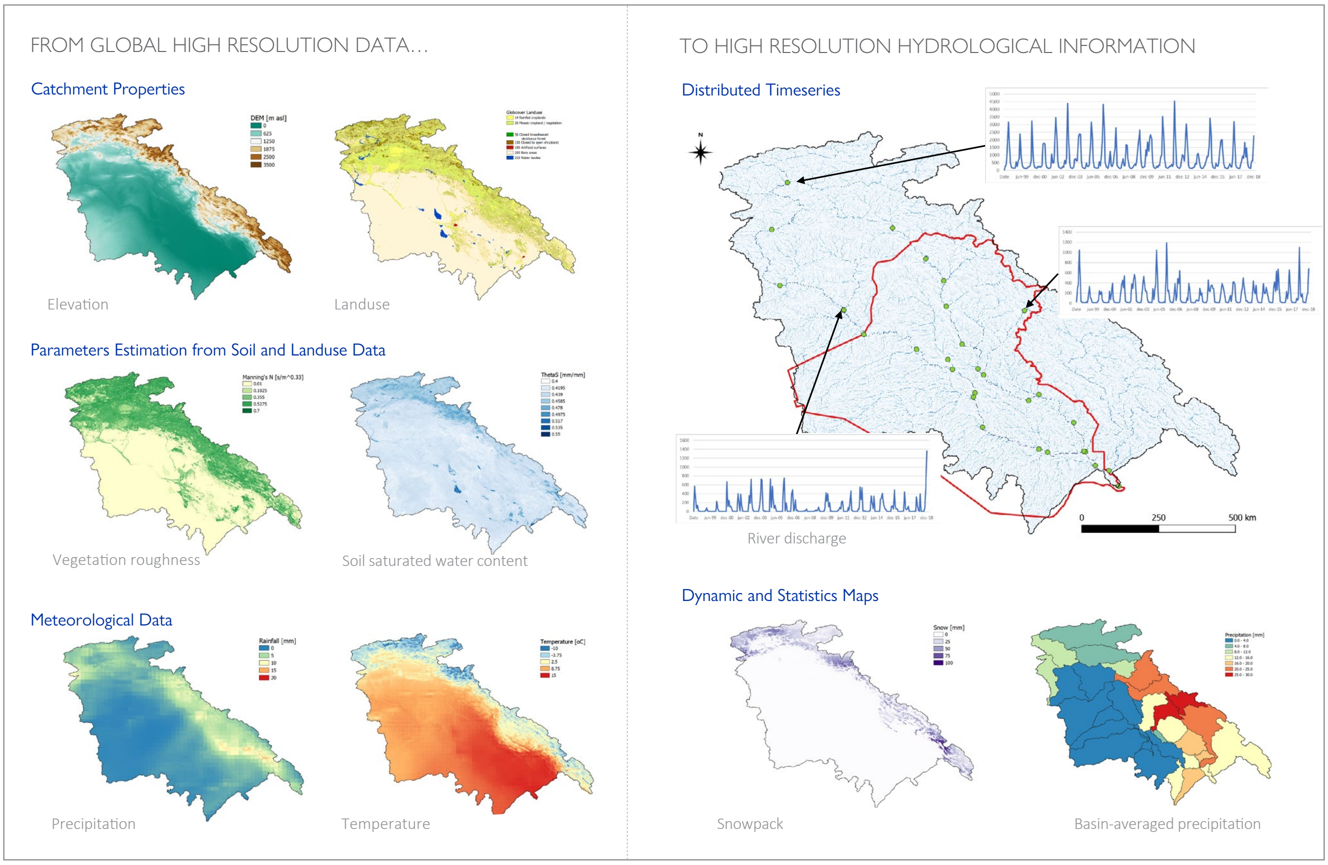
- Wflow: hydrological model that converts rainfall into river flow;
- RIBASIM: water resources model that simulates the water balance between water availability and demands, considering man-made structures and their operation;
- DWAQ: integrated in the RIBASIM model to simulate water quality aspects of the water resources situation in the basins.

In the following paragraphs a short overview of the models is presented.

Wflow: From Rainfall to River Flow

In this distributed model, the catchment and hydrological processes are solved at a grid of regular cells with their own physical characteristics, such as land use and soil type. A combination of global data sets and measured data are used for both the model setup and the running of the model. Input is rainfall and output is river flows, which form the input towards the RIBASIM model.

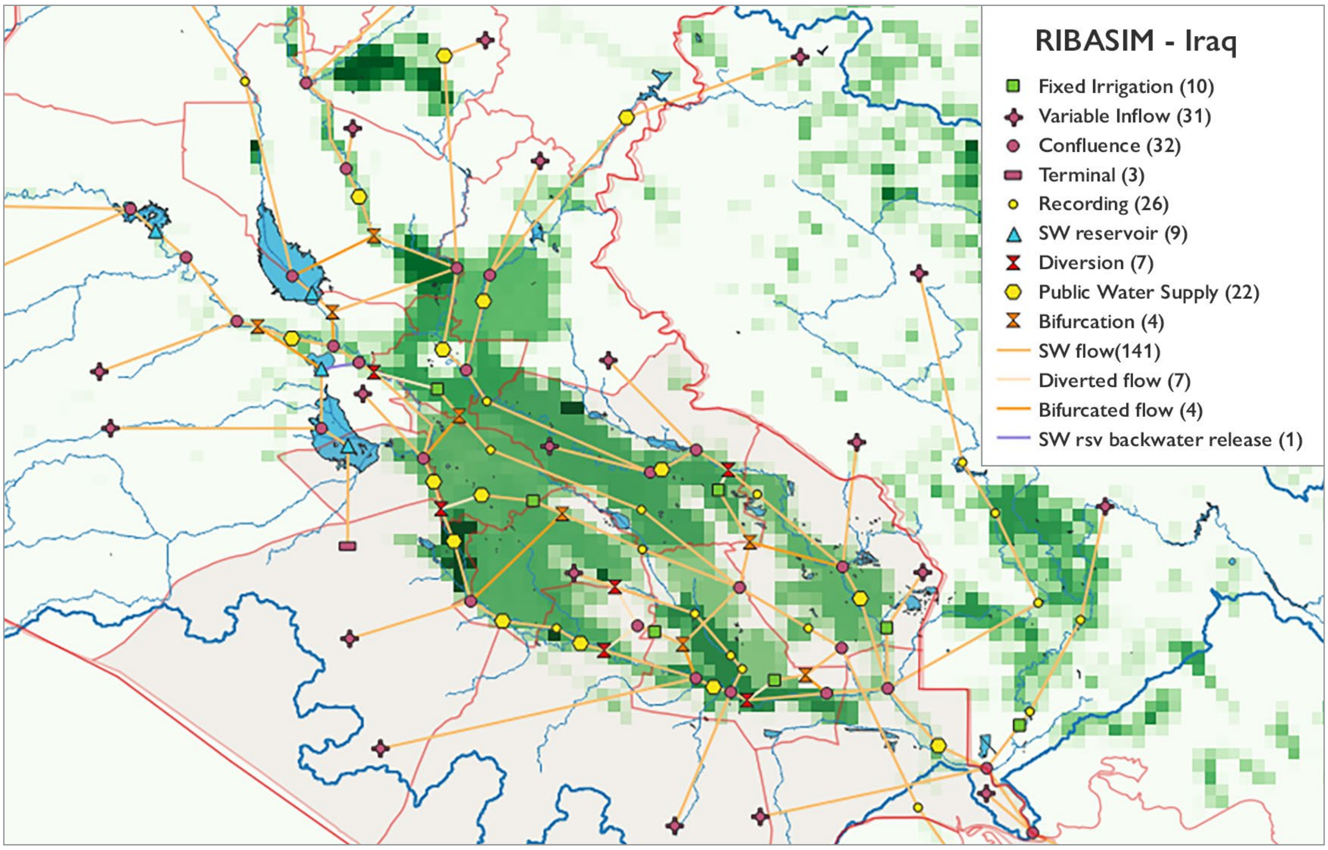
Figure 1. Wflow Distributed Modelling Approach



RIBASIM: From Discharges to Water Availability for Various Users

RIBASIM (River Basin Simulation Model) is a software package that allows the simulation of water systems, both surface and groundwater. The RIBASIM software makes simulations of a water system based on a network of nodes and links. The nodes represent all the water-related items, such as water demand locations and the various control structures. The links are simply the connections between these nodes. A schematization is made with the combination of nodes and links, representing with a certain level of precision the current system, as well as the foreseen new infrastructure.

Figure 2. RIBASIM Schematization of Tigris-Euphrates with Global Irrigation Data



DWAQ: Assessing Levels of Pollution

DWAQ is a water quality model that simulates the fate and transport of substances in water. The DWAQ model provides quantitative insight into the impact of changes such as increased emissions resulting from socioeconomic development or reduced loads when wastewater treatment is improved. Pollution sources that are typically included in the model are population, agriculture and industry, but other sources may be included when considered relevant.

ANNEX B: DISPLACEMENT-RELEVANT WATER INDICATORS BY SUBDISTRICT

Table 6. Displacement-Relevant Water Indicators and Index by Subdistrict

Colours indicate relative score per parameter				
Lowest 20%	20 to 40%	40 to 60%	60 to 80%	highest 20% (80 to 100%)

Governorate	District	Subdistrict	IDPs by Subdistrict of Origin[14]	Contributing Water Parameters			
				PWS Shortage	Irrigation Shortage[15]	TDS	F.Coli
Basra	Abu Al-Khaseeb	Al-Siba	21	0	NA	1148	93362
		Markaz Abu Al-Khaseeb	0	0	NA	1148	93362
	Basra	Al-Hartha	0	0	NA	1148	93362
		Markaz Al-Basra	0	0	NA	1148	93362
	Al-Faw	Al-Bahhar	85	0	NA	1148	93362
		Markaz Al-Faw	0	0	NA	1148	93362
	Al-Midaina	Al-Howweir	0	0	NA	1148	93362
		Markaz Al-Midaina	0	0	NA	1148	93362
		Talha	0	0	NA	1148	93362
	Al-Qurna	Al-Dair	12	0	NA	1148	93362
		Al-Thagar	158	0	NA	1148	93362
		Markaz Al-Qurna	0	0	NA	1148	93362
	Al-Zubair	Markaz Al-Zubair	0	0	NA	1148	93362
		Safwan	0	0	NA	1148	93362
		Um Qasr	0	0	NA	1148	93362
	Shat Al-Arab	Al-Nashwa	0	0	NA	1148	93362
		Markaz Shat Al-Arab	0	0	NA	1148	93362
		Outba	0	0	NA	1148	93362
Al-Muthanna	Al-Khidhir	Markaz Al-Khidhir	25	12	14	1165	44092
	Al-Rumaitha	Al-Hilal	28	12	14	1165	44092
		Al-Majd	0	12	14	1165	44092
		Al-Najmi	42	12	14	1165	44092
		Al-Warka	0	12	14	1165	44092
		Markaz Al-Rumaitha	0	12	14	1165	44092
	Al-Salman	Markaz Al-Salman	0	12	14	1165	44092
	Al-Samawa	Al-Sowair	0	12	14	1165	44092

14 Source: DTM Emergency Tracking. Seven rounds conducted from April 2018 to January 2019.

15 In subdistricts were irrigation was considered relatively small, no separate results were reported from the model, and the table shows 'NA': not applicable.

Governorate	District	Subdistrict	IDPs by Subdistrict of Origin[14]	Contributing Water Parameters			
				PWS Shortage	Irrigation Shortage[15]	TDS	F.Coli
Al-Najaf	Al-Kufa	Al-Huriya	205	16	NA	913	13070
		Markaz Al-Kufa	0	16	NA	913	13070
	Al-Manathera	Al-Heera	0	16	NA	913	13070
	Al-Najaf	Al-Haydariya	0	16	NA	913	13070
		Al-Shabaka	0	16	NA	913	13070
		Markaz Al-Najaf	0	16	NA	913	13070
Al-Qadissiya	Afaq	Al-Bdair	437	12	NA	944	24430
		Al-Fawwar	0	12	NA	944	24430
		Markaz Afaq	0	12	NA	944	24430
		Sumer	86	12	NA	944	24430
	Al-Diwaniya	Al-Daghara	0	12	NA	944	24430
		Al-Saniya	3	12	NA	944	24430
		Al-Shafeia	0	12	NA	944	24430
		Markaz Al-Diwaniya	0	12	NA	944	24430
	Al-Hamza	Al-Sadeer	0	12	NA	944	24430
		Al-Shinafiya	0	12	NA	944	24430
		Markaz Al-Hamza	15	12	NA	944	24430
	Al-Shamiya	Al-Mihanawiya	0	12	NA	944	24430
		Ghammas	0	12	NA	944	24430
Babil	Al-Hashimiya	Al-Qasim	0	10	0	1067	68248
		Al-Shomaly	4	10	0	1067	68248
		Al-Madhatiya	0	10	0	1067	68248
	Al-Hilla	Al-Kifil	0	10	0	1067	68248
		Abi Gharaq	0	10	0	1067	68248
		Markaz Al-Hilla	0	10	0	1067	68248
	Al-Mahaweel	Markaz Al-Mahawil	0	10	0	1067	68248
		Al-Emam	0	10	0	1067	68248
		Al-Mashroo	0	10	0	1067	68248
	Al-Mussyab	Jurf Al-Sakhar	0	10	0	1067	68248
		Al-Iskandaria	0	10	0	1067	68248
Kerbala	Ain Al-Tamur	Markaz Ain Al-Tamur	19	8	NA	895	7609
	Al-Hindiya	Al-Jadwal Al-Ghrabi	0	8	NA	895	7609
		Markaz Al-Hindiya	0	8	NA	895	7609
	Kerbela	Markaz Kerbela	0	8	NA	895	7609
		Al-Hassainya	0	8	NA	895	7609

Governorate	District	Subdistrict	IDPs by Subdistrict of Origin[14]	Contributing Water Parameters			
				PWS Shortage	Irrigation Shortage[15]	TDS	F.Coli
Maysan	Al-Amara	Kumait	117	0	99	954	98349
		Al-Teeb	0	0	99	954	98349
	Ali Al-Gharbi	Markaz Ali Al-Gharbi	25	0	99	954	98349
		Ali Al-Sharki	0	0	99	954	98349
	Al-Kahla	Beni Hasheem	0	0	99	954	98349
		Al-Msharah	62	0	99	954	98349
		Markaz Al-Kahla	6	0	99	954	98349
	Al-Maimouna	Al-Salam	30	0	99	954	98349
		Markaz Al-Maimouna	318	0	99	954	98349
	Al-Mejar Al-Kabir	Al-Aziz	54	0	99	954	98349
		Al-Adel	47	0	99	954	98349
	Qalat Saleh	Markaz Qalat Saleh	0	0	99	954	98349
Thi Qar	Al-Chibayish	Al-Fuhood	20	6	19	1985	113676
		Al-Hammar	0	6	19	1985	113676
		Markaz Al-Chibayish	5	6	19	1985	113676
	Al-Rifai	Al-Fajer	0	6	19	1985	113676
		Al-Nasr	0	6	19	1985	113676
		Markaz Al-Rifai	0	6	19	1985	113676
		Qalat Siker	15	6	19	1985	113676
	Al-Shatra	Markaz Al-Shatra	0	6	19	1985	113676
		Al-Gharraf	110	6	19	1985	113676
		Al-Dawaya	1292	6	19	1985	113676
	Al-Nasiriya	Al-Battha›a	0	6	19	1985	113676
		Markaz Al-Nasiriya	21	6	19	1985	113676
		Said Dekhil	20	6	19	1985	113676
		Al-Islah	50	6	19	1985	113676
	Suq Al-Shoyokh	Garmat Beni Said	20	6	19	1985	113676
		Al-Tar	0	6	19	1985	113676
		Al-Fadhliya	0	6	19	1985	113676
		Akaika	0	6	19	1985	113676

Governorate	District	Subdistrict	IDPs by Subdistrict of Origin[14]	Contributing Water Parameters			
				PWS Shortage	Irrigation Shortage[15]	TDS	F.Coli
Wassit	Al-Hai	Al-Bashaer	12	0	0	875	89874
		Al-Mowafaqiya	30	0	0	875	89874
	Al-Kut	Wasit	50	0	0	875	89874
		Shaekh Saad	0	0	0	875	89874
		Markaz Al-Kut	14	0	0	875	89874
	Al-Namaniya	Al-Ahrar	0	0	0	875	89874
		Markaz Al-Noamaniya	0	0	0	875	89874
	Al-Suwaira	Al-Zubaidiya	0	0	0	875	89874
		Al-Shehamiya	0	0	0	875	89874
		Markaz Al-Suwaira	0	0	0	875	89874
		Al-Hafriya	0	0	0	875	89874
		Al-Aziziya	10	0	0	875	89874
	Badra	Markaz Badra	0	0	0	875	89874
		Jassan	0	0	0	875	89874

ANNEX C: SUMMARY RESULTS OF WHAT-IF SCENARIOS

Table 7. Summary of Scenario Results for Public Water Supply – Percentage of Time During Which Demand Is Not Met

	Base Case	Irrigation Demand Increase	Irrigation Efficiency Increase	CC GFDL	CC HadGem	Inflow -20%	Inflow +20%	No Lake Thartar
Babil	10	23	0	19	8	19	4	35
Wassit	0	0	0	2	0	0	0	0
Kerbala	8	20	0	17	7	17	4	35
Al-Najaf	16	29	1	22	17	25	10	36
Al-Qaddisiya	12	23	0	20	10	20	6	36
Missan	0	0	0	0	0	0	0	0
Thi Qar	6	11	1	10	2	10	2	31
Al-Muthanna	12	23	0	21	12	21	8	37
Basra	0	0	0	0	0	0	0	0

Table 8. Summary of Scenario Results for Irrigation Water Supply – Percentage of Time During Which Demand Is Not Met

	Base Case	Irrigation Demand Increase	Irrigation Efficiency Increase	CC GFDL	CC HadGem	Inflow -20%	Inflow +20%	No Lake Thartar
Babil	0	6	0	7	0	4	0	22
Wassit	0	0	0	2	0	0	0	0
Missan	99	100	95	98	96	100	98	99
Thi Qar	19	48	1	30	21	38	8	38
Al-Muthanna	14	44	0	30	24	35	8	67

Table 9. Summary of Scenario Results for Long-Term Average TDS Levels in Main Watercourses

	Base Case	Irrigation Demand Increase	Irrigation Efficiency Increase	CC GFDL	CC HadGem	Inflow -20%	Inflow +20%	No Lake Thartar
Babil	1067	1111	1075	1954	1622	1194	983	1011
Wassit	875	842	973	1783	1460	957	806	673
Kerbala	895	959	806	1666	1372	998	826	816
Al-Najaf	913	980	820	1705	1401	1021	840	850
Al-Qadissiya	944	1043	838	1836	1455	1084	862	1028
Missan	954	949	999	1986	1530	1085	861	894
Thi Qar	1985	2964	1149	4158	2783	2763	1583	2751
Al-Muthanna	1165	1468	933	2553	1845	1470	1016	1815
Basra	1148	1198	1018	2379	1791	1346	1025	1292

Table 10. Summary of Scenario Results for Long-Term Average F.Coli Levels in Main Water Courses (1000 MPN/m^3)*

	Base Case	Irrigation Demand Increase	Irrigation Efficiency Increase	CC GFDL	CC HadGem	Inflow -20%	Inflow +20%	No Lake Thartar	Primary Treatment	Secondary Treatment
Babil	68	58	120	73	70	73	66	88	61	51
Wassit	90	84	110	122	110	103	73	163	81	68
Kerbala	8	9	7	9	8	9	6	14	7	6
Al-Najaf	13	15	12	16	14	16	11	26	12	10
Al-Qaddisiya	24	36	19	41	27	36	19	95	22	18
Missan	98	97	111	135	112	120	78	218	89	74
Thi Qar	114	193	60	178	110	180	81	411	102	85
Al-Muthanna	44	62	34	71	50	64	35	196	40	33
Basra	93	105	78	136	103	123	76	279	84	70

* Results for F.Coli are only proof of concept and results should be considered with care.

Table 11. Summary of Scenario Results for Long-Term Average BOD5 Levels in Main Watercourses*

	Base Case	Irrigation Demand Increase	Irrigation Efficiency Increase	CC GFDL	CC HadGem	Inflow -20%	Inflow +20%	No Lake Thartar	Primary Treatment	Secondary Treatment
Babil	6	5	10	6	6	6	5	7	4	1
Wassit	8	8	10	11	10	10	7	15	7	3
Kerbala	1	1	1	1	1	1	1	1	1	0
Al-Najaf	1	1	1	2	1	2	1	2	1	0
Al-Qaddisiya	2	3	2	4	2	3	2	8	2	1
Missan	9	9	10	13	11	11	8	20	7	3
Thi Qar	10	17	5	16	10	15	7	35	8	3
Al-Muthanna	4	5	3	6	4	5	3	16	3	1
Basra	9	10	7	13	10	11	7	25	7	3

* Results for BOD5 are only proof of concept and results should be considered with care.

WATER QUANTITY AND WATER QUALITY IN CENTRAL AND SOUTH IRAQ:

A PRELIMINARY ASSESSMENT IN THE CONTEXT OF DISPLACEMENT RISK

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