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Anbar Agricultural Water Resources Management and Conservation Study

Improving Climate Resilience and Social Cohesion in Anbar (ICCA)

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1 Introduction

1.1 Background

This report is an analysis of the challenges of water scarcity and climate change in Anbar Governorate, Western Iraq. These factors are pivotal in shaping both the current state and prospects of the governorate, at times labelled as the food basket of the country. The west of Iraq has suffered from severe droughts and changes in water resources quantity and quality, affecting agricultural livelihoods (Rohstoffe, 2013).

Anbar Governorate accounts for 31.7% or 137,808 km^2 of Iraq's total area (Al-Ansari, 2013), making it one of the largest Governorates in the country. It has a population growth rate of 2% and an average water consumption of 392 litre/day for domestic purposes (Hasham and Ramal, 2022). The Anbar Governorate is located along the length of the Euphrates River, the main water supply source for domestic, agricultural and industrial uses in the area (Sulaiman et al., 2021). The Euphrates River Basin is shared with Turkey, Syria, and Iran.

Anbar Governorate consists of 11 administrative districts: Ramadi, Fallujah, Hit, Al-Qaim, Al-Rutba, Haditha, Ana, Rawa, Al-Amiriya, Al-Khalidiyah, and Al-Karma. The distribution of the population in these districts largely follows the availability of water for agriculture, the presence of mineral resources and industrial facilities, as well as the position as connection points in the transport network. Several cities have been inhabited since ancient times, for example, Hit, Al-Qaim, Al-Rutba, Haditha, Ana and Rawah.

Out of the total area of the Governorate, 658,480 hectares are potentially suitable for agriculture, equivalent to 4.7% of the total area (table 1.1). These agricultural areas are placed along the Euphrates River, starting from Hit District, and ending at Al-Amiriyah and Fallujah.

Beneficiary of the Farmer Field School programme in Anbar

Table 1.1: Ratio (%) of agricultural areas to the total areas in the administrative units of Anbar Governorate.

Sequence	District in Anbar	Ratio (%) of the district with respect to Anbar's total area	Agricultural areas % (as part of the district)
1	Ramadi	**6.1**	23.7
2	Fallujah	**3.5**	60.2
3	Al-Qaim	**8.1**	5.1
4	Rutbah	**60.5**	7.0
5	Rawah	**6.6**	0.9
6	Ana	**6.3**	0.7
7	Haditha	**2.9**	0.5
8	Hit	**6.0**	1.9
Total		**100**	**100**

Source: Unpublished data. Iraqi Ministry of Agriculture. Agriculture Directorate – Anbar - Planning Department.

The actual agricultural area in Anbar was 221,250 hectares in 2015 (Sulaiman et al., 2021), with more than half of it (115,310 hectares) reported as the net irrigated area (Kamel et al., 2013), growing a variety of crops including wheat, barley, onions, corn, sunflower, sesame, orchards, and winter and summer vegetables, with surface irrigation being the major irrigation method. Within the agricultural areas, salinity and drought effects have a large bearing on productivity. Cropping patterns are recording a shift as a result of these changes.

1.2 Overall challenges

Iraq is a semi-arid country facing extreme water shortages and high evapotranspiration losses (Sulaiman et al., 2021; Shafaq, 2023). The weather in Iraq is characterized by a long and hot summer season, and short winter season extending from December till early March (Verner et al., 2018). Iraq in general and Anbar Governorate in particular are facing real water shortage problems characterized by a decrease in the water supply from the Euphrates River, particularly after the launch of the Southeastern Anatolia Project (**Turkish**: Güneydoğu Anadolu Projesi – **GAP**) in Turkey, which consists of constructing around 22 dams (Shafaq, 2023). Iraq's water supply decreased around 30% from the 1980s and is expected to decrease further reaching 50% by 2030, side by side with at least 30% anticipated reduction in yield (UNU, 2023).

Moreover, the current and anticipated changes in the climate system will have substantial and harmful effects on both human and natural systems. Climate change impacts are concurrent with other challenges, including increasing and rapidly urbanizing populations (UN, 2022), land and water degradation (Sobhi, 2023), increased damage to infrastructure (Unpublished Secondary Data), biodiversity loss (Sayl et al., 2020) and food insecurity (Sayl et al., 2020). The entire

Mediterranean Basin is particularly vulnerable to climate change impacts and will probably experience further reduction in annual rainfall and widespread warming. The Eastern Mediterranean and Middle East region has even been classified as a 'climate change hotspot' by Zittis et al. (2022). The combined effect of prolonged droughts, warming temperatures, and dwindling water resources (both surface water and groundwater) is a critical challenge to agriculture and a serious threat to food security. It is driving an unavoidable transformation in agricultural systems. While rainfed agriculture is also important for food production in many Mediterranean countries, these systems are increasingly vulnerable to climate shocks. Anbar is no exception to this scenario. **Chapter 2** describes the changing meteorological conditions in Anbar Governorate, in particular the rainfall patterns.

A case study by Dagher and Obead (2023) using CROPWAT model has shown that annual increases in temperature for Anbar Governorate are 1.1° and 1.85° C for the reference period SSP1 (2020-2039) and SSP2 (2040-2059), respectively. Besides, the estimated annual decrease in precipitation is 3.61 and 4.63 mm in Anbar Governorate for SSP1 and SSP2, respectively. The average water demand for Anbar is 1.28 billion cubic meters as reported by the Ministry of Water Resources (MoWR) in Iraq (Al-Rubaie and Al-Musawi, 2019). With the temperature increase, Bhatti et al. (2019) indicate that the need for irrigation water in Anbar Governorate will increase. Water requirements under surface irrigation method are estimated at 14,180 m3/ha for summer crops, 8,030 m3/ha for winter crops, and 32,620 m3/ha for trees. According to the projections of Mohammed et al. (2021), the agricultural demand will be 2,611 million cubic meters (MCM)/year if the whole agricultural area is cultivated, making the water deficit increase to reach 1,591 and 1,715 MCM/year in 2030 and 2035, respectively. Khaleefa and Kamel (2021) used the Water Evaluation And Planning (WEAP) model to simulate the current water demand scenarios for Anbar Governorate and they reported that the water demand for domestic, agriculture and industrial sectors will be 2,819.35 MCM/year for the reference scenario (2040), while it will be 2,639.54 MCM/ year if a water price is charged. This shows the potential of saving 179.81 MCM/year with the water tax scenario. Further details on water saving will be addressed in **Chapter 7**.

Water issues in Anbar extend beyond just the quantity of water to include quality problems. The Euphrates and Tigris Rivers in Iraq suffer from water quality deterioration due to reduced inflows and increased wastewater discharge (Al-Ansari, 2013). This is discussed in more details in **Chapter 3**. Previous studies using the WEAP model has shown that the main challenge in wastewater management is poor planning and site selection for wastewater treatment plants to match the agricultural needs for reusing it (Khaleefa and Kamel, 2021).

Furthermore, part of the irrigation resource in this area is groundwater. Yet fresh groundwater resources in Anbar are at a premium. There is – as throughout the MENA region – already much evidence of falling groundwater tables, indicating that consumption exceeds replenishment of groundwater. A large portion of the groundwater has high salinity levels and hence cannot be used without treatment or blending. This is discussed in detail in **Chapter 4**.

1.3 Study Context

Effective management of water resources is crucial in the Anbar Governorate in Iraq, where scarcity of water causes serious problems for the environment, industry, livelihoods, and agriculture. The availability of water resources and their sustainable use are essential to maintaining environmental sustainability, economic growth, and food security. However, because of population growth, curtailed water inflows, climate change, and ineffective water management and wasteful water use practices, the Anbar region is facing more frequent and more intense water-related problems. To address these issues, an investigation into the management and conservation of water resources is now essential. The present document aims to leverage existing data, research, and stakeholder perspectives to offer pragmatic suggestions for sustainable water management approaches and for re-framing policies to mitigate the effects of climate change and facilitate Al-Anbar's socio-economic advancement.

The overarching aim of the Anbar Agricultural Water Resources Management and Conservation Study is to assess the current state of water resources in the Anbar Governorate, evaluate their sustainability, and formulate actionable policy recommendations that contribute to effective water management and conservation in the face of the combined pressure on the system.

The study has the following additional objectives:

- Conduct comprehensive desk research to review, analyse and evaluate relevant existing body of literature.
- Analyse existing data and research on water resources in the Anbar Governorate, incorporating insights from stakeholder consultations and experts' inputs.
- Evaluate – based on existing data - the quality and quantity of surface and groundwater in the Anbar Governorate, considering factors such as contamination levels, salinity, and recharge rates.
- Assess current and projected water demand across the agricultural sector and identify areas for improved water use efficiency.
- Review existing water infrastructure and management practices, pinpointing strengths, weaknesses, and opportunities for enhancement.
- Formulate and analyse alternative water utilization methods that rationalize water use in agriculture, considering economic feasibility and environmental impact.
- Develop actionable recommendations for sustainable water resources management, incorporating feasible water conservation strategies and policies.
- Disseminate the study's findings, recommendations, and knowledge gains to all relevant stakeholders, policymakers, and the wider community.

The present report leverages existing data, published and unpublished, integrates stakeholder perspectives, offers pragmatic suggestions for sustainable water management approaches, and re-frames policy reforms to mitigate the effects of climate change and bolster Al-Anbar's sustainable development. The report first takes stock of three defining elements for water resource management in Anbar: the effect of climate change on reduced rainfall (**Chapter 2**), the status of the water quality in the Euphrates, the main lifeline in Anbar (**Chapter 3**) and the situation with respect to groundwater, in particular the quality of groundwater (**Chapter 4**). The subsequent chapters discuss the resource use systems – the surface irrigation system (**Chapter 5**) and the use of rainwater harvesting (**Chapter 6**). The report concludes with recommendations to strengthen water resource management in Anbar Governorate (**Chapter 7**).

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2 Climate Vulnerability and Droughts

2.1 Introduction

With the reduced inflow of transboundary water into the area, it is very important to examine the climate change impacts and precipitation trends in Anbar Governorate. Only local limited studies have been conducted in this field. This chapter is meant as a deep-dive and aims to develop qualitative and quantitative understanding of the impacts of climate change based on meteorological data collected from five different stations in Anbar Governorate. Providing comprehensive information on the type and severity of impacts of local climate change on water resources can help decision-makers adopt more optimized and data-driven management strategies and make informed decisions.

Drought is a natural hazard which is challenging to quantify in terms of severity, duration, areal extent, and impact. It occurs when an area does not receive enough precipitation for a long time, leading to water shortages (Khaleefa and Kamel, 2021). Meteorological drought refers to a meteorological natural disaster due to long-term lack of precipitation that causes insufficient soil moisture and damage to crop water balance (Liu et al., 2021). Since drought is mainly caused by a deficiency in rainfall, drought characteristics can be evaluated using rainfall patterns. The Standardized Precipitation Index (SPI) is used in this study to reflect the changes in drought characteristics across time and space scales in Anbar using meteorological data from five different regions. This preliminary analysis provides the basis to evaluate the drought characteristics and trends of the Anbar region and its effect on the performance of the agriculture sector.

2.2 Methodology

The rainy months in Anbar are mainly spread between October and May. This study uses meteorological data collected at a station level. This approach was previously recommended by Kamel et al. (2013) who emphasized the importance of downscaling to simulate present and future climate trends and to obtain very fine resolution and catch the sub-grid scale climate features like topography and clouds in the area. First, the study develops a downscaling model to estimate current precipitation trends in each station. Second, the Standard Precipitation Index (SPI) values are calculated at four accumulated periods, i.e., 3, 6, 9, and 12 months using the DrinC tool developed by the National Technical University of Athens, Centre for the Assessment of Natural Hazards and Proactive Planning & Laboratory of Reclamation Works and Water Resources Management[1]. Third, the data is analysed statistically to understand the trends.

The SPI developed by McKee et al. (1993) is used in the evaluation of drought conditions based on long-term monthly precipitation data (Khan et al., 2008) observed at five meteorological stations during different periods depending on the available data (**Table 2.1**) (Hasham and Ramal, 2022). The five meteorological stations were selected to represent, as much as possible, the various climatic conditions in Anbar Governorate (**Table 2.1**).

Standardized Precipitation Index used in this study is calculated as follows:

$$SPI = \frac{(X_i - X_m)}{SD}$$

Where, *SPI* is the Standardized Precipitation Index (or drought index); X_i is the monthly, seasonal and annual precipitation; X_m is the long-term mean; *SD* is the standard deviation.

SPI is used to identify the level of drought (or wetness) by examining 3-, 6-, 9-, and 12-monthly precipitation totals as compared to historical precipitation period in the area (Karabulut, 2015). The interpretation of SPI differs based on the time scale used. While 3-month SPI provides estimations of seasonal precipitation, 6- and 9-month SPI define meso-scale trends in precipitation conditions (Wu et al., 2001). Lastly, 12-month SPI shows the long-term precipitation variations. The SPI values and their corresponding drought intensity can be classified into different categories (Table 2.2) (Mckee et al., 1993).

1 https://drought-software.com

Table 2.1: Meteorological stations in the Anbar Governorate and the corresponding water years

Meteorological station	Water year	Latitude *Decimal degrees*	Longitude *Decimal degrees*
Rutba	1929-2017	**33.033**	40.283
Hit	1953-2010	**33.633**	43.750
Haditha	1967-2017	**34.133**	42.350
Anna	1982-2010	**34.37**	41.98
Ramadi	1982-2010	**33.433**	43.250

Source: Hasham and Ramal, 2022

Table 2.2: Drought categories defined for the Standardized Precipitation Index (SPI) values

SPI Value	Drought Category	Time in category
0 to -0.99	Mild Drought	**~ 24%**
-1.00 to -1.49	Moderate Drought	**9.2%**
-1.50 to -1.99	Severe Drought	**4.4%**
≤ -2.00	Extreme Drought	**2.3%**
		~40%

Source: McKee et al., 1993

2.3 Results

2.3.1 Rainfall Pattern

The average annual rainfall in Iraq is 154 mm (**Figure 2.1**), ranging from less than 100 mm over 60% of the country's area up to 1200 mm in the northeast (Al-Ansari, 2013). Notwithstanding the dependence of Iraq on cross-border water resources, Iraq's precipitation levels have been decreasing, exacerbating the water supply challenges in the country, particularly for rainfed agriculture. Iraq has witnessed an abnormally dry summer in 2018, with rainfall approximately a third below average (Lossow, 2018). Dagher and Obead (2023) predicted a 3.61 mm and 4.63 mm decline in precipitation for Anbar for the reference periods 2020-2039 and 2040-2059, respectively. The trend analysis in this part reflects on the change in rainfall patterns in Anbar based on data from five meteorological stations over the last nearly 100 years.

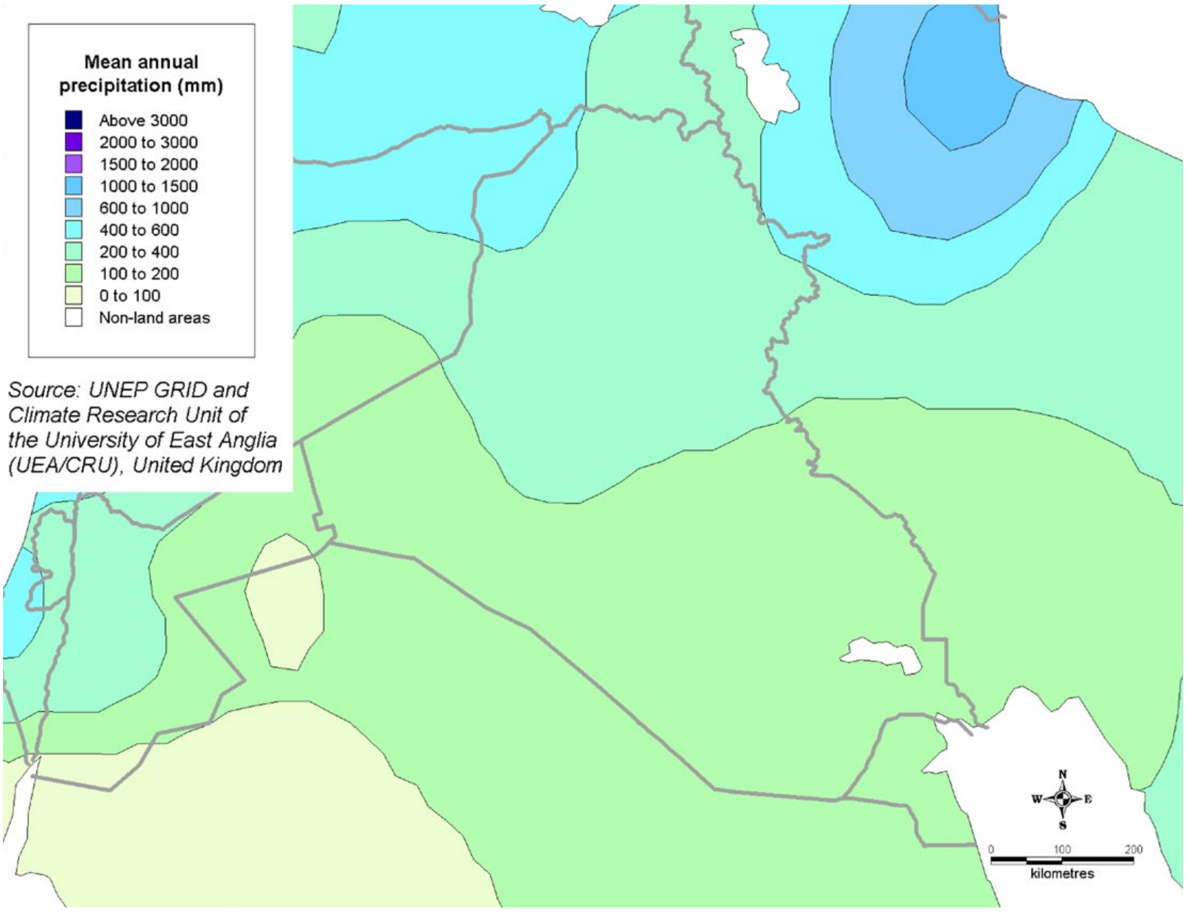
Results of the meteorological data have shown a general decrease in the annual rainfall in the five stations in the studied timeframe, with the decline being more pronounced in some stations than the others. The long-term mean annual rainfall is 112.3, 142.2, 115.2, 121.8, 114.0 mm for Rutba, Anna, Hit, Haditha, and Ramadi, respectively. All the reported means are below the country's average reported by Al-Ansari (2013). The mean annual rainfall in Jordan from 1970 to 2013 was 258 mm/year, almost double the means observed in Anbar. Nonetheless, the east and southwest of Jordan, which is largely arid is relatively close to Anbar in terms of rainfall being on the border line, with 137 mm/year reported by Rahman et al. (2015). In contrast, Turkey, bordering Iraq from the north, has a much higher annual precipitation with the average reported being 573 mm between 1991 and 2020 (Nacar, 2023), varying between 295 and 2220 mm depending on the location and elevation (Deniz et al., 2011).

The rainfall bar graphs show an overall decline in precipitation across the five stations (**Figure 2.2** till **Figure 2.6**). The recession was most pronounced in Haditha (**Figure 2.4**) and Ramadi (**Figure 2.6**) stations, and least pronounced in the Anna station (**Figure 2.5**) which had the highest average rainfall (142.2 mm). This decline in rainfall is translated to a discernible decrease in water surface area in major lakes in the area between Haditha and Al-Fallujah, which is further discussed in **Chapter 3** with reference to satellite images.

The Rutba station recorded the lowest average precipitation (112 mm) for the period extending from 1929 to 2017. The simulation results from Osman et al. (2017) that are based on meteorological data from the same area predict a decline in precipitation in Rutba for the 2080-2099 period with no or minor changes in the near (2011-2030) and medium (2046-2065) future periods. Osman et al. (2017) highlights that the precipitation decline in Rutba is more pronounced than other areas in Iraq, like Singar, Sulaimaniya and Basra. Overall, meteorological results also show that although rain is becoming less frequent, rainfall events are becoming more intense. This explains the high standard deviation values observed at the five stations showing high variability in rainfall in the last nearly 100 years. This agrees with the analysis of Al-Ansari (2013) who showed the average monthly rainfall in Iraq tends toward a reduction varying between 10.83% and 13.93% for the reference periods 2040-2059 and 2060-2079, respectively, as compared to the benchmark 2020-2039. Climate change will exacerbate these changes, changing the wet/dry spell lengths. Reduced but more intense rainfall, along with higher temperatures, is expected to result in increased droughts and more severe flooding (Al-Ansari, 2013).

Figure 2.1

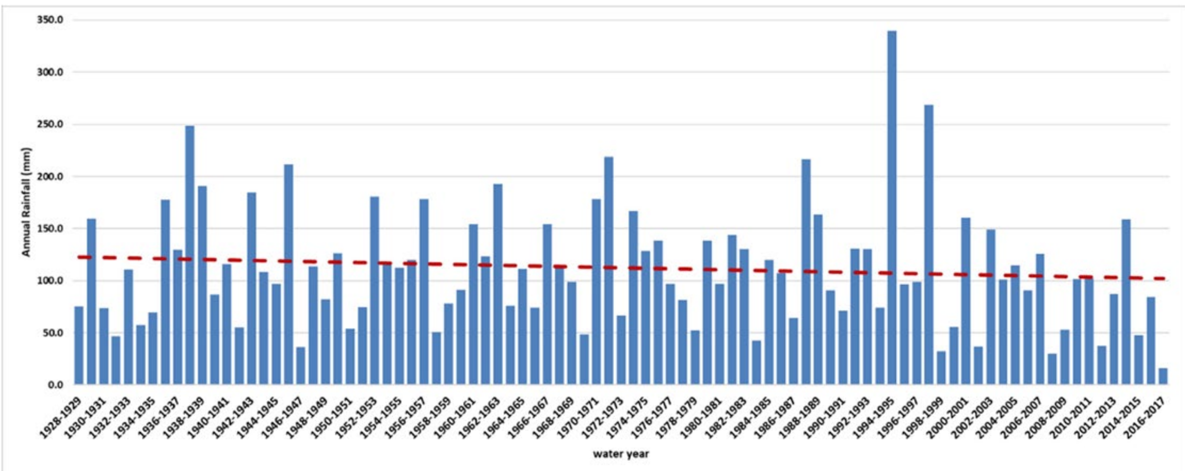
Mean annual rainfall (mm) in Iraq.



Source: Al-Ansari, 2013

Figure 2.2

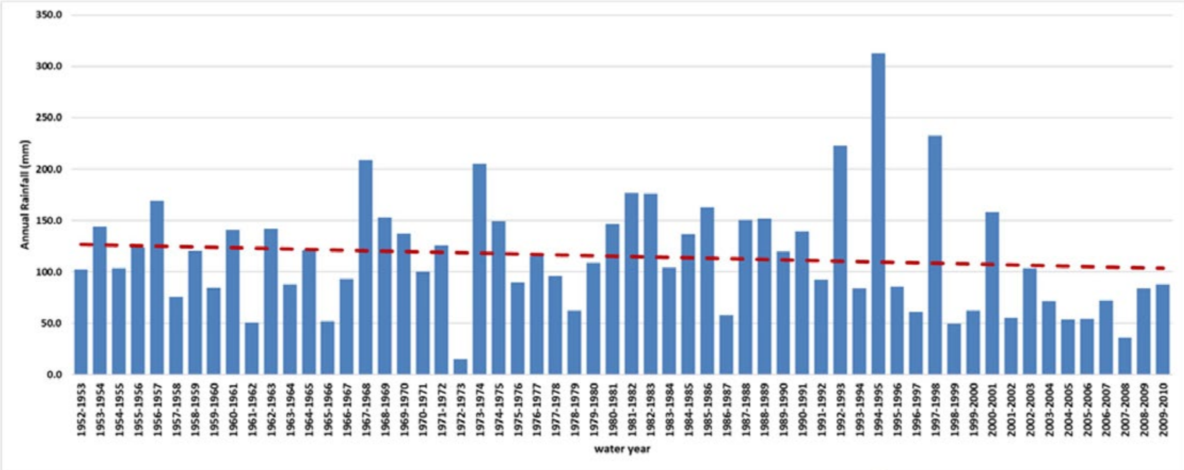
Annual rainfall at Rutba meteorological station (1928-2017).



Source: Own work

Figure 2.3

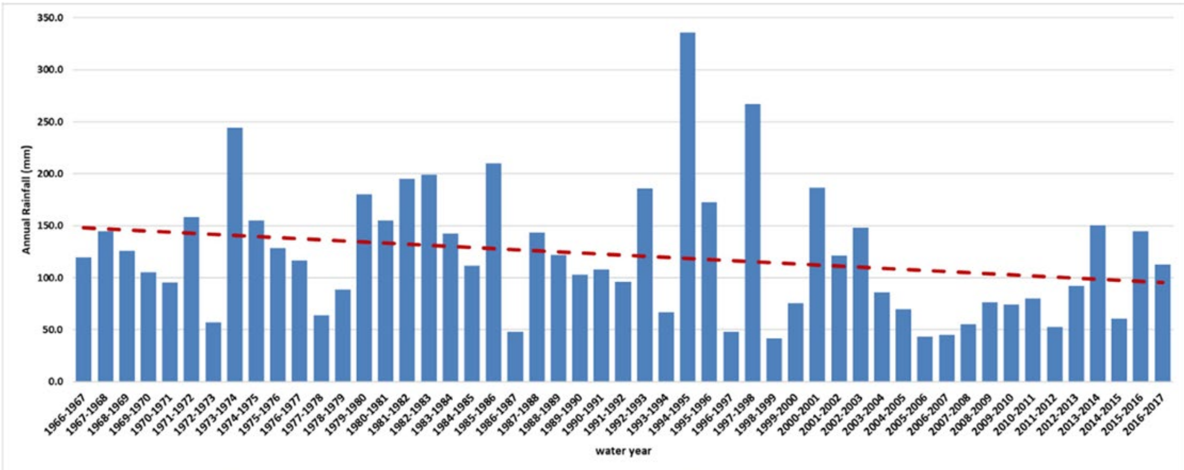
Annual rainfall at Hit meteorological station (1952-2010).



Source: Own work

Figure 2.4

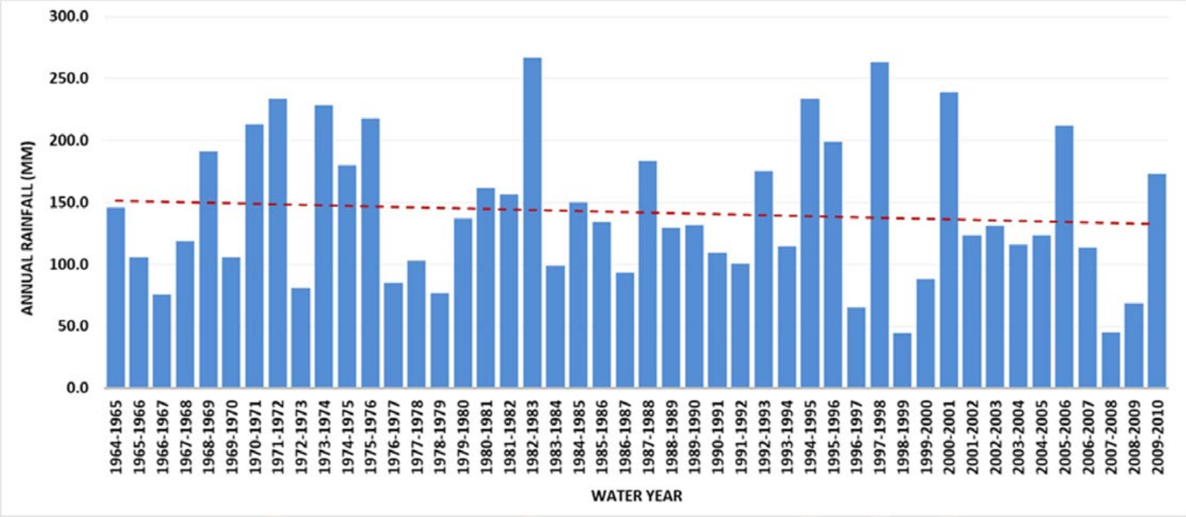
Annual rainfall at Haditha meteorological station (1966-2017).



Source: Own work

Figure 2.5

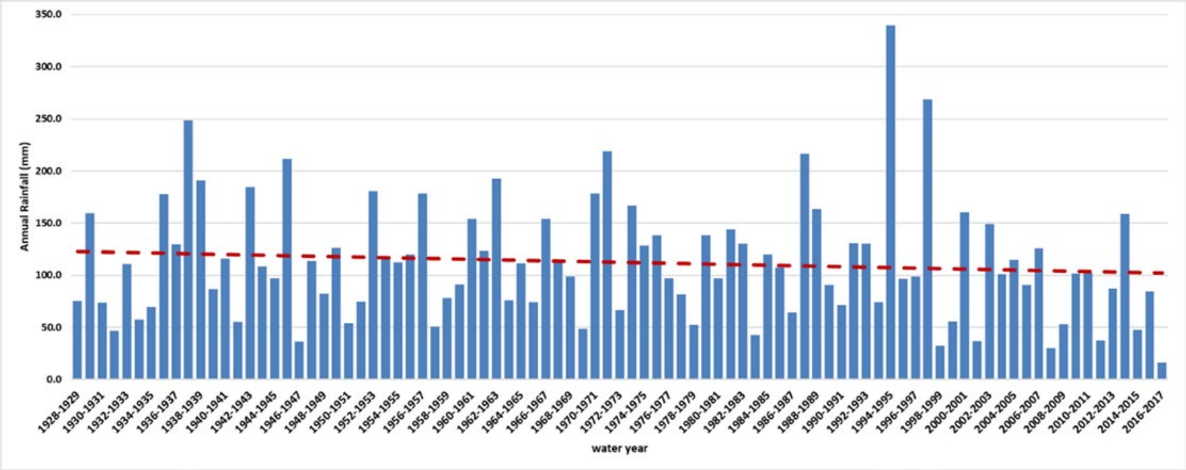
Annual rainfall at Ana meteorological station (1964-2010)



Source: Own work

Figure 2.6

Annual rainfall at Ramadi meteorological station (1928-2017)



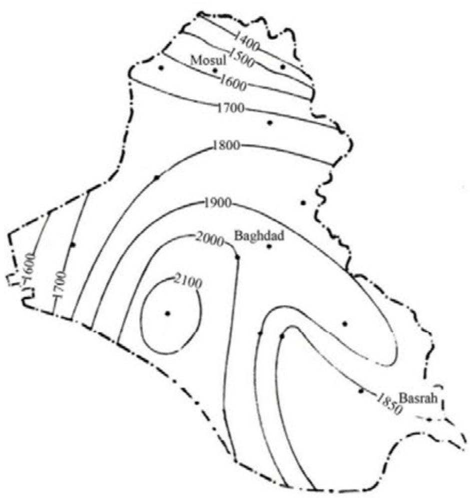
Source: Own work

2.3.2 Potential Evapotranspiration (PET)

Potential evapotranspiration (PET) plays a key role in the study of agricultural water management and climate change. It is particularly important for planning irrigation activities. The Blaney-Criddle model (Dalin et al., 2019; World Bank, 2006) was used to estimate the monthly potential evapotranspiration (PET) (Drebee et al., 2022; Ahmed et al., 2023). The overall average evapotranspiration and evaporation in Iraq are around 1900 mm per year (**Figure 2.7**). Based on meteorological records, temperature and evaporation show an increasing trend from the northeast toward the southwest of Iraq (Al-Ansari, 2013). More than three quarters of Iraq's total area are arid and semi-arid zones (**Figure 2.8**). Anbar, in particular, is mostly arid. Thus, the area suffers from high evaporation losses. The average annual evaporation in Anbar is slightly less than the overall Iraq average ranging between 1600 and 1700 mm per year (Al-Ansari, 2013). Dagher and Obead (2023) simulated the effect of climate change on reference evapotranspiration (ET0) and reported a potential increase to 202 and 206 mm for the periods 2020-2039 and 2040-2059, respectively, as compared to 157 mm for the reference period 1995-2014.

Figure 2.7 and 2.8

Average annual evapotranspiration (mm) in Iraq (left) | Climate zones of Iraq (right)



Source: Al-Ansari, 2013

The average monthly PET shows similar trends for Rutba and Ramadi stations (**Figure 2.9** and **Figure 2.10**, respectively). The months from May to September show relatively high values, equal to or more than 160 mm per month, and the months of October to April showed the lowest PET, equal to or less than 120 mm per month. The simulations of Dagher and Obead (2023) for Anbar predict an increase in reference evapotranspiration (ET0) to reach more than 200 mm per month and less than or equal 150 mm per month for the near (2020-2039) and medium (2040-2059) future periods for Anbar. The annual PET values were 1,512.1 and 1,631.3 mm per year for Rutba and Ramadi, respectively. This is lower than the overall average of Iraq (1900 mm/year), but relatively close to Anbar's evaporation levels (1600-1700 mm/year). This shows that PET exceeds the annual mean rainfall in Anbar, causing water deficit.

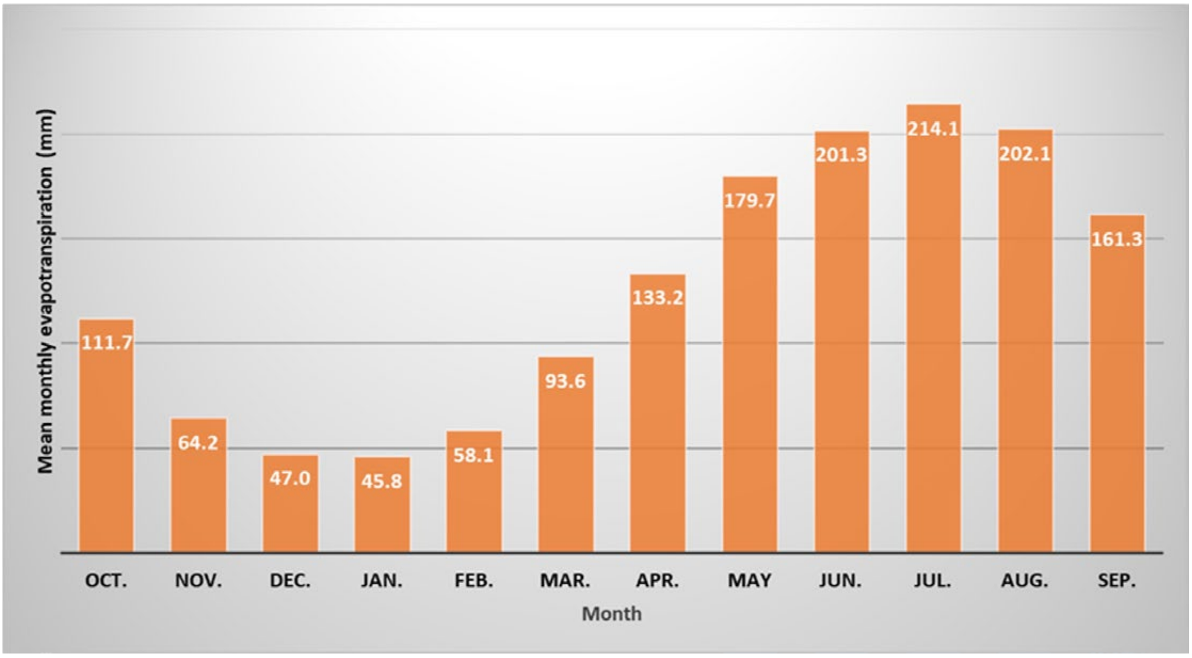
Although the PET trend from Haditha (**Figure 2.11**) is similar to those from Rutba and Ramadi, the monthly PET values are lower. The highest PET values fell between May and September, with a maximum of around 160 mm reached in July. The lowest PET values fell between October and March, ranging between 62 mm and 72 mm at most (**Figure 2.11**). The annual PET calculated for Haditha was 1,050.1 mm per year, less than the previous two stations.

Another method which depends on the mean monthly temperature data (Unpublished data) between 1981-1982 and 2007-2008 was used to estimate the annual PET in Hit station (**Figure 2.12**) using the Thornthwaite method (Farhan et al., 2020). The mean annual PET was 1700 mm per year in Hit, the closest to the value observed at Ramadi station.

Increased PET coupled with reduced precipitation can lead to reduced soil moisture and groundwater recharge, hence an increased demand for irrigation. Dagher and Obead (2023) implemented the CROPWAT model and reported an increase in the total annual irrigation water requirement for Anbar from 1,100 MCM (1995-2014) to 1,430 MCM (2020-2039) and 1,460 MCM (2040-2059).

Figure 2.9

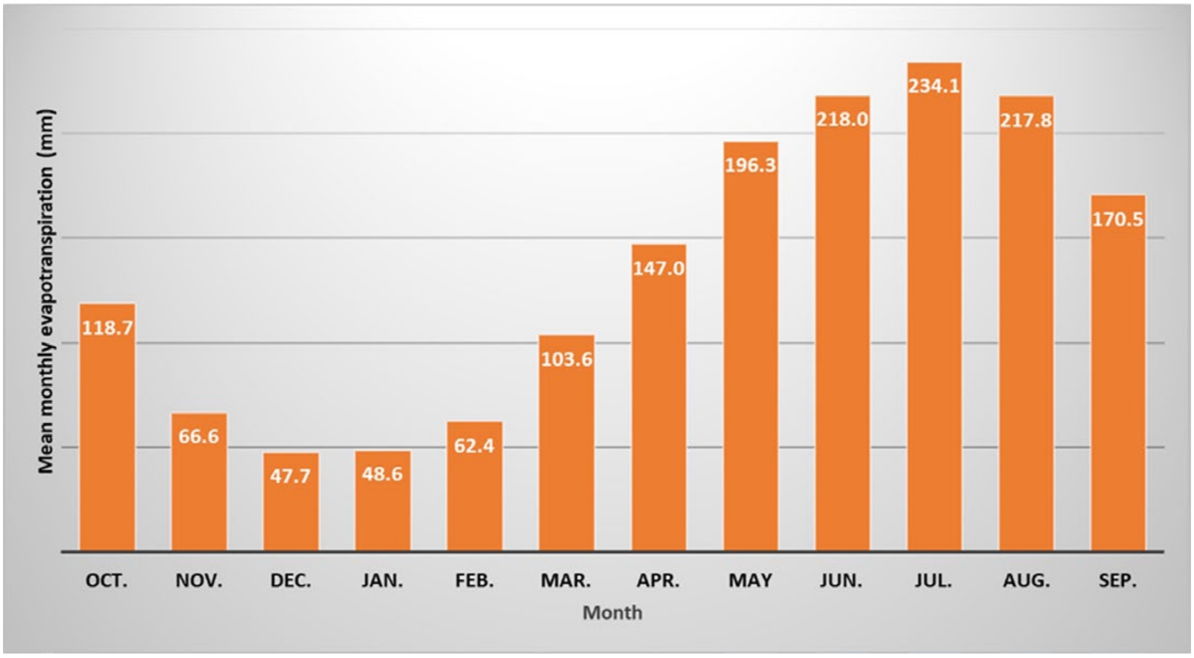
Mean monthly potential evapotranspiration at Rutba meteorological station using Blaney-Criddle model



Source: Own work

Figure 2.10

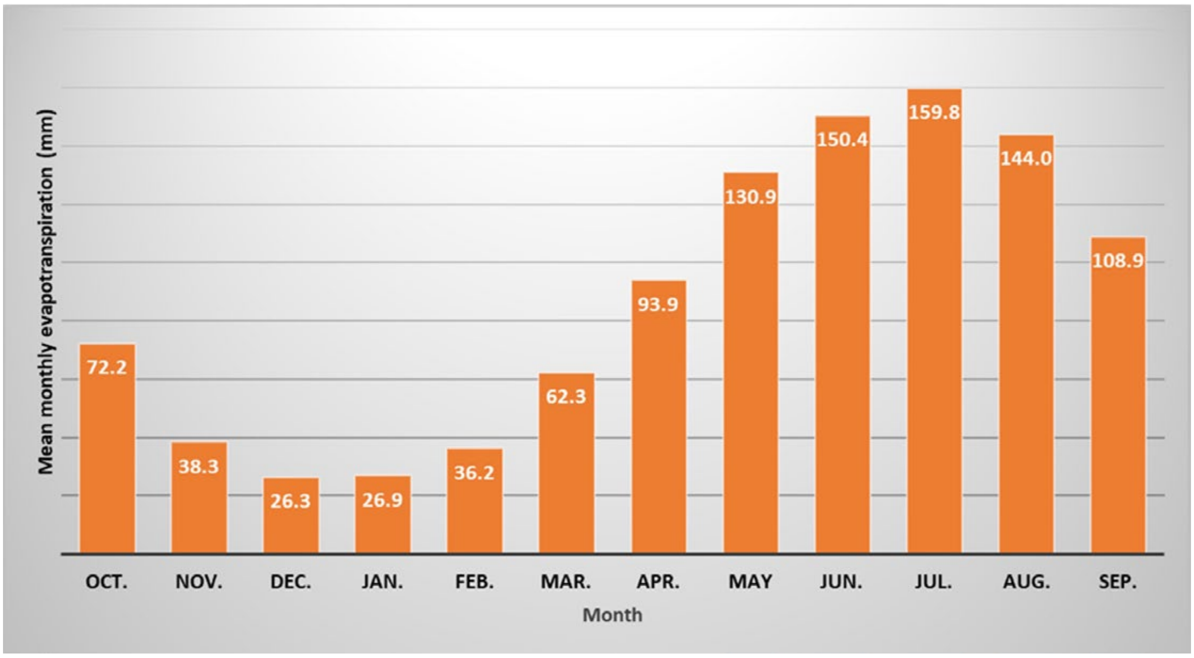
Mean monthly potential evapotranspiration at Ramadi meteorological station using Blaney-Criddle model



Source: Own work

Figure 2.11

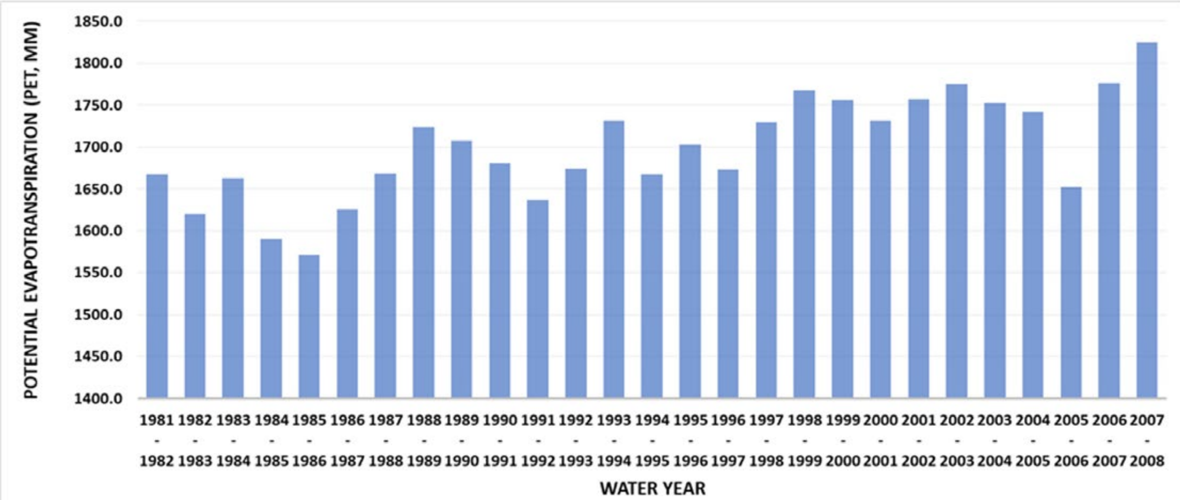
Mean monthly potential evapotranspiration at Haditha meteorological station using Blaney-Criddle model



Source: Own work

Figure 2.12

Mean monthly potential evapotranspiration at Hit meteorological station using Thornthwaite method



Source: Own work

2.3.3 Standardized Precipitation Index (SPI) Analysis

One of the adverse impacts of climate change is drought. Besides rainfall and PET changes, the application of drought index analysis is useful for drought adaptation and mitigation methods to deal with climate change. Understanding how drought episodes develop, spread, and affect us is crucial to knowing how to better prepare and plan for them and mitigate their impacts.

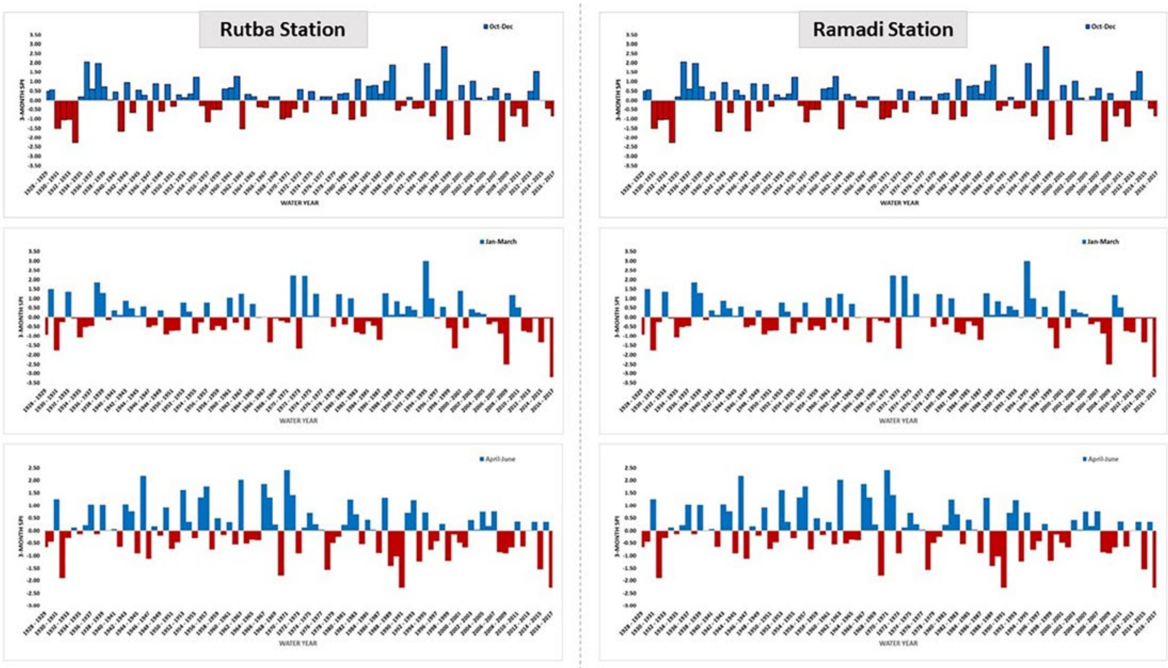
Results revealed that there are noticeable differences in the sensitivity of SPI values at different time scales (3, 6, 9, and 12-month), and even at the same time scale (3-month or 6-month). This is mainly due to the accumulated amount of rainfall over the investigated time scale. Among all the 3-month time scales from the five stations (**Figure 2.13** and **Figure 2.14**), moderately drought (-1.00 ≤SPI≤-1.49)[2] was the most dominant drought category. Regarding the two 6-month time scales (Oct-March and April-Sep), moderate and severe droughts were the most dominant drought categories (**Figure 2.15** and **Figure 2.16**). The moderate drought observed over 3- and 6-month time scales can be referred to as an agricultural drought, mostly affecting crop production and livelihoods over the short term. As far as the 9-month (**Figure 2.17**) and 12-month (**Figure 2.18**) time scales, moderate drought was the most dominant drought category. The severe (-1.50 ≤SPI≤ -1.99) and extreme (SPI ≤ -2.00) droughts were the second and third in order, respectively. The 12-month SPI results define a long-term moderate drought affecting the different areas in Anbar. Overall, the incidences of droughts of any category have increased in the last twenty years and there are fewer wet years.

The four different intervals depict that moderate drought is most common, but after 1998-1999, severe drought events occurred more frequently, particularly in the summer and winter periods, whereas periods with above normal rainfall have become less common for the same period.

2 *K* is drought threshold, set to be less than or equal to -1 in this study, means the drought level is greater than moderate drought, *T* is the duration of the drought process.

Figure 2.13

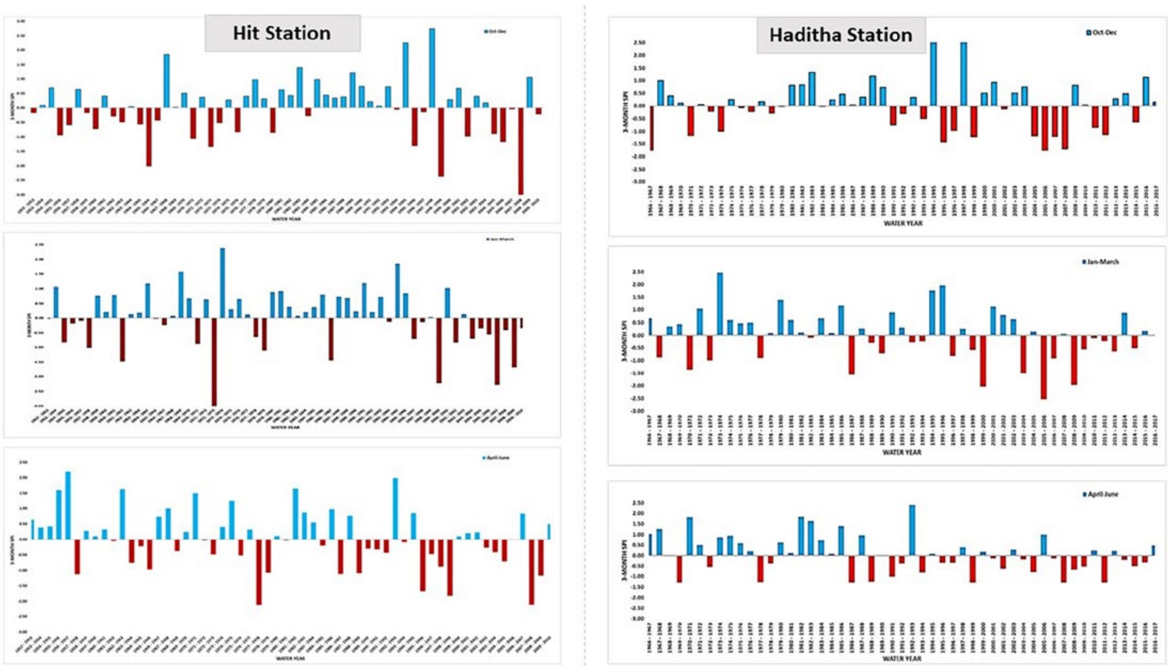
Three-month SPI for Rutba (left) and Ramadi (right) stations
for the periods of Oct-Dec, Jan-Mar and Apr-Jun.



Source: Own work

Figure 2.14

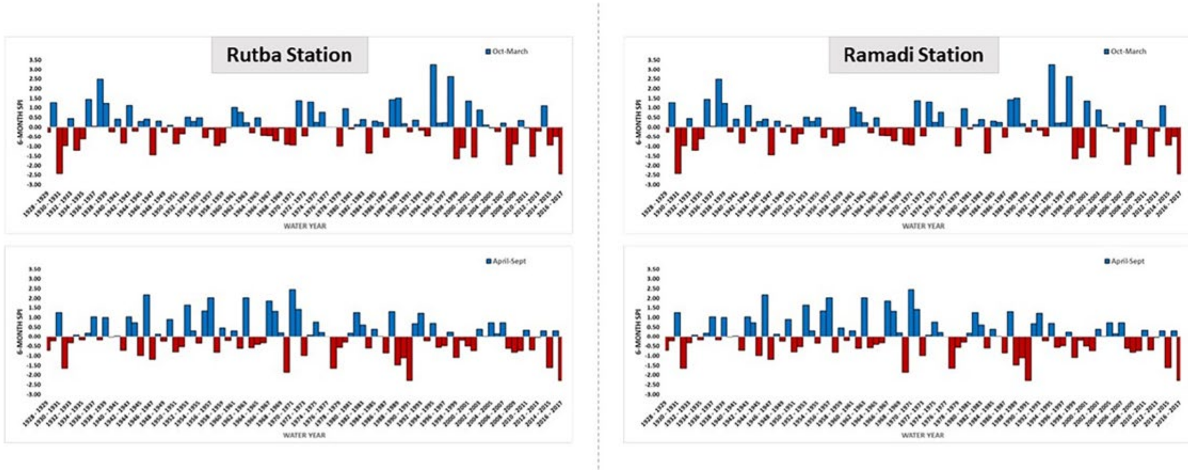
Three-month SPI for Hit (left) and Haditha (right) stations
for the periods of Oct-Dec, Jan-Mar and Apr-Jun.



Source: Own work

Figure 2.15

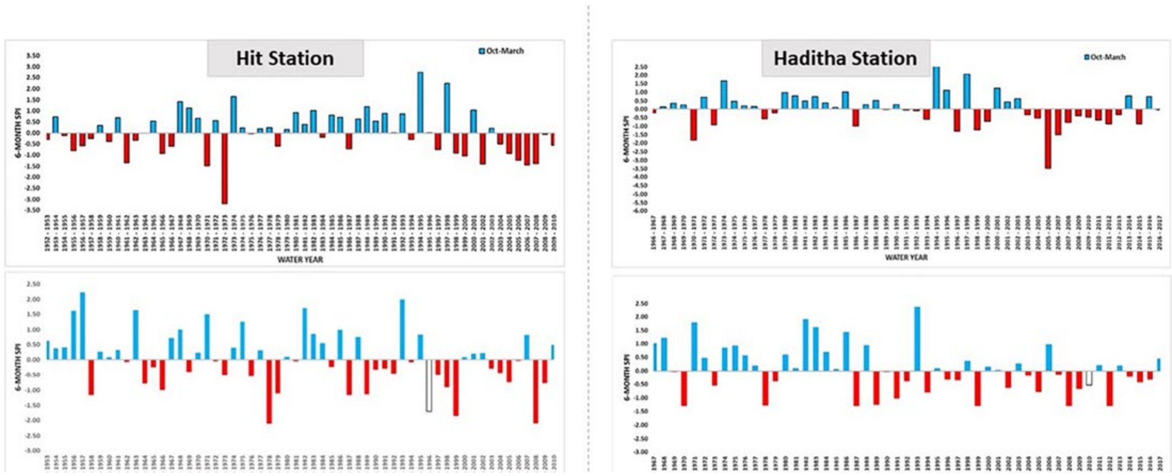
Six-month SPI for Rutba (left) and Ramadi (right) stations for the periods of Oct-Mar and Apr-Sep.



Source: Own work

Figure 2.16

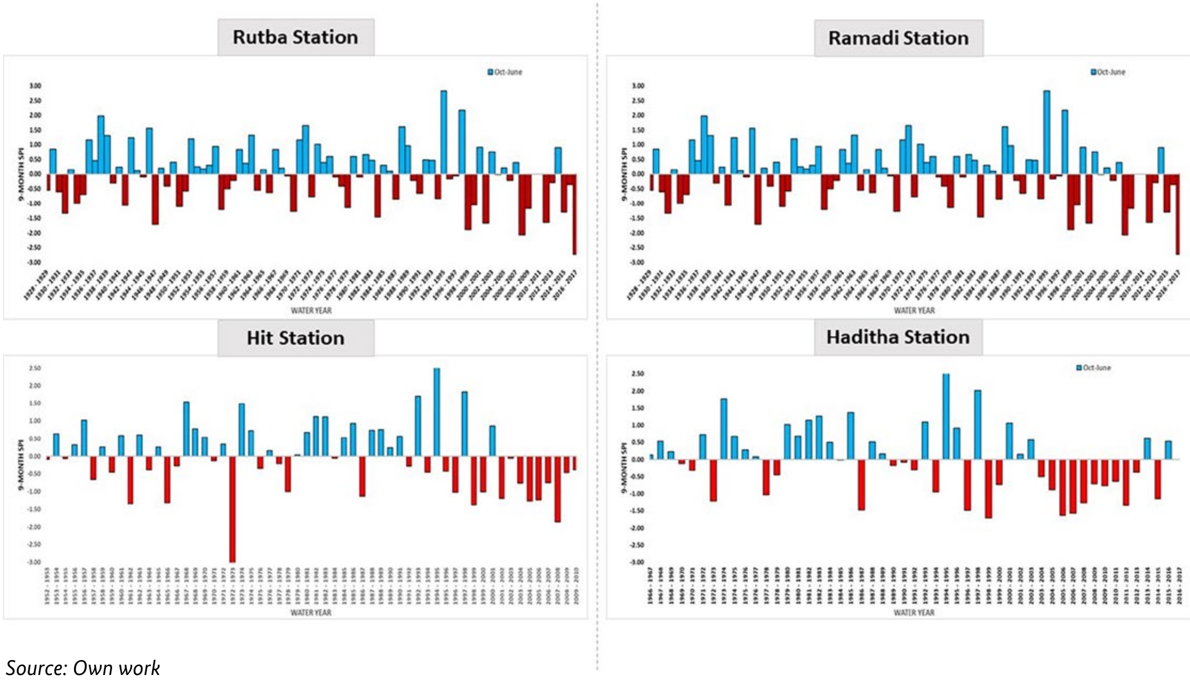
Six-month SPI for Hit (left) and Haditha (right) stations for the periods of Oct-Mar and Apr-Sep.



Source: Own work

Figure 2.17

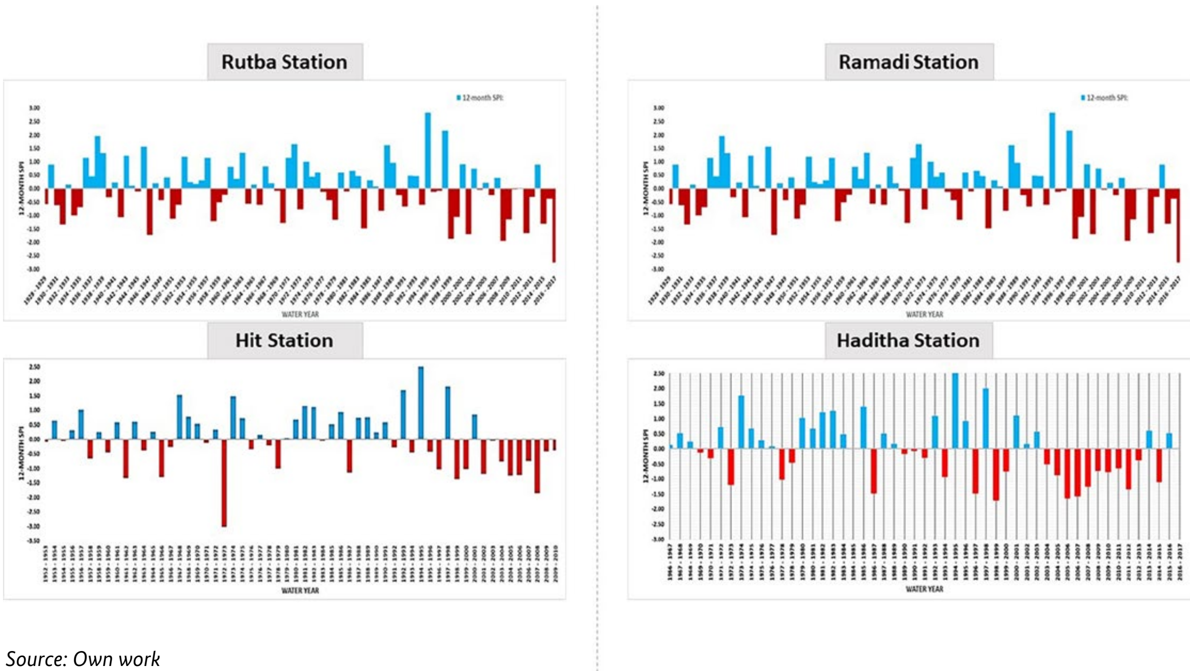
Nine-month SPI for Rutba (top left), Ramadi (top right), Hit (bottom left) and Haditha (bottom right) for the period Oct-Jun..



Source: Own work

Figure 2.18

Twelve-month SPI for Rutba (top left), Ramadi (top right), Hit (bottom left) and Haditha (bottom right) for 12-month period



Source: Own work

2.4 Discussion

Although there are multiple variations in the definition of drought, there are explicit trends that indicate drought conditions (Brewer and Heim, 2011). One of them is the meteorological drought targeted in this report to reflect on drought conditions in Anbar governorate. A meteorological drought is defined as "an increase in the daily and annual temperature range with a decline in the amount of rain to less than 100 mm". The meteorological data reported here has shown a recession in precipitation in the five observatory meteorological stations in Anbar Governorate, with the decline being more pronounced in some areas than the others, such as Haditha and Ramadi stations. A previous study by Al-Fahdawi (2020) reported a negative rainfall rate (-11.6 mm) at Ramadi station between 2009 and 2014. In fact, rainfall volumes decreased in both Al-Qaim and Ramadi stations between 1989 and 2014 (Al-Fahdawi, 2020), coinciding with the meteorological analysis presented in this report.

The study evaluated the minimum, maximum and mean annual precipitation over the long-term in various stations. The highest mean annual precipitation was observed in Ana with 142.2 mm, while the lowest was recorded in Rutba station with 112.3 mm. Regarding drought analysis, the SPI values reflected, primarily, moderate droughts in the five stations, with some variabilities at different time scales and within the same scale. This is mainly a result of the accumulation of rainfall over the investigated time scale. The 3-, 6-, and 9-month SPI revealed meteorological droughts, which are translated to agricultural droughts, while the 12-month SPI showed long-term moderate drought conditions, which creates hazards for reservoir storage, stream flows, and groundwater levels (Łabędzki, 2007). In all five stations for which data were analysed, the trend is in the last twenty years for severe droughts to increase and good rainfall years to become less common. Extremely drought condition was mostly observed at Al-Rutba and Ramadi stations at a 12-month time scale (**Figure 2.18**), in line with Kasim et al. (2021) who confirmed that these two areas fall under extreme drought, the worst type of droughts because it affects water availability that is most critical for agriculture. Severe and extreme droughts, although less commonly, were also observed in Anna, Haditha and Hit stations but they were more commonly observed at 3-, 6- and 9-month intervals. Based on the environmental sensitivity index to desertification (ESAI) used by Hamad et al. (2021), Ana, Hit and Haditha can be classified as critical to desertification (C3>1.53) with an index ranging between 1.57 - 1.73.

In comparison with the MENA region, Turkey is another drought-affected region, with high precipitation fluctuations. A study was conducted in Antakya in the eastern part of the Mediterranean region of Turkey, known for its important fertile plains, for the period of 1975-2010. The study reported slightly reduced precipitation total in winter, spring and summer seasons, as well as increased drought frequency, especially for the northern part of the area. Analysis of the meteorological data from this study revealed that the study area is exposed to droughts more frequently (Karabulut, 2015). Because drought is one of the most damaging and complex natural disasters, it is important that every nation develops its own drought preparedness strategy and mitigation plan to reduce its greater societal and environmental impacts.

2.5 Conclusion

From the analyses of SPI for annual (12 months), meso-scale (6 and 9 month) and seasonal (3 months) and precipitation data series, it can be concluded that precipitation characteristics of the area is changing and drought events becoming more frequent for the study area. Although this data is preliminary, both the meteorological data and the SPI results depict an increase in climate vulnerability in Anbar Governorate because of reduced precipitation and increased drought frequency and intensity. Anbar is on the path to a drought issue, with slow but consistent changes. This is evident in previous studies that also used meteorological data to simulate future climate trends in Iraq. For example, Osman et al. (2017) simulated a decrease in precipitation in Rutba for the far future (2080-2099). However, they predicted the autumn and winter to be wetter on a seasonal basis. In contrast, the simulations of Hassan et al. (2023) revealed an increase in the annual precipitation ranging from +6.09% to +20.97% depending on the period and the scenario used in the model. They associated this increase with extreme rain events that may occur and distribute the rain unevenly during the rainy season. This poses multiple risks such as damage to the infrastructure and flooding in the drainage systems. The development of rainwater harvesting techniques can be particularly useful in this regard, which is discussed in more details in **Chapter 6**.

The current data can be useful in simulating climate change impacts in Anbar for the near, medium and far future, as previously conducted by Osman et al. (2017) and Hassan et al. (2023). The observed results are alarming because of the damage they may cause to the agricultural production and livelihoods in the Anbar Governorate, given the strategic value of this region as a food basket for the country. They underscore the need to inform decision-makers on enhanced strategies for water resources management in the area. The lack of rain is leading to inadequate moisture supply for agricultural lands, slow replenishment of groundwater reserves, and devastating conflicts over water shares. The current meteorological drought is just paving the way for more intense hydrological and agricultural droughts (Brewer and Heim, 2011). This puts the productivity of agricultural crops on the edge. Wheat cultivation in Anbar region already decreased 8% between 1957 and 2011, while barley-cultivated area decreased 71% during the same period (Unpublished material).

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3 Euphrates River: Water Flow and Quality

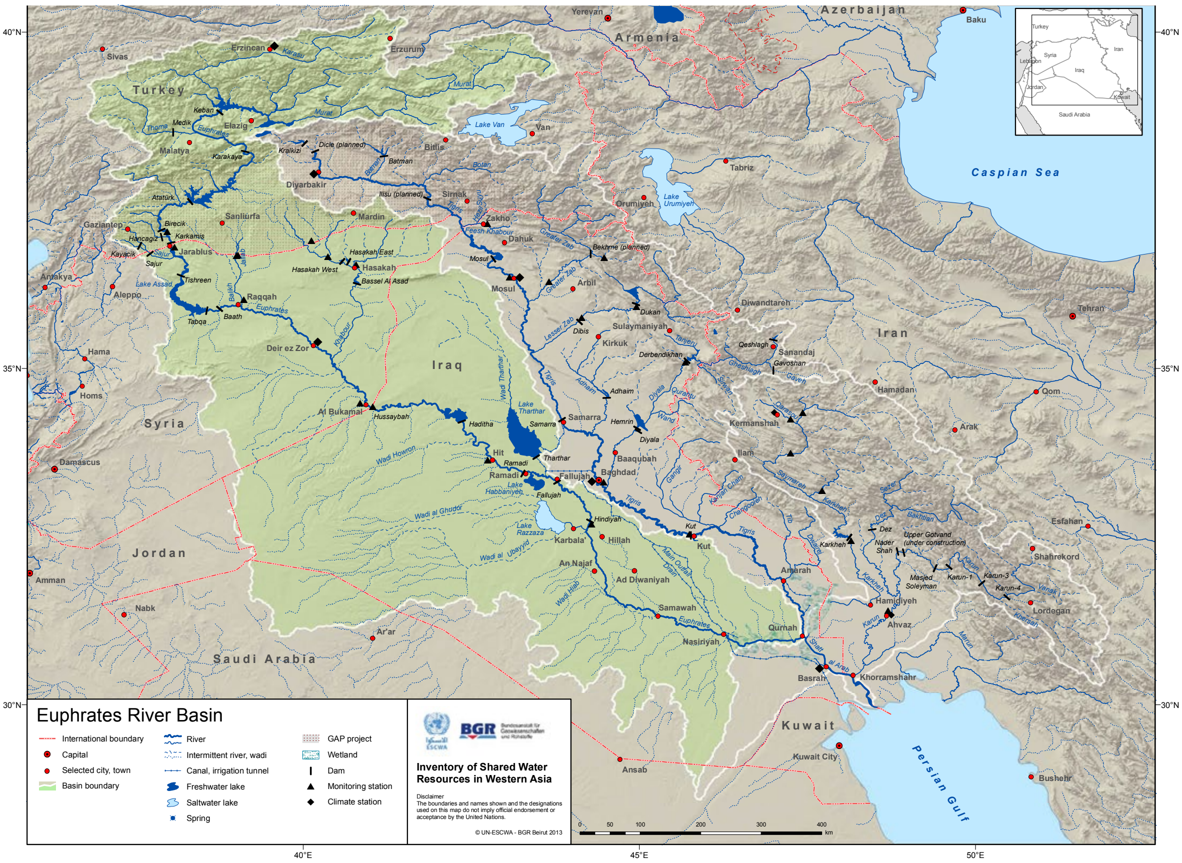
3.1 Introduction

Anbar governorate is largely dependent on the Euphrates River. The Euphrates River, originating from southeast Turkey, flows through three riparian nations—Iraq, Syria, and Turkey—and its basin is shared by five nations, namely Turkey, Syria, Iraq, Jordan and Saudi Arabia, a region historically known as the "Fertile Crescent". **Figure 3.1** shows the Euphrates River Basin and **Figure 3.2** illustrates the distribution area among the five nations. The Euphrates River rises in a mountainous region of the Mediterranean climate, which is known for its hot, dry summers and cold, rainy winters. The mean annual precipitation in the Euphrates River basin is shown in **Figure 3.3**.

Irrigation, domestic water supply, and hydropower are the main priorities of water management in Turkey, Syria, and Iraq. Irrigated agriculture is prevalent (>70%) throughout the Euphrates Basin, resulting in a substantial return flow of drainage water, which in turn causes water pollution and increase water salinity. Turkey's water infrastructure initiatives, especially Southeastern Anatolia Project (Turkish: Güneydoğu Anadolu Projesi – GAP), have had a significant impact on the basin's water resources, changing the Euphrates' River natural flow regime and influencing the water use patterns of other riparian nations, Iraq and Syria (Khudair et al., 2022).

Figure 3.1

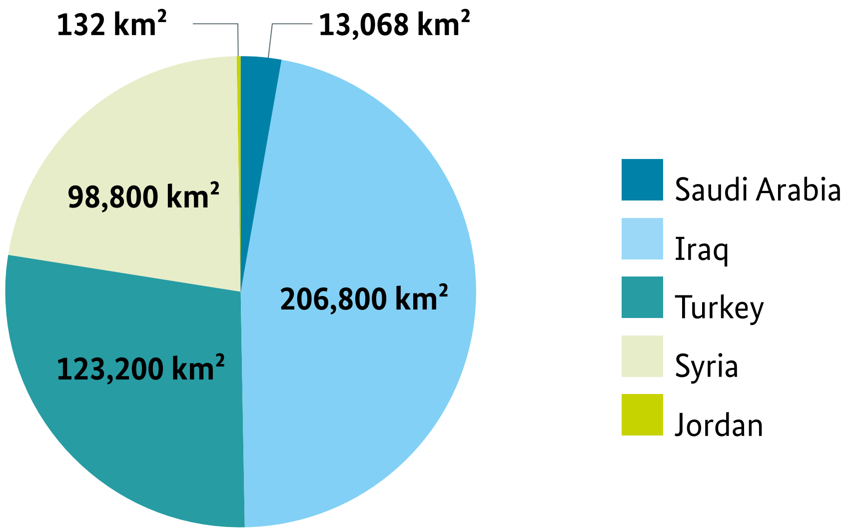
Euphrates River Basin



Source: UN-ESCWA, 2013

Figure 3.2

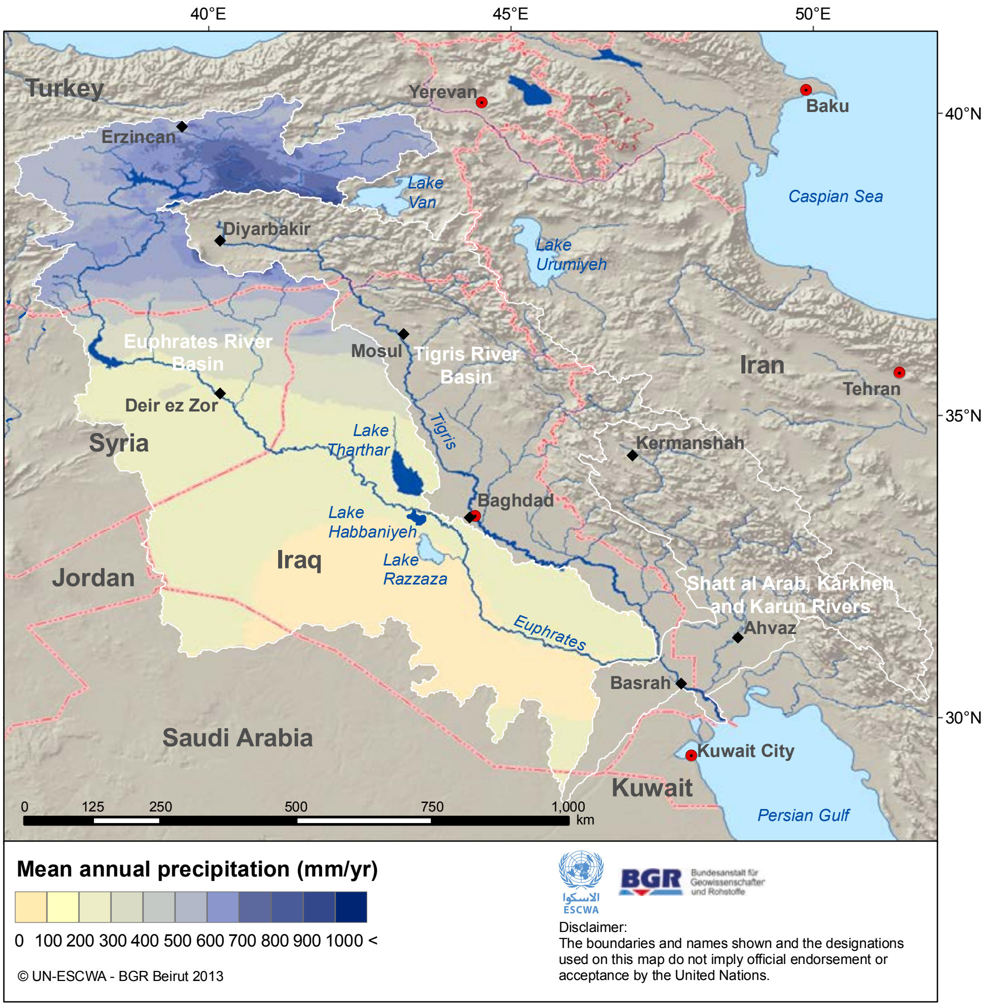
Distribution of the Euphrates Basin area



Source: UN-ESCWA, 2013

Figure 3.3

Mean annual precipitation in the Euphrates Basin



Source: UN-ESCWA, 2013

The reduced inflows also affect water quality. Iraq is currently contending with two types of water quality issues. One is salinity. The other is the concentration of pollutants in the water caused by municipal, industrial and agricultural activities that introduce return flows into freshwater sources (Mutasher et al., 2021). Drainage and wastewater discharged into the Euphrates is largely untreated.

Development of agriculture throughout the Euphrates and Tigris watershed, both inside and outside Iraq, is leading to a progressive increase in the salinity of the waters of the Euphrates, Tigris and other rivers in Iraq. Economic development and population growth are also contributing to rising loads of various contaminants. Deterioration in water quality is exacerbated by droughts and is a major contributing factor to desertification of agricultural land. This chapter delves into the status of water quality in different water bodies along the Euphrates in Anbar with the aim to assess their suitability for irrigation based on local (Iraqi) and international (World Health Organization) standards. Multiple physicochemical parameters are considered. In addition, satellite images are used to assess chlorophyll-a contamination and Total Dissolved Solids (TDS) level in open water bodies.

3.2 Status of Water Quality in the Euphrates River

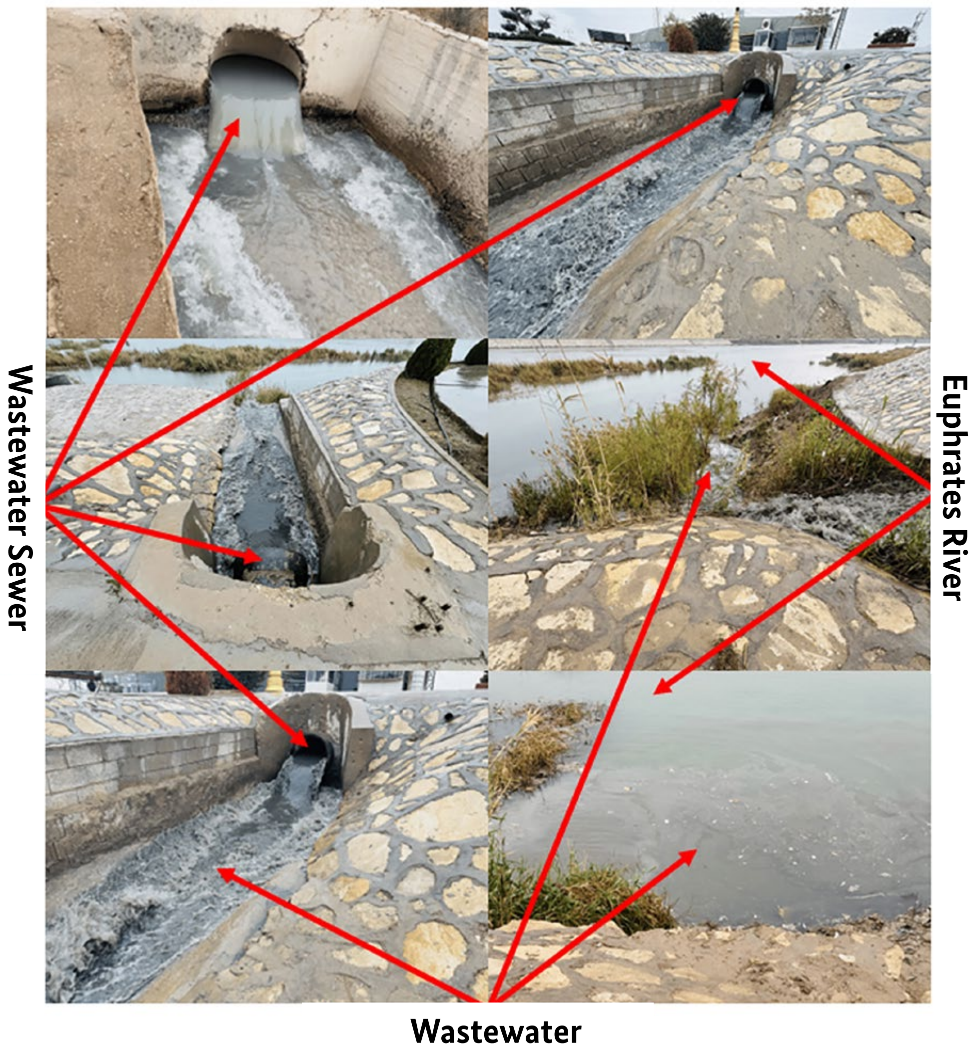
Lakes and reservoirs formed by dams play a crucial role as vital surface water sources in Iraq. They also serve as significant indicators of fluctuating water conditions, providing insights into the country's strategic water reserves. All these important reservoirs such as Haditha reservoir and Habbaniyah lake in the Anbar Governorate have seen a discernible decrease in water surface area during the last four years from around 370 km^2 to around 170 Km^2. This decline can be attributed to reduced water inflows due to damming and excessive water abstraction in the upstream riparian states, especially Turkey and Syria, discharge of untreated wastewater (**Figure 3.4**) and the impact of climate change, including a significant reduction in rainfall coupled with escalating evaporation rates (Masoud et al., 2022). **Figure 3.5** shows that Haditha Lake has almost completely vanished. This clearly expresses the severity of the water crisis and its detrimental effects on the region's ecosystems and water bodies.

Iraq experiences a multifaceted water crisis that is expected to persist. In Iraq, public water supply is considered a priority over other water uses. The agriculture sector consumes the largest volume of fresh water, which experiences an imbalance between water supply and water demand, especially in dry years. Shafaq News, an environmental and climate observatory, reported on the 9th of May 2023 a water crisis affecting the southern regions of Ramadi, the capital of Anbar Governorate, impacting approximately 13,000 residents (Ali Al Ahmadi et al., 2019). The crisis has compelled inhabitants of these areas to flee their homes in search of potable water resources. Environmental challenges as such are among the drivers of displacement and migration, along with political, demographic, economic and social implications.

The availability of good quality water free of pollutants is central to water security. The water availability in a country decreases when water quality deteriorates. Sufficient water of adequate quality is an essential precondition for human life, socioeconomic development, and environmental sustainability. The third target of the water goal (Sustainable Development Goal 6 (SDG-6: target 6.3) underlines the importance of water quality protection *"By 2030, improve water quality by reducing pollution, eliminating dumping and minimising the release of hazardous chemicals and materials, halving the proportion of untreated wastewater, and substantially increasing recycling and safe reuse globally"* (Atikul Islam et al., 2017). Data of 2022 on the indicator 6.3.1 of the SDG-6 showed that 42% of domestic wastewater in Iraq is safely treated, implying 58% is not. Comprehensive and accurate water quality assessment at the local and national level remains a challenge. For example, the proportion of safely treated industrial and domestic wastewater could not be appropriately estimated due to insufficient and sometimes inaccurate data.

Figure 3.4

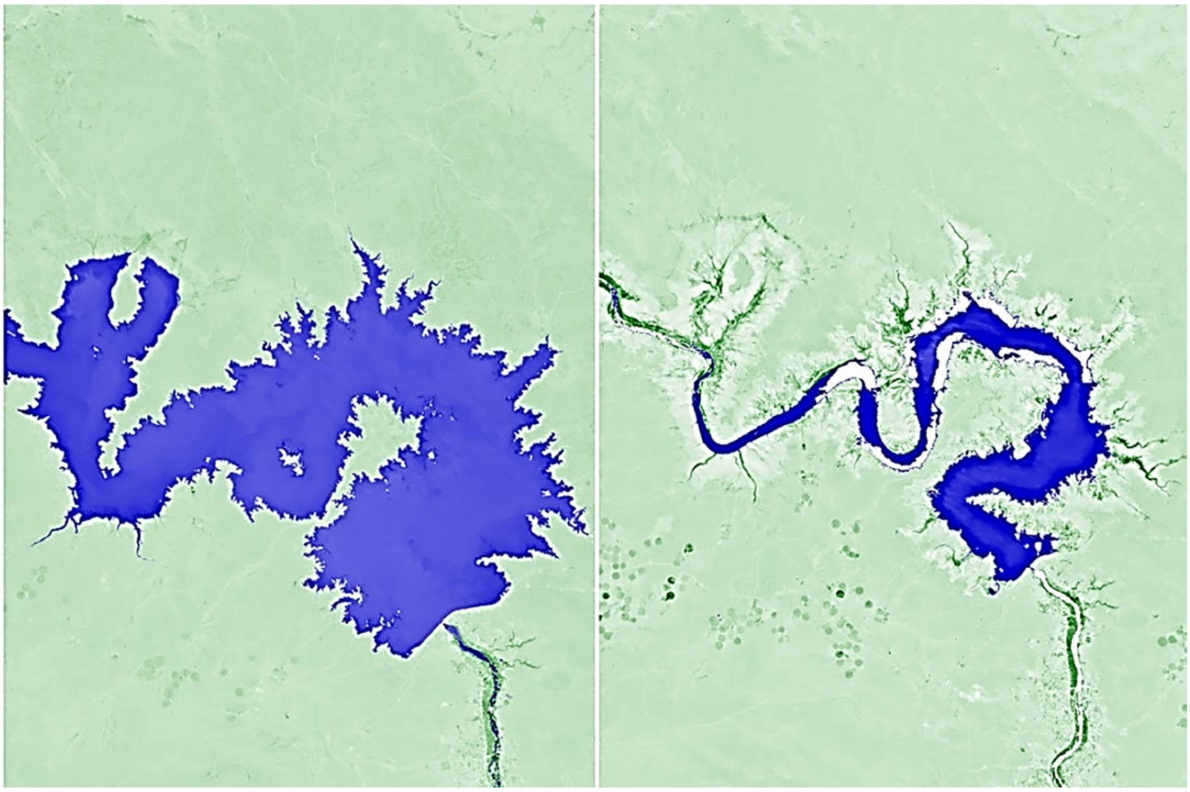
Discharge of untreated wastewater



Source: Own pictures. Date 2025. Location: Ramadi

Figure 3.5

Comparison between Haditha Lake in July 2019 (left) and July 2023 (right)



Source: The Century Foundation, 2023 -EO Browser

Water quality reaching Iraq from the Riparian countries at Al-Qaim on the Euphrates River and Phishkhabour on the Tigris River is as important as the quantity. For example, water with a Total Dissolved Solids (TDS) value above 1,000 ppm (parts per million) is not recommended for human consumption. A TDS above 2,000 ppm entails “severe restrictions” on the use of water for irrigation.

This section aims to evaluate the quality of the Euphrates River through the analysis of the TDS concentrations at six sites where data is available between October 2004 and September 2022. Only the TDS concentration was considered in this analysis.

3.3 Impact of climate change and anthropogenic interventions

Around half of Iraq's water resources is coming from outside the country (Osman et al., 2017). This makes it highly vulnerable to climate change impacts. The flow rates in Iraq's main surface water sources, the Tigris and Euphrates Rivers, have dwindled to less than one-third of their usual levels (IAU, 2011). These rates are anticipated to decline further. Results from multiple scientific studies have documented discernible impact of climate change on decreased precipitation and reduced flow rate in the region (Gumus et al., 2022; Ay et al., 2018; Yildiz et al. 2016). It is estimated that precipitation and snowfall in the Euphrates River Basin from the Turkish part will decrease by 30-40% by the end of the century (Daggupati et al., 2017).

The second root cause of the drought in Iraq is a combination of climate change (see chapter 2), lack of sustainable management of water resources, aging infrastructure at the national level, unilateral damming, intensive water abstraction, and water diversion in the riparian states, particularly Turkey and Syria that share the water with Iraq.

Over the last three decades, Iraq has suffered mild to extremely severe drought episodes. These drought episodes varied in severity, length, and spatial extent. The construction of large dams and water diversion by neighbouring countries has further aggravated the situation (Sulaiman et al., 2021). Moreover, inefficient water management practices, such as excessive use of municipal water, overexploitation of groundwater, disposal of untreated wastewater to the river corridors, and inefficient irrigation systems, have all contributed to the increase in water shortages and the deterioration of its quality (Al-Ansari, 2013).

Riparian countries, particularly Turkey and Syria, still intend to build more dams and implement water transfer systems between basins in their territories. This entails that the flows of the shared watercourses are projected to drop further both in quantity and quality.

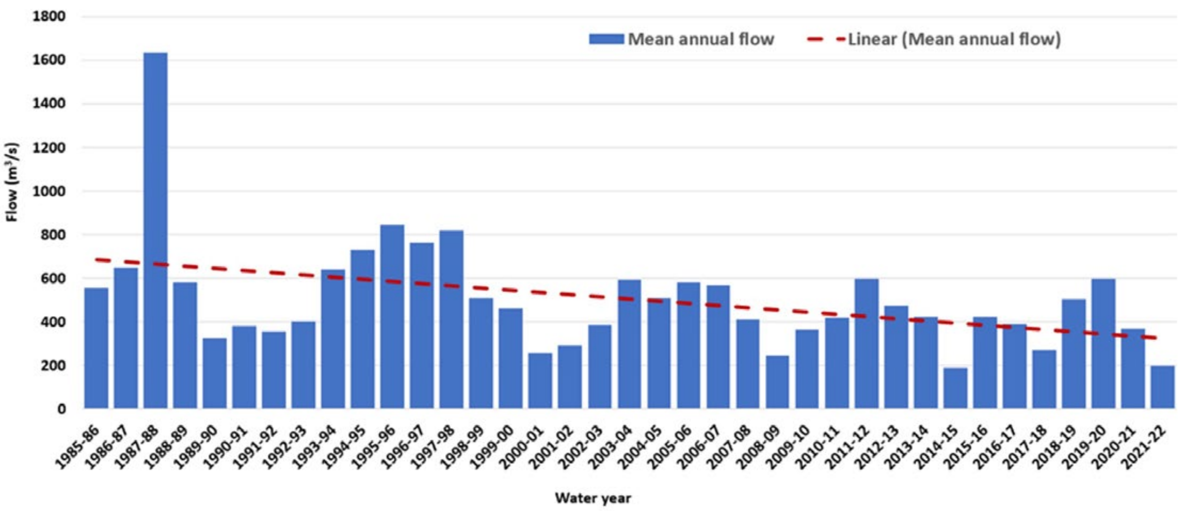
The natural flow regimes of the Euphrates River have been largely impaired due to this upstream damming and flow diversion. What matters is how the upstream countries, especially Turkey operate their large dams (Ministry of Environment, 2020). However, the amount of precipitation falling in the Euphrates River Basin in any given hydrological year is a vital determinant of flows into Iraq. This is because the types of the hydrological years (dry, normal or wet) will be a key driver to the mode in which Turkey and Syria operate their dams to meet their water needs (Raphaeli, 2009).

Figure 3.6 shows the mean annual inflow to Haditha Dam on the Euphrates River (unpublished data) between the water years 1986 and 2022. The dotted red line shows a clear downward trend in the mean annual inflow to the Haditha Dam, which affects the hydropower generation, the domestic water supply and the irrigated agriculture requirements downstream. The decrease in the inflow is attributed to the joint impact of both upstream anthropogenic interventions and climate change.

A study by Al-Ansari (2013) projected an increased water deficit in the Anbar Governorate being primarily dependent on the Euphrates River. The deficit is projected to increase to reach 1,672 and 1,860 MCM/year by 2030 and 2035, respectively. According to recent estimates, more than 80% of water withdrawal is used for agricultural activities in the governorate, with considerable waste of water and contamination due to the use of surface irrigation method (Khudair et al., 2021).

Figure 3.6

The mean annual inflow to Haditha Dam on the Euphrates River



Source: Own work.

3.4 Assessment of Water quality along the Euphrates River

3.4.1 Conventional Laboratory Analysis

This section focuses on assessing the variations in the water quality along the Euphrates River between Al-Qaim and Al-Falluja in the last two decades through in-situ sampling. Due to significant missing records of water quality parameters, only the Total Dissolved Solids (TDS) concentration was analysed.

3.4.1.1 Total Dissolved Solids (TDS) Results

Total Dissolved Solids (TDS) concentration was analysed at six stations for data recorded between May 2004 and September 2022 along the Euphrates, including Al-Qaim, upstream Haditha Dam, Haditha Dam, Hit, Al-Ramadi and Al-Falluja. The mean TDS values were 635, 591.6, 635.7, 689.1, 689.6, and 733.5 ppm, respectively (**Table 3.1**). More descriptive statistics including quartiles and median are included in Annex I for reference. In general, results showed an increasing TDS trend as the sampling moved from Al-Qaim toward Al-Falluja. According to FAO guidelines for Conventional Water Quality for Irrigation (Ayers and Westcot, 1985; FAO, 2010), the current TDS values at the six locations pose slight to moderate restriction (450<TDS<2000) on the use of the sampled water for irrigation.

Table 3.1: Summary of the minimum and maximum TDS concentrations and the corresponding mean monthly flow concentrations along with the month and the year in which the minimum and maximum concentrations observed at 6 sites along the Euphrates River.

Euphrates River/Site	Max TDS (ppm)	Month/ Year	Mean monthly flow (cumec)	Min TDS (ppm)	Month/ Year	Mean monthly flow (cumec)	Mean TDS (ppm)	Standard Deviation (ppm)
Al-Qaim	1,046	**May-09**	229	175	**Aug-07**	655	635.0	188.6
Upstream Haditha Dam	1,116	**May-09**	210	170	**May-07**	540	591.6	182.1
Haditha Dam	1,140	**Jun-09**	280	260	**Aug-12**	692	635.7	143.3
Hit	1,186	**Sep-09**	355	250	**Aug-12**	682	689.1	160.3
Al-Ramadi	1,198	**Jul-09**	345	104	**Jul-08**	580	689.9	193.0
Al-Falluja	1,946	**May-21**	381	184	**Jul-07**	800	733.5	213.3

Source: Own work.

Starting with Al-Qaim region (**Figure 3.7**), high TDS can largely be impacted by the agricultural return flows, domestic sewage and industrial effluents that are pumped into the river on the Turkish and Syrian sides. Moreover, the reduction in the river flow rates is another major driver for high TDS values. Untreated drainage water may explain the high TDS observed at Hit (689.1 ppm) (**Figure 3.10**). Unpublished secondary data showed that two stormwater drains discharge into the Euphrates River at Hit. Al-Sufei stormwater drain discharges into Wadi Al-Basayer, which flows into the Euphrates River, as well as Al-Dawarra stormwater which drains into the Euphrates River. Masoud et al. (2022) reported that Sulphur springs in Hit City is one of pollution sources on the Euphrates River because of direct drainage from rural areas into the river. Furthermore, studies showed that sewage sewers of the cities along the Euphrates River drain directly to the river. Additionally, the hazardous waste from hospitals and the usage of explosive materials by fishermen causes serious water pollution in the Euphrates River (Ali Al Ahmadi et al., 2019).

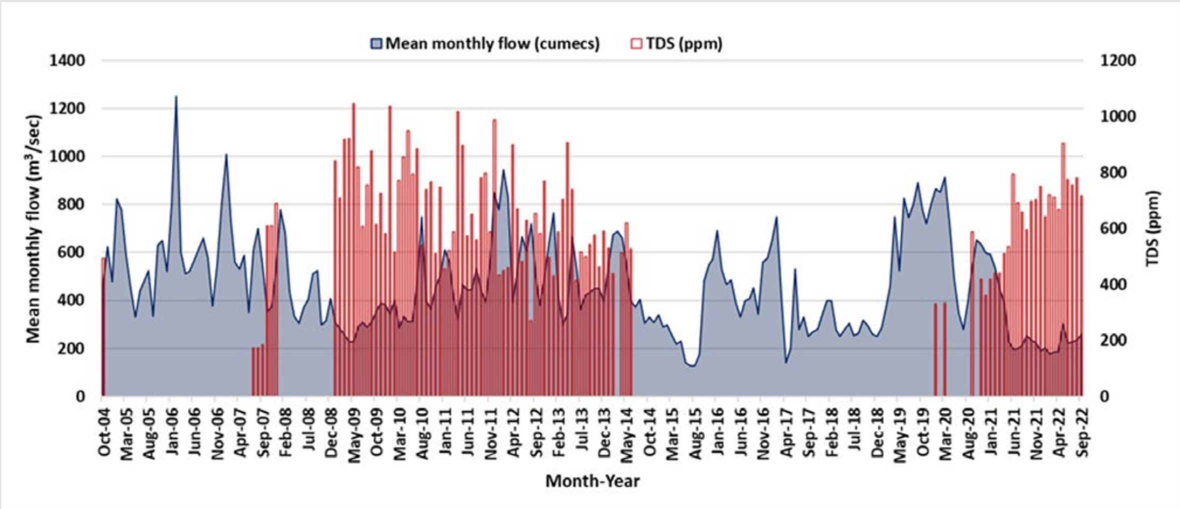
As for the high TDS at Al-Ramadi (**Figure 3.11**), information provided by the Environmental Policies Unit (Atikul Islam et al., 2017) mentioned that H1 stormwater drains discharge into Al-Warrar canal that conveys the water to the Habbaniyah Lake.

The limited available TDS data of the Tharthar-Euphrates canal between October 2012 and September 2022 showed that the average TDS was 1,047.6 ppm. High TDS concentrations of the Tharthar-Euphrates canal would contribute to an increase in the TDS levels of the Euphrates level at Al-Falluja.

Because of the size of missing records, it became very difficult to devise a relationship between the flow rate and the TDS. However, results showed low TDS concentrations can be associated with high flow rates, and the inverse is true.

Figure 3.7

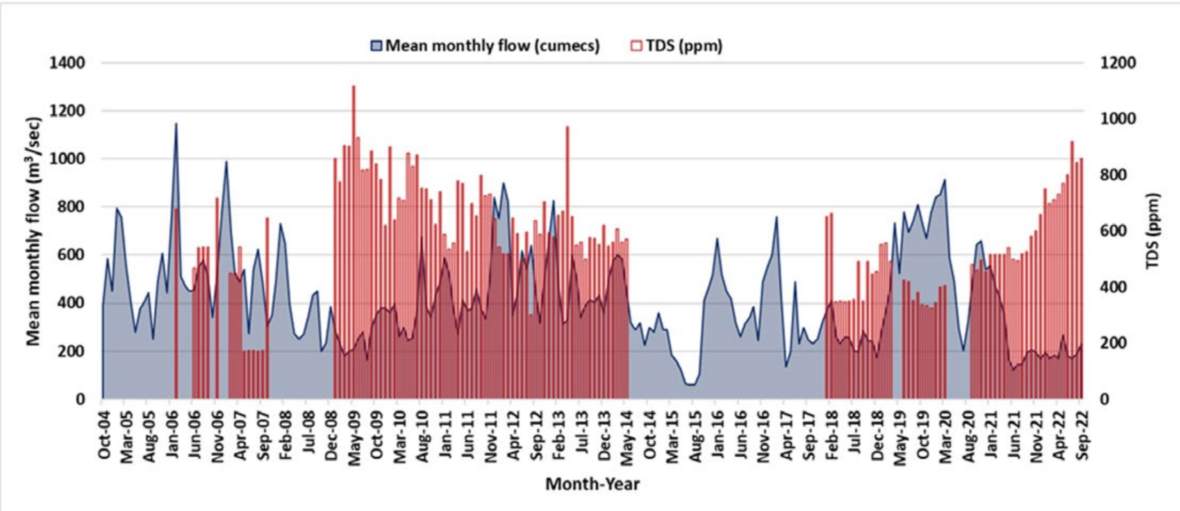
Monthly variations of flow and TDS concentrations of the Euphrates River at Al-Qaim
between October 2004 and September 2022.



Source: Own work.

Figure 3.8

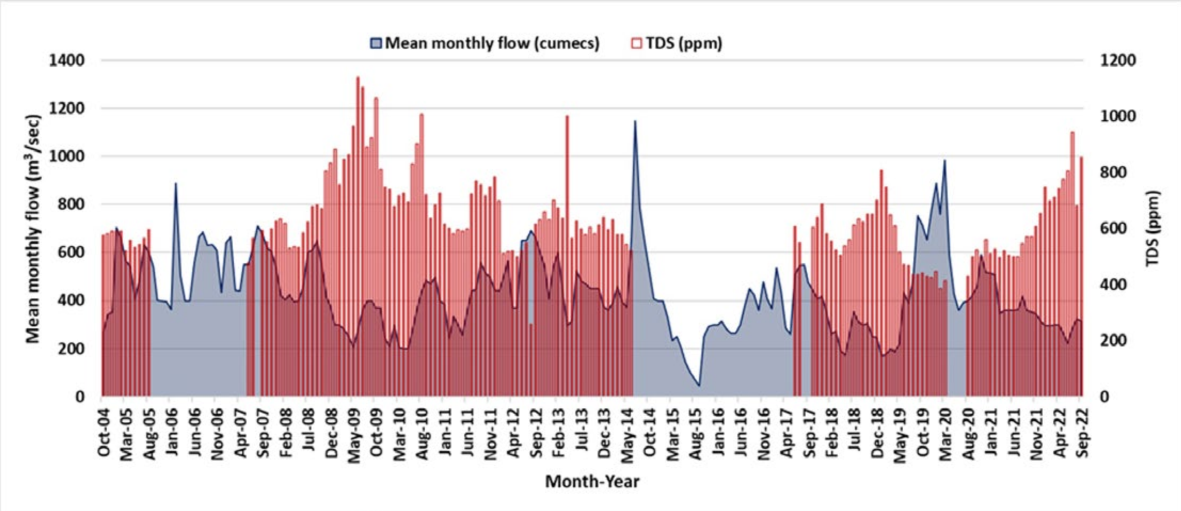
Monthly variations of flow and TDS concentrations of the Euphrates River upstream Haditha Dam
between October 2004 and September 2022.



Source: Own work.

Figure 3.9

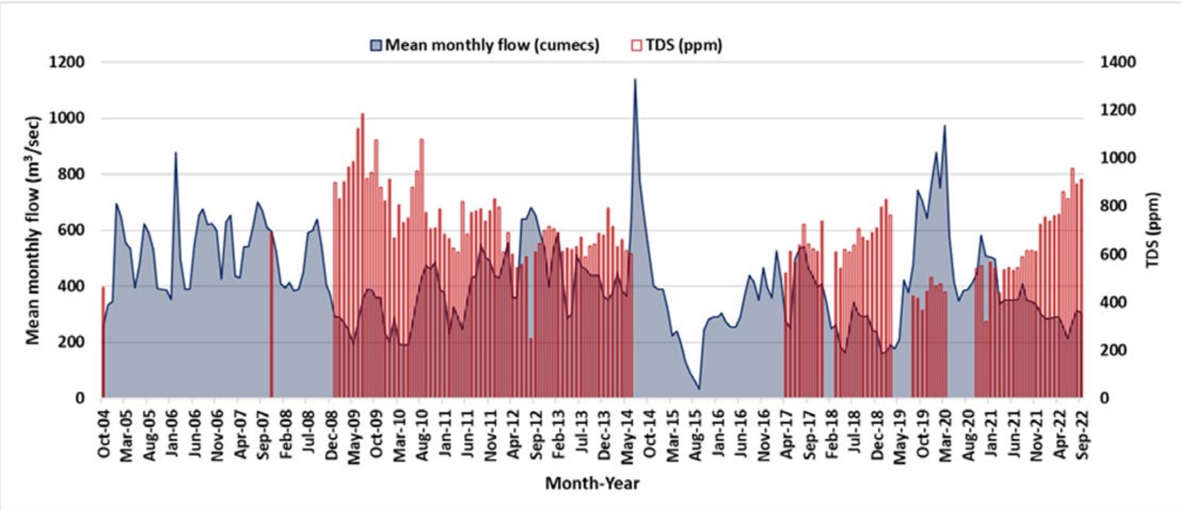
Monthly variations of flow and TDS concentrations of the Euphrates River at Haditha Dam between October 2004 and September 2022



Source: Own work.

Figure 3.10

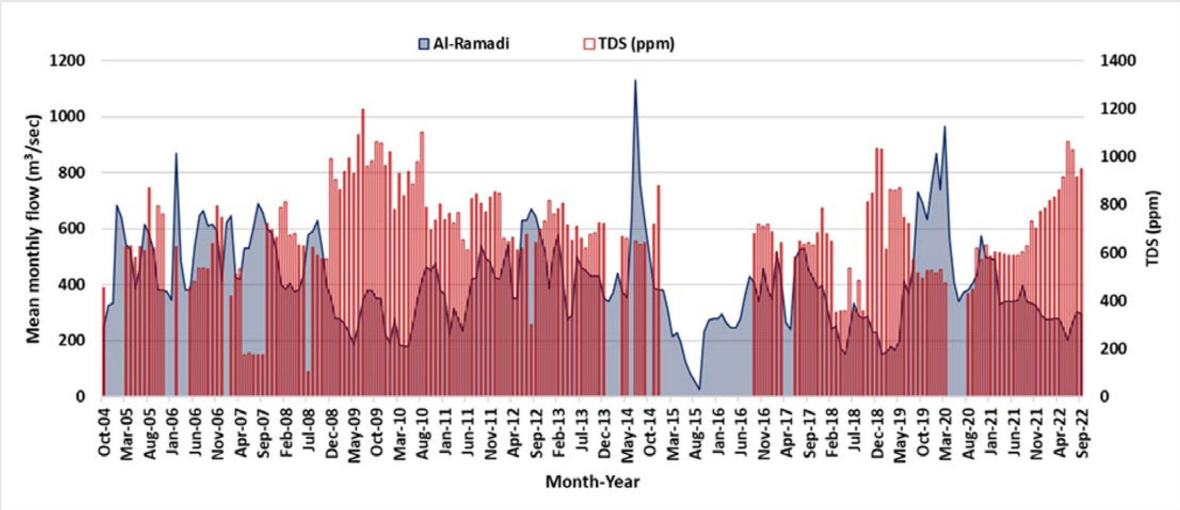
Monthly variations of flow and TDS concentrations of the Euphrates River at Hit between October 2004 and September 2022



Source: Own work.

Figure 3.11

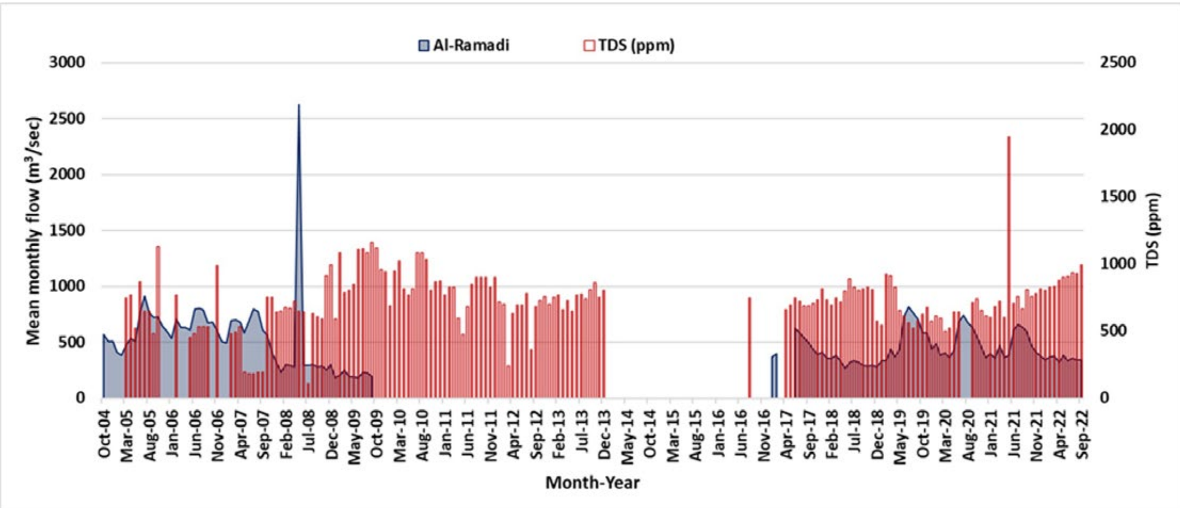
Monthly variations of flow and TDS concentrations of the Euphrates River at Al-Ramadi between October 2004 and September 2022



Source: Own work.

Figure 3.12

Monthly variations of flow and TDS concentrations of the Euphrates River at Al-Falluja between October 2004 and September 2022.



Source: Own work.

3.4.2 Eutrophication Analysis Using Satellite Images

Several studies have reported increased incidences of eutrophication along the Euphrates River. Eutrophication is a result of water enrichment with nutrients, primarily nitrogen and phosphorus, which stimulate algal blooms (excessive primary aquatic plant production) and cause a reduction in dissolved oxygen in open water bodies (UNEP, 2003; Vilmin et al., 2018). Eutrophication is toxic to water bodies and may cause loss of biodiversity and structure of the water bodies (Pérez-Ruzafa et al., 2019). This section evaluates two water quality parameters, namely chlorophyll-a [Chl-a], as a fairly accurate method for measuring algal growth, and Total Suspended Solids (TSS), as a measure of water transparency, using Sentinel-2 satellite images for the period between April 2017 and May 2024 for spatial and temporal analysis. For this purpose, a tool called "MAGO Water Quality Monitoring Tool" developed by MAGO, a PRIMA (Partnership for Research and Innovation in the Mediterranean Area)-funded project, was used. This tool enables efficient environmental monitoring of lakes and reservoirs, reducing the need for continuous in-situ sampling. The targeted study area is the same one sampled in-situ along the Euphrates River, mainly extending from Al-Qaim till Al-Falluja. **Figures 3.13** and **3.14** highlight the colour scale and the colour classification map used in the tool to help the reader understand the satellite images produced.

Figure 3.13

Color scale for minimum and maximum concentrations. Source: MAGO-PRIMA tool.

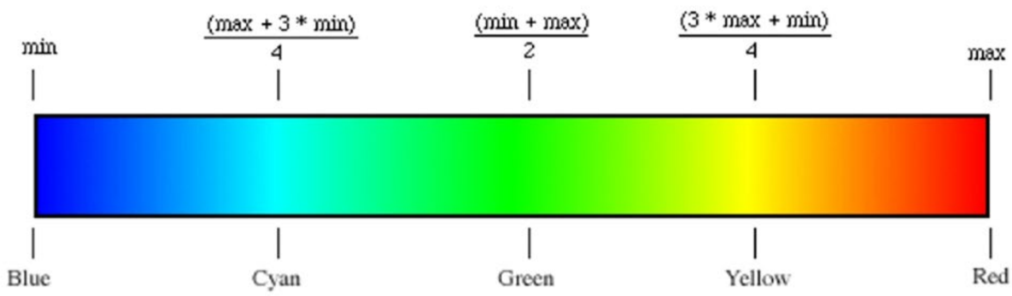


Figure 3.14

Scene Classification Map (SCL) for providing a pixel classification map (removing pixels containing clouds) with values from 0 to 11

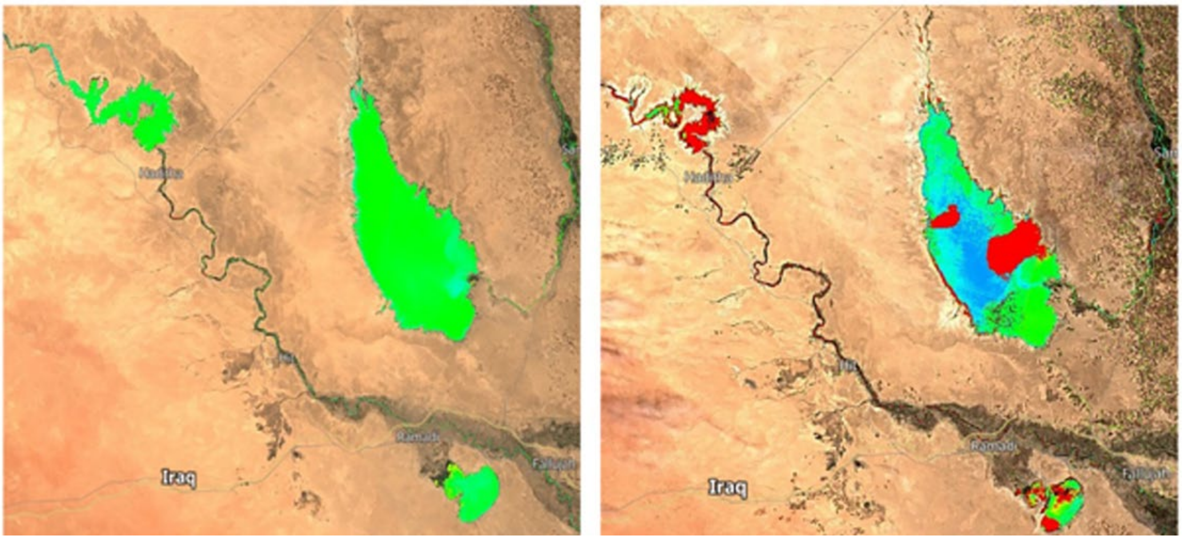
Label	Classification
0	NO_DATA
1	SATURATED_OR_DEFECTIVE
2	DARK_AREA_PIXELS
3	CLOUD_SHADOWS
4	VEGETATION
5	NOT_VEGETATED
6	WATER
7	UNCLASSIFIED
8	CLOUD_MEDIUM_PROBABILITY
9	CLOUD_HIGH_PROBABILITY
10	THIN_CIRRUS
11	SNOW

Source: MAGO-PRIMA tool.

3.4.2.1 Chlorophyll-a Results

Figure 3.15

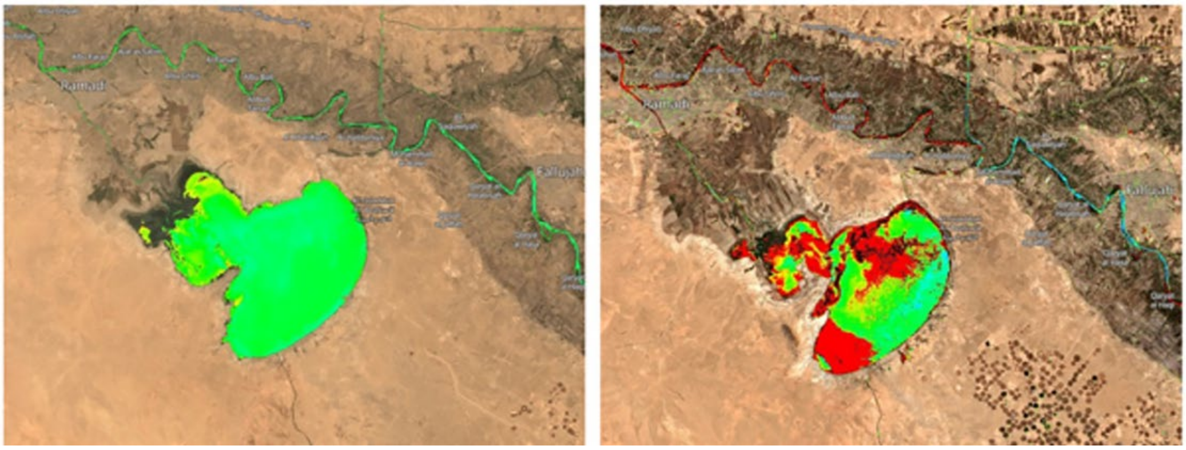
Chlorophyll-a maps along the Euphrates River obtained using Sentinel-2 images between May 2017 (left) and May 2024 (right) (Sentinel Hub EO Browser)



Eutrophication is characterized by the expansion of microalgae biomass because of excessive nutrient input in water bodies (Zhan et al., 2021). The intensity of eutrophication can be assessed by measuring Chlorophyll-a concentration, a photosynthetic pigment of phytoplankton (Gitelson et al., 2009). In remote sensing, Chlorophyll-a is evaluated through correlating the water optical properties, specifically the absorption spectrum of visible light, with phytoplankton biomass (Soomets et al., 2020). Results displayed in **Figure 3.15** depict a clear increase in the Chlorophyll-a content between May 2017 (left) and May 2024 (right). The green areas are the areas less affected by pigment absorption, while red areas highlight pigment absorption peaks (Delegido et al., 2014). Besides the decrease in the water surface in Haditha Lake (**Figure 3.5**), a deterioration in the lake water quality is clearly occurring. This is partly a result of reduced water levels in the lake that caused increased sediment accumulation and transportation with heavy rain events. Other factors responsible for this deterioration are the reduced water levels, caused by reduced precipitation as shown in **Chapter 2**, and higher exposure to high temperature resulting in algae blooms, expansion of intensive agricultural areas, discharge of untreated or partially treated wastewater, and mining activities, particularly for phosphorus which is very common in the area.

Figure 3.16

Chlorophyll-a maps for Al-Habbaniyah Lake using Sentinel-2 images
for the period between May 2017 (left) and May 2024 (right)

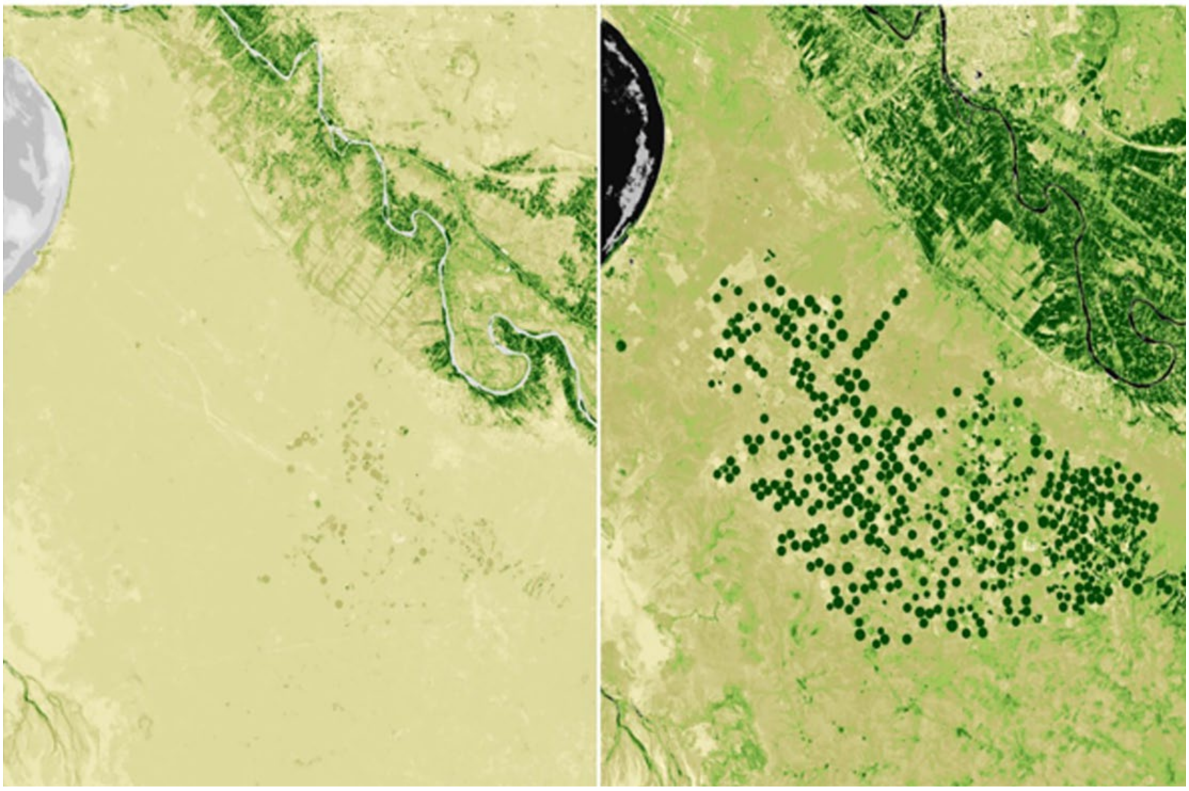


Source: Sentinel Hub EO Browser

Zooming in to Al-Habbaniyah Lake, a 140-square-kilometer man-made body, located halfway between Ramadi and Al-Falluja, we could see the increase in Chlorophyll-a concentration more clearly (**Figure 3.16**). This is mainly driven by the expansion of unregistered agricultural lands to the south of the lake as can be seen in the bottom right corner of **Figure 3.16.** Subhi (2023) reported, in The Century Foundation, this expansion in agricultural areas using NDVI images (**Figure 3.17**), highlighting the absence of governmental monitoring and control actions. The decrease in water levels and water surface area of the lake (**Figure 3.18**) is major cause on the increase in Chlorophyll-a concentrations, as the water becomes closer to sediments.

Figure 3.17

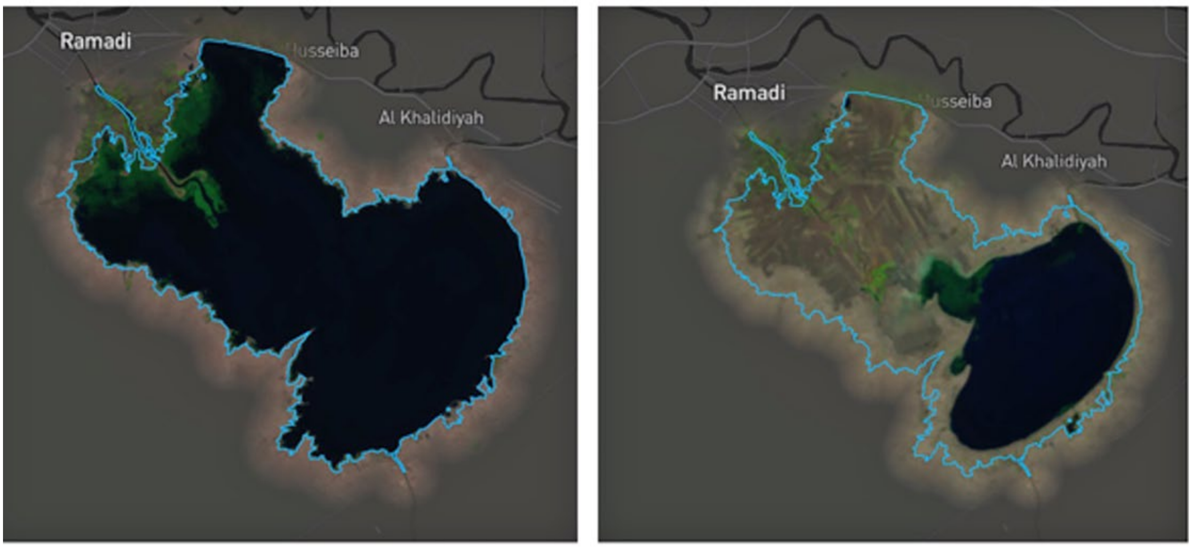
The increase in center pivots from June 2017 (left) to March 2023 (right)
in the south of Lake Habbaniyah in Anbar (Source: Sentinel Hub Satellites (EO Browser), NDVI Images)



Source: Sentinel Hub Satellites (EO Browser), NDVI Images

Figure 3.18

Water Surface area of Al-Habbaniyah Lake between May 2017 (left) and May 2024 (right)

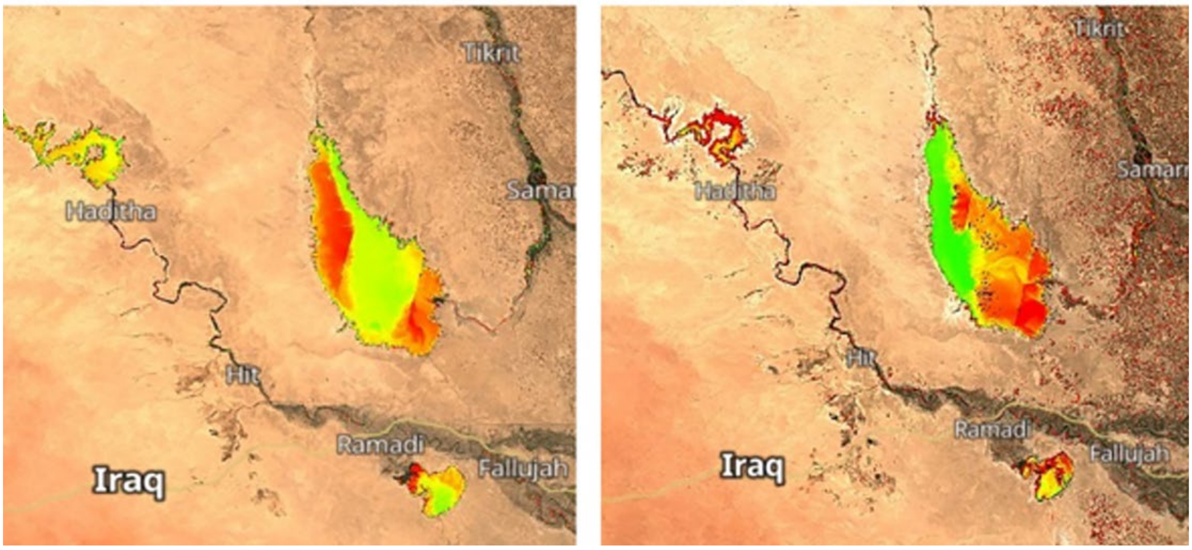


Source: Global Water Watch, HydroATLAS

3.4.2.2 TSS Results

Figure 3.19

Total Suspended Solids (TSS) maps along the Euphrates River using Sentinel-2 images for the period between May 2017 (left) and May 2024 (right)



Source: Sentinel Hub EO Browser

Total suspended solids (TSS) is another important water quality parameter that reflects the transparency/turbidity of water. Results show increased magnitude and different distribution of high TSS levels in May 2024 (right) as compared to May 2017 (left) (**Figure 3.19**). The darker the orange colour is, the higher the TSS concentration. Maximum TSS concentrations are observed on the borders of the lakes, partly due to shallow water depth near the shores of the lakes (Zhan et al., 2021). Like Chlorophyll-a results, the Haditha Lake (top left) and Al-Habbaniyah Lake (bottom right) show very high TSS concentrations. The reasons for this increase are relatively the same as those mentioned for Chlorophyll-a.

3.5 Discussion and conclusions

Table 3.1 (p. 40) shows a summary of the descriptive statistics of the TDS concentrations and the corresponding mean monthly flows along with the month and the year at 6 sites along the Euphrates River. TDS is commonly used as an indicator of salinity in water (Masoud et al., 2022). According to WHO specifications for drinking water, the TDS concentration up to 500 ppm is the highest desirable level, and up to 1500 ppm is the maximum permissible value (Khudair et al., 2021). As per the guideline of the Iraqi drinking water quality specifications standard IQS/417, the permissible TDS concentration is 1000 ppm (Qadir et al., 2014). Concerning, the appropriateness for irrigation, The Food and Agriculture Organization (FAO) irrigation water quality guidelines mentioned that TDS levels between 450 ppm and 2,000 ppm could have slight to moderate influence on crop production, while TDS level higher than 2,000 ppm cause severe effect on crop production (Mateo-Sagasta and Burke, 2010).

Findings revealed that the mean TDS level increases considerably by nearly 16% between Al-Qaim and Al-Fallujah. The higher values of TDS downstream are mostly explained by the effect of uncontrolled discharge of sewage water, as also attributed by Al-Heety et al. (2011) for the area between Heet and Al-Ramadi. Nonetheless, the TDS values observed in this study were less than that reported by Al-Heety (2011) with an average of 1,612.73 mg/l, which exceeded the WHO permissible limits. However, the TDS concentrations of samples taken between November 2020 and February 2021 in Al-Qaim, Rawah, Anah, Haditha, Al-Baghdadi, Hit, Al-Ramadi and Al-Falluja were 335, 390, 410, 430, 432, 438, 442, and 496 ppm, respectively, thus meeting the permissible limits of WHO and Iraq standards (Muhammad Karim, 2018). Sulaiman et al. (2019) pointed out that there was a gradual increase in the salinity of the water from Al-Qaim to Fallujah. Moreover, they mentioned that TDS values increased significantly at the Fallujah Barrage. This could be attributed to the influence of water flow from Tharthar Lake, a highly saline lake, thus washing the salts downstream (Sulaiman et al., 2019). The expansion of agricultural areas near Fallujah (**Figure 3.17**) and absence of treatment for drainage water is another reason for this phenomenon.

There are multiple reasons leading to this degradation in quality of surface water in the river, many of them influenced by natural factors such a rainfall, soil erosion, temperature, weathering of rock and the dissolution of water-soluble salts. But anthropogenic activities such as pumping the sewage, disposal of untreated industrial wastewater, and the irrigation return waters into the river corridor also contribute to exacerbating quality degradation (Anggraini and Slamet, 2021). The reduction in the flow rate entering Iraq due to excessive water abstraction, damming and inter-basin water transfer systems in the upstream riparian states, particularly Turkey, has added additional pressure on the water quality (Şimşek et al., 2023).

Figure 3.20 displays the monthly variation of the TDS concentrations of the Euphrates River at six sites between Al-Qaim and Al-Falluja for the period October 2004 to September 2022, with missing records from August 2014 to November 2017 due to political instability in the country. The scatter diagrams suggest that there is either no correlation between the TDS and time or very weak-to-weak relationship between the two variables. The correlation coefficient at the Hit site is comparatively high compared to others (r=0.395), reflecting a moderate decreasing correlation, i.e., TDS decreased as time passed. This trend was similar in Haditha Dam, Upstream Haditha Dam an Al-Qaim, but to a lesser extent. Al-Ramadi and Al-Falluja showed an opposite increasing TDS trend with time, but a weak one. The six sites, however, have shown an increase in TDS after November 2017. In comparison to the situation before 2014, this increase in TDS coincides with the return of people to their homes and resuming agricultural activities. It can be concluded that the changes in the TDS concentrations are not limited to the changes in the amount of flow, but further to the agricultural runoff and residential (urban) runoff, leaching of soil contamination, and point source water pollution from industrial or sewage treatment plants. Therefore, anthropogenic activities have a key role in water quality control. Osman et al. (2017) explained that variation in the Euphrates River level at the Hit station is highly dependent on the operational status of the Haditha Dam and climatic conditions (precipitation volume). This can also have a direct effect on TDS levels.

With regards to the observations obtained using satellite imagery, results showed critical situation of open water bodies in Anbar with remarkable changes in water quality, both spatially and temporally. Both chlorophyll-a concentration, which is a sign of phytoplankton growth, and TSS, which is an indication of low transparency in water, showed an increase over time. Just like

TDS, the increase in chlorophyll-a and TSS was also more significant downstream, such as at the Al-Habbaniyah lake, located between Al-Ramadi and Fallujah. Agricultural runoff and sewage water are two driving factors for the eutrophication observed from satellite images, especially that both are rich sources of nutrients like nitrogen and phosphorus. This signifies the need for urgent control and remedy actions. Control points should be identified, and an action plan should be drafted. The expansion in intensive agriculture areas and aquaculture ponds, as well as poor wastewater management strategies and mining strategies should be addressed.

The findings from this analysis will support the understanding of the river's water quality changes, detecting the sources and hotspots of pollutions to the river[3], and guiding legislative actions. The findings will also aid in understanding the factors influencing the Euphrates River's TDS levels and informing management plans for protecting and conserving this important resource. Therefore, quality monitoring is essential for the sustainable management of surface water for various purposes, mainly where the surface water abstraction and excessive contaminant load from improper disposal of drainage water and urban wastewater are inadequately controlled. Monitoring of wastewater dumping into water bodies is crucial to enforcing regulations to reduce pollutant discharges and protect water resources. Reliable and up-to date water quality statistics support achieving SDG6. Access to accurate information and up-to-date water quality data is central to evidence-based decision-making by policymakers and supportive institutions to develop national and local action plans. Efforts are needed to ensure water quality protection by minimizing the direct discharge of untreated or inadequately treated wastewater to the environment while maximizing the flows of adequately treated wastewater for safe and productive reuse or discharge by following environmentally feasible approaches.

Having only the TDS as a water quality parameter is not sufficient to judge water quality because TDS is mainly an indicator of salinity. There are plenty of other parameters that are related to wastewater discharge and agricultural pollutants, such as organic pollutants, nutrient pollutants, heavy metals, and microbiological contaminants. For example, a study by Osman et al. (2017) on the Euphrates water quality assessment revealed that concentration of Fe^{2+}, Ni^{2+} and Zn^{2+} exceeded the permissible limits based on Iraqi standard IQS, WHO and USEPA, while Cr^{3+}, Pb^{2+}, and Mn^{2+} were non-existent. Based on their evaluation, the Euphrates River is considered to have low heavy metal pollution, partially explained by the high discharge of the river causing a dilution effect in the heavy metals.

3 The sources of pollution can be summarized as follows: 1) Sewage water, 2) Drainage water, 3) agricultural runoff and 4) industrial sewage.

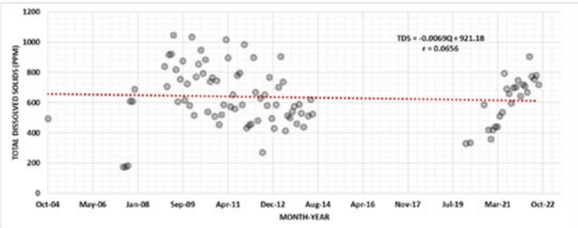
The hotspots of TDS pollution are mainly the areas located downstream from the Euphrates River such as Al-Ramadi and Al-Falluja.

Figure 3.20

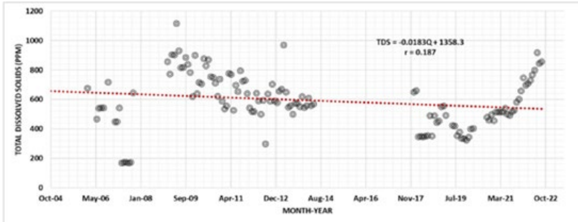
Monthly variation of TDS of the Euphrates River at Al-Qaim

between October 2004 and September 2022

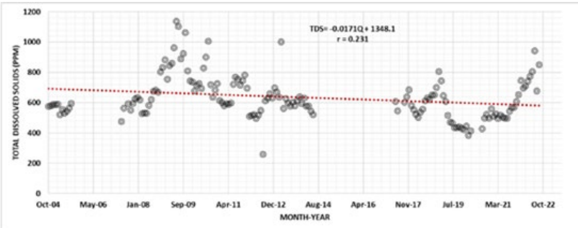
Al-Qaim



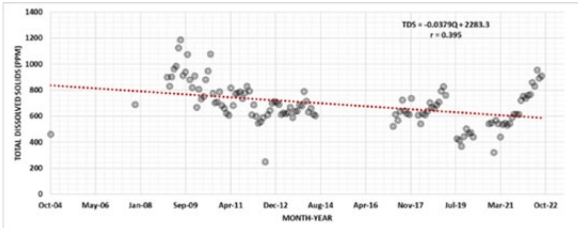
Upstream Haditha Dam



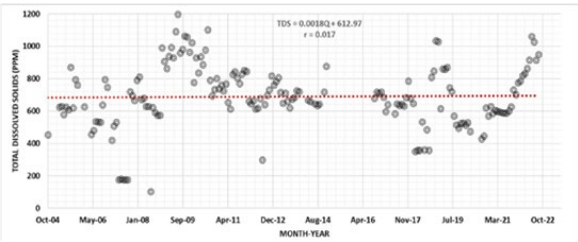
Haditha Dam



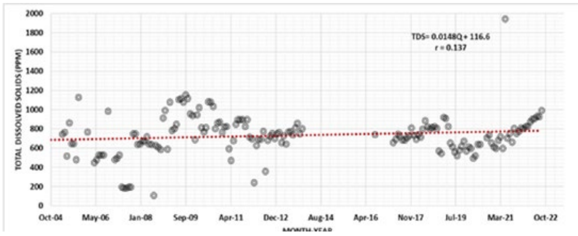
Hit



Al-Ramadi



Al-Falluja



Source: Own work

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4 Groundwater quality

4.1 Introduction

Sustainable management of water resources, particularly in arid and semi-arid areas, is becoming increasingly challenging due to a combined effect of rapid population growth associated with overexploitation of water resources, and impact of climate change. Climate change is projected to intensify frequency and severity of extreme events, particularly drought episodes in arid and semi-arid climatic regions. Rapid population growth coupled with accelerated socio-economic activities in arid and semi- arid regions results in harmful stress on the already limited surface and groundwater resources.

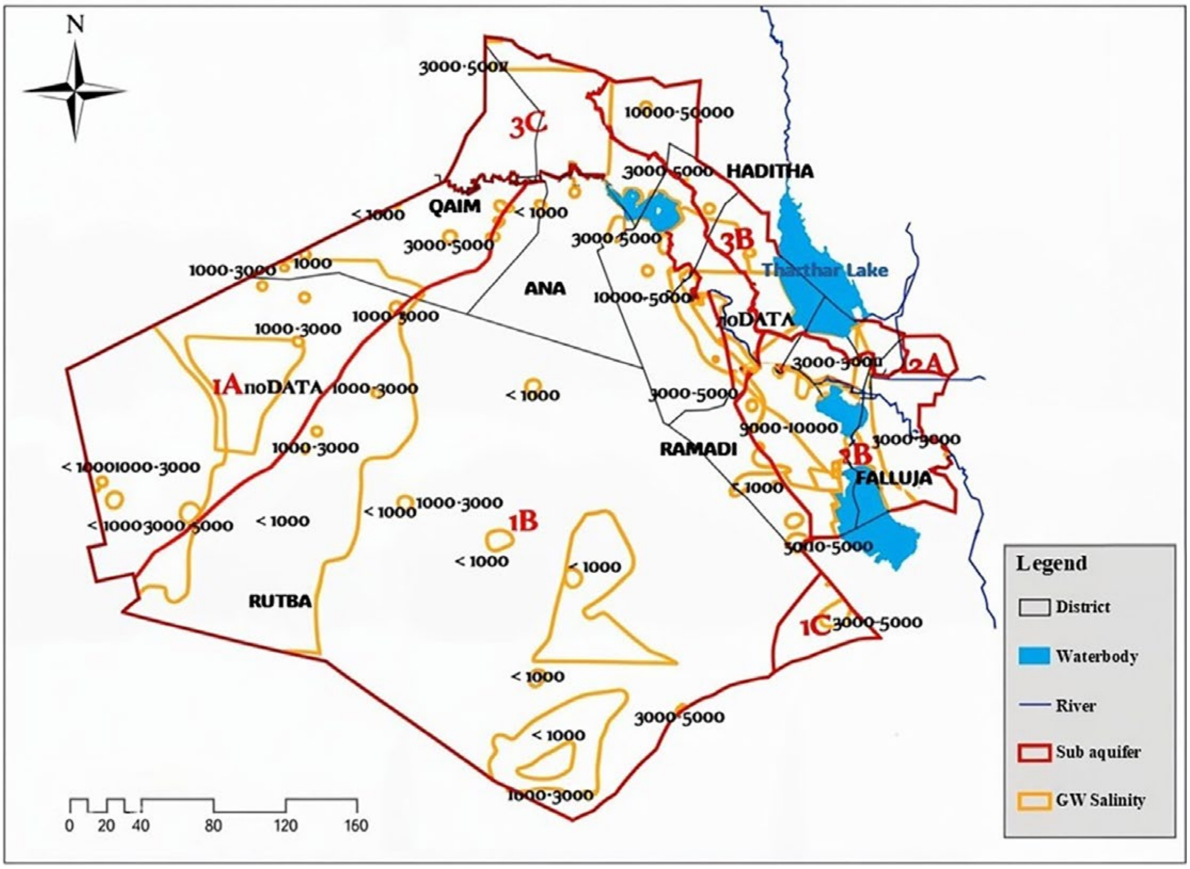
In many countries where surface water is overcommitted, groundwater has emerged as the primary additional source of water used in agriculture. As a result, concerns on possible depletion and use of low-quality groundwater for irrigation have grown in recent years. Iraq is facing a severe water crisis shaped by many factors, including prolonged drought events, concerns about the continuous damming and excessive water abstraction in the upstream riparian countries, especially Turkey and Iran, limited water management capabilities and aging infrastructure. These factors have contributed to a growing crisis of water shortage affecting millions of people (Hassan et al., 2023).

During the 20th century, there was an enormous boom in well construction for urban water-supply, irrigation and industry, facilitated by advances in drilling and pump technology, geological knowledge, and support from state subsidies, especially for irrigation. However, groundwater use is often unsustainable. Groundwater supplies are diminishing in some regions, with an estimated 20% of the world's aquifers being overexploited (Osman et al., 2017). Groundwater quality deterioration is also increasingly becoming evident. It is essential that these trends are reversed to sustain the critical role of groundwater.

The invisibility of groundwater aquifers, coupled with uncertainties regarding their dynamics and stored water volume, make groundwater management more difficult to control than surface water management (Hassan et al., 2023). **Figure 4.1** shows the groundwater aquifers and their level of salinity in Anbar.

Figure 4.1

Hydrological Overview of Anbar

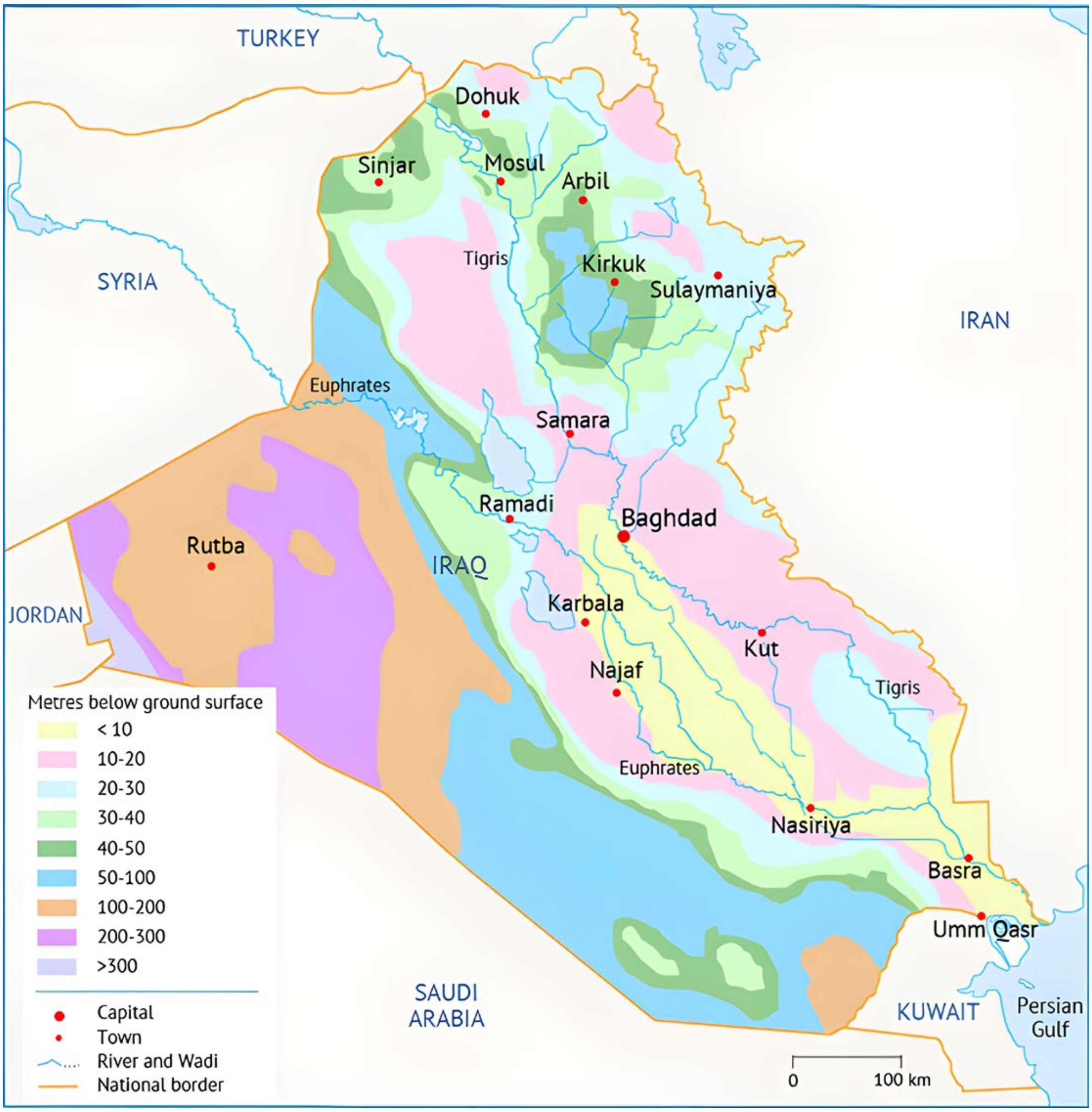


Source: own map

The World Bank stated that groundwater resources are about 1.2 BCM and account for about 2% of the total water resources of Iraq (Rohstoffe, 2013). The depth of groundwater in Iraq's hydrogeological zones is depicted in **Figure 4.2**. It is evident that there was significant variation in the depth of groundwater in the Anbar Governorate, ranging from 100 to 300 meters below the surface. Groundwater may reach a depth of more than 300 meters at the strip that borders Jordan and Iraq.

Figure 4.2

Depth of the groundwater in Iraq's hydrogeological zones.



Source: Fanack Water

Although the agricultural sector is an important sector in Iraq, its contribution to the Gross Domestic Product (GDP) declined from 26.93% in 1991 to 10.86% in 2004, 7.23% in 2010, and 4.77% in 2020 (Sulaiman et al., 2019). Recent figures estimate a further decline of in agriculture GDP contribution to less than 3% (World Bank, 2023).

The consumption of groundwater is the source of much concern. No quantitative data could be found as part of this study on the extent of groundwater use in Anbar. Remote sensing images however show the rapid development of groundwater-fed centre pivot systems in the last five years in the Euphrates plain (**Figure 3.17**). There is an urgent need to monitor and regulate the use of groundwater in Anbar as it concerns a strategic resource, that should not be depleted. At the same time, groundwater quality in Anbar is precarious.

Al-Hadithy and Mallah (2023) conducted a water quality analysis of surface and groundwater in July 2022 in Haditha City in Anbar. The results indicate that the surface water is suitable for drinking and irrigation while groundwater in the region is not suitable for drinking (except few wells) and suitable for irrigation purposes only.

A study by Fayydh et al. (2020) investigated the groundwater quality and type in Kubaysa and Al-Waffa areas in Anbar. The study region is highly influenced by the tar and sulphate springs within Abu-Jir Fault. Ten wells in each area were sampled for the period (October 2018-March 2019). The physic-chemical parameters of groundwater in Al-Waffa and Kubaysa areas are shown in **Table 4.1**, which reveals that most parameters exceeded the permissible limits and assures that the groundwater in this region is not suitable for drinking and water is earth alkaline with prevailing sulphate and chloride concentrations (Kamil and Shallal, 2023). Moreover, **Table 4.1** shows electric conductivity (EC) values of 4,479 µS/cm and 5,818 µS/cm for Al-Waffa and Kubaysa, respectively, exceeding the WHO limits. The same trend applies to TDS. Calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^{+}) all exceeded the WHO limits, with Na^{+} concentration at Kubaysa (666 mg/L) being at least three times above the WHO permissible limit (200 mg/L). This shows that groundwater in the area is highly saline, with risks to public health and the environment.

Table 4.1: The physic-chemical parameters of groundwater in Al-Waffa and Kubaysa areas

Variable	Al-Waffa				Kubaysa				WHO Guidelines (2011)
	Mean	Min.	Max.	Std. Dev.	Mean	Min.	Max.	Std. Dev.	
Temp (°C)	22	18	33	3	22	19	32	2	-
Turb (NTU)	1.6	0.2	8.0	1.6	9.3	0.1	117.0	20.0	5
pH	7.12	6.71	7.71	0.22	7.05	6.72	7.50	0.16	6.5-8.5
EC (µS/cm)	**4479**	2702	6512	839	**5818**	3270	10011	1451	2500
TDS (mg/l)	**3604**	2430	5310	624	**4013**	2412	7246	956	500
TSS (mg/l)	5	1	15.0	3	26	3	288	52	-
TH (mg/l)	1851	990	2411	319	1571	1107	2818	345	100
Ca^{2+} (mg/l)	473	188	616	111	346	200	667	103	75
Mg^{2+} (mg/l)	162	102	239	33	168	105	280	35	50
Na^{+} (mg/l)	**344**	134	680	135	**666**	129	1050	205	200
K^{+} (mg/l)	**26**	11	54	10.16	**48**	12	88	18	10
F^{-} (mg/l)	2.2	0.7	6.5	1.2	0.67	0.13	1.22	0.26	1
HCO_3^{-} (mg/l)	204	108	309	57	1.8	0.5	6.1	0.9	500
Cl^{-} (mg/l)	**676**	397	1213	171	229	135	311	37	250
SO_4^{2-} (mg/l)	**954**	576	1061	100	**1545**	438	2603	457	250
NO_3^{-} (mg/l)	**368**	30	730	196	**551**	222	1033	220	45
SiO_2 (mg/l)	20.1	11.1	28.7	3.5	19.3	11.3	42.2	6.4	-
S^{2-} (mg/l)					23	2	45	10	-

Source: Fayydh et al., 2020

Table 4.2 displays the Monthly variation of dissolved oxygen (DO) and chemical oxygen demand (COD) levels in groundwater samples of the study area. Both DO and COD exceeded the standard limits in both areas, yet COD levels were much higher at Kubaysa than Al-Waffa. This means the groundwater at Kubaysa is high in oxidizable organic materials. This situation can be critical for aquatic ecosystems, especially that high COD depletes water oxygen.

Table 4.2: Monthly variation of DO and COD levels in groundwater samples of the study area

No	Data	Al-Waffa		Kubaysa	
		DO mg/l	COD mg/l	DO mg/l	COD mg/l
1	October 2018	7.2	119	5.8	135
2	November 2018	7.5	27	5.9	236
3	December 2018	7.1	17	5.7	334
4	January 2019	8.7	14	9.8	190
5	February 2019	7.8	13	7.9	231
6	March 2019	7.5	11	7.4	340
Standard limits		5>	10>	5>	10>

Source: Fayydh et al., 2020

Another study analysed the potential of the presence of high concentrations of Radon gas in the shallow groundwater in Abu-Jir region in Anbar (Rohstoffe, 2013). The results indicated that the potential source of Radon is uranium-rich hydrocarbons that may seepage to the surface along the Abu-Jir Fault. Even though the study did not indicate any hazardous concentrations (according to Environmental Protection Agency standards) of Radon gas in the groundwater within the region, the researchers strongly recommended to define a new Iraqi standard that set the permissible level of Radon Gas concentrations.

Groundwater quality normally varies laterally and vertically affected mainly by aquifers' boundary conditions moving from one aquifer system to another or even from one geological formation to another in one system. Moreover, water salinity usually develops progressively within a flow media even if it is a single bed due to its salts content dissolution because of groundwater migration between recharge and discharge zones.

The quality of groundwater can be changed by land use development, mining, climate change, or from natural chemical weathering as it flows through the subsurface, interacts with soil layers and rocks, and generally leads to increasing levels of dissolved solids (Kamil and Shallal, 2023).

Groundwater quality emerging from the Euphrates aquifer alone was assessed by Kamil and Shallal (2023) using 226 well samples. The TDS of the aquifer samples ranged between a low of 368 mg/l and a high of 8,898 mg/l (Sulaiman et al., 2021; Kamil and Shallal, 2023).

At present, systematic governorate wide information on groundwater quality is not available for Anbar. This chapter attempts to provide an overview of groundwater quality in Anbar Governorate on several parameters.

4.2 Methodology

Ninety-nine groundwater samples were collected by the study team in the Anbar Governorate and analysed to assess the groundwater appropriateness for irrigation purposes. Most of the collected samples were from agricultural areas. These samples were gathered from different operating wells of nine aquifers namely Umm Er Radhuma, Muhaiwir, Mulussa, Euphrates, Fatha, Anah, Euphrates+Umm Er Radhuma, Dammam+Annah, and Ga'ara. The discharge of the wells varied between 3 litres/second and 20 litres/second with a depth ranging between 22 m and 502 m. This section describes the groundwater quality status for irrigation purpose using different water quality indices, including electric conductivity (EC), sodium absorption ratio (SAR), percent sodium (%Na), permeability index (PI), Magnesium hazard (MH), and total dissolved solids (TDS) based on primary parameters, such as potassium (K^+), calcium (Ca^{2+}), sodium (Na^+), magnesium (Mg^{2+}), nitrates (NO^{3-}), and bicarbonates (HCO_3^-). The purposes of the current chapter are two-fold: (1) to assess the general situation of groundwater quality in the Anbar Governorate using recently collected data; and (2) to provide interpretation of the suitability of quality for irrigation.

4.3 Ground water quality indices

Six water indices were evaluated to assess groundwater quality in Anbar. Electrical Conductivity (EC), measured and reported in micro-Siemens per Centimetre (μs/cm), provides an indication of the concentration of conductive ions in the solution. Higher EC values indicate a higher concentration of ions, suggesting greater salinity or dissolved solids. Water with high EC is unsuitable for irrigation. Hence, EC is an important criterion for irrigation water quality (Al-Ansari et al., 2018). The EC values of the examined groundwater samples varied between a minimum of 668.0 μs/cm and a maximum of 30,200 μs/cm with an average of 3,345 μs/cm (**Table 4.3**). **Table 4.4** shows the appropriateness of water for irrigation purposes according to different ranges of EC values. Results showed that the majority (75%) of the groundwater samples are associated with EC value > 2,250 μs/cm, thus can be considered unsuitable for irrigation purposes. Findings also revealed that 22% of the samples can be considered doubtful, and very low percentage of samples (3%) can be categorised good for irrigation purposes.

The EC results depict an alarming situation in groundwater quality in Anbar region. Estimates indicate that 4% of irrigated areas in Iraq are severely saline, 50% are of medium salinity and 20% of slight salinity (Kamil and Shallal, 2023). This situation increases Iraq vulnerability to desertification (Kamil and Shallal, 2023). Hoegh Guldberg et al. (2018) were able to show that rainwater recharge under laboratory conditions was able to decrease EC in a sample from West Anbar from 5,600 to 4,290 μS/cm. Although the final EC value is still above safe irrigation limit, groundwater recharge using a range of techniques, whereby part of the rain or flood run-off is used to infiltrate, appears to be a promising method to restore groundwater quality, yet more case studies and long-term experiments are needed to quantify the significance of the number of salts washed with rainwater recharge. This is discussed in more details in **Chapter 6**.

Table 4.3: Descriptive statistical analysis of different groundwater quality parameters in Anbar

Parameter (unit)	Mean	Minimum	Maximum	Standard deviation	1st Quartile (Q1)	3rd Quartile (Q3)
EC (µS/cm)	**3,345.0**	668.0	**30,200.0**	3,270.1	2,310.0	3,715.0
TDS (mg/l)	**2,381.7**	473.0	**19,828.0**	2130.6	1,628.8	2,720.3
SAR	9.0	1.7	20.8	3.9	6.2	10.9
% Na	310.2	32.0	1,748.0	208.3	236.3	403.8
MH	33.2	18.2	44.4	5.2	30.3	37.1
PI	53.4	30.3	86.2	10.6	48.4	57.3

Source: Own research

Total dissolved solids (TDS) is another indicator of salinity. TDS values of less than 450 mg/l are ideal for irrigation, those of 450–2,000 mg/l are mildly to moderately restricted, and those of more than 2,000 mg/l are inappropriate for use in agriculture. The TDS values that were observed ranged from 473 to 19,828 mg/l, with 2,381.7 mg/l for the mean (**Table 4.3**). The study's findings indicated that none of the examined samples would be preferred for irrigation. Half (50%) of the tested samples fall into the inappropriate category (TDS>2,000 mg/l); the remaining samples exhibit mild to moderate restrictions on irrigation use. A study by Osman et al. (2017) similarly reported high TDS values of groundwater samples from both West and East parts of Anbar. The same study demonstrated the potential of rainwater recharge in decreasing TDS and improving the groundwater quality.

Sodium Absorption Ratio (SAR) is one of the universal measures used to gauge the suitability of water for irrigated agriculture that was also analysed (Giorgi, 2006; Bongaarts, 2019; Betts et al., 2018). The SAR is a relative ratio of sodium (Na^{+}) ions to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions present in the water sample (**Equation 1**).

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+}}{2}}}$$

where Na^{+}, Ca^{2+} and Mg^{2+} are in Milliequivalents per Litre (mEq/l).

The average SAR value of the groundwater samples under examination is 9.0 and ranged from 1.7 (no hazards) to 20.8 (high hazards). Based on **Table 4.4**, 25% (Q1) of the groundwater samples had no to low sodium hazard, and 75% (Q3) of the samples had medium to high sodium hazard. SAR influences percolation time of water in the soil. Therefore, a low value of SAR of irrigation water is desirable.

Irrigating with high SAR water can cause compaction and severe permeability problems in soil as a result of sodium saturation. Increase in SAR of waters leads to increased build-up of sodicity and salinity in soils (Minhas et al., 2019). As soils become saline, sodic or saline-sodic, crop productivity declines as documented in Singh et al. (1992). Combined with high EC in irrigation water, SAR can trigger salinity and sodicity of soil, especially if EC exceeds 12,000 μS/cm. The maximum EC value observed from this analysis is 30,200 μS/cm, which is an alarming value. Leaching of accumulating salts on soils with high SAR becomes difficult and costly, and ultimately soils become unsuitable for cropping. As a result, farmers are forced to shift to tolerant crops, which sometimes have lower economic value. Although alleviation measures exist, such as drainage, chemical amelioration of soil, gypsum amendments and growing tolerant crops, these are typically costly, and the soil situation is irreversible most of the times. Therefore, preventive measures should be given priority.

The percent sodium (% Na) is a widely used index for judging the quality of water for irrigation purpose (Noon et al., 2021; Tao et al., 2019; Yaqob et al., 2015) . The sodium (Na^+) ion reacts with carbonate (CO_3^{2-}) and forms alkaline soils, while sodium (Na+) reacts with Chloride (Cl^-) and forms saline soils. Sodium-affected soil (alkaline/saline) retards crop growth. **Equation 2** is used to calculate the %Na. **Table 4.4** displays the classification of (%Na) to measure the quality of water for irrigation.

$$\%Na = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$$

where Na^+, Ca^{2+}, K^+, and Mg^{2+} are in Milliequivalents per Litre (mEq/l).

Excess of sodium (Na^+) can degrade soil structure, reduce soil permeability and reduces the plants' yield. The computed %Na values ranged between the minimum 25 and 78.6 with an average of 49.7 (**Table 4.3**). Findings revealed that the computed %Na were between good and doubtful ranges of restriction for irrigation. Based on the classification given in **Table 4.4**, 75% (Q3) of the examined groundwater samples lies between permissible and doubtful regions of restriction for irrigation purposes. None of the investigated samples can be considered as excellent or unsuitable.

Excess concentration of magnesium (Mg^{2+}) in groundwater affects the soil quality by converting it into alkaline, thus decreasing the crop yield (Wilhite and Glantz, 1985). Magnesium hazard (MH) is the ratio of magnesium (Mg^{2+}) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions. A value less than or equal to 50 is considered suitable for irrigation, whereas MH more than 50 indicates the unsuitability of water for irrigation. **Equation 3** is used to compute the MH value.

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$$

where Na^+, Ca^{2+}, and Mg^{2+} are in Milliequivalents per Litre (mEq/l).

The computed MH values varied between 18.2 and 44.4 with an average of 33.2 mEq/l. Results showed that 100% of the surveyed groundwater samples were considered suitable for irrigation with MH<50 mEq/l (**Table 4.4**).

The permeability index (PI) is the last indicator used to study the suitability of water for irrigation purpose. Water movement capability in soil (permeability) is influenced by the long-term use of irrigation water (with a high concentration of salt) as it is affected by sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and bicarbonate (HCO_3^-) ions of the soil. **Equation 4** is used to calculate the permeability index. PI can be categorized in three classes: class I (>75%, suitable), class II (25–75%, good) and class III (<25%, unsuitable). Only water under class I and class II are recommended for irrigation.

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+}$$

where Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- are in mEq/l.

Table 4.4 shows the classification of the PI for irrigated agriculture. The computed PI values ranged between 30.3 and 86.2 with a mean of 53.4. Findings revealed that all studied groundwater samples lie in class II (25–75%, good), i.e., recommended for irrigation.

Table 4.4: Indices used to measure the suitability of water for irrigated agriculture

Parameter	Range	Category
Sodium Percentage (% Na)	Na<20	Excellent
	20≤ Na≤40	Good
	40≤ Na≤60	Permissible
	60≤ Na≤80	Doubtful
	Na>80	Unsuitable
Sodium Adsorption Ratio (SAR)	SAR<2	No Hazards
	2≤ SAR ≤10	Low Hazards
	10≤ SAR ≤18	Medium Hazards
	18≤ SAR ≤26	High Hazards
	SAR >26	Very High Hazards
Magnesium Hazard (MH) (%)	MH≤ 50	Suitable
	MH >50	Unsuitable

Doneen's Permeability Index (PI) (%)	PI< 25 (Class III)	Unsuitable
	25≤ PI ≤75 (Class II)	Good
	PI> 75 (Class I)	Excellent
Electrical Conductivity (EC) (µS/cm)[a]	≤700	None
	700-3000	Moderate
	≥3000	Severe
Total Dissolved Solids (TDS) (ppm)[a]	≤450	None
	450-2000	Moderate
	≥2000	Severe

[a] *FAO Guidelines for Conventional Water Quality for Irrigation (Ayers and Westcot, 1985; FAO, 2010)*

4.4 Conclusion

Although groundwater accounts for a small volume of total Iraq's water resources, it is still an essential source of water because most surface water in Iraq is imported from outside the country with ongoing trespassing on the Euphrates. Even when surface water is available and sufficient, groundwater should still be sustainably managed to improve climate change adaptation and enhance the resilience of livelihoods. Using a variety of water quality metrics, this study sought to determine whether the Anbar Governorate's groundwater quality was suitable for irrigation. The preliminary study findings help water managers and decision-makers create a solid plan, choose the best course of action, and use integrated water resources management tools to protect groundwater from potential sources of contamination, use it sustainably, and start an initiative for sustainable groundwater development and agriculture in the region.

The suitability of groundwater in the Anbar Governorate for irrigation was evaluated using six indices: sodium percentage (Na%), sodium adsorption ratio (SAR), magnesium hazard (MH), permeability index (PI), total dissolved solids (TDS), and the Electric Conductivity (EC). It is still necessary though to conduct additional research using a greater number of groundwater samples and more diverse quality parameters.

The findings indicate that, when considering salinity, the Anbar Governorate's electrical conductivity in groundwater poses one of the biggest challenges, with 75% of measurements falling in an area that is unsuitable for agricultural use. The TDS results indicated that none of the examined samples would be ideal for irrigation, unless treated or blended with other sources of water. Half of the analysed samples fall into the inappropriate category (TDS>2,000 mg/l) with a median of 2,270.5 mg/l. Combined with the SAR results, findings suggest increased salinity and sodicity risks to soils in the area, which if not urgently addressed, might cause an irreversible land degradation with high threat to food security and agricultural livelihoods in Anbar.

An essential component of a long-term risk assessment program should be the ongoing monitoring of groundwater quantity and quality. The groundwater authorities should investigate the effectiveness of any artificial recharge structures and rainwater harvesting structures in the study area to restore the high quality of groundwater.

The outcomes of this study show that index-based irrigation water quality can be useful in decision-making processes such as identifying number of suitable wells for irrigation systems and prevent the damage of crops and production. It is also suggested that regular monitoring of irrigation water quality and pollution is essential to help farmers and the concerned department for making irrigation policy to the Anbar local government.

4.5 References

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5 Irrigation and drainage systems

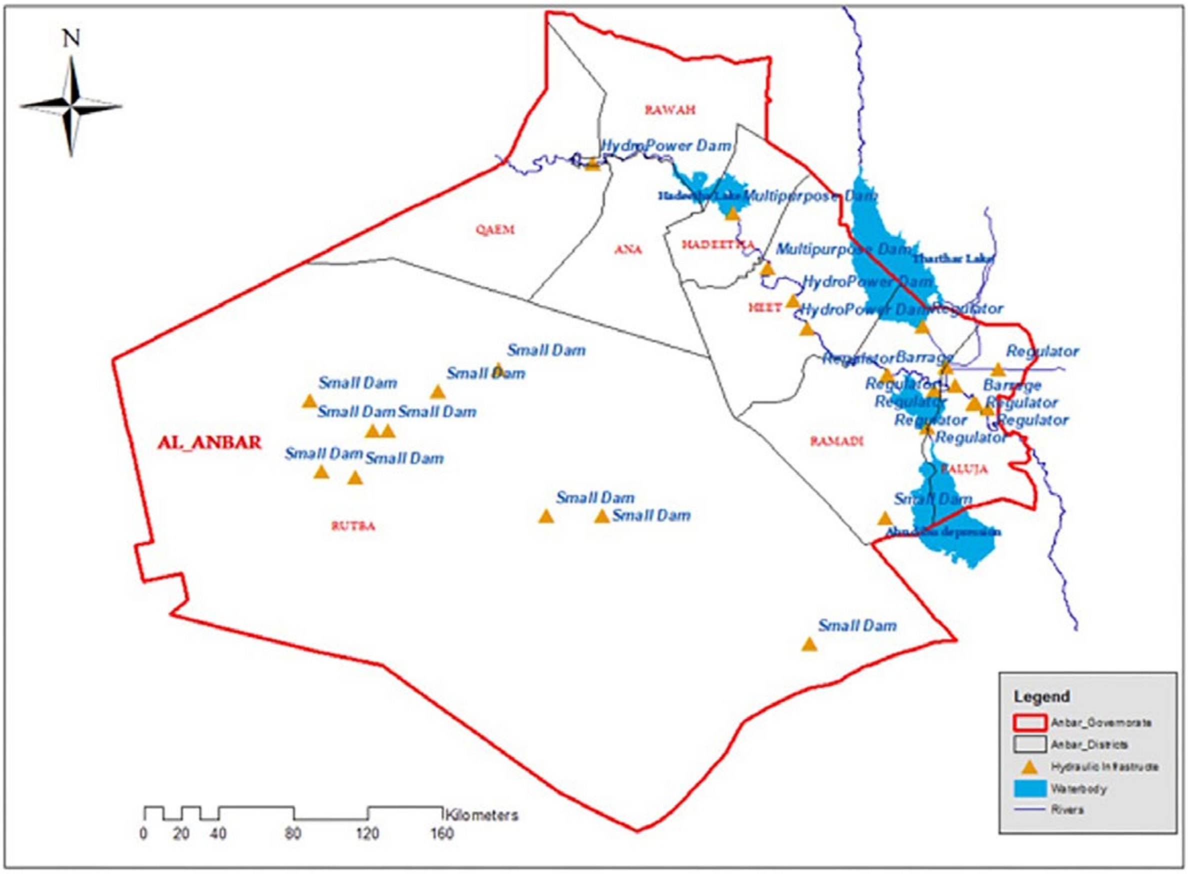
5.1 Introduction

As irrigation is also the major water consumer in the Anbar governorate, it is central to improved water resource management in Anbar. The agricultural area in Anbar was 221,250 hectares in 2015 (Sulaiman et al., 2021), with 115,310.5 hectares reported as the net irrigation area (JICA, 2016). A variety of crops is traditionally grown with surface irrigation: wheat, barley, onions, corn, sunflower, sesame, orchards, and winter and summer vegetables. The irrigation system is combined with power generation from on-stream and off-stream reservoirs. The main reservoirs in Anbar Governorate are shown in **Figure 5.1**.

The Haditha reservoir is on the Euphrates River. This hydraulic complex was put into operation in 1985. This multi – purpose reservoir regulates the Euphrates River flow, already partially regulated by the Keban and Tabqa reservoirs, to meet the irrigation requirements of Iraq, produce hydropower electric energy, and regulate flood discharges.

Figure 5.1

Hydraulic structures in Anbar Governorate



Source: GOPA-AFC

The Habbaniyah reservoir is an off – channel – location reservoir, sited on the right bank of the Euphrates River, in the natural depression banked on the east. The reservoir is used for partial regulation of the Euphrates River flow. Together with adjoining structures the Habbaniyah reservoir forms a single hydraulic complex including the Ramadi barrage, the water regulator and head reach canal, the Dibban tail race canal and regulator, the Mojarra escape canal and regulator, and the Abou – Dibbs depression used for admitting surplus flood water and drainage runoff from the Karbala district.

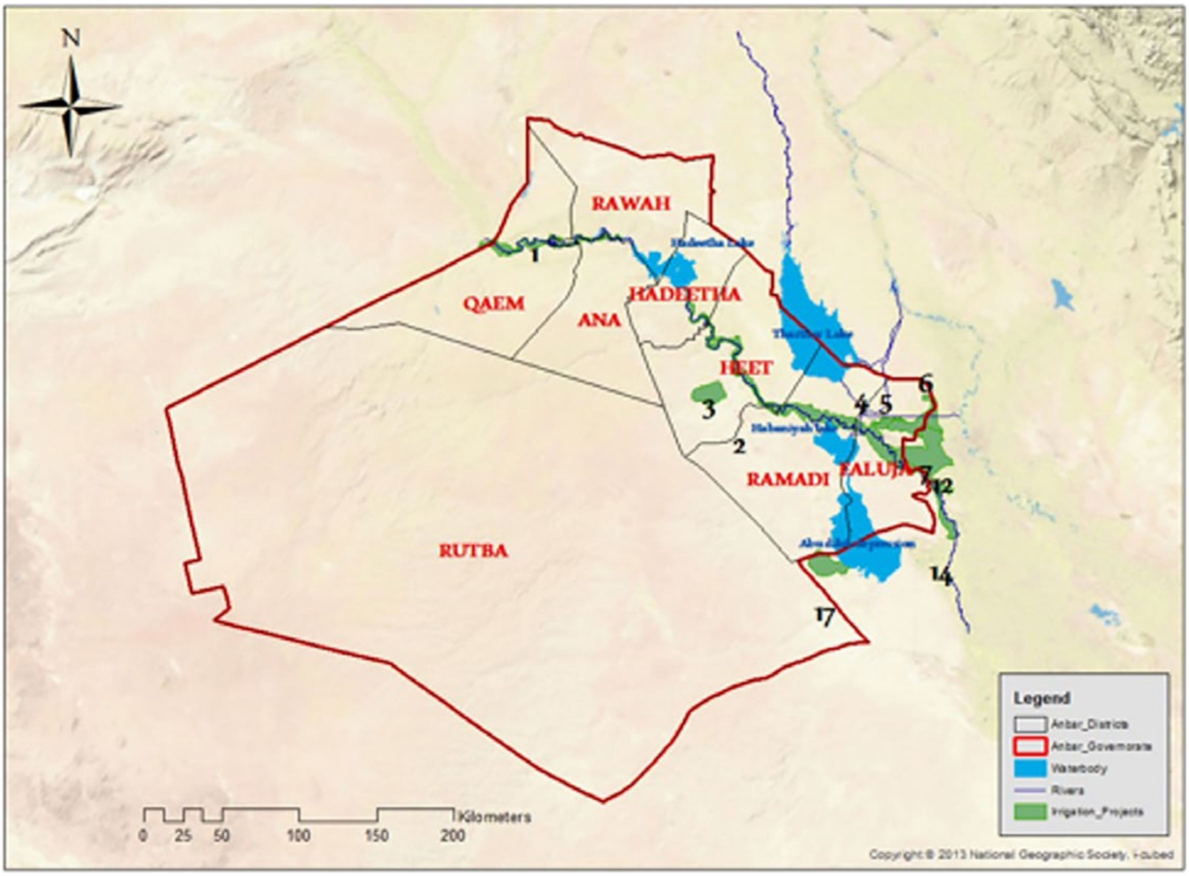
The Fallujah hydraulic complex was constructed in 1985. It aims at steadying the water intake to the existing canals of Saqlawiya, Abou – Ghraib, Yousfiyah, Latifah and Iskanderiyah. For this purpose, a canal will start from the upper pool of the Fallujah project, run along the left bank of the Euphrates River, intersect with all the mentioned canals (except for Saqlawiya) and unite them into a large irrigation system, named the Great Abou – Ghraib. The Hydraulic complex includes a diversion sluice dam, navigation lock, fish pass, water intake structures and stilling basin. Barrages of the Kifil – Shanafiyah project were built in different periods of time on the Kufa and Shamiyah arms and on Yao branch with the aim of managing the water regime of the arms and creating afflux for irrigation purposes. These barrages are as follows: Upper and Lower Mishkhab on the Kufa arm, Shamiyah on the Shamiyah arm, and Yao on the branch under the same name.

5.2 Irrigation systems in Anbar

The irrigated area in Anbar is relatively small, yet the reservoirs located in Anbar are supplying water to the irrigation systems in other Governorates as well. The irrigation systems are supplied either directly from the Euphrates – by gravity flow or pumping from reservoirs or from springs. The system is described in **Table 5.1**. **Table 5.1** is based on fact finding in 2023/2024, using a range of sources to come to the breakdown.[4]

Figure 5.2

Anbar Governorate Irrigation Projects (IPs)



Source: GOPA-AFC

4 The total command area (193,000 ha) and the net irrigated area (169,185 ha) are adding up to different totals than the figures from JICA (2016) quoted earlier. This is due to the use of different sources and the increase in area actually irrigated between 2016 and 2023.

Table 5.1: Irrigation systems in Anbar Governorate

IP-no	Description	Location/ Governorate	Source of water/ type of intake	Gross area (in hectares)	Net irrigated area (in hectares)
IP-1	Small farms from Syrian border to Hadeetha dam (Watet Al-Rahbah – Reha-na – Sagrah – AlA-khder – AlKhasfe - AlHa-sah)	Both banks of the Euphrates River/Anbar	Surface Water - Euphrates River	14,750	12,939
IP-2	Small farms from the Hadeetha dam up to the boundary of the Ramadi project (Sekran) - Left bank of Euphrates river south of Hadeetha dam	Both banks of the Euphrates River / Anbar	Surface Water - Euphrates River	11,750	10,307
IP-3	Small farms at springs in the Anbar Governorate in the Euphrates river	Near of Kubaysah / Anbar	Groundwater	250	219
IP-4	Ramadi-Habbaniya	West of Baghdad, on both banks of the Euphrates River / Anbar	Surface, Euphrates River	33,750	29,500
IP-5	Faluja -Amreah & (Small farms from the Ramadi-Faluja boundary up to Baghdad city boundary)	South of Faluja / Anbar	Surface Water - Euphrates River	14,000	12,275
IP-6	Saqlawiyah	East of Al Fallujah to the west of Kadhimiya district / Anbar	Surface, Euphrates River and Tharthar Tigris Arm	35,000	30,702
IP-7	Abu-Ghraib	Southwest of Baghdad / Baghdad	Surface, Euphrates River	51,500	45,175
IP-12	Faluja Al-Muahada	In between of Euphra-tes River and Faluja Main Canal, 35 km to the South-East of Bagh-dad / Anbar/ Babil/Baghdad	Surface Water - Euphrates River	13,500	11,850
IP-14	Jarf Al Sakhr & Ruwaiyah	West of Jurf Al Sakhar / Babil	Surface Water - Euphrates River	9,500	8,325
IP-17	Small farms at spring irrigated in Karbala Muhafadha (Ain Al Tamur)	West of Shithathah / Karbala	Groundwater	2,500	2,193
IP-141	Farms in the north of Saqlawiyah from Euphra-tes River and in the left of Saqlawiyah stream	34 km East of Ramadi city / Anbar	Surface Water - Euphrates River	6,500	5,700

Source: Personal fact finding

Because of the salinity of the soil and the lay of the land, drainage complements irrigation for much of the area in Anbar. The drainage system is operated with several drainage pumping systems and a network of open drains. The drainage water is usually not treated and not systematically reused. It is almost without exception released back to the Euphrates River.

5.3 Challenges

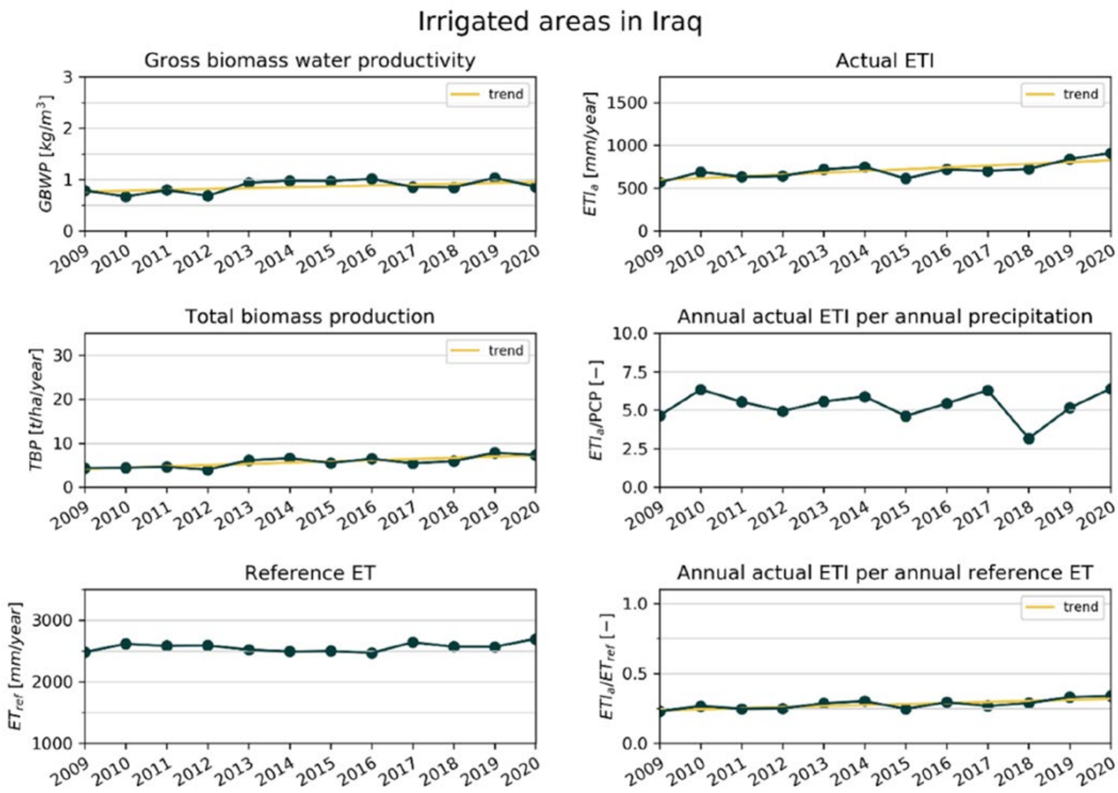
The conflict and war in Iraq had a severe impact on the functioning of the irrigation and drainage systems – with wilful damage and gross neglect. The wars that took place and their effects on society in Iraq in general as well as in Anbar led to a cessation or even a decline in the implementation of the development plans.

Data processed from the WAPOR data base of FAO (https://wapor.apps.fao.org/home/WAPOR_2/1) shows the recovery from the period of war. In the irrigated croplands of Iraq, several variables have shown a significant positive trend throughout 2009 – 2020 (**Figure 5.3**). The most significant trend is the 58% rise in total biomass production, representing overall yield (**Table 5.2**). Compared to the total biomass production, the evapotranspiration (ETa), reflecting water consumption, has also increased by 35% in Iraq – largely by increased water application. The effect of climate change in this 12-year period on water demand was relatively small, ET reference (which reflects the atmospheric water demand) being only 3%. This means that due to climate change atmospheric water demand increased slightly, probably largely related to temperature changes. There are several other climate effects, described in **Chapter 2**, in particular the change in precipitation and the threat of atmospheric drought. These (seriously) affect water availability, but do not have a strong effect on crop water requirements, which is inter alia linked to atmospheric water demand and dryness of the air.

Biomass production has increased more than the ETa, which indicates that water productivity improved as well. Overall, the Gross Biomass Water Productivity increased significantly with 23% (**Table 5.2**), which shows that less water is needed to produce the same amount of biomass over the years. The major drivers of this improvement may be in the restoration and resumption of irrigation services, improved irrigation practices or better farming.

Figure 5.3

WaPOR results for the mean annual values of Iraq (2009-2020) for irrigated cropland



Source: WaPOR database-FAO

Table 5.2: Overview of trend analysis results for irrigated croplands in Iraq over the period 2009-2020

Dataset	Average 2009-2020	Change over 12-year period * [%]	
GBWP	0.87 kg/m3	**+23%**	**Significant (p=0.046745)**
TBP	5.704 t/ha/year	**+58%**	**Significant (p=0.011175)**
ETref	2561 mm/year	+3%	Tendency
ETa	709 mm/year	**+35%**	**Significant (p=0.004932)**
ETa/PCP	5.33	+5%	Tendency
ETa/ETref	0.28	**+32%**	**Significant (p=0.007488)**

Source: WaPOR database-FAO

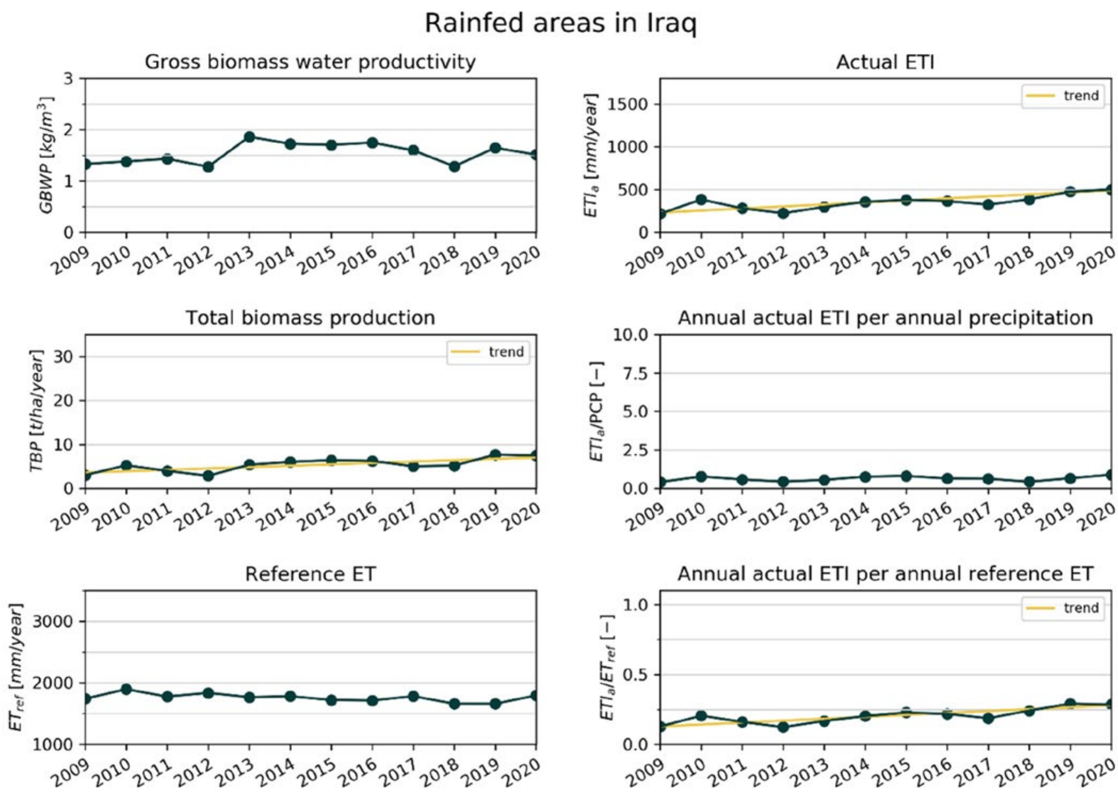
* *The percentage change over 12 years is determined by the slope multiplied by the duration (12 years) divided by the mean annual value over the period 2009-2020.*
The trends were tested against a significance threshold of .05 using the Mann-Kendall test. The value of p indicates the significance of the trend. When a trend was found to be not significant, this is indicated with "NS".

Analysis with WAPOR data base indicates that this corresponds to a trend in the country. An incredible increase in ETa (evapotranspiration, reflecting water use) of 81% is observed in the rainfed areas of Iraq (**Table 5.3**). The increasing ETa goes together with an increase in the total biomass production of 70%. This is remarkable as the country is dealing with increases in temperatures and fluctuations in rainfall.

The Gross biomass water productivity (GBWP) reflecting the ability to convert rainfall and run-off into crop production fluctuated a lot over the research period (2009-2020). Before 2013, the trend in GBWP was lower than after 2013. In 2013, an increase in biomass production occurred. This trend has been slightly decreasing ever since. In 2018, a low GBWP was observed, resulting in a low biomass production during that year (**Figure 5.4**).

Figure 5.4

WaPOR results for the mean annual values of Iraq (2009-2020) for rainfed cropland



Source: WaPOR database-FAO

Table 5.3: Overview of trend analysis results for rainfed croplands in Iraq over the period 2009-2020

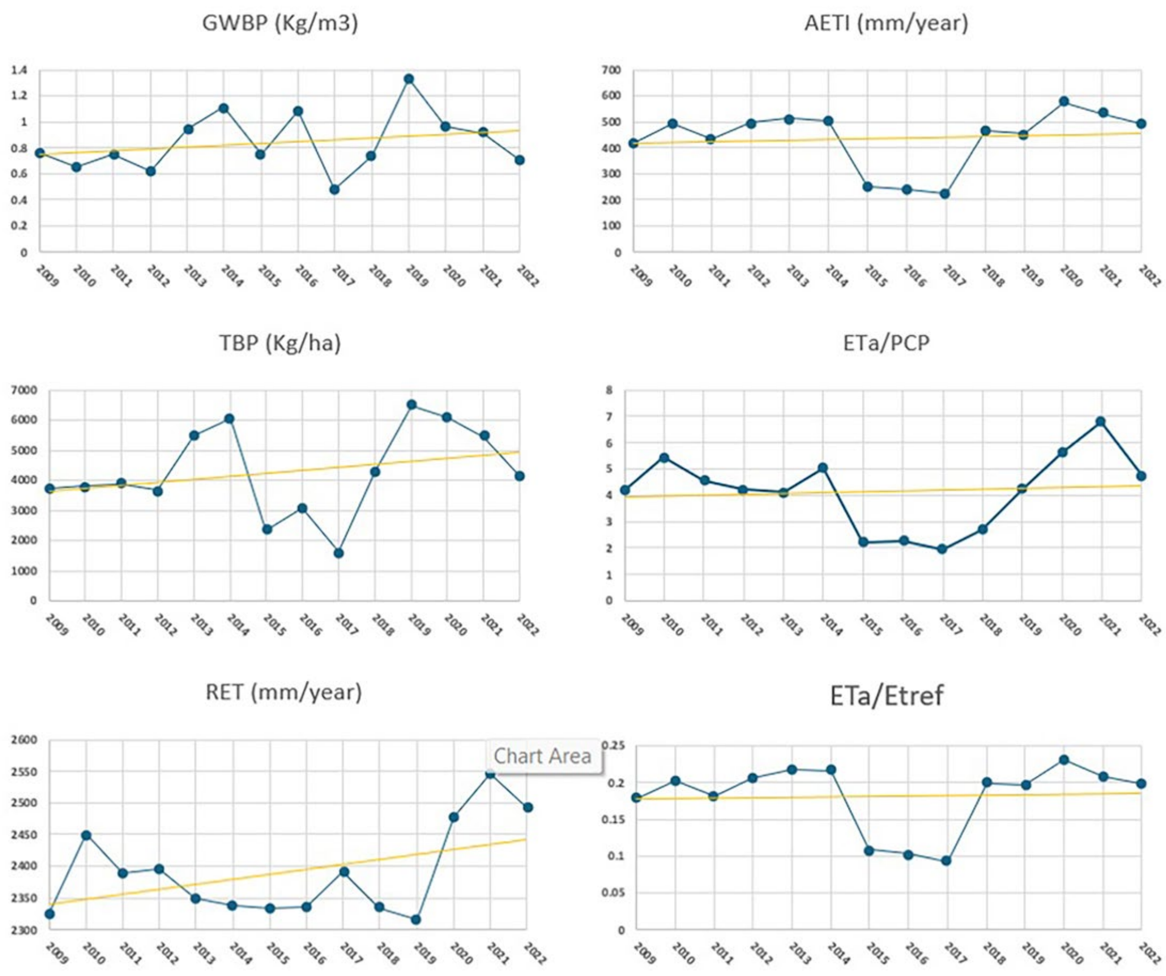
Dataset	Average 2009-2020	Change over 12-year period * [%]	
GBWP	1.54 kg/m^3	+12%	Tendency
TBP	5369 t/ha/year	**+70%**	**Significant (p=0.023642)**
ETref	1762 mm/year	-8%	Tendency
ETa	348 mm/year	**+81%**	**Significant (p=0.004932)**
ETa/PCP	0.63	+31%	Tendency
ETa/ETref	0.20	**+81%**	**Significant (p=0.004932)**

Source: WaPOR database-FAO

* *The percentage change over 12 years is determined by the slope multiplied by the duration (12 years) divided by the mean annual value over the period 2009-2020.*
The trends were tested against a significance threshold of .05 using the Mann-Kendall test. The value of p indicates the significance of the trend. When a trend was found to be not significant, this is indicated with "NS".

Figure 5.5

WaPOR results for the mean annual values (2009-2022) for irrigated areas in Ramadi in Iraq



Source: WaPOR database-FAO

Table 5.4: Overview of trend analysis results for irrigated area in Ramadi over the period 2009-2022

Dataset	Average 2009-2022	Change over 12-year period * [%]	
GBWP	0.8 Kg/m3	20%	NS (p=0.701134)
TBP	4290.7 Kg/ha/year	28%	NS (p=0.324423)
ETref	2391.2 mm/year	4%	NS (p=0.511220)
ETa	434.9 mm/year	8%	NS (p=0.511220)
ETa/PCP	4.1 mm/year	10%	NS (p=0.661415)
ETa/ETref	0.2 mm/year	3%	NS (p=0.742556)

Source: WaPOR database-FAO

* *The percentage change over 12 years is determined by the slope multiplied by the duration (12 years) divided by the mean annual value over the period 2009-2022.*
The trends were tested against a significance threshold of .05 using the Mann-Kendall test. The value of p indicates the significance of the trend. When a trend was found to be not significant, this is indicated with "NS".

The trends were also reflected in Anbar. **Figure 5.5** and **Table 5.4** illustrate the impact of the conflict in 2014 on Al-Ramadi irrigation system. The numbers depict the recovery following this period of unrest. All variables resulting from WaPOR data analysis within the irrigation system follow the broader trend observed in Iraq's irrigated area, which has shown a positive trend from 2009 to 2020 (**Table 5.4**). The most notable trend is a 28% increase in total biomass production, indicating higher overall yield. Concurrently, evapotranspiration (ETa), reflecting water consumption, has risen by 8%. Biomass production has outpaced the increase in ETa, indicating improved water productivity. Gross Biomass Water Productivity has consequently improved by 20%, indicating greater efficiency in biomass production per unit of water used. Over the 12-year period, the impact of climate change on water demand has been relatively minor, with ET reference (reflecting atmospheric water demand) rising by only 4% (**Figure 5.5**). These factors underscore the effect of the restoration and enhancement of irrigation services and the overall improvement in the irrigation system.

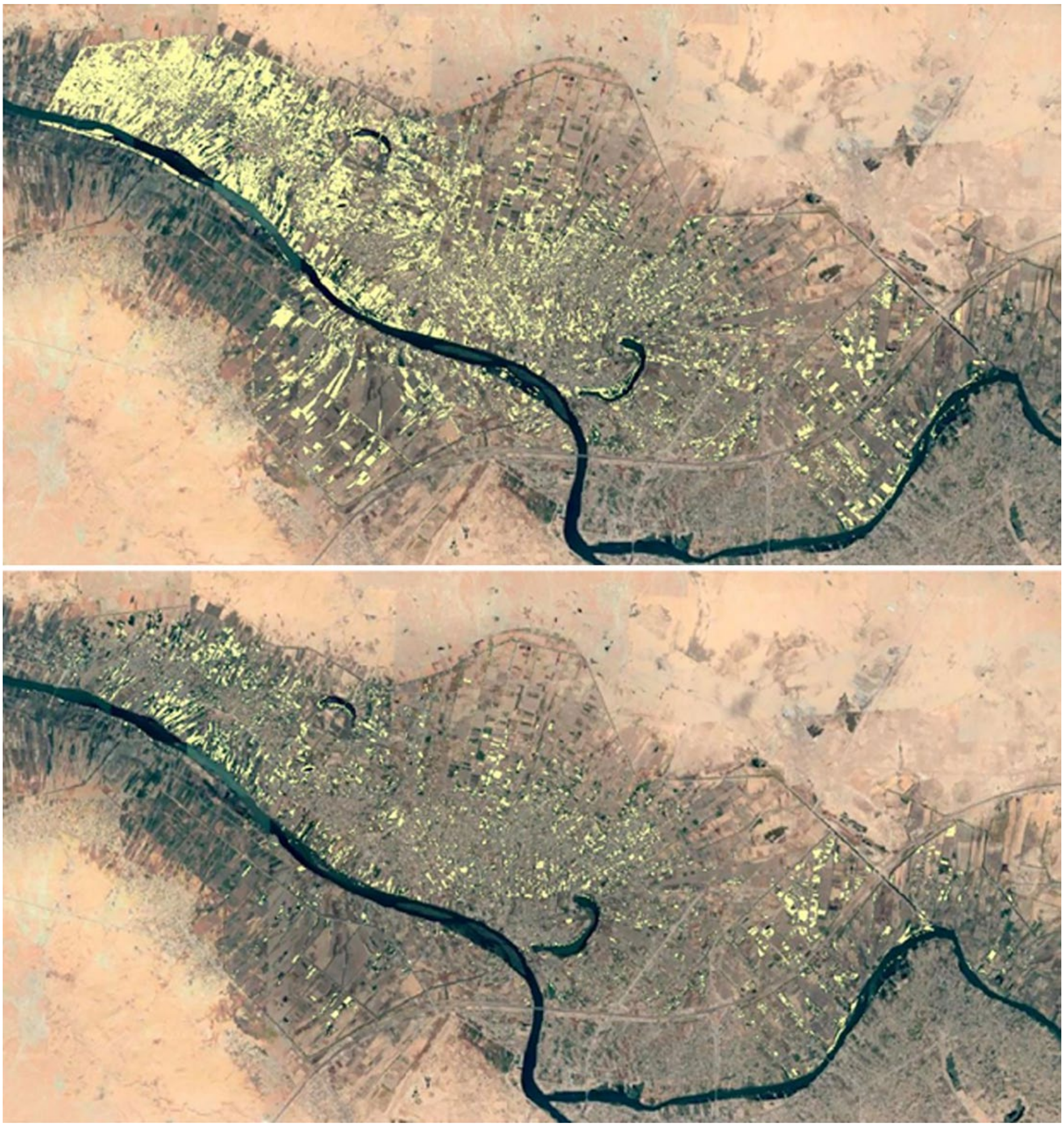
This maybe the result from different projects that restored system infrastructure and introduced better water management practices. As part of RePLECA project, GIZ commissioned the evaluation of the impact of canal rehabilitation on crop productivity and crop selection using remote sensing tools in Anbar governorate near Ramadi and Fallujah (MASAE Analytics 2022). The area has been largely affected by the "Islamic States" (IS) conflict in 2014, leading to major damages in its infrastructure, including irrigation canals and water pumps. While the agricultural sector started to recover after the end of conflict, multiple factors have slowed down and even interrupted recovery efforts including frequent droughts, construction projects upstream in the riparian countries and governmental strategies to deal with low water levels. In addition to these challenges, access to water is controlled by water quotas, recently instilled by the government. Field inspections from this project have shown an expansion in fodder crop cultivation on the expense of cereal cultivation being more profitable. In contrary, remote sensing findings revealed a positive evolution of cereal cultivation. Both field and remote sensing data revealed a reduction in vegetables cultivation, which might partly explain the increase in cereal cultivation.

The governmental regulation lacks a clear policy that supports produce in the national market. There is no agricultural calendar that would prohibit the import of specific crops during their peak season local production. Instead, the market is then often flooded with imported commodities outcompeting local produce. A case is to be made to link import and export policies with the agricultural calendar.

Another driving factor for the decrease in vegetables production is the price of fertilizers and seeds which has increased more than threefold due to the dollar price increase by 20%. GIZ's rehabilitation efforts of water infrastructure increased cereal cultivation area (**Figure 5.6**), while a negative impact was observed on fodder cultivation. The NDWI and NDVI values reflected a positive effect on cereals (better water access) and on fodder crops (better health) in the rehabilitated areas, respectively.

Figure 5.6

Evolution of cereal cultivation before (below) and after (above) rehabilitation efforts



Source: Masae Analytics

Overall, farmers in Anbar have reduced their crop diversity and most of them are switching to fodder crops being a long-lasting crop that can be combined with livestock (mixed farming).

The opportunities appear in three fields:

(1) **Rehabilitation and improvement of irrigation and drainage infrastructure**

(2) **Improved water allocation and water distribution**

(3) **Improved field water management practices.**

5.4 Opportunities

5.4.1 Rehabilitation and improvement of irrigation and drainage infrastructure

Figure 5.7

Damage to irrigation system

Source: MASAE 2024: Monitoring Maintenance and Rehabilitation Needs of Irrigation Networks in Anbar, Iraq, unpublished reports

A systematic condition assessment of the irrigation system is ongoing, but from field assessment and focus group discussion undertaken as part of this study large parts of the irrigation and drainage systems are damaged, with some parts being totally non-functional (**Figure 5.7**, MASAE, 2024). A common problem is the damage to canal lining and damage shoulders, the excessive vegetation in open drains and the inoperability of gated control structures. There is also damage to the larger infrastructure, as in some of the pumping stations. This situation leads to lower control in irrigation delivery, seepage loss and water logging in certain areas.

The status of 580 km of canals in Anbar was assessed. Out of 580 km of channels, the situation was as follows:

- Damaged lining: **11,547 m**
- Damaged mastic: **38 m**
- Damaged shoulders: **3,283 m**
- Full repair needed: **22,341 m**

The assessment also covered 849 hydraulic structures. Again, there is still considerable disrepair, i.e., **29%** of head regulators, **26%** of cross regulators, **10%** of bridges over canal and **47%** of outlets need a partial or full repair.

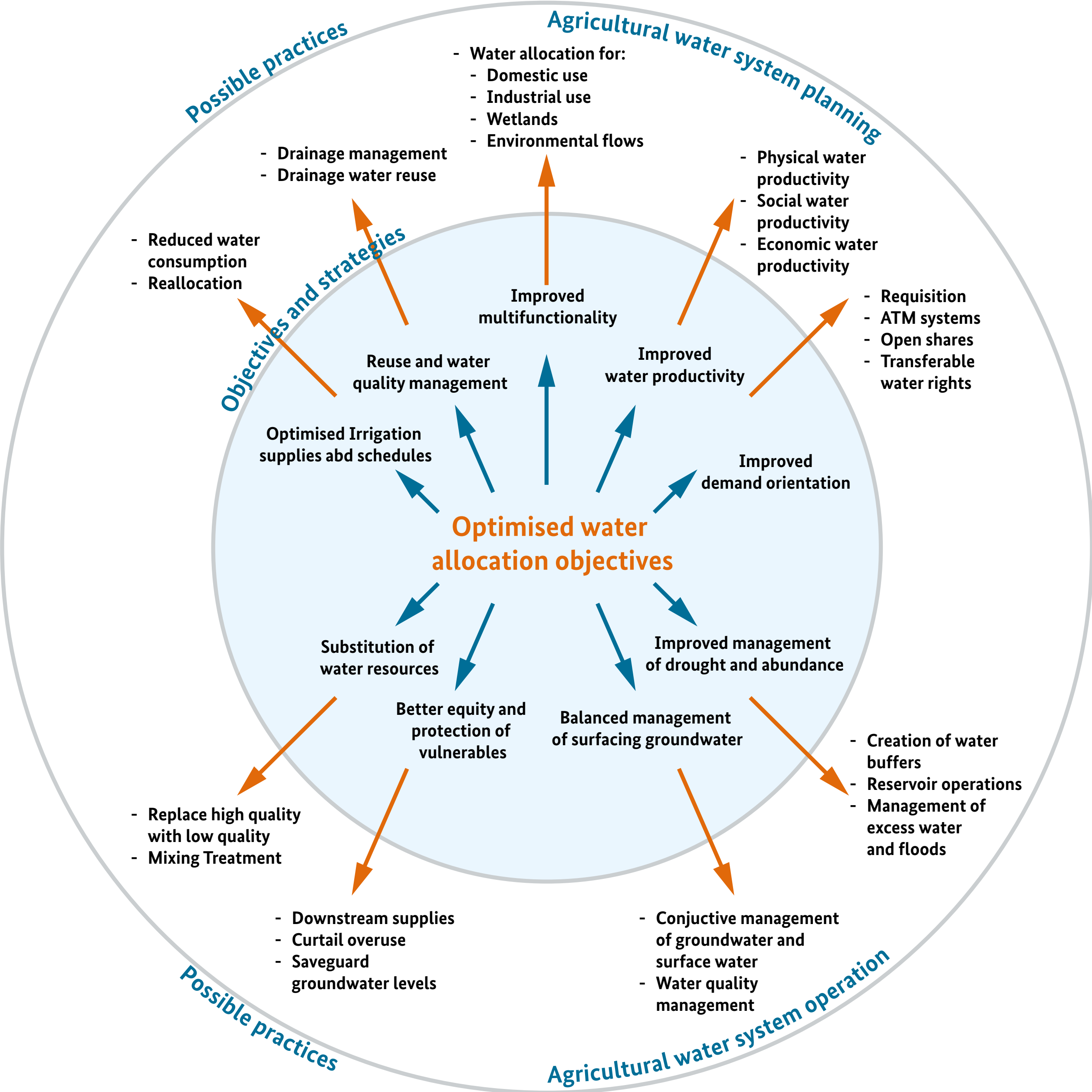
This needs to be addressed under clear priority setting: when repairing what needs to go first? Investment that restores storage and improves water use efficiency appears to be most urgent. To save water, efficient transportation and distribution systems must be developed, maintained and improved, such as by lining current canals, using pipe distribution networks, and introducing efficient and modern field irrigation smart systems. Improved water management at field level needs to be matched with improved water allocation and distribution at system level (see next section). There is already a practice of farmers creating field storage. In general, given the severe and partly persistent scarcity storage options throughout the irrigation systems need to be mapped and supported. Finally, in rehabilitating the irrigation system, an assessment is needed for the areas that may be currently and/or in the future difficult to serve, given the water shortage. Efforts to rehabilitation may be deprioritized in these areas.

5.4.2 Improved water allocation and distribution

In Anbar, as elsewhere, the system of water allocation in the irrigation systems has scope for improvement with water not necessarily delivered in the right quantities, at the right time for the right duration throughout the irrigation systems. It is necessary to recalibrate the water allocation system, as well as the water distribution over the areas. This is best done based on a thorough understanding of the current arrangements and the system that oversees this. Changing water allocation and water distribution requires investment in discussion with the main stakeholders and water user representatives. **Figure 5.8** below is an overview of possible improvements in water allocation, taking from the **Guidelines on Water Allocation in Irrigated Agriculture** of the League of Arab States. This overview gives the wide spectrum of possible improvements to consider.

Figure 5.8

Options for improved water allocation



Source: MetaMeta Research, adapted from League of Arab States, 2022

An in-depth assessment of the water allocation systems was undertaken. The main point is that the system is well-regulated, at the highest level in the irrigation systems.

There is a set of effective laws, decisions and instructions related to the work of the Ministry of Water Resources that refers to (improving) water allocation and preserving the sources of water resources and their prohibitions, such as:

- Ministry of Water Resources Law No. (50) of 2008, amended.
- Irrigation Law (6) of 1962 (amended).
- Irrigation and drainage networks maintenance law No. (12) of 1995, as amended.
- Legislation related to water wells and the use of spring water.
- Water Resources Conservation System No. (2) of 2001.
- Preventing construction in the Tigris River drainage area.
- Legislation related to collecting fees for departments of the Ministry of Water Resources for services provided to others.
- Legislation regarding irrigation of remote areas, penalties for water pollution, and allocation of beaches.
- There is also a political and regulatory process through which arable water can be allocated.

Institutionally water allocation is steered centrally by the Supreme Council for Water Management. This high-level body represents all relevant Ministries and operates under the Prime Minister. Operationally the Ministry of Water Resources and its units in the centre and the governorates are responsible. Regular improvement and modification of water allocation is an integral part of the powers. The focus is on the higher-level allocation of water, less on the distribution and timing of water supplies within the irrigation canals for instance.

The right of agricultural users to obtain water is recognized and registered. The Ministry of Water Resources through its several decentralized units ensures the availability of water according to the official quotas. There is a water standard in place for all agricultural lands, with quota based on the nature of the land and the type of crop. The entitlement to water for non-agricultural users is registered and recognized as well and follows the applicable water standard according to the type of use.

There is regular contact between water network operators, water users, and other stakeholders in the field of water, and one of its priorities is improving water allocation and water usage. Though the overall systems are well-articulated, particularly at the level of the irrigation system, there is scope for practical improvement and fine-tuning the system, with engagement of the organized water users and other stakeholders.

There is scope to do better, and a willingness and mechanism to implement improved water allocation. In Anbar Governorate the agenda in resetting the water allocation within the irrigation systems could consist of:

- Controlling the proliferation of large fish farms taking water directly from the main river
- Exploring the opportunities for increased water storage during high water flows
- Rationalizing irrigation supplies – so as to give incentive for local water saving
- Reducing water logging – avoiding excess water building up
- Reusing drainage water, e.g. collecting excess water and blending it with fresh water, in order to return this to irrigation system
- Exploring conjunctive use, e.g. combining surface irrigation, water harvesting and/or shallow groundwater use and optimizing water availability and water quality for various uses.
- Exploring the reuse of treated wastewater, making it a complementary non-conventional part of the irrigation system

These improvements would benefit from a stronger organization at the local level – with Water Users Associations (WUAs) playing a larger role in local water management and as an interface with the main service provider. In the past decades in many countries there has been a large movement in forming WUAs, so as to create a lower-level tier in the water system and have an interface with the agricultural water users. These represent almost everywhere the largest group of water consumers, but in many instances they are hardly organized, resulting in water wastage and tensions and conflicts. Frequently such WUAs were established with external support, often as part of investment in new or rehabilitated irrigation infrastructure. The WUAs then took care of inputs to the design of the systems and of the beneficiary cost contribution. The organizations typically had a formal organization, with a board and members, but after the external support was over stopped functioning in this formal shape. Though the WUAs stopped having regular meetings, in many cases new relations were forged between agricultural water users, that helped in the operation of the irrigation system.

There is a need to do better than this, and have WUAs not created as a project vehicle, but as a formal tier in the overall water management system with distinct responsibility for water distribution, water management and system operation at the important lower level. The WUAs may also benefit from exchange and negotiation with other WUAs – so as to build up capacity and relations. Experience is that if WUAs have such formal position and are encouraged to perform that they do very well.

5.4.3 Field water management

Despite the (increasing) water scarcity, farmers are profligate in their use of water. With the lack of investment in more advanced irrigation techniques and its low capital requirements, surface irrigation, also known as flood irrigation, is the most widely used traditional method, accounting for 81.4% of the irrigated area in Anbar. Only 40% of the water is genuinely utilized by crops using this technique, which causes water logging /salinization and high non-beneficial evapotranspiration.

The Ministry of Agriculture, in cooperation with the Ministry of Water Resources has been promoting and financially supporting efficient field irrigation measures. The strategy is to deploy sprinkler irrigation systems for growing grain crops and drip irrigation systems for growing vegetables and irrigating fruit and date-palm trees. In addition, tunnel greenhouses are promoted. Nevertheless, there is clearly scoped to do much more.

Apart from the micro-irrigation techniques, there is much to be gained in improved field water management as well, for instance in ridge cultivation, in particular in areas that are sensitive to salinity, and improved field drainage.

For this to happen, several enabling factors may be considered. First, a system of overall water allocation (see section 5.4.2) that promotes and rewards better local water management by farmers; second, a system of financial incentives – be it water prices or investment subsidies, whereby improved field water management makes business sense; and third, the easy availability of the services needed to make better field water management possible (suppliers, mechanics, training). Finally, field water management is not only concerned with water saving, but it also relates to soil health.

Water management also needs to take account of salinity: it is necessary to constantly wash the soil to get rid of accumulated salts. This requires a sufficient amount of low-salinity water, use organic fertilizers, and use a water harvesting system. This is in addition to complementary measures that must be taken, which include continuous awareness to rationalize water use through the use of modern applications. The type of agricultural water system most suitable for the different soil types as they occur in Anbar are given below (**Table 5.5**).

Table 5.5: Soils in Anbar Governorate

Type of soil	Description	Percentage of area	Location	Agricultural water use
Gravelly limestone desert soil	The most widespread soil type, with depth ranges from 10 - 25 cm, with medium salinity and sandy	> 40%	Upper Euphrates and western part of Governorate borders	Suitable for growing crops with pivot sprinkler and non-moving irrigation systems
Stony desert soil	Second largest soil type is 10 cm deep, but it is highly permeable to water	21%	Throughout the Governorate	Requires fertilizers and biological additives, such as local biomass with high fibre content that disintegrates slowly, for exploitation
Calcareous desert soil	Soil type with low organic matter, high calcium carbonate content, and high-water permeability	> 12%	West of the Governorate	Not suitable for agriculture
Gypsum desert soil	Climate has played a major role in its formation. It is characterized by drought and contains gypsum, lime and sand, moderate salinity, and low agricultural productivity	> 12%	Along river edges, desert valleys, and sand depressions in Upper Euphrates region (Al-Qaim)	Agriculture possible with suitable fertilizers with high water holding capacity, continuous soil reclamation, drip irrigation system, or cultivation in greenhouses
Mixed gypsum desert soil	A combination of gypsum, lime, and sand, with low fertility and limited water retention capacity	12%	Ramadi and Fallujah districts	Possibility of greenhouse cultivation
Alluvial plain soil	Alluvial plain soil mainly consists of fine silt and clay particles and belongs to the most fertile farmlands worldwide with high nutrient and water retention capacity.	1.8%	Northwest of Ramadi to end of Fallujah, along the Euphrates	Suitable for growing most types of crops, although some area encroached upon for urban construction
Flood plain soil	A light mixture soil that generally consists of clay and lime. Its depth reaches 2 meters, and the percentage of organic matter is 8%	< 0.3%	Syrian-Iraqi border to Hit District	Suitable for growing many crops with high-quality production

Source: Osman et al. 2017

5.4.4 Conclusions

The management of the irrigation systems in Anbar Governorate is a main opening to improved water security, particularly in a situation where the overall water supplies into the country and the Anbar Governorate are being reduced. With irrigation by far the largest water consumer, the curtailed water supplies make themselves felt very much in the irrigation system. The transition to low delta fodder crops is a manifestation of this development. To deal with the rising water scarcity, solution have also to be found in the same irrigation system – to do better with the reduced water resources.

There are several important avenues to achieve this:

- Rehabilitation of broken irrigation infrastructure – damaged because of the combination of conflict and neglect.
- Improved water allocation within the irrigation systems, along a number of directions, such as the systematic reuse of drainage water and the reuse of treated wastewater, balanced conjunctive water use of surface and groundwater within the irrigation system, controlling water logging and controlling out of sanction water use, in particular the large fishponds that have been created in recent years
- Improved water use efficiency at field level, combined with better tailored allocations of the main system. This can have many elements, e.g. the introduction of efficient controlled systems, but also the systematic use of ridge cultivation that is known to make a huge impact in terms of water use, yields and reduced agri-inputs.

All of this needs to be based on effective and capacitated organizations. We recommended in particular to create WUAs that are part of the overall water management systems and are empowered as such. The other important element is building on the well-established practice of optimizing water allocation under the direction of the Ministry of Water Resources and to further finetune the delivery of irrigation water supplies in terms of timing, quantities, mixes at the lower level in the irrigation systems, where this really matters.

The analyses with WAPOR show that water productivity in Anbar has bounced back from the time of intense conflict, that more water is used, but even more produced. Even so, there is considerable scope to move further on this trajectory of improved water productivity.

5.5 References

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6 Run-off and flood water harvesting

6.1 Background

With the current pressure on surface water and groundwater in Anbar, it is imperative to retain more water and make it available for direct use in rain-fed or flood-dependent agriculture, or in recharging aquifers. Iraq's freshwater resources are under immense pressure because of the country's reliance on transboundary rivers shared with Iran and Turkey, prolonged droughts, inefficient use of water, and rapid population growth along with socio-economic development. The Anbar region has been experiencing major challenges in providing and managing water for its economic activities. This chapter explores run-off and flood water harvesting options in Anbar and identifies potential areas for rainwater harvesting (RWH).

6.2 Run-off and flood water harvesting options

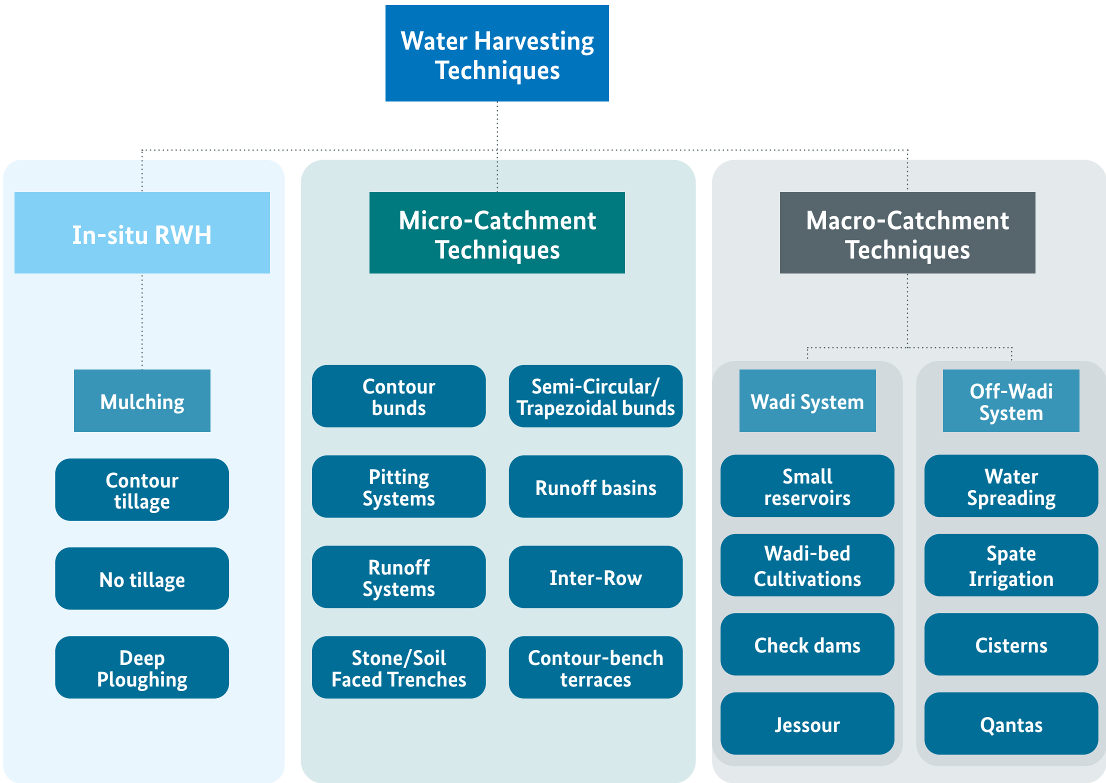
There are a large range of possible measures to retain rainfall and run-off in Anbar Governorate. They need to be carefully chosen and planned. Several dams are in place in the southern part of the Governorate that store stormwater, for example Al-Abila dam in Horan Valley, also discussed below.

Rainwater harvesting (RWH) can be a practical solution in areas that are exposed to drought and floods. There are different classifications of RWH techniques depending on the ratio of catchment to the crop area: In-situ and off-situ or micro- and macro catchment systems. In-situ systems collect rainwater within farms or just off-farm and store water in the soil. Micro catchment systems typically measure less than 1000 square meter. Macro-catchment systems are usually used to collect large runoff from high intensity rainfall and mainly applied for flood water. See **Figure 6.1** (Woldegiorgis, 2017).

The widely used technical criteria to evaluate appropriate RWH techniques involve: overall rainfall and rainfall pattern including peak rainfall, slope, soil texture, as well as socioeconomic factors such as cost, availability of labour, land tenure, distance to communities and road accessibility (Abdelkader et al., 2023).

Figure 6.1

Classification of water harvesting techniques



Source: based with modifications on: Woldegiorgis, 2017

Given the low rainfall in Anbar Governorate, macro-catchment systems are most appropriate: such as flash flood/ storm water harvesting or point recharge. These are focused on areas where run-off is collected and combined. Various options for point recharge exist, without the sedimentation risk, with proven efficacy in replenishing groundwater. Examples are subsurface dams, leaky dams, cascade dams, sand dams and riverbed stabilizers. Despite their success elsewhere, these techniques have not been explored in Anbar, where low rainfall is a concern for groundwater availability. Alternative run-off captures and storage techniques should be introduced near groundwater-irrigated areas in critical areas, serving to substitute the overstretched groundwater sources. Additionally, local groundwater management is crucial to achieving balance by increasing supply and reducing overuse. Promising experience exist in the People's Republic of China, where wells have been metered and water is accessed with an ATM-card, on the basis of a predetermined quota. Another example is to promote local participatory hydrological monitoring, encouraging groundwater users to make water balances on the basis of their own observations, and plan water consumption reducing measures.

The other major opportunity to balance groundwater is to directly use flash floods for productive use. This may be agriculture, grazing area improvement or forestry. There is a long history in such flood-based systems in North Africa and South Asia, that may be studied, see also www.floodbased.org. With new diversion techniques, like mini-barrages or flood water spreading weirs these flash floods are attenuated and spread over a large area, where they feed the soil moisture. In many areas of such flood-based systems, the soil moisture is conserved after the flash flood event through soil mulching or deep ploughing to be utilized later for productive use – such as the cultivation of coarse grains, wheat, legumes, or oilseeds. Such systems deserve serious attention in Anbar governate.

6.3 Potential areas

In Iraq's Western Desert, studies were conducted on the sustainable management of water resources (Sulaiman et al., 2019). Remote sensing and numerical analysis tools were used to estimate the annual water harvesting rate of each basin. New water collection locations were found for a variety of agricultural applications and community development. Mohammed et al. (2022) examined the possibility of constructing a series of small dams to replenish the groundwater and improve the ecosystem.

Table 6.1: Characteristics of valleys with potential for water harvesting

Valleys	Area (km^2)	Length (km)	Slope (%)	Yearly harvesting (m^3/km^2)
Horan	13,340	490	0.162	15,355.36
Al-Abeith	6,515	340	0.169	4,582.31
Al-Ghadaf	5,900	165	0.236	7,098.64
Ameg	5,399	170	0.223	6,405.22
Al-Awaj	1,246	60	0.280	4,782.34

Source: Adham et al., 2018

A study established that the Al-Anbar Governorate in western Iraq contains a large number of seasonal flood valleys (Sulaiman et al., 2019). Some of these valleys stretch to the borders of Saudi Arabia, Jordan, and Syria. **Table 6.3** lists the most promising valleys for potential RWH to be taken into account in future strategic projects in Iraq (Sulaiman et al., 2019). Each site is described in detail below. Error! Reference source not found. shows these main valleys in the western desert of Iraq (Al-Muqdadi, 2012).

6.3.1 Horan Valley

It is the largest valley in the western zone in Iraq, stretching from the Saudi border to the borders of Jordan and Syria with a watershed area 13,370 km^2 (**Figure 6.2**) (Kamil and Shallal, 2023). The length of the mainstream is more than 486 km from the Iraq-Saudi Arabia boarders to its end in the Euphrates River downstream Haditha dam. The mean annual rainfall is about 120 mm, of which 50% falls in the winter, 35% in spring, and the remaining 15% in autumn (Kamil and Shallal, 2023). The valley is completely dry for most of the year, but it carries short intense floods in rainy season. Hard limestone is the main rock type in Horan (Ammar, 2017).

Table 6.3 lists the main parameters and a possible scoring system to be considered by water resource planners in the selection of suitable RWH sites (Adham et al., 2018; Sayl et al., 2021).

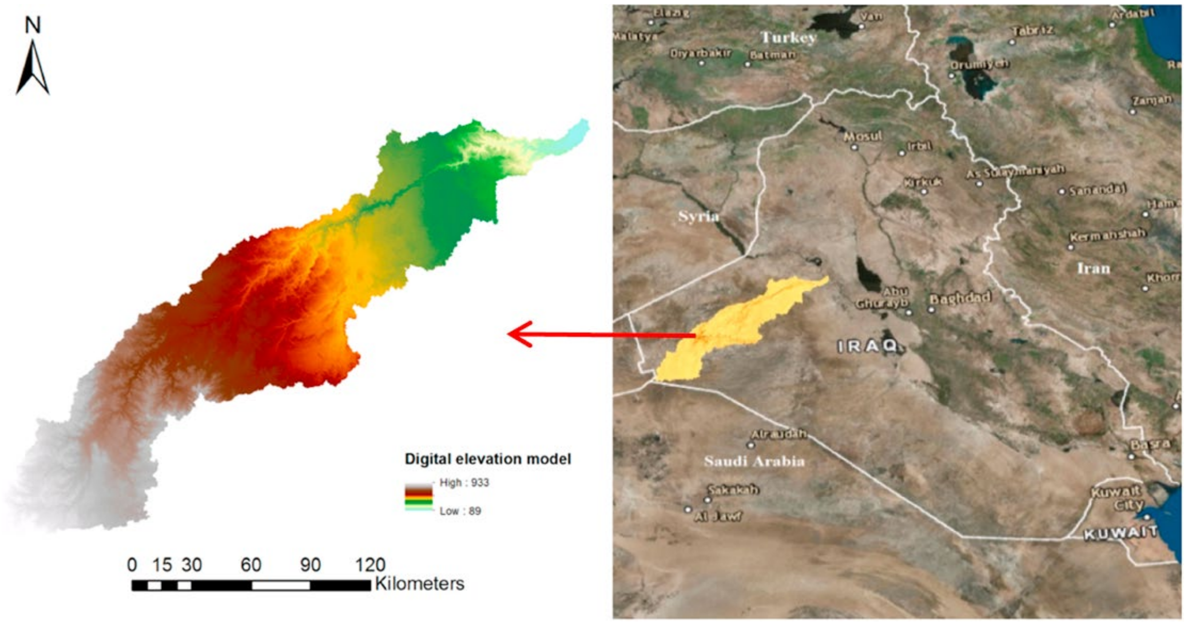
Table 6.2: Criterion for identifying potential sites of RWH in arid and semi-arid regions

Criterion	Class	Value	Score
RunOff depth	Medium suitability	80-90	8
	Very high suitability	70-80	9
	Suitable	60-70	4
	Low suitability	50-60	3
	Very low suitability	<50	1
Slope	Flat	< 1.5	3
	Undulating	1.5-2.5	9
	Rolling	2.5-4.5	5
	Hilly	4.5-7.5	2
	Mountainous	> 7.5	1
Land use/cover	Farmland and grass	Very high	9
	Moderately cultivated	High	7
	Bare soil	Medium	5
	Mountain	Low	1
	Water body, urban area	Restricted	Restricted
Soil texture	Very high suitability (clay)	> 20	9
	High suitabiliy (silty clay)	15-20	7
	Medium suitability (sandy clay)	11-15	4
	Low suitability (sandy clayey loam and sandy loam)	8-11	3
	Very low suitability (other)	< 8	1
Stream order	Very high suitability	> 7	9
	High suitability	7	8
	Medium suitability	6	3
	Low suitability	5	2
	Very low suitability	< 4	1

Source: Sayl et al., 2021

Figure 6.2

Location of Horan Valley

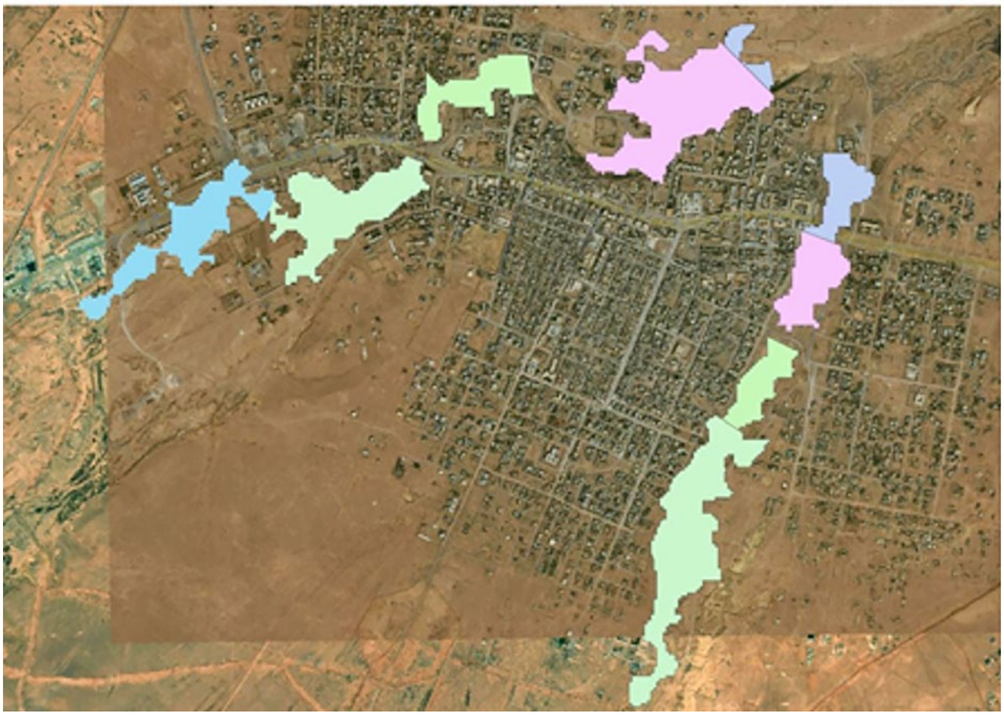


Source: Kamil and Shallal, 2023

Horan valley enters Rutba city from the south-western part passing 4 km inside the city before it leaves the city in the north-eastern part (**Figure 6.2**). Whereas Al-Masad valley enters the city from the southern part and moves a distance of about 2.75 km and meets Horan valley in the north-eastern part of the city, see **Figure 6.3** and **Figure 6.4** (Al-Kubaisi and Al-Kubaisi, 2023; Kamil and Shallal, 2023). Ammar (2017) found that most of the soil texture in Horan valley consists of clay and silty clay with high water-holding capacity and thus high suitability for the construction of RWH systems. Based on soil type in Horan, Ammar (2017) further recommended that gentle to moderate slopes (1.5-4.5) should be considered in site selection in Horan and areas with slopes of ≥ 5% should be avoided because these areas are subject to erosion due to irregular runoff distribution and therefore large earthworks are required. In addition, where there is ample flat land in the valley bottom, the direct diversion of floods for spate irrigation may be considered.

Figure 6.3

Potential sites of interceptive dams' lakes on Horan and Al-Masad valleys



Source: Al-Kubaisi and Al-Kubaisi, 2023

Figure 6.4

Rutba City with its two main valleys (Horan and Al-Masad)

Source: Kamil and Shallal, 2023

6.3.2 Al-Ghadaf Valley

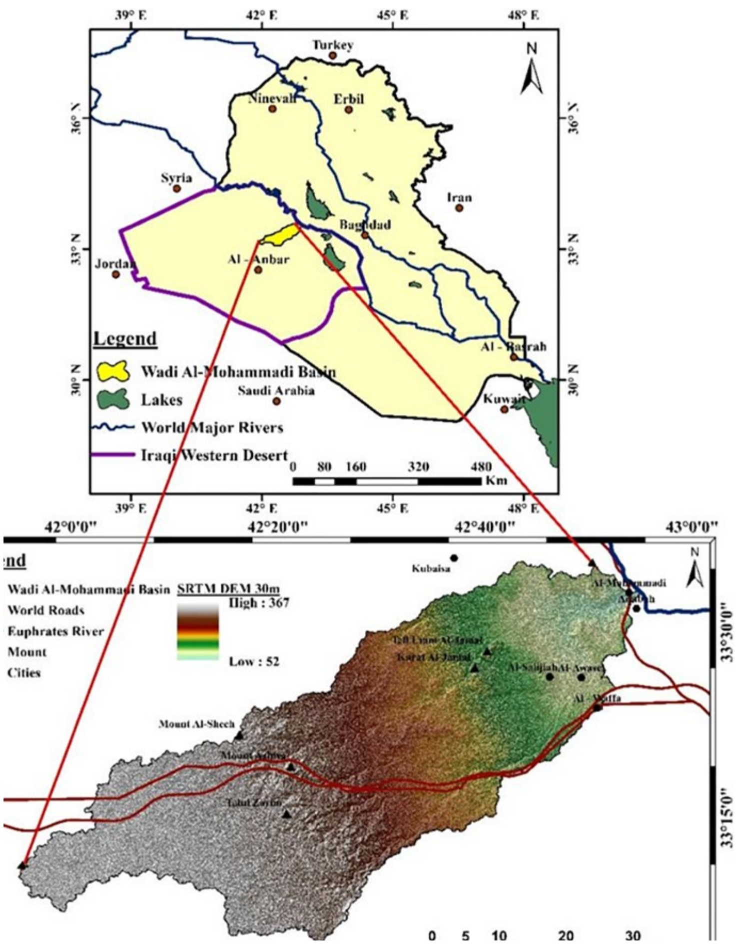
Al-Ghadaf valley (Sayl et al., 2021) is situated to the east of the Euphrates River in the western desert of Iraq in the Anbar Governorate with a catchment area of 8,513 km^2. The soil of the valley is fertile, and the limestone rocks are largely spread in the area, which can be beneficial for dam construction. The valley receives high runoff volume during the rainy season, thus the RWH would be a useful tool for easing the dry season's water scarcity.

6.3.3 Al-Mohammadi Valley

The basin is approximately 2,287 km^2 in size and ranges in elevation from 52 to 367 m above sea level. **Figure 6.5** shows the location of the Al-Mohammadi valley (Al-Kubaisi and Al-Kubaisi, 2023). The valley is bounded to the north by the Kubaisa basin's Al-Hajiya valley, to the east by the Euphrates River, to the west by the Abu-Jir depression, and to the east by the Kilo-160 area.

Figure 6.5

Location of the Al-Mohammadi valley



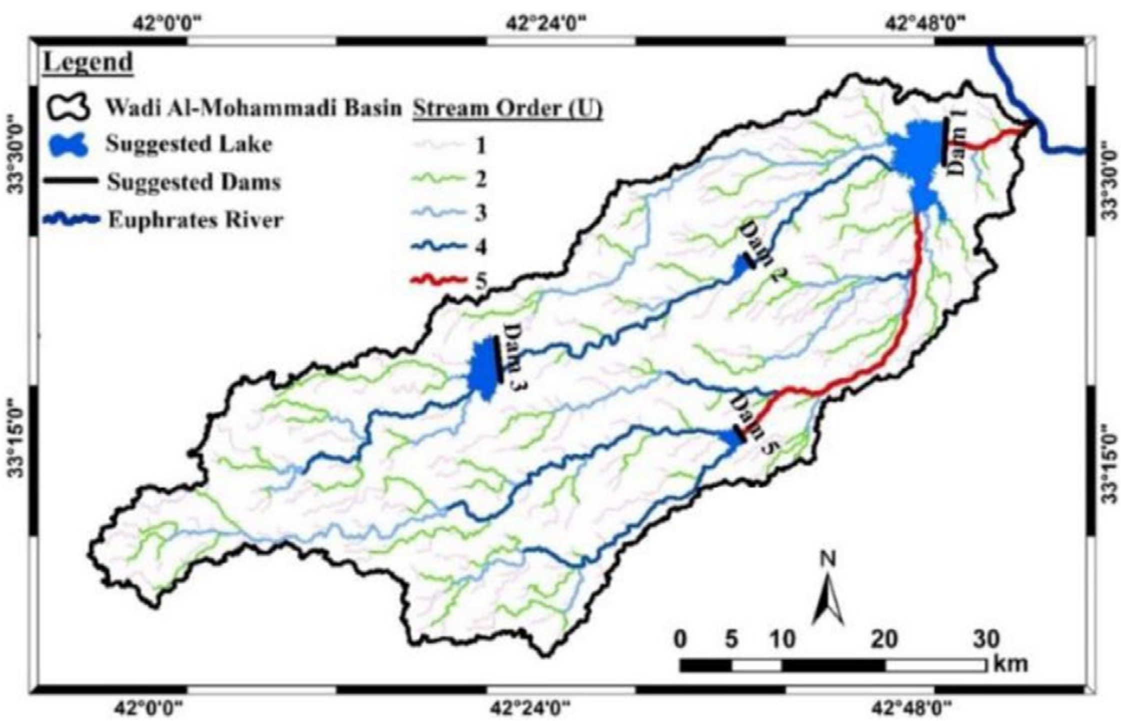
Source: Al-Kubaisi and Al-Kubaisi, 2023

Al-Kubaisi and Al-Kubaisi (2023) used a weighted evaluation factor that consists of five factors to rate the level of suitability to select the site selection of dams for RWH of Al-Mohammadi Valley. The suitability index was rated as highly suitable (90-100), suitable, (80-90), moderately suitable (70-80), not suitable (60-70) and highly unsuitable (<60). The factors are the distance to villages, the distance to faults, the elevation, the slope, and the distance to roads.

From this analysis four dam sites were pre-selected, see **Figure 6.6**. Site 1 at the outflow of the valley emerges as the site most promising. According to the pre-assessment by the authors, the dam would have a height of 65 meter and a width of 3,995 meter with a storage capacity of 186,000,000 m^3 covering 33 km^2. Much more work would need to be done to establish the feasibility such as the sedimentation measurement, geotechnical assessment and planning of the multiple use, including a possible command area.

Figure 6.6

Location of possible dam sites in the Al-Mohammadi valley



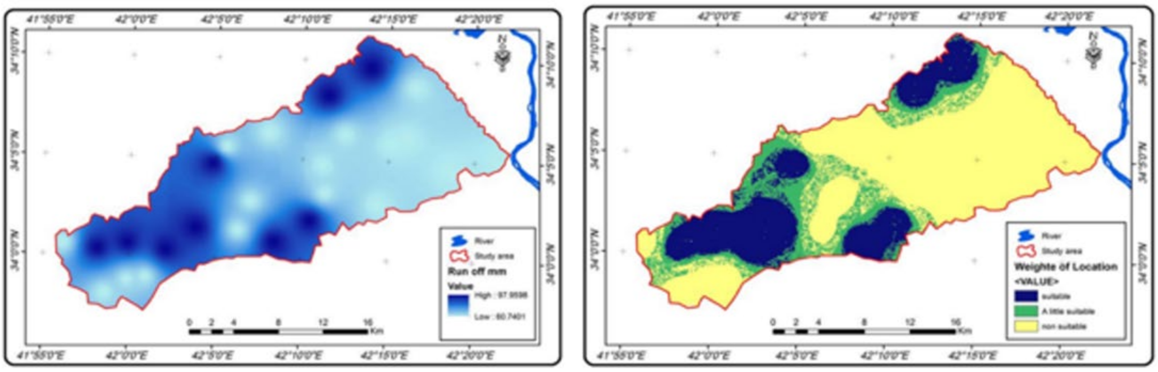
Source: Al-Kubaisi and Al-Kubaisi, 2023

6.3.4 Haqlan valley

Haqlan valley is in western Iraq and surrounded by Haditha Lake from the north, Horan valley from the south and south-east, and Al-Fahami valley from the west. The catchment area is about 452.6 km^2 and lies within the Euphrates formation. **Figure 6.7** shows the runoff depth map (left) and rainwater harvesting potential map (right). The results extracted from the study "GIS-based approach for rainwater harvesting site selection" indicated that about 28% of the study area is totally suitable for RWH and 21% is moderately suitable (Sayl et al., 2020).

Figure 6.7

The runoff depth map (left) and rainwater harvesting potential map (right)



Source: Al-Kubaisi and Al-Kubaisi, 2023

6.3.5 Combine RWH with water management

The key to successful run-off and flood water systems lies not only in the ability to capture and retain the water, but also to conserve it and use it efficiently.

The reliability of RWH system represents the ability of the system to deliver the required amount of water within a certain time. Adham et al. (2023) evaluated the system of Al-Abila dam within Horan valley by using a water budget simulation model (time and volumetric based) for three scenarios (wet, average, and day years). The authors found that water-capturing and storage performance never exceeds 50% in all scenarios, and that beyond a certain size increasing storage capacity does not add value in this regard. Performance evaluation of rainwater harvesting system is of high importance to see how efficient the system is under different scenarios of design and management. Various hydrological modelling techniques can be adopted to evaluate and optimise the facilities of the RWH system.

The other important element in water management in RWH systems is the management of water on the land. In arid areas such as Anbar this is a huge area for creating better results, as also discussed in **Chapter 5**. Where run-off and flood water are captured in a dam, as in the Al-Abila Dam, the same measures as in perennial irrigation system apply.

However, in other run-off and flood-water dependent systems where there is no surface storage and water use efficiency is not achieved by water saving from the stored floodwater, but by preserving soil moisture in the most optimum conditions. This varies with the soil conditions. In general, however a combination of soil mulching and deep ploughing will help preserve moisture from floods. This may be most relevant for Anbar. In more rain-dependent systems, where water is available in steady quantities in the rainy period, conservation agriculture and zero-tillage in contrast may be preferred.

6.4 Conclusions

Unlike other countries there has been almost no community or private investment in flood or rainwater harvesting in Anbar. There is a need to bring all those together with an agenda on rainwater and floodwater harvesting and create a critical mass effort and a strategic plan. This should widen the repertoire of interventions, beyond the now default option of dam building.

There is a large range of measures appropriate to arid valleys, also using the macro-catchment approach where run-off and flood water is harvested from the dry valley rivers and drainage system. The rain run-off and flood water may be harvesting for direct productive use or for groundwater recharge. The priority is for a watershed approach to operationalize arid zone basin management, sub-area by sub-area. The contribution of improved flood water utilization, recharge, better water buffering to groundwater security and climate change adaptation can be large.

In applying a watershed approach for Anbar the following is recommended:

i. Working at an intensive scale and combining different interventions is most effective as it allows one to see a significant local effect on the water tables, changing moisture levels in the landscape and even changes in micro-climate and vegetation.
ii. Local planning is important to identify the best interventions and aim for practices that are relatively low cost.
iii. Watershed management should cover a large range of options – from improved soil moisture conservation to flood water management to groundwater recharge to surface water storage. The most important step in planning for run-off and flood water harvesting systems is selecting the most promising sites. A systematic review indicated that catchment area, rainfall, slope, soil, and land use/cover, distance to agricultural area, distance to urban areas, and population density can be in RWH sites in Anbar Governorate. It is essential to create more thorough RWH system frameworks that support reduced water pollution, sustainability, and the preservation of natural resources in the Anbar Governorate.
iv. This may lead to a RWH Master Plan for the Governorate Water harvesting and retention should be done through the entire landscape and should also include for instance the protection of gravelly riverbeds (which enable subsurface flows and facilitate recharge to aquifer systems) or the use of roads for water harvesting.

What is recommended operationally is to:

- Bring a large number of stakeholders together – government, civil society, community groups and private business with an interest to develop the arid parts of Anbar.
- Explore and introduce a large number of options appropriate to the arid conditions of large part of Anbar Governorate, including but not limited to subsurface dams, sand dams, spate irrigation structures, flood water spreading weirs, infiltration galleries, and other macro-basin water harvesting and groundwater recharge techniques.
- Combine this with a better appreciation of field water management and moisture conservation as appropriate in arid environments.
- Do the assessment on watershed-by-watershed basis, understanding run-off and floodwater opportunities as well as subsurface flows in the dry rivers.
- Match this with implementation modalities and business models to operate the systems effectively.

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7 Recommendations

The water management situation in Anbar Governate presents large challenges, that are partly representative for the country as a whole. The preceding chapters described these challenges and the changed reality and as much as possible quantified these. They include the reduced trans-boundary surface water inflow, the reduced rainfall trend, the increased pressure on the finite and partly non-renewable resources and the weakened resource base. These challenges have already translated in a degradation of the resource base, increasing the vulnerability of the people and activities dependent on them. It is fair to say that a new reality has set in.

At the same time there are also underutilized opportunities to off-set some of the challenges. Several improved practices have not been introduced. Steps to regulate the management and use of the water resource base have not been taken and some vital data are not known such as the flow of the Euphrates at different locations or the extent of groundwater usage. Steps are required to be taken concerning regulatory and planning measures, investments and programming and the introduction of new practices.

To improve water management in Anbar Governorate and to reverse the trend of decline and neglect the following main recommendation are proposed:

1. Improve overall water resource management
2. Improve water management in the irrigation system
3. Regulate groundwater use
4. Set in place rain-run off and flood water harvesting
5. Control water quality
6. Improve legislation

AFC trainer guiding farmers during a group activity in the Farmer Field School programme in Anbar

7.1 Improve overall water resource management

The following actions are recommended to improve overall water resource management in Anbar Governorate, which are first mentioned and then discussed below:

- **Develop a vision of water resource use and management for Anbar Governorate**
- **Enlarge functions within the Water Resources Department**
- **Review legislation and regulations with a view at implementability**
- **Create a platform of water stakeholders**
- **Activate WUAs and local organizations in water management**
- **Consider water charging as an instrument for demand management**

Develop a vision of water resource use and management for Anbar Governorate

The water resources situation in Anbar Governorate has changed as a result of reduced releases from upper riparian countries and because of a changed climate. The result is a drier and more drought-prone situation. Pressure should be applied – with international partners - with neighboring Turkey and Syria on the construction of new upstream dams and the operation of the existing dams. At the same a vision should be prepared by Anbar Governorate – engaging all concerned parties – on water management in Anbar, considering the current situation and a present and future that are drier and insecure. The vision should not look at water management per se but place the challenges in the larger perspective of the economy of the Governorate.

Enlarge functions within the Water Resources Department

There are a number of emerging mandates in water management that go beyond the competencies of the Water Resources Department, in particular monitoring and regulating groundwater use, promoting water harvesting and facilitating wastewater reuse. A review of the Water Resources Department mandate and actual staff strength and facilities is recommended with a view to see what functions need to be added and what functions are of lower priority.

Review legislation and regulation with a view at implementability

The new water-related challenges and opportunities require a relook at the current legislation and regulation. Below some of the most important legislations are given.

Sequence	subject of the law, decision, or instruction	Number	Year
1	Irrigation Law (with amendments).	6	1962
2	System for the maintenance of sewage and public water from pollution.	25	1967
3	Irrigation Projects Implementation Law.	138	1971
4	Instructions for purchasing, owning, and installing pumps.	3883	1981
5	Instructions for applications of the Irrigation Projects Implementation.	1	1987
6	River's edge Exploitation Law	59	1987
7	Instructions for drilling water wells and controls on their sale and rent.	3	1988
8	Conditions for selling and renting irrigation pumping stations.	4961	1989
9	Irrigation and Drainage Networks Maintenance Law.	12	1995
10	Irrigation Law.	11	2017

What is recommended is to review the current legislation with the associated regulations and to see whether they are practical and adequate to address challenges and opportunities in water resource management in Anbar Governorate and if so, what adjustments are needed. Particular challenges to consider are: (1) reuse of wastewater (2) reuse of drainage water and other improvement in local water allocation in the irrigation systems (3) regulation of groundwater development and usage (4) promotion of water harvesting and water retention and (5) control of fishpond development.

Create a platform of water stakeholders

In the current situation, water use has become ever more interdependent. The need for integrated water resource management is inevitable – with different sectors interconnecting, cities and agricultural production systems, and government and different levels – including the local government. There is hence a need for a regular exchange and platform between the different stakeholders, in the shape of a water committee, or a regular program of meetings with a prepared agenda. The development of the vision, as above, can be the starting point.

Activate WUAs and local organizations in water management

Water management relies much on local action, local regulation and local problem solving. This requires the activation of local organizations with the capacity to contribute to local water management. In particular, WUAs may be engaged to play a role beyond operation and maintenance and contribute to improved local water management, in coordination with other WUAs, for instance in harmonizing water delivery and promoting good practice. Where needed, the current regulation and legislation may be reinforced. The same applies for local government that may, in addition to their administrative task, help in solving conflicts and contributing to local coordination.

Consider water charging as an instrument for demand management

At present water charges are neglectable, particular if set against the value of water in terms of crop production and the use of other inputs. It is important to dive deeper into the charging of water and explore how It may affect the demand for water, either as a price incentive or as an awareness tool. In general, the low current charges create a policy trap – because raising charges now to a level where they would make a difference may come with unrest and upheaval. There is a need however to sort out the issue, also in groundwater use and make resource pricing one of a gamut of interventions.

7.2 Improved water management in irrigation and drainage systems

With irrigation being the largest water user in Anbar, improved irrigation water management plays a large role on several agendas: water security, food security and improved incomes and livelihoods. In the past, there has been investment in rehabilitating the systems after years of neglect and disturbance. This recovery is not yet complete. At the same time, there is an urgent need to invest in better water management within the irrigation systems, so as to optimize its outcomes.

The following measures are proposed:

- **Rehabilitation and new investment in irrigation infrastructure, with priority setting**
- **Water allocation (incl drainage reuse) plan**
- **Promote efficient field water management and salinity control**
- **Agronomic measures for salinity management**

Rehabilitation and new investment in irrigation infrastructure, with priority setting

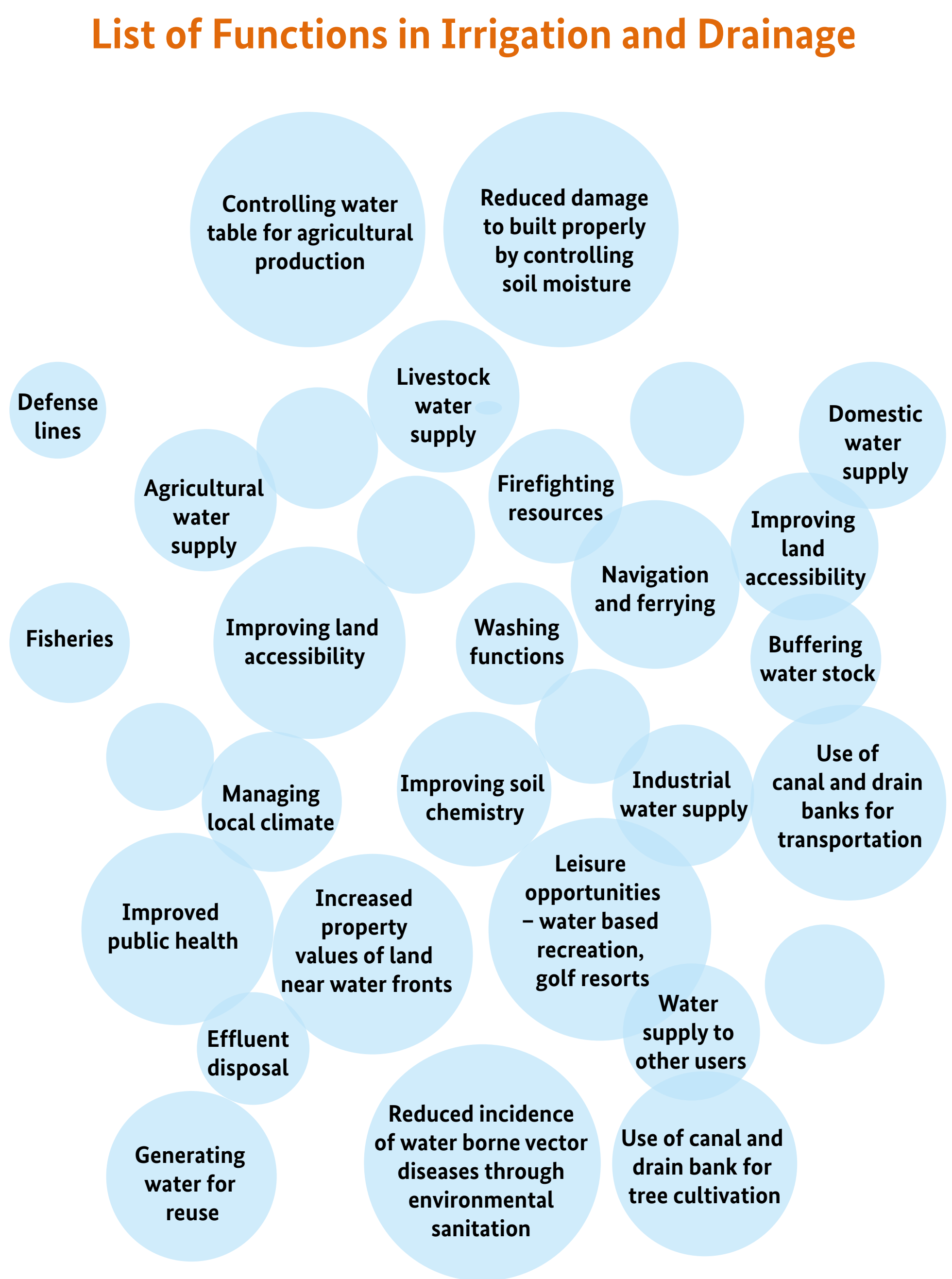
At present an inventory of the damage to irrigation systems is undertaken. It is clear that the key to a productive irrigation system is a reliable conveyance system, something that was imperiled during the conflict and the ISIS occupation. There is an important rehabilitation agenda and some new investment to be done. It is important also to make this subject to priority setting, as with the reduced inflows and the repeated droughts farmers have adjusted their cropping patterns and some areas have been abandoned – the latter either as a result of scarcity and/or conflict damage. Hence, the areas that have the best potential need to be selected and prioritized for investment.

Local water allocation (incl drainage reuse) plan

Key to irrigation system performance is how throughout the irrigation system water allocation is organized, at the main level and within the command area. Irrigation systems also serve other functions than irrigation, see Figure 7.1 and these may be considered as well in a plan for improved water allocation. An immediate priority is to factor in drainage reuse in water allocation and to accommodate the reduced inflows and the changed actual command area. The development of the water allocation plan is to be done within the boundaries of the vigorous legislation and with involvement of main stakeholders, including WUAs.

Figure 7.1

Possible functions in irrigation system



Promote efficient field water management and salinity control

In spite of the prevailing shortage of water, the inefficient methods of field irrigation, such as field flood irrigation, are still common. Drip and sprinkler systems have gained a foothold in many areas, as has tunnel farming – yet the adaptation is not uniform. It is recommended that the reason for the non-adaptation is investigated, so that measures for more effective promotion (credits, horizontal exchange) can be developed. At the same time, the slow adaptation of the new measures should be assessed, also against the overall economic perspective, and menacing water shortage to see what a feasible expectation in this regard would be.

Agronomic measures for salinity management

Salinity is a feature of the irrigation systems in Anbar. The negative effects of these may be mitigated by various agronomic measures, including fertigation, but also very much with the use of salt-tolerant crop varieties. There have been many breakthroughs in the last years, where of many crops, salt tolerance has been tested of different existing local varieties. It became clear that for many crops some varieties have very conducive characteristics, hence can be better promoted.

7.3 Regulate groundwater use

As elsewhere in MENA, groundwater is emerging as a new resource for irrigated agriculture. This raises justified concerns on the effect on groundwater reserves and the effects of using groundwater of marginal quality. The rapid increase of center-pivots systems close to the banks of the Euphrates is a development that needs to be closely followed.

A number of activities are recommended under this heading.

- **Regulate groundwater development**
- **Promote groundwater recharge**
- **Protect high quality groundwater sources**
- **Explore opportunities for conjunctive use**

Regulate groundwater development

There is legislation in place to guide and control the development of groundwater abstraction. The efficacy of this legislation needs to be checked and if needed supplementary measures may be considered. This will benefit from engaging the main stakeholders, i.e., the groundwater dependent farmers. It is also recommended to improve the awareness and basic knowledge on groundwater in a much larger community.

Promote groundwater recharge

An entire chapter is dedicated to the opportunities of capturing more rainfall (**Chapter 6**). This may be applied in the high potential areas, where a reasonable return can be expected on the efforts of creating the structures. There is no large tradition of rainwater harvesting in Iraq, so capacity building would need to be developed.

Protect high quality groundwater sources

Groundwater is a strategic resource; its availability is independent of good and poor rainfall year or even changing climate. This makes groundwater very important for long term supplies to major consumers, like industries. It is recommended to identify good quality groundwater resources in Anbar, on the basis of existing hydrogeological studies, and protect the status of these reserves by prohibiting abstraction for low value uses, such as agriculture.

Explore opportunities for conjunctive use

Seepage of surface water supplies leads to the rich replenishment of the shallow aquifers underneath the irrigation system. This shallow groundwater can then be used in conjunction with the surface irrigation, creating an on-demand irrigation system. The surface water supplies should be balanced so that they are not so generous as to prevent the needs for supplementary groundwater irrigation, nor so scarce that there is no seepage and recharge.

7.4 Set in place rain-run off and flood water harvesting

The potential to harvest rain-fall run-off and flood water in the non-Euphrates area of Anbar Governorate is largely unknown and certainly heavily unutilized. With the increase pressure on the water resources of the Governorate, it is imperative that these opportunities are developed. This should be backed up by a better understanding of the techniques at hand, the management models that go with it and overall, a zoom in on the most promising areas/ sub catchments in the arid valleys of Anbar.

The following actions are proposed:

- **Bring together all main stakeholders and create critical mass for strategic planning and action**
- **Explore new techniques for macro-catchment water harvesting and arid area field moisture conservation**
- **Make a watershed-by-watershed assessment and identify high potential areas for water har-vesting, using an integrated approach.**

Bring together main stakeholders

A critical mass and community of practice is to come in place on run-off and flood water harvesting and groundwater recharge. The Ministries of Agriculture and Water Resources are pivotal here, as are the NGOs active in this field, community organizations, local government and private sector. Shared platform enables strategic interventions concerning best approaches – in terms of techniques, management models and supporting arrangements.

Explore new techniques

There are many techniques appropriate to harvest water on macro-catchment basis, but they are unknown and not part of the water management repertoire in Anbar. The current repertoire is focused narrowly on dam building. Examples of other and often better macro-catchment options are subsurface dams, sand dams, spate irrigation structures, flood water spreading weirs, infiltration galleries, and various groundwater recharge techniques. In addition, there are proven techniques to manage and preserve soil moisture. These should be shared with main stakeholders, but also find their way in programs of implementation and in standard practices as taught in educational programs.

Identify high potential areas on basis of systematic scan and assessment

The current best opportunities and locations should be better understood in the vast arid territory of Anbar Governorate. With the community of practice (see above) and the use of new information technologies scans should be undertaken to identify the most promising areas for an integrated approach to run-off and flood water management.

7.5 Managing water quality

Water quality is a concern. The reduced flows in the Euphrates affect river water quality and the lower levels in the main storage reservoirs and lakes cause eutrophication.

**There is a need to make water quality more of a central concern.
The following actions are proposed.**

- **Create awareness on water quality pollution**
- **Promote wastewater reuse from all major urban centres**

Create awareness on water quality pollution

There is systematic monitoring on surface water quality in Iraq for the Tigris, Euphrates, Diyala, Shatt al-Arab and some tributaries within the Iraqi borders. In Anbar, seven stations were installed, starting from Al-Qaim, and ending in Fallujah. **Table 7.1** shows the water quality classification according to the 2019 WQI Water Quality Index values, which is still in effect. In principle, reporting is on a weekly basis. If detected, pollution is punished.

Table 7.1: Water Quality Classification according to Central Statistical Organization

Water Quality index				
No.	**River Water Condition**	**What does each score mean**	**Color**	**Range**
1	Excellent	Mostly healthy and thriving		95-100
2	Good	Impact by pollution but still resilient		80-94
3	Fair	Significantly impacted by pollution		65-79
4	Bad	Severely impacted by pollution		45-64
5	Very Bad	Threat to human health and native species		0-44

There is a need to share this information more widely and create awareness on the causes and risk of deteriorating water quality. With the legislation available, it is possible to act against polluters. This may form the basis to engage pro-actively in setting up water treatment facilities.

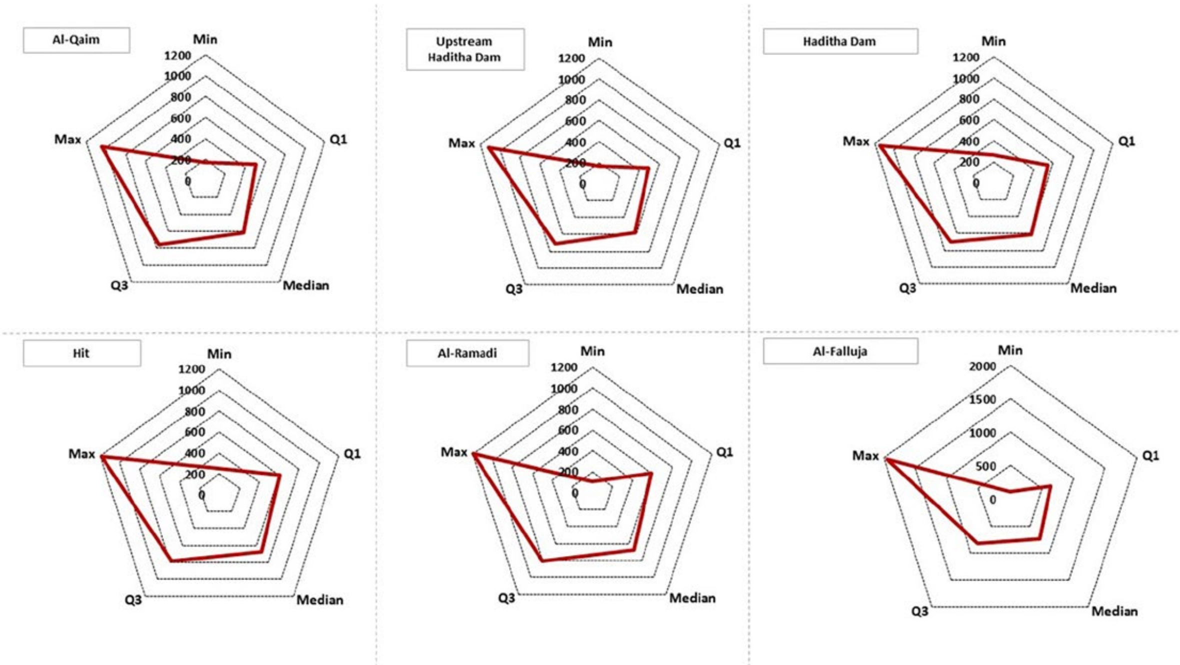
Promote wastewater reuse from all major urban centres

One cause for low surface water quality is the release of untreated wastewater from urban and industrial areas. This brings serious environmental and health hazards. A development that has progressed very much in other countries in the MENA region is the treatment and reuse of wastewater, in low value uses such as agriculture. Successful examples from other countries in the region ca be replicated in Anbar Governorate, while also exploring the possibility of reusing the sludge emerging from the. treatment as a by-product.

Annex I: TDS along Euphrates River

Descriptive statistics of Total Dissolved Solids (TDS) in 6 sites along the Euphrates River, including minimum, maximum, Q1, median and Q3.

TDS along Euphrates River



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Registered offices
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Dag-Hammarsskjöld-Weg 1-5
65760 Eschborn
T +49 61 96 79-0
F +49 61 96 79-11 15
E info@giz.de
I www.giz.de/e

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Text
GOPA AFC GmbH
Baunscheidtstr. 17 | 53113 Bonn, Germany
T +49 228 923940 00 | F +49 228 923940 98
info-afc@gopa.eu | www.gopa.eu

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Barbara Reuter | Oberursel, Germany | barbarareuter-grafik@web.de

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