Chapter 5

Shatt al Arab, Karkheh and Karun Rivers

INVENTORY OF
SHARED WATER RESOURCES IN WESTERN ASIA (ONLINE VERSION)

german cooperation
DEUTSCHE ZUSAMMENARBEIT

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

ESCWA
United Nations Economic and Social Commission for Western Asia

How to cite

UN-ESCWA and BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe). 2013. Inventory of Shared Water Resources in Western Asia. Beirut.

Shatt al Arab, Karkheh and Karun Rivers

EXECUTIVE SUMMARY

The Shatt al Arab River is formed by the confluence of the Euphrates and Tigris Rivers near the city of Qurnah in southern Iraq. Downstream of Qurnah, the area draining to the Shatt al Arab region is shared between Iran and Iraq. In addition to the Euphrates and Tigris Rivers, the Karkheh and the Karun sub-basins contribute water to the Shatt al Arab. Both the Karkheh and the Karun Rivers originate in the Zagros Mountains in Iran and discharge into the Shatt al Arab.

The Shatt al Arab River forms the main source of freshwater for the Persian Gulf and plays an important role for marine habitats in the Gulf's north-eastern coastal areas. However, the large-scale development of upstream water regulation and dam structures, together with the drainage of the Mesopotamian Marshes have caused severe salinization of the river. This not only threatens marine ecosystems in the Gulf, but also jeopardizes agricultural activity along the Shatt al Arab.

There are no water agreements in place for the Shatt al Arab, Karun or Karkheh Rivers. However, Iran and Iraq have agreed to cooperate on issues of common concern.

KEY CONCERNS

WATER QUANTITY

Intensive water resource development (mainly dams and irrigation infrastructure) in the upstream areas of the Euphrates and Tigris Basins has resulted in a reduction of flows to the Shatt al Arab River and Mesopotamian Marshes.
Iraq has voiced concern over recent Iranian plans to construct a levy along the Iran-Iraq border through the Haweizeh Marshes. Such a levy would reduce freshwater flow to Iraq, further threatening the marsh ecosystems.

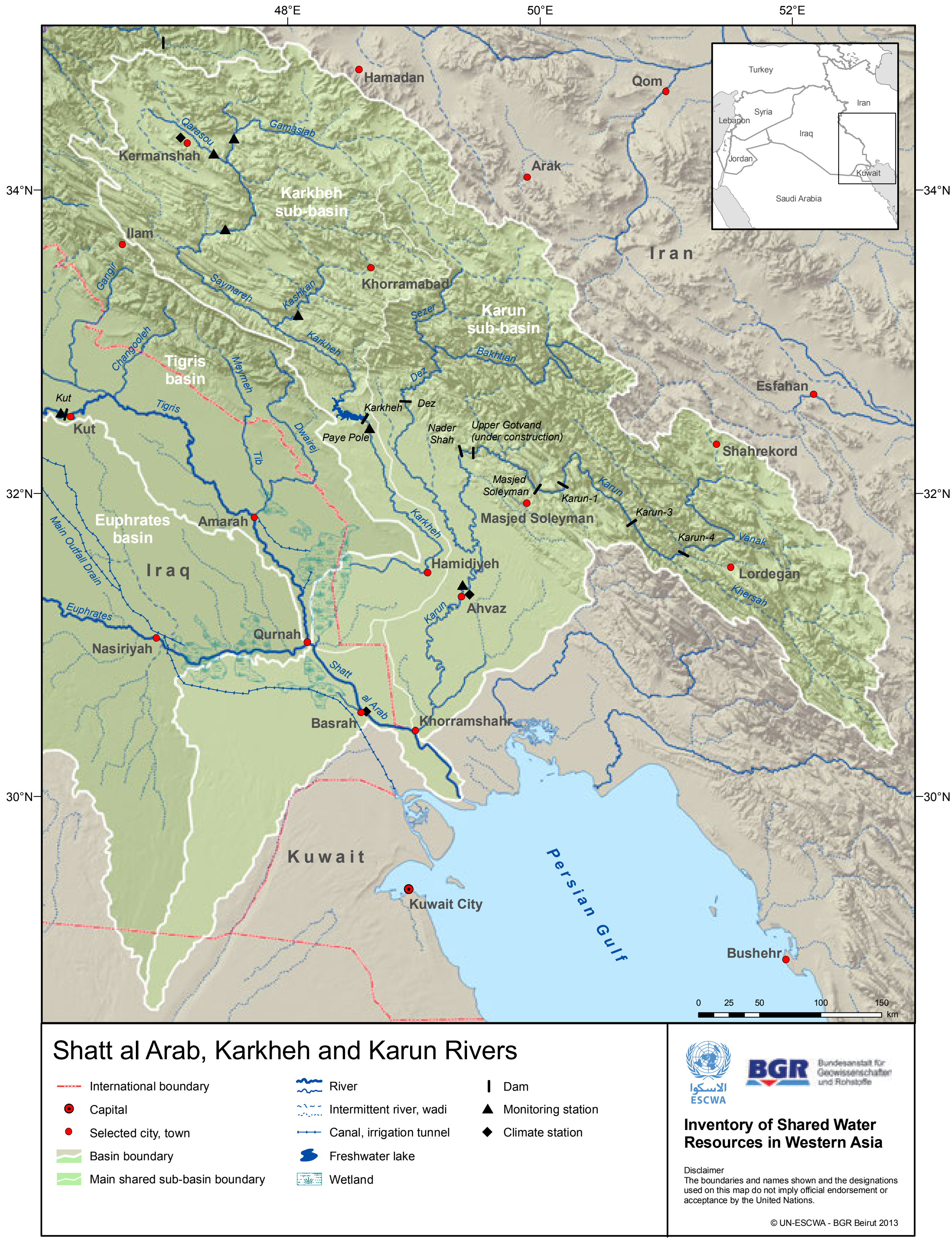
WATER QUALITY

The drainage of the Mesopotamian Marshes has had a negative impact on the Shatt al Arab and the Persian Gulf: the increase in salinity levels in the Shatt al Arab has caused noticeable degradation of coastal areas in Kuwait due to the presence of toxic sediments in the Gulf. Increased pollution from agricultural, industrial and domestic effluents forms an additional problem.

FACTS

RIVER	SHATT AL ARAB RIVER	KARKHEH RIVER BASIN	KARUN RIVER BASIN
RIPARIAN COUNTRIES	Iran, Iraq	Iran, Iraq	-
BASIN AREA SHARES	-	Iran 98%, Iraq 2%	Iran
BASIN AREA	-	51,110 km²	71,980 km²
RIVER LENGTH	192 km	964 km	867 km
MEAN ANNUAL FLOW VOLUME	..	5.8 BCM	24.5 BCM
MAIN DAMS	-	2 (max. storage capacity 7.9 BCM)	6 (max. storage capacity 12.4 BCM)
PROJECTED IRRIGATED AREA	..	..	..
BASIN POPULATION	-	4 million	3.5 million

OVERVIEW MAP



CONTENTS

FIGURES

TABLES

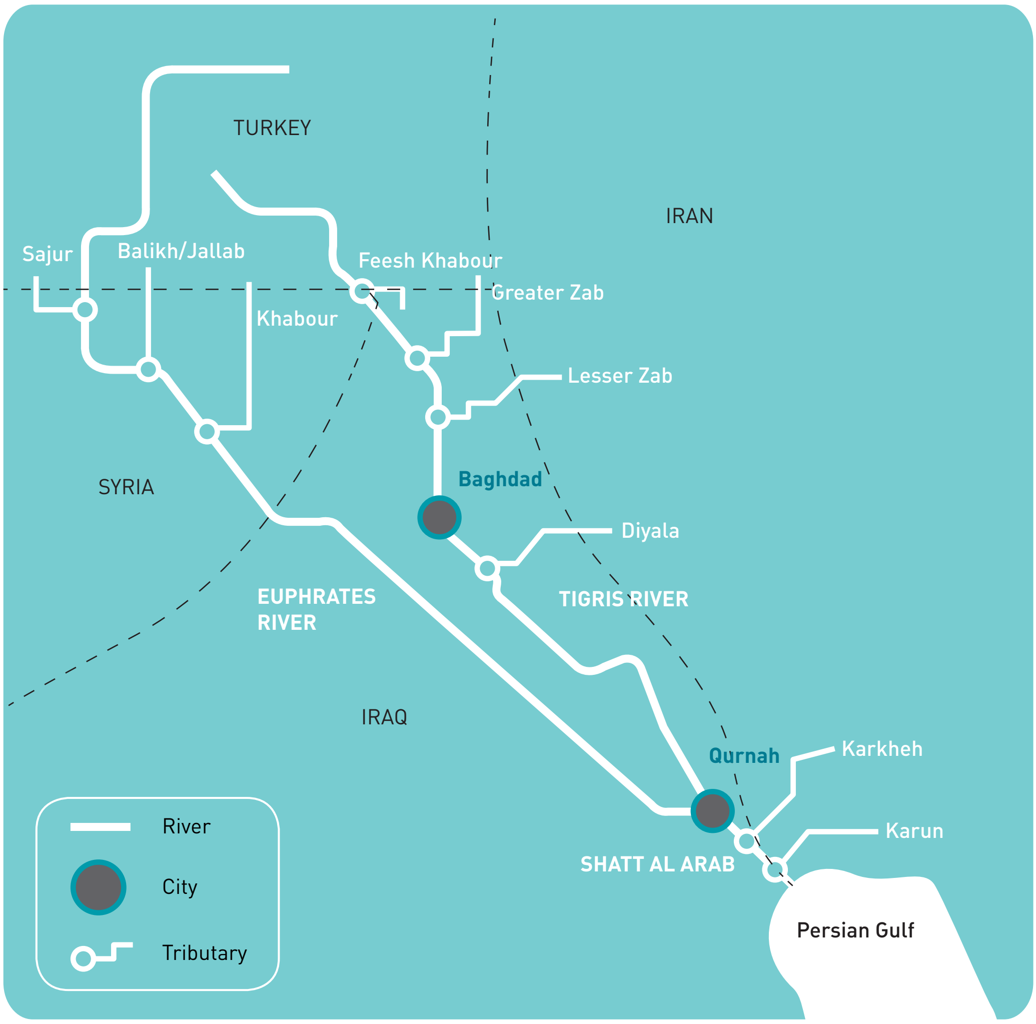
BOXES

Defining the Euphrates-Tigris-Shatt al Arab Basins

The Euphrates-Tigris-Shatt Al Arab river system constitutes by far the largest surface water resource in the study area. Its combined topographic catchment covers more than 900,000 km² from the headwaters in the Taurus-Zagros Mountain Range to the Mesopotamian lowlands and the only outlet to the Persian Gulf, the Shatt Al Arab (Fig. 1). The overall basin is also home to around 54 million people in Iran, Iraq, Syria and Turkey. Given its importance and in order to adequately reflect the specific conditions as well as its complex hydrology, the Inventory dedicates five chapters to this river system.

The Euphrates River Basin (Chap. 1) and Tigris River Basin (Chap. 3) each have a different dynamic and set of characteristics, particularly with regard to their riparian countries, tributaries and contribution to discharge, as well as water use patterns and water quality. The shared tributaries of the Euphrates River (Chap. 2) and the major shared tributaries of the Tigris River (Chap. 4) are covered in more detail in two separate chapters in order to highlight the role of these rivers and draw attention to local water issues and transboundary impacts. Chapter 4 also provides information on water use in Iran, which does not share the watercourse of the Tigris River itself but hosts important tributaries within the Tigris Basin. Finally, the Shatt al Arab River is discussed together with two additional major tributaries, the Karkheh and the Karun Rivers, which discharge directly into the Mesopotamian Marshes or the Shatt al Arab itself, and are hence neither part of the Euphrates or Tigris River basins (Chap. 5).

Figure 1. Sketch of the Mesopotamian river system



Source: Compiled by ESCWA-BGR.

Geography

The area draining to the Shatt al Arab includes the Euphrates Basin, the Tigris Basin, and two major sub-basins: the Karkheh and the Karun (see Chap. 1, Overview Map, Fig. 1). The Shatt al Arab River is born from the confluence of Euphrates and Tigris Rivers near the Iraqi town of Qurnah and is shared between Iran and Iraq. The area draining to the Shatt al Arab covers about 145,190 km^2, excluding the Euphrates and Tigris Basins (upstream of Qurnah), but including the Karkheh and Karun sub-basins (see Overview Map).[1]

The Karkheh and Karun Rivers both originate in the Zagros Mountains in Iran and discharge into the Shatt al Arab. Unlike the Karkheh Basin, the Karun Basin lies entirely in Iran. The Karun is nevertheless included in this chapter as it contributes significantly to the Shatt al Arab, which defines part of the Iran-Iraq border.

CLIMATE

The climate in the Shatt al Arab region is hot and arid. Based on data from the city of Basrah, average temperatures in the Shatt al Arab region vary from 9°C to 41°C; temperature lows occur in January, highs in July.[2] Annual precipitation rates range from 100 mm in the western part of the delta to about 200 mm in the east.[3] The city of Basrah has a mean annual precipitation of about 100 mm.

By contrast, cold winters and mild summers are the norm in the northern, more mountainous areas. Temperatures across the basin vary from a minimum of -25°C in winter to a maximum of 50°C in summer. Mean annual precipitation in the Karkheh Basin was estimated at 450 mm, ranging from 150 mm in the lower plains to 750 mm in the upper mountainous regions.[4] Rain- and snowfall occur mainly in winter and spring.[5]

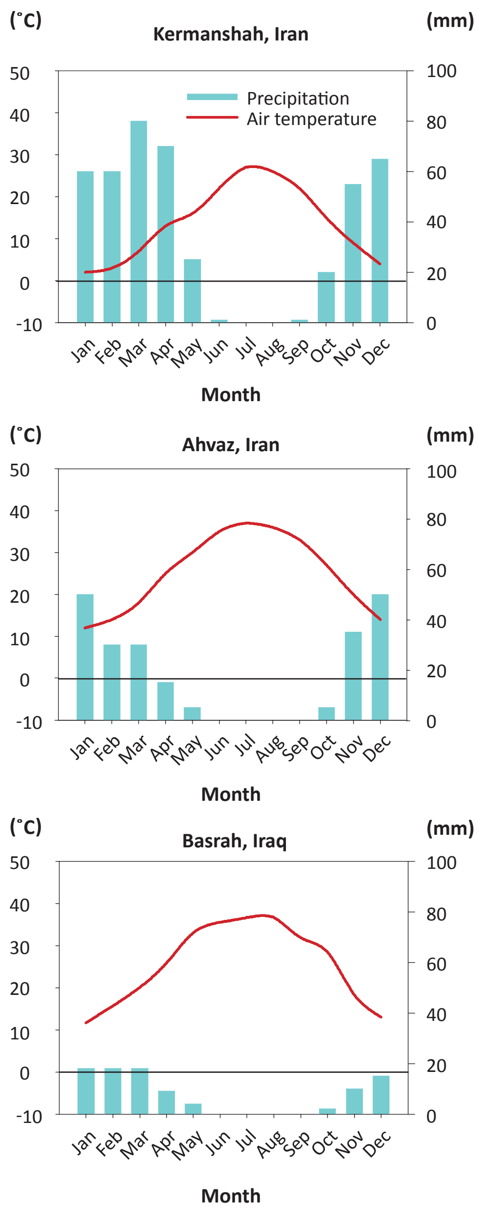
The Karkheh sub-basin has a varied climate that is strongly influenced by the basin's diverse topography. The Khuzestan Plain and the southern parts of the basin are arid, with mild winters and long, hot summers (Figure 2, Ahvaz climate diagram).

The Karun sub-basin covers three climatic zones: a mountainous zone, a zone of foothills and inland desert, and a coastal desert zone.

The climate ranges from extremely hot, dry summers with air temperatures above 50°C to cold winters with sub-zero temperatures.

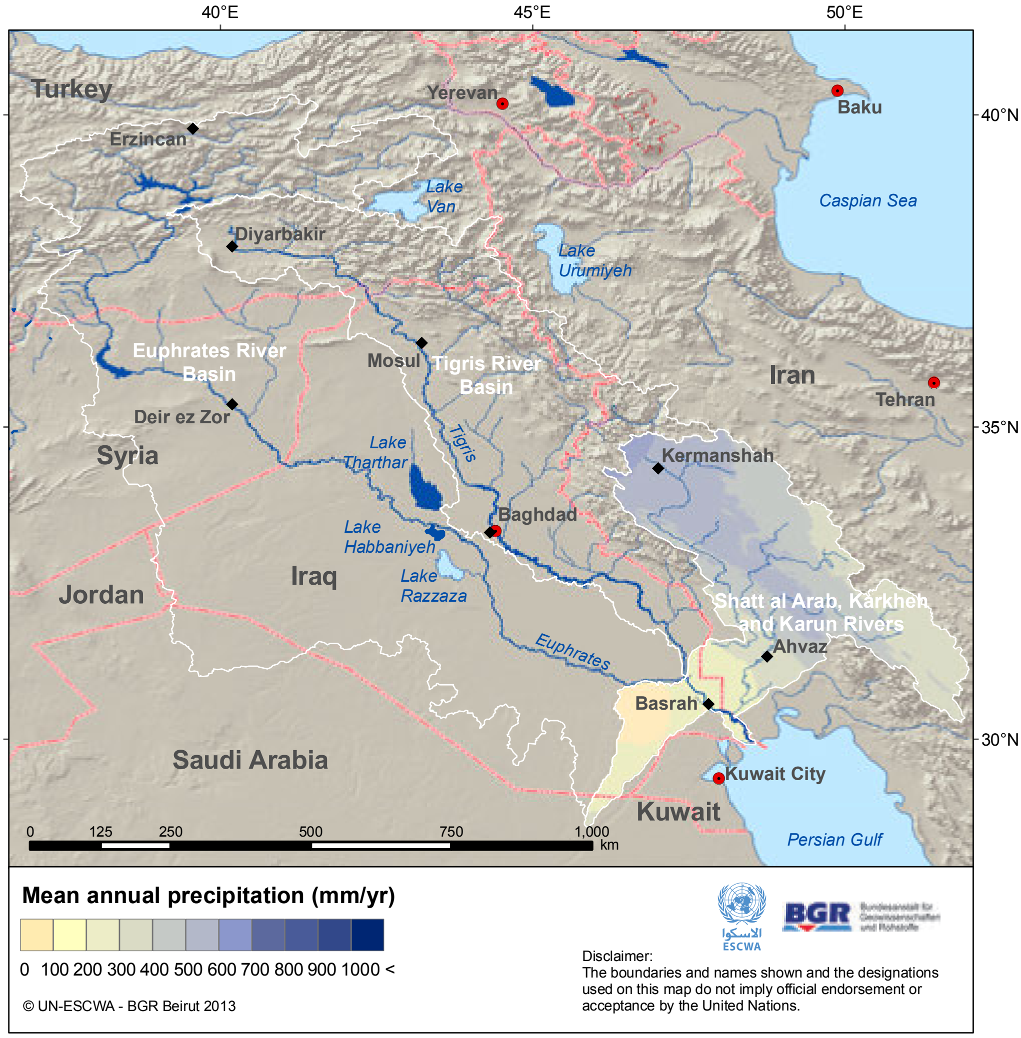
Total annual precipitation ranges from 150 mm in the plain to 1,200 mm in the mountains.[6] As in the Karkheh Basin, precipitation falls mainly between November and April.

Figure 2. **Climate diagrams for Kermanshah in Iran, Ahvaz in Iran and Basrah in Iraq**



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011; Climate Diagrams, 2009; Phytosociological Research Center, 2009; Masih, 2011.

Figure 3. Mean annual precipitation in the Shatt al Arab region, including the Karkheh and Karun Basins



Source: Compiled by ESCWA-BGR based on data provided by WorldClim, 2011.

POPULATION

Exact population figures are not available for the Shatt al Arab region. However, the largest city in the region, Basrah, has 3.5 million inhabitants, giving an indication of population numbers in the area.

The Karkheh Basin population[7] was estimated at 4 million in 2002, of which about one third resides in rural areas.[8] The basin's annual population growth rate is estimated at around 2.6%.[9] The Karun Basin has a population of about 3.5 million.[10]

Shatt al Arab

The Shatt al Arab River is formed after the confluence of the Euphrates and the Tigris Rivers near the city of Qurnah in southern Iraq (see Overview Map). The southern part of the river constitutes the border between Iran and Iraq until it discharges into the Gulf.

With a total length of 192 km, the Shatt al Arab widens over its course, expanding from a width of 250-300 m near the Euphrates-Tigris confluence to almost 700 m near the city of Basrah and more than 800 m as it approaches the river mouth. An area of 145,190 km^2 drains directly to the Shatt al Arab region downstream of the Euphrates-Tigris confluence (excluding the Euphrates and Tigris Basin areas). Several tributaries join the Shatt al Arab during its course, most importantly the Karkheh and the Karun Rivers.

The Shatt al Arab Delta area is classified as estuarine-deltaic because the river's sediment seeps into a shallow, narrow part of the Persian Gulf.[11]

The Shatt al Arab Delta is 140 km wide and splits into more than 10 branches.[12] The landscape is characterized by green marshy areas, lakes, lagoons and estuaries, bordered by irrigated lands and date palm plantations and surrounded by desert.[13]

BOX 1

Evolution of the Shatt al Arab Delta

The Shatt al Arab River is one of Earth's newest geological features, created by the relentless retreat of the shoreline. Research suggests that the Persian Gulf did not exist in its present form at the beginning of the Holocene (12,000 years ago), with the Euphrates and Tigris Rivers flowing through a marshy area and draining into the Arabian Sea at the Strait of Hormuz.[14] During the Holocene Period, seawater poured into the low-lying marsh area, flooding the land at a rate of up to one kilometre per year. Approximately 6,000 years ago, the shoreline had retreated more than 400 km beyond its present location, flooding most of lower Mesopotamia.[15] Vast quantities of alluvial deposit from the Euphrates, Tigris, Karkheh and Karun Rivers eventually restored the shore to its present-day location, although the four rivers continued to drain separately into the Gulf.[16] It was only in the early modern period (16th-18th century) that these rivers merged to form the modern Shatt al Arab.[17]

The Coast of the Arabs

Shatt al Arab means the riverbank/coast of the Arabs. In the past, this region of lakes and marshes was home to the Marsh Arabs, a population group composed of different tribes. Most of these populations were displaced when the marshes were drained in the 1990s. The Shatt al Arab is referred to as Arvand Rud in Persian.

HYDROLOGICAL CHARACTERISTICS

Figure 4 shows estimates of the potential long-term mean annual discharge (73.6 BCM or approx. 2,340 m^3/s) of the Shatt al Arab into the Gulf. The total flow volume is calculated as the sum of the long-term mean annual flow estimates of the four Shatt al Arab tributaries, with the following values:[18] the Karun contributes 24.5 BCM (measured at Ahvaz gauging station), the Karkheh 5.8 BCM,[19] the Euphrates 17.6 BCM (measured at Hindiyah

The Shatt al Arab, Iraq, 1992. Source: Ed Kashi/VII.

gauging station)[20] and the Tigris 25.7 BCM (measured at Kut).[21] However, these long-term mean annual flow contributions, specifically from tributaries such as the Karkheh and Karun, are not measured directly at the Shatt al Arab confluence and it is likely that actual flow contributions vary significantly (e.g. due to abstractions and evaporation) from the estimates given here.[22] Detailed investigations on this topic, including process-based modelling studies and measurements of the water balance components, could therefore be valuable. In the absence of more precise data, values from Figure 4 can only be considered potential flow contributions, indicating each major tributary's relative contribution to the total Shatt al Arab flow volume and not taking into account abstractions and important evaporation losses.[23]

A 2009 study that includes annual water balance data for a common Euphrates-Tigris-Shatt al Arab Basin before regulation assumes large water losses through evaporation.[24] The same study points to discrepancies between runoff measurements on the Euphrates and Tigris Rivers and the point where the Shatt al Arab discharges into the Gulf. Estimated runoff formed in the Taurus and Zagros Mountains was about 3,500 m^3/s, while the Shatt al Arab discharged 1,450 m^3/s (45.7 BCM/yr), indicating total runoff losses of around 60% (2,050 m^3/s)[25] as a result of surface evaporation from lakes and swamps in the Mesopotamian Marshes.

WATER RESOURCES MANAGEMENT

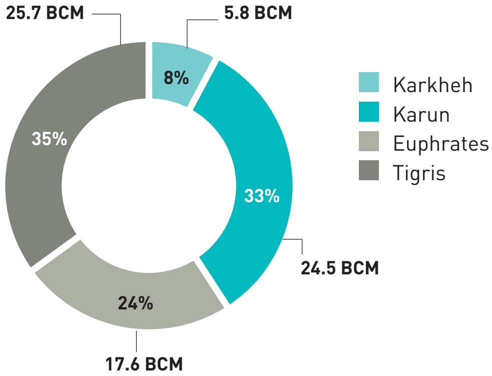
The Shatt al Arab is an important water body as it allows for agricultural production in an arid area with a hot and humid climate. In the 1970s the Shatt al Arab Delta had the largest date palm forest in the world with around 18 million date palms. Thirty years later more than 80% of this palm forest had disappeared due to reduced freshwater flows, increased salinity and damage caused by the Iran-Iraq war.[26]

There is limited information on water resource development projects in the Shatt al Arab region. However, in 2011 the Iraqi Ministry of Water Resources announced plans to construct a 129-km channel to divert water from the Shatt al Arab River for irrigation purposes. The irrigation channel will transfer about 30 m^3/s of water for use on agricultural land in Basrah Governorate.[27]

WATER QUALITY & ENVIRONMENTAL ISSUES

The Shatt al Arab River is the Persian Gulf's main source of freshwater and therefore plays a major role in maintaining the ecological balance of marine habitats in the northern Gulf.[28]

Figure 4. Potential mean annual flow contributions to the Shatt al Arab



Source: Compiled by ESCWA-BGR based on data provided by Ministry of Environment in Iraq et al., 2006; GRDC, 2011; Masih, 2011.

The drainage of the Mesopotamian Marshes has had a negative impact on the Persian Gulf, which is now noticeably degraded along the Kuwaiti coast. According to a study of sediment quality in Kuwait's northern coastal zones, the drainage of the Mesopotamian Marshes resulted in a rise in toxic sediments between 2001 and 2003.[29] The study concluded that under normal conditions the marshes would act as a filter, removing pollutants before the water flows into the Shatt al Arab and on to the Gulf. The deterioration of the Mesopotamian Marshes has also caused the decline of coastal fisheries, probably due to increased pollution, which has affected spawning areas and nursery grounds for species such as the penaeid shrimp.[30] This has in turn affected the area's lucrative shrimp business.

The salinization of the Shatt al Arab first became an issue in the 1960s. The situation further deteriorated from the 1970s onwards with the construction of dams and reservoirs on the Euphrates and Tigris Rivers. The regulation of the Euphrates and, to a lesser extent, the Tigris, led to a decrease in runoff, which eventually resulted in the degradation of the delta, as accumulated salt was no longer adequately drained.[31] Low river runoff and high evaporation rates up to 41% in the extreme north-western part of the Gulf further contribute to high salinity.[32] The average salinity value (in TDS) of the Shatt al Arab at Sayhan (south of Khorramshahr) was 1,945 mg/L in 2010 and 2,408 mg/L in 2011.[33] These values far exceed the guidelines for irrigation,[34] limiting agricultural activities to highly salt-tolerant date palms.[35]

The oil pipelines running along the Shatt al Arab River pose a further pollution risk, as do Kuwait's oilfields near the river mouth.

Karkheh

The main headwaters of the Karkheh, the Saymareh and Kashkan Rivers (see Overview Map), originate in the middle and south-western Zagros Mountain range in western Iran. These two tributaries join at Pole Dokhtar to form the Karkheh River. Before the river reaches the Haweizeh Marshes,[36] a large wetland shared by Iran and Iraq, it meanders through a flat plain. After covering a distance of about 964 km, the Karkheh discharges into the Shatt al Arab south of the city of Qurnah and the Euphrates-Tigris confluence.

The Karkheh River is the third largest river in Iran (in terms of water yield), after the Karun and Dez Rivers. The Karkheh drains a large catchment of 51,110 km^2.[37]

HYDROLOGICAL CHARACTERISTICS

The Karkheh River Basin lies almost entirely in Iran (>95% basin area) and most likely contributes close to 100% of discharge. Hydrologically, the basin can be divided into five sub-basins: the Gamasiab, Kashkan, Qarasou, Saymareh and South Karkheh. The major tributaries of the Karkheh River are the Gamasiab, Kashkan, Qarasou and Saymareh Rivers.

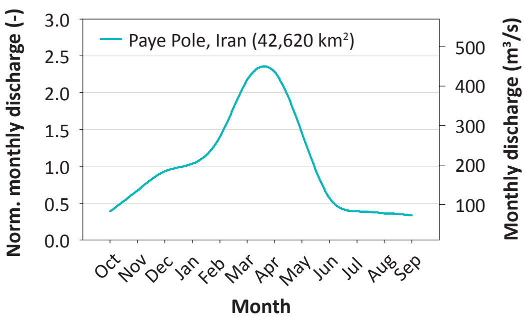
Annual discharge variability

The five Karkheh River sub-basins exhibit dry and wet periods. The analysis of long-term river flow data from 1961 to 2001 shows that all sub-basins experienced a maximum flow during the 1968/1969 wet year (e.g. 12.59 BCM for the Karkheh River at Paye Pole, Table 1) and minimum flows during the 1999/2000 drought year (e.g. 1.92 BCM for the Karkheh River at Paye Pole). During this drought the Gamasiab River ran dry for two to three months.

Flow regime

The flow regime of the Karkheh River shown in Figure 5 can be considered near natural, as operation of the Karkheh Dam only started at the end of the observation period in 2001. However, widespread irrigation in the upper and middle part of the basin is likely to have affected the flow regime, specifically during low-flow periods in the dry summer months. Peak flows in winter and early spring (March and April) are dominated by snow-melt and rainfall. Peak flows are probably not significantly affected by agricultural activities as irrigation demand is very low during this period.

Figure 5. **Mean monthly flow regime of the Karkheh River at the Paye Pole gauging station (1961-2001)**



Source: Compiled by ESCWA-BGR based on Masih, 2011.

Table 1. **Summary of annual flow volume statistics for the Karkheh River and its major tributaries in Iran (1961-2001)**

SUB-BASIN	RIVER	STATION (DRAINAGE AREA, km^2)	MEAN (BCM)	MINIMUM (BCM)	MAXIMUM (BCM)
Gamasiab	Gamasiab	Pole Chehre (10,860)	1.08	0.198	2.85
Kashkan	Kashkan	Pole Dokhtar (9,140)	1.64	0.645	3.21
Qarasou	Qarasou	Ghore Baghestan (5,370)	0.72	0.104	1.91
Saymareh	Saymareh Karkheh	Holilan (20,863) Jelogir (39,940)	2.43 4.97	0.607 1.790	6.19 10.77
South Karkheh	Karkheh	Paye Pole (42,620) Hamidiyeh (46,121)	5.83 5.15	1.920 1.070	12.59 11.32

Source: Compiled by ESCWA-BGR based on Masih et al., 2009.

Groundwater

Due to the basin's complexity and limited data availability, groundwater flow and the interaction with surface water in the Karkheh Basin are not well documented. Generally, groundwater availability in the northern part of the basin is limited to valley floors, characterized by relatively large depths, high infiltration rates and good water quality. In the southern arid plains, the productivity of the aquiferous materials is reduced, mainly as a result of limited thickness and low infiltration rates, as well as increased salinity.[38]

WATER RESOURCES MANAGEMENT

Water in the Karkheh Basin is used for domestic purposes,[39] agricultural production and limited industrial activity. The basin ranks third in terms of surface water use in Iran and fourth in groundwater use.[40] It is considered the country's most productive basin, comprising 9% of Iran's total irrigated area and producing around 11% of its wheat supply.[41] A hydrology and water resources assessment from 1993-94 estimated the total amount of irrigation water diverted from surface and subsurface resources in the Karkheh Basin at 3.9 BCM, of which 63% were from surface water and 37% from groundwater.[42] The same study projected total planned water allocation in the basin for 2011 at 7.9 BCM, of which about 87% was allocated to agriculture with an upward trend (Table 2).[43] However, in reality, current actual water use is probably much lower as progress on project planning and implementation is slow.

Until the completion of the Karkheh Dam in 2001, the basin was not regulated by large dams. However, following the implementation of several major development and irrigation projects, land and water use in the basin are evolving and irrigated agriculture is playing an increasingly prominent role.[44]

BOX 2

Piping Karkheh Water to Kuwait

In December 2003, Iran and Kuwait signed a contract in which Iran committed to supplying Kuwait with drinking water for a period of 30 years. At a cost of USD 2 billion, 300 MCM of water from the Karkheh River is to be conveyed to Kuwait through a 540-km pipeline.[45] It is unclear whether this project is still being pursued.

The Karkheh Dam is a multi-purpose dam in north-western Khuzestan Province in Iran, not far from the city of Andimeshk. It is designed to produce 520 MW of hydroelectric power,[46] prevent downstream floods and provide irrigation water for about 350,000 ha in the Khuzestan Plains in the lower Karkheh region. The dam has been operational since 2002 and has a maximum storage capacity of about 4.7 BCM.[47] Accumulated dam outflow was measured at 2.8 BCM in November 2002 and October 2003.[48]

Several other dams and irrigation schemes are currently being studied and planned. These developments are likely to turn the Karkheh into a heavily regulated river.[49]

Today the basin faces several challenges, including growing competition for water between different sectors and between upstream and downstream users, as well as groundwater depletion, poverty and land degradation.[50]

Table 2. Current and planned water allocations in the Karkheh Basin in Iran

SECTORS	EVOLUTION OF WATER ALLOCATION (MCM/yr)					
	2001	2006	2011	2016	2021	2025
Rural areas	59	62	66	69	70	67
Urban areas	203	231	242	259	278	295
Mining	0	1	1	1	2	2
Industry	23	30	57	76	93	113
Agriculture	4,149	6,879	6,814	7,135	7,476	7,416
Fish farming	14	119	249	379	477	510
Environment	500	500	500	500	500	500
Total	4,949	7,822	7,929	8,419	8,896	8,902

Source: Compiled by ESCWA-BGR based on JAMAB, 1999 in Ahmad and Giordano, 2010.
Note: Water resources include surface water, groundwater and reservoirs.

Table 3. Constructed dams in the Karkheh Basin in Iran

NAME	RIVER	COMPLETION YEAR	CAPACITY (BCM)	PURPOSE[a]	BACKGROUND INFORMATION
Hamidiyeh	Karkheh	1957	..	I	Irrigated area: 20,000 ha
Karkheh	Karkheh	2002	4.7	HP, I, FC	Reservoir capacity: 7.5 BCM Live storage capacity: ~4.7 BCM According to plans from 2003, water from the dam reservoir will be pumped to Kuwait.
Saymareh	Saymareh	2009	3.2	HP, FC	Hydropower capacity: 380 MW

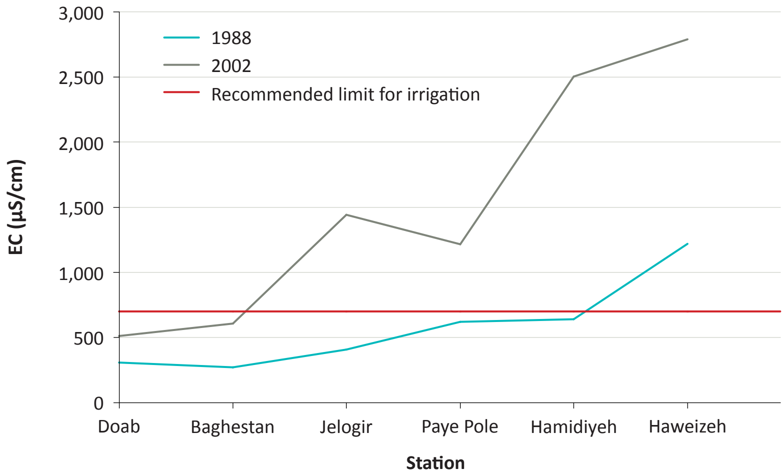
Source: Compiled by ESCWA-BGR based on Plants Around The World, 2010; Masih et al., 2009; Water Resources Directorate in Iran, 2009.
(a) Irrigation (I), Hydropower (HP) and Flood Control (FC).

WATER QUALITY & ENVIRONMENTAL ISSUES

Over the years, changes in land use, soil erosion and lack of rainfall have negatively impacted the watershed's biodiversity, resulting in the deterioration of water quality and increased flooding risk.[51] Water sampling at different stations revealed a steady deterioration of water quality along the river course. The difference in upstream and downstream salinity levels is significant. Figures from 2002 show that while Electrical Conductivity (EC) values in the upper Karkheh were around 500 µS/cm in 2002, they increased to >2,500 µS/cm at the Hamidiyeh and Haweizeh[52] stations, which are located downstream from a series of agricultural development zones.[53] More recent data (2003-2007) indicates that the highest salinity values along the river course were measured at the Haweizeh gauging station.[54]

More specifically, variations in the salinity of the river can be ascribed to the expansion of agricultural lands and urbanization in the basin.[55] Water quality data from 1988 and 2002 shows significant increases in salinity (Figure 6).[56] For instance, while the EC value at Hamidiyeh was around 600 µS/cm in 1988, it had increased to 2,500 µS/cm by 2002.[57] Rapid agricultural and urban development over recent decades has led to an increase in irrigation return flows, as well as a rise in domestic and urban sewage discharge in the river.[58] The 1999/2000 drought and the resulting decline in river discharge is considered an important further factor in reducing Karkheh River water quality.[59]

Figure 6. Changes in mean Electrical Conductivity (EC) values along the Karkheh River (1988 and 2002)



Source: Compiled by ESCWA-BGR based on Mahmoudi et al., 2010.

BOX 3

The Haweizeh Marshes

Reduced to an area of around 137,700 ha today, the Haweizeh Marshes (also Haur al Haweizeh) used to extend over a vast area of between 300,000 ha (in average conditions) and 500,000 ha (in flood periods).[60] While the Tigris River is an important contributor to the marshes, the Karkheh River is their main source of freshwater.[61] The Haweizeh Marshes are central to maintaining biodiversity in the Mesopotamian Marshes as a whole, as species retreat here to reproduce and subsequently recolonize the neighbouring Central and Hammar Marshes. Iran's construction of a levy running along the international border through the Haweizeh Marshes is likely to significantly reduce freshwater contribution from the Karkheh River and further jeopardize the subsistence of this important ecosystem.[62]

Karun

The Karun (historically known as the Ulai or the Rud-e Karun in Persian) is Iran's only navigable river[63] and forms the country's largest river basin.

The Karun has a total length of about 867 km and originates in the Zard Kuh Mountains in the Zagros Mountain range about 75 km south-west of Esfahan. From there it flows westwards through ridges and valleys to the Khuzestan Plain at Gotvand. Several tributaries including the Dez and the Kuhrang discharge into the Karun before it reaches Ahvaz, the capital of Khuzestan Province in Iran. From there the river continues towards the Shatt al Arab. The Karun Basin drainage area is estimated at 71,980 km^2 and is situated entirely in Iran. The Karun can, however, be considered a shared basin due to the fact that it discharges into the Shatt al Arab, which forms the Iran-Iraq border.

The Karun has a sinuous course, which has shifted repeatedly through history (Box 4). The coastal areas of some of the former riverbeds have filled with seawater.

BOX 4

The Many Courses of the Karun

In the past, the Karun was not connected to the Shatt al Arab and instead flowed to the Persian Gulf through several channels, three of which are known today: the Shatt al Qadimi (Ancient River), the Shatt al Ameh (Blind River) and the Bahmanshir River. The first two channels are now filled with seawater, and the Karun flows through the artificial Haffar Channel built for navigational purposes in 1765. The shifting river course sparked border disputes between Iran and the Ottoman Empire that were settled only in 1847 with the signing of the Treaty of Erzurum, which gave Iran access to the Shatt al Arab and the right to use it as a waterway.

Source: Encyclopaedia Britannica, 1995.

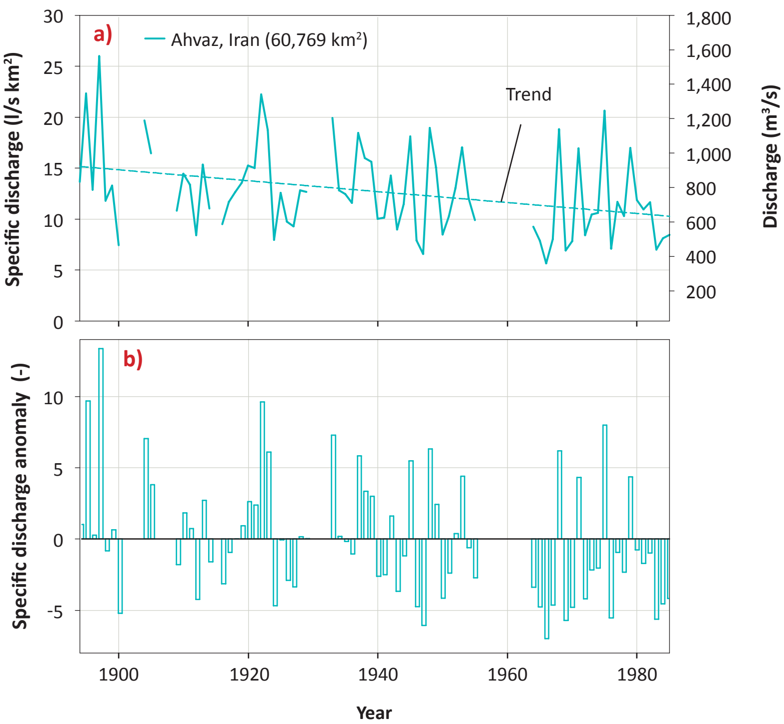
Main Karun tributaries

With a length of 470 km, the Dez has two main tributaries. The Bakhtiari River (or Ab Zalaki River) originates in the Bakhtiari Mountains and runs north-east until it joins the Sezer River, the second main tributary of the Karun, which rises in the north of Lorestan Province.[64] After the Bakhtiari-Sezer confluence and below the Dez Dam, the Dez enters the Khuzestan and Dezful Plains, eventually discharging into the Karun River at Band e Ghir. Much of the Dez River is used for irrigation in Khuzestan Province, especially since the construction of the Dez Dam.

HYDROLOGICAL CHARACTERISTICS

The Karun has the highest discharge of Iran's rivers. Figure 7 shows long-term observed discharge for the Karun River at Ahvaz from 1894 to 1985 close to the confluence with the Shatt al Arab. The mean annual specific discharge time series shows a significant negative trend, most likely due to the construction of large hydropower dams in the basin since 1963. Another factor could be the impact of climate change, possibly driven by the decrease in precipitation in the study region, though this observation requires further detailed investigation. Mean annual discharge was reduced from a rate of 818 m^3/s (25.7 BCM) before 1963 to 651 m^3/s (20.5 BCM) after 1963. Generally, there is a frequent alternation of wet and dry years (approximately every two to three years). The only exceptions are the occurrence of a persistent wet period around 1920 and a long dry spell that lasted for more than five years from 1980. Maximum annual flows (1,581 m^3/s) were recorded in 1897, while minimum annual flows (344 m^3/s) occurred in 1966. The mean annual flow of the Karun is estimated at 24.5 BCM. More recent values mentioned in the

Figure 7. a) Mean (specific) annual discharge, b) discharge anomaly time series of the Karun at Ahvaz (1894-1985)



Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011.

literature state a lower mean annual flow of 22 BCM, though the gauging station and time period are not specified.[65]

Flow regime

The natural mean monthly flow regime of the Karun River is characterized by snow-melt-dominated peak flows in March and April and low flows in September and October (Figure 8). The highest mean monthly discharge was recorded in April 1969 (2,995 m³/s) and the lowest discharge in October 1949 (163 m³/s). The river's flow regime changed following the construction of dams on the river after 1963, with a decrease in spring peak flows and summer low flows and an increase in (extreme) low flows in autumn.

WATER RESOURCES MANAGEMENT

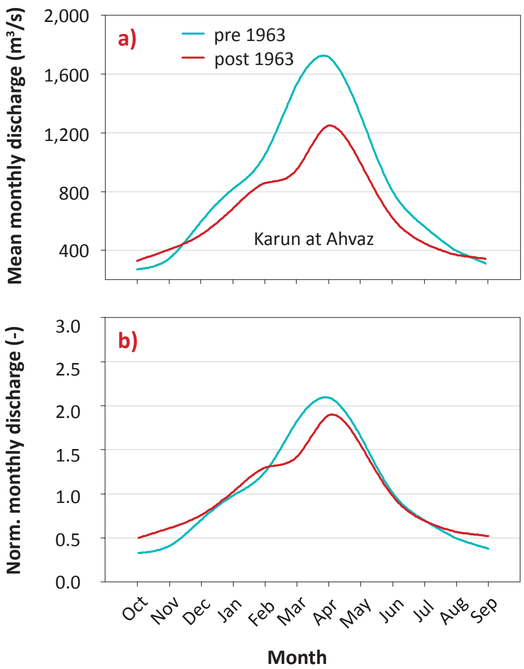
The Karun is an important commercial waterway in Iran, particularly for the transport of oil to the Persian Gulf. Both the Dez and Karun Rivers provide drinking and industrial water to users in the region.[66] Water from the Karun primarily serves large-scale irrigation projects, as well as fish-farming activities and domestic and industrial purposes.[67] Total water use in the basin is estimated at 11.2 BCM/yr (Figure 9).[68]

The Karun Basin is heavily regulated by six large multi-purpose dams that serve to generate hydropower, provide flood control and supply irrigation water in Iran (Table 4). There are five dams on the Karun River itself, with a distance of only 50 km between the Karun I and Masjed Soleyman Dams. In 1997, Iran started building the country's highest earth-fill dam, the Upper Gotvand Dam. Located between the Masjed Soleyman and Nader Shah Dams, the Upper Gotvand Dam is designed to generate hydroelectricity, control floods and mitigate drought impacts in the Khuzestan region.[69] The impounding of the dam started in July 2011, creating a reservoir with a length of 90 km.

Completed in 1963, the Dez Dam was designed to regulate the Dez River as part of the Dez Multi-Purpose River Project, which is a development programme in Khuzestan Province in Iran. In 1957 Iran requested a World Bank loan for the project that aimed to provide irrigation water for around 110,000 ha, supply electric power to several regional cities, and reduce peak floods and flood damage.[70] After the World Bank did an initial assessment of the project, Iran revised it and presented the Dez Irrigation Project, a 40,000 ha irrigation scheme that was to be implemented in two stages.[71] In 1960, the World Bank lent the country USD 42 million for the pilot phase. The Dez Irrigation Project is the largest of a number of irrigation projects in the basin.

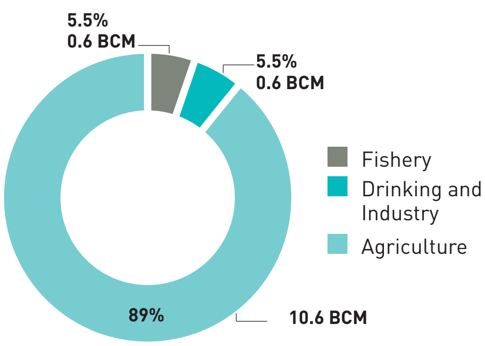
The Karun-3 Dam on the Karun River, Iran, 2008. Source: M. Samadi.

Figure 8. **Mean monthly flow regime of the Karun River at Ahvaz for different time periods (1894-1985)**



Source: Compiled by ESCWA-BGR based on data provided by GRDC, 2011.

Figure 9. **Water use in the Karun Basin in 2007**



Source: Compiled by ESCWA-BGR based on Afkhami et al., 2007.

Table 4. Main constructed and planned dams in the Karun Basin in Iran

NAME	RIVER	COMPLETION YEAR	CAPACITY (MCM)	PURPOSE[a]	BACKGROUND INFORMATION
Dez	Dez	1962	3,340	I, HP, WS	Accumulation of sediments from upstream areas is causing a loss in reservoir capacity. The area currently irrigated by the dam reservoir (16,000 ha) falls well short of the projected 80,000 ha.
Karun I (Shahid Abbaspour Dam)	Karun	1976	3,139	I, HP	The first in a series of dams on the Karun River. Reservoir capacity: ~3.1 BCM Reservoir surface area: 54.8 km^2
Masjed Soleyman (Godar e Landar)	Karun	2001	230	I, HP	Hydropower capacity: 2,000 MW The dam's spillway gates are said to be the largest of their kind in the world.
Karun III	Karun	2004	2,000	I, HP, FC	Reservoir capacity: 2,970 MCM Reservoir surface area: 48 km^2
Nader Shah	Karun	..	1,620	..	-
Karun IV	Karun	2010	2,190	HP	The Karun IV Dam is the highest dam in Iran. Its installed capacity increases Iran's hydropower potential by more than 1,000 MW. Reservoir surface area: 29 km^2
Upper Gotvand	Karun	2015 (expected)	4,500 (planned)	HP, I	Construction began in 1997. Once completed, the Upper Gotvand will be Iran's tallest earth-fill dam, supplying one of the country's largest power stations. The impounding of the dam started in July 2011.

Source: Compiled by ESCWA-BGR based on FAO, 2009; Iran Water and Power Resources Development Co., 2006; Karamouz et al., 2004; Naddafi et al., 2007.
(a) Irrigation (I), Hydropower (HP), Water Supply (WS) and Flood Control (FC).

WATER QUALITY & ENVIRONMENTAL ISSUES

As a navigable river, the Karun is severely impacted by pollution from agricultural, industrial and domestic sources, which increases along the river course. Agriculture and industries are the main polluters, and include sugar-cane plantations, fish-farming activities, petrochemical factories, as well as other heavy industries located along the river course.[72] A large proportion of irrigation water is returned to the Karun through agricultural and agro-industrial drainage.[73] Moreover, most industries discharge their effluents directly into the river without treatment, with an annual total of 315 MCM of industrial sewage flowing into the Karun.[74] Municipal wastewater collected from the different cities along the river is also released untreated, with an annual volume of 210 MCM discharging into the river.[75] As a result, the water quality of the Karun is rapidly deteriorating.[76] Besides increasing contamination from heavy metals, the rising salinity of the river is a key concern. While the Karun Basin's geological composition makes the river prone to salinization,[77] human activity is the main cause of current salinization rates, with extremely high levels that increase along the river course.[78] In 2001, an average EC value of 533 µS/cm was observed[79] in the basin's headwaters (Dez Dam). However, at the river's confluence with the Shatt al Arab at the city of Khorramshahr, the average salinity was almost seven times higher in the same year, and almost three times higher than in the 1970s.[80] The increased salinity means that the Karun is unsuitable for drinking water use for much of the year.[81]

Apart from salinity issues, high concentrations of three heavy metals (Cr, Ni, Cu) were observed in the downstream part of the Karun as a result of human activities.[82]

The various sources of pollution have endangered aquatic life in the basin.[83] In addition, the high salinity levels have destroyed flora and fauna habitats and affected local endemic species. The high level of pollution also threatens Ramsar-listed wetlands such as Shadegan wetland.[84]

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place on the Karkheh, Karun or Shatt al Arab Rivers. Control of the Shatt al Arab and the definition of an international border along the river course have caused tensions since the 1639 Peace Treaty between the Ottoman Empire and Persia. In 1975, Iran and Iraq signed the Algiers Agreement, which states that the international border between the two countries is defined by the thalweg of the Shatt al Arab. Five years later, the Iran-Iraq war was partly triggered by unresolved issues surrounding access to and control of the Shatt al Arab. Iraq did not accept the boundary until 1990 after its failed invasion of Kuwait.[85]

The Shatt al Arab remains a source of dispute: Iraq still questions the validity of the Algiers Agreement, while Iran carries out military operations in the Shatt al Arab and claims the river as part of Iranian territorial waters.[86]

COOPERATION

In 2004, Iraq's Ministry of Water Resources protested against Iranian plans to exploit the water of shared rivers and divert them without prior notice. The ministry underscored that dams on the Karkheh impact the environmental balance of the Haweizeh Marshes and reduce water flow to Iraq. Furthermore, dams in the Karun Basin and the diversion of the Karun River through the Hamanshir Canal impact the environment of the Shatt al Arab and agricultural activities nearby. Following these complaints, the two countries created a joint technical committee, which meets regularly to discuss shared water issues. This technical cooperation over shared water issues was further cemented by ministerial meetings in 2009 and 2011, during which officials from the ministries of Foreign Affairs and Water Resources from both countries met.[87]

OUTLOOK

Upstream water development projects in the Euphrates and Tigris Basins have implications for the sustainability of the Shatt al Arab River and associated ecosystems. Iran's ongoing development of water infrastructure projects in the Karkheh and Karun Basins will further impact water resources and ecosystems in the Shatt al Arab region and the Mesopotamian Marshes in the coming years. Initial discussions aimed at encouraging cooperation over water issues have to date not resulted in any joint measures to combat environmental degradation. The development of a joint water management strategy would help avert further environmental degradation and sustain socio-economic development activities in the Shatt al Arab region.

The Shatt al Arab, Iraq, 1992. Source: Ed Kashi/VII.

Notes

1. Basin area was estimated from a digital elevation model (HydroSHEDS) similar to Lehner et al., 2008.
2. The Iraq Foundation, 2003.
3. Isaev and Mikhailova, 2009, p. 391.
4. JAMAB, 1999 cited in Masih et al., 2009, p. 330.
5. Masih et al., 2009, p. 330.
6. Vali-Khodjeini, 1994.
7. The following Iranian provinces fall entirely or partly in the Karkheh Basin: Hamedan, Ilam, Kermanshah, Khuzestan and Lorestan.
8. Masih, 2011, p. 12.
9. Ibid.
10. The following Iranian provinces fall entirely or partly in the Karun Basin: Chaharmahal & Bakhtiari, Esfahan, Khuzestan and Lorestan. The basin population figure is based on a 2006 estimate by the Statistical Center of Iran, 2006.
11. Isaev and Mikhailova, 2009, p. 389.
12. Coleman and Huh, 2004.
13. Isaev and Mikhailova, 2009, p. 391.
14. Teller et al., 2000.
15. Cooke, 1985.
16. Isaev and Mikhailova, 2009.
17. The Iraq Foundation, 2003.
18. Discharge data from 1894 to 1985 provided by GRDC, 2011.
19. Masih et al., 2009; Masih, 2011.
20. See Chap. 1.
21. See Chap. 3.
22. For instance Muthuwatta et al., 2010, studied the Karkheh Basin from November 2002 to October 2003 and estimated the maximum amount of water lost from the whole Karkheh Basin at about 1.5 BCM, taking into account evapotranspiration from the Haweizeh Marshes in the basin. As for the Karun River, mean annual flow is reported as 22 BCM in Afkhami et al., 2007.
23. Some mean annual flow estimates in the respective literature are around 80 BCM for the Euphrates and Tigris Rivers together. See UNEP-DEWA and GRID, 2001; Jones et al., 2008.
24. Isaev and Mikhailova, 2009.
25. Ibid.
26. UNEP, 2010.
27. Iraq Business News, 2011.
28. Al-Yamani and Bishop, 2000.
29. Beg and Al-Ghadban, 2003.
30. Al-Yamani and Bishop, 2000.
31. Isaev and Mikhailova, 2009, p. 393.
32. Ibid. p. 389.
33. Ministry of Water Resources in Iraq, 2012. The salinity range was 1,112-3,645 mg/L in 2010 and 1,304-9,230 mg/L in 2011.
34. Based on FAO, 1994 the salinity guideline for irrigation water was set at <450 mg/L as TDS.
35. UNEP, 2010; FAO, 1993.
36. The Haweizeh Marshes, also known as Haur al Azim, are a complex of marshes along the Iran-Iraq border.
37. Masih et al., 2009, p. 330 give a value of 50,764 km^2. However, a publication from the Ministry of Environment in Iraq et al., 2006, p. 88 states 48,500 km^2 as the size of the drainage basin. Muthuwatta et al., 2010 mention 51,000 km^2.
38. Masih, 2011, p. 17.
39. Muthuwatta et al., 2010, p. 461.
40. Mirzaei et al., 2011.
41. Muthuwatta et al., 2010, p. 461.
42. Masih et al., 2009, p. 331. The total stream flow for the hydrological year 1993-94 was stated as 7.5 BCM.
43. JAMAB, 1999 in Ahmad and Giordano, 2010.
44. Masih et al., 2009, p. 330.
45. Haghiabi and Mastorakis, 2009, p. 120.
46. Plants Around The World, 2010.
47. Live storage capacity is about 4.7 BCM (Masih et al., 2009, p. 330).
48. Muthuwatta et al., 2010, p. 463.
49. Masih et al., 2009, p. 330.
50. Masih, 2011, p. 12.
51. Mahmoudi et al., 2010.
52. Ibid.
53. After the Karkheh Dam, the river passes through six main agricultural zones: Evan, Dosalegh, Erayez, Bagheh, Ghods and Karkheh Sofla (Karamouz et al., 2006).
54. Mirzaei et al., 2011.
55. Salajegheh et al., 2011; Mahmoudi et al., 2010.
56. Ibid.
57. Concentrations of anions and cations in the river also nearly doubled during this period (Mahmoudi et al., 2010).
58. Mahmoudi et al., 2010.
59. Ibid; Salajegheh et al., 2011.
60. UNEP-DEWA, 2001.
61. Ministry of Environment in Iraq et al., 2006, p. 99.
62. Ibid., p. 100.
63. Isaev and Mikhailova, 2009, p. 389.
64. Khosronejad and Ashraf, 2011.
65. Afkhami et al., 2007.
66. Afkhami, 2003.
67. Afkhami et al., 2007.
68. Afkhami et al., 2007 mentions plans to increase this amount by about 80% over the coming five years.
69. Iran Water and Power Resources Development Co., 2011.
70. World Bank, 2011.
71. Watkins, 2009.
72. Diagomanolin et al., 2004; Naddafi et al., 2007.
73. Karamouz et al., 2004; Naddafi et al., 2007.
74. Afkhami et al., 2007.
75. Ibid. Domestic sewage effluents entering the Karun from the cities of Ahvaz and Khorramshahr present salinity rates of 4,000 µS/cm and 5,400 µS/cm respectively.
76. Ibid.
77. Ibid.; Afkhami, 2003.
78. Diagomanolin et al., 2004; Afkhami, 2003; Naddafi et al., 2007.
79. Afkhami, 2003.
80. Afkhami, 2003 states that average salinity rose from 1,388 µS/cm in the 1970s to 3,607 µS/cm in 2001.

81. Naddafi et al., 2007; Afkhami, 2003.
82. Diagomanolin et al., 2004. Sampling was carried out in 1996 at different stations along the Karun River.
83. Naddafi et al., 2007.
84. Afkhami, 2003.
85. Martsching, 1998.
86. BBC News, 2007.
87. Ministry of Water Resources in Iraq, 2012.

Bibliography

Afkhami, M. 2003. Environmental Effects of Salinity in the Karun-Dez Basin, Iran. In **Seventh International Water Technology Conference.** Egypt.

Afkhami, M., Shariat, M., Jaafarzadeh, N., Ghadiri, H., et al. 2007. Developing a Water Quality Management Model for Karun and Dez Rivers. **Iranian Journal of Environmental Health Science & Engineering**, 4(2): p. 99-106.

Ahmad, M.-u.-D. and Giordano, M. 2010. CPWF Project Report 2010: Karkheh Basin Focal Project. Published by CGIAR-CPWF (Consultative Group on International Agricultural Research-Challenge Program on Water and Food). Available at: http://cgspace.cgiar.org/bitstream/handle/10568/3870/PN57_IWMI_Project%20Report_May10_final.pdf;jsessionid=3FF5ADD44B3CC67A58B73DCF4F75E307?sequence=1. Accessed on February 9, 2012.

Al-Yamani, F. and Bishop, J. 2000. Trans-Border Environmental Side Effects of the Civil Works in Upstream Countries of Tigris-Euphrates Basin on the Northern Gulf Marine Environment. Published by UN-ESCWA (United Nations Economic and Social Commission for Western Asia).

BBC News. 2007. Murky Dividing Lines of Shatt al-Arab. Available at: http://news.bbc.co.uk/2/hi/uk_news/6496559.stm. Accessed on July 10, 2010.

Beg, M. U. and Al-Ghadban, A. N. 2003. Impact of Draining of Iraqi Marshes on Sediment Quality of Kuwait's Northern Marine Area. **Bulletin of Environmental Contamination and Toxicology**, 71: p. 60-67.

Climate Diagrams. 2009. Climate Diagrams. Available at: http://climatediagrams.com/. Accessed on September 20, 2011.

Coleman, J. M. and Huh, O. K. 2004. Major World Deltas: A Perspective from Space. Published by Coastal Studies Institute, Louisiana State University. Available at: http://128.138.136.5/science/groups/wessman/projects/wdn/papers/colemanManuscript.pdf. Accessed on February 9, 2012.

Cooke, G. A. 1985. Reconstruction of the Mesopotamian Coastline in the Holocene. In **Annual Meeting of the Geological Society of America.** Published by University of Pittsburgh: Orlando, FL, USA. Available at: http://www.osti.gov/energycitations/product.biblio.jsp?osti_id=6614268. Accessed on February 9, 2012.

Diagomanolin, V., Farhang, M., Ghazi-Khansari, M. and Jafarzadeh, N. 2004. Heavy Metals (Ni, Cr, Cu) in the Karoon Waterway River, Iran. **Toxicology Letters**, 151: p. 63-68.

Encyclopaedia Britannica. 1995. Karun River. Available at: http://www.uv.es/EBRIT/micro/micro_314_57.html. Accessed on November 11, 2011.

FAO (Food and Agriculture Organization of the United Nations). 1993. Date Palm Products. In **FAO Agricultural Services Bulletin 101**. Available at: http://www.fao.org/docrep/t0681E/t0681e02.htm. Accessed on April 11, 2012.

FAO (Food and Agriculture Organization of the United Nations). 1994. Water Quality for Agriculture. In **Irrigation and Drainage Paper 29**. Rome. Available at: http://www.fao.org/DOCREP/003/T0234E/T0234E00.htm. Accessed on March 11, 2012.

FAO (Food and Agriculture Organization of the United Nations). 2009. Irrigation in the Middle East Region in Figures, Aquastat Survey 2008. In **FAO Reports 34**. Rome.

GRDC (The Global Runoff Data Center). 2011. Available at: http://www.bafg.de/GRDC/EN/Home/homepage__node.html. Accessed on January 6, 2012.

Haghiabi, A. H. and Mastorakis, N. E. 2009. Water Resources Management in Karkheh Basin, Iran. In **Proceedings of the 3rd International Conference on Energy and Development - Environment - Biomedicine.** Athens. Available at: http://www.wseas.us/e-library/conferences/2009/vouliagmeni2/EDEB/EDEB-18.pdf. Accessed on February 9, 2012.

Iran Water and Power Resources Development Co. 2006. Masjed Suleiman Project. Available at: http://en.iwpco.ir/MasjedSoleiman/default.aspx. Accessed on February 9, 2012.

Iran Water and Power Resources Development Co. 2011. Iran's Highest Earth-Fill Dam Impounded in the Presence of President Ahmadinejad. Available at: http://en.iwpco.ir/Lists/News/DispForm.aspx?ID=119. Accessed on February 9, 2012.

Iraq Business News. 2011. 129 km Irrigation Channel for Basra. Available at: http://www.iraq-businessnews.com/2011/07/22/129-km-irrigation-channel-for-basra/. Accessed on January 5, 2012.

Isaev, V. A. and Mikhailova, M. V. 2009. The Hydrography, Evolution, and Hydrological Regime of the Mouth Area of the Shatt al-Arab River. **Water Resources**, 36(4): p. 380-395.

Jones, C., Sultan, M., Yan, E., Milewski, A., et al. 2008. Hydrologic Impacts of Engineering Projects on the Tigris-Euphrates System and its Marshlands. **Journal of Hydrology**, 353: p. 59-75.

Karamouz, M., Akhbari, M., Moridi, A. and Kerachian, R. 2006. A System Dynamics-Based Conflict Resolution Model for River Water Quality Management. **Iranian Journal of Environmental Health Science & Engineering**, 3(3): p. 147-160.

Karamouz, M., Mahjouri, N. and Kerachian, R. 2004. River Water Quality Zoning: A Case Study of Karoon and Dez River System. **Iranian Journal of Environmental Health Science & Engineering**, 1(2): p. 16-27.

Khosronejad, A. and Ashraf, A. 2011. Hydrological Studies of Dez Dam Watershed. In **White papers**. Available at: http://www.hydro-international.com/whitepaper/id5-Hydrological_studies_of_Dez_dam_watershed.html. Accessed on February 12, 2012.

Lehner, B., Verdin, K. and Jarvis, A. 2008. New Global Hydrography Derived From Spaceborne Elevation Data. **EOS, Transactions American Geophysical Union**, 89(10): p. 93-94.

Mahmoudi, B., Bakhtiari, F., Hamidifar, M. and Daneh, A. 2010. Effects of Land Use Change and Erosion on Physical and Chemical Properties of Water (Karkheh Watershed). **International Journal of Environmental Research**, 4(2): p. 217-228.

Martsching, B. 1998. Iran-Iraq War and Waterway Claims. Published by The Inventory of Conflict and Environment, Trade and Environment Database. Available at: http://www1.american.edu/ted/ice/iraniraq.htm. Accessed on February 2, 2012.

Masih, I. 2011. Understanding Hydrological Variability for Improved Water Management in the Semi-Arid Karkheh Basin, Iran. Doctorate Thesis. Delft University of Technology, Institute for Water Education. Delft.

Masih, I., Ahmad, M.U.D. and Uhlenbrook, S. 2009. Analysing Streamflow Variability and Water Allocation for Sustainable Management of Water Resources in the Semi-Arid Karkheh River Basin, Iran. **Physics and Chemistry of the Earth**, 34: p. 329-340.

Ministry of Environment in Iraq, Ministry of Water Resources in Iraq and Ministry of Municipalities and Public Work in Iraq. 2006. Main Water Control Structures (Dams and Water Diversions) and Reservoirs (Annex III). In **New Eden Master Plan for Integrated Water Resources Management in the Marshlands Area.** New Eden Group. Italy-Iraq.

Ministry of Water Resources in Iraq. 2012. Country Consultation with the Republic of Iraq. In **Country Consultations for the Inventory of Shared Water Resources in Western Asia 2011-2012**. Beirut.

Mirzaei, F., Alizadeh, H. A. and Taheri-Gravand, A. 2011. Study of Water Quality in Different Stations of Karkheh River Based on Langelier and Ryzner Indices for Determining Potential Clogging of Droppers. **Research Journal of Applied Sciences, Engineering Technology**, 1: p. 61-66.

Muthuwatta, L. P., Ahmad, M.U.D., Bos, M. G. and Rientjes, T. H. M. 2010. Assessment of Water Availability and Consumption in the Karkheh River Basin, Iran Using Remote Sensing and Geo-Statistics. **Water Resources Management**, 24: p. 459-484.

Naddafi, K., Homari, H. and Ahmadi, M. 2007. Water Quality Trend Analysis for the Karoon River in Iran. **Environmental Monitoring and Assessment**, 134: p. 305-312.

Phytosociological Research Center. 2009. Worldwide Bioclimatic Classification System. Available at: http://www.globalbioclimatics.org/plot/diagram.htm. Accessed on September 20, 2011.

Plants Around The World. 2010. Hydroelectric Power Plants in Iran. Available at: http://www.industcards.com/hydro-iran.htm. Accessed on September 19, 2011.

Salajegheh, A., Razavizadeh, S., Khorasani, N. and Hamidifar, M. 2011. Land Use Changes and its Effects on Water Quality (Case Study: Karkheh Watershed). **Journal of Environmental Studies**, 37(58): p. 22-24.

Statistical Center of Iran. 2006. Iran Statistical Yearbook 1385. Available at: http://amar.sci.org.ir/index_e.aspx. Accessed on September 21, 2011.

Teller, J. T., Glennie, K. W., Lancaster, N. and Singhvi, A. K. 2000. Calcareous Dunes of the United Arab Emirates and Noah's Flood: The Postglacial Reflooding of the Persian (Arabian) Gulf. **Quaternary International**, 68-71(1): p. 297-308.

The Iraq Foundation. 2003. Physical Characteristics of Mesopotamian Marshlands of Southern Iraq Draft Report In **Background Material Prepared for the Technical Advisory Panel Eden Again Project**. Baghdad. Available at: http://www.iraqfoundation.org/edenagain/publications/pdfs/physicalcharreport.pdf. Accessed on February 9, 2012.

UNEP-DEWA (United Nations Environment Programme-Division of Early Warning and Assessment). 2001. The Mesopotamian Marshlands: Demise of an Ecosystem. In **Early Warning and Assessment Technical Report**. Nairobi.

UNEP-DEWA and GRID (United Nations Environment Programme-Division of Early Warning and Assessment; Global Resources Information Database). 2001. UNEP Study Sounds Alarm About the Disappearance of the Mesopotamian Marshlands. Geneva.

UNEP (United Nations Environment Programme). 2010. Atlas of Our Changing Environment-Site Details Shatt al-Arab. Available at: http://www.mendeley.com/research/unep-atlas-changing-environment-site-details-shatt-alarab/. Accessed on July 10, 2011.

Vali-Khodjeini, A. 1994. Regional Generalization of Flood Characteristics in Karun River Basin. In **The Braunschweig Conference.** Published by IAHS (International Association of Hydrological Science). Braunschweig.

Water Resources Directorate in Iran. 2009. List of Reservoirs and Dams in Iran. Available at: http://daminfo.wrm.ir/home-fa.html. Accessed on November 12, 2011.

Watkins, T. 2009. The Dez Multipuropose Dam Project in Iran. Available at: http://www.applet-magic.com/irandez.htm. Accessed on November 11, 2011.

World Bank. 2011. Dez River Project. Available at: http://www.worldbank.org/projects/search?lang=en&searchTerm=dez. Accessed on November 11, 2011.

WorldClim. 2011. Global Climate Data. Available at: http://www.worldclim.org. Accessed on September 20, 2011.