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From Mesopotamia to the Third Millennium: The Historical Trajectory of Water Development and Use in the Karkheh River Basin, Iran

Sara Marjanizadeh, Asad Sarwar Qureshi, Hugh Turral and Parviz Talebzadeh

International Water Management Institute

CGIAR Challenge Program on WATER & FOOD

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Marjanizadeh, S.; Qureshi, A. S.; Turral, H.; Talebzadeh, P. 2009. *From Mesopotamia to the third millennium: the historical trajectory of water development and use in the Karkheh River Basin, Iran*. Colombo, Sri Lanka: International Water Management Institute. 51p. (IWMI Working Paper 135) doi:10.3910/2010.206

/ river basin development / history / water use / water policy / water rights / water scarcity / land use / land policies / water depletion / groundwater / stream flow / wetlands / Iran /

ISSN 2012-5763

ISBN 978-92-9090-723-7

Please direct inquiries and comments to: *iwmi@cgiar.org*

A free copy of this publication can be downloaded at
www.iwmi.org/Publications/Working_Papers/index.aspx

Acknowledgements

The authors would like to thank Prof. Willibald Loiskandl, Dr. Gertrud Haidvogl, Dr. Charlotte de Fraiture and Prof. Mathias Jungwirth for their assistance in carrying out this study.

Project

CGIAR Challenge Program on WATER & FOOD

This research study was conducted as part of the Karkheh Basin Focal Project of the CGIAR Challenge Program on Water and Food (CPWF).

Partners

This study is a collaboration of the following organizations.

IWMI International Water Management Institute

International Water Management Institute, Karaj, Iran

BOKU

Universität für Bodenkultur Wien, Vienna, Austria

Agricultural Research and Education Organization (AREO), Tehran, Iran

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Contents

Summary

The Karkheh River Basin is the third largest basin in Iran after Karoon and Dez, and occupies a strategic position on the western boundary of the country. The basin is better endowed with water and land resources than many others in the country, and is also the center of Iran's oil and gas production. At the same time, its rural population is poor, and has suffered displacement and massive hardship as a result of the Iran-Iraq War in the 1980s.

The basin has seen remarkable ancient feats of engineering, and has a long history of wheat and barley production, complemented by horticulture. Agriculture has waxed and waned with different external influences and nomadic pastoralism became the dominant way of life from the middle of the second millennium until the twentieth century. With the growth of the modern nation-state of Iran, water development has progressed steadily in tandem with rising populations and urbanization. Groundwater development has been widespread in the upper basin, largely with private funding, whereas major publicly-funded civil engineering projects have been undertaken and continue to be developed in the arid lowland.

The Karkheh River feeds the remnants of the internationally renowned Mesopotamian Marshes, a major Ramsar site (wetlands of international importance designated under the Ramsar Convention) that has been in serious decline since the Iran-Iraq War. The development of new water resources in major dam storages now threatens further dessication of the wetlands once irrigation systems are completed and fully developed. The recent completion and filling of the Karkheh Dam transformed the state of water use in the basin from relatively un-developed to fully developed, more or less at a stroke. Groundwater abstraction has been excessive and is now regulated (in theory) but continues to provide close to 60% of irrigation supplies.

The report aims to understand the historical setting and present situation of water development and allocation, in relation to rural development and agrarian policy. It provides the contextual backdrop for further research on the management of water to improve livelihoods in the basin through integrated and sustainable management of land and water resources. It provides preliminary, basin-level water balances, using an accounting approach that defines depletion of water, rather than diversion or allocation. It provides further information on the changes in surface flows out of the component subbasins and looks at the development, use and consequences of groundwater abstraction.

INTRODUCTION

The Karkheh Basin has been a cradle of civilization for more than 3,000 years and has experienced several periods of agrarian development based on settled agriculture and the development of irrigation from the river. The region has also been the front line between Persian and Arab cultures and politics, both in terms of trade and administration and in conflict. As it is one of the best endowed river basins in Iran, it has recently seen extensive development and further planned exploitation of its water resources, with major consequences unfolding for the core remnants of the internationally renowned Mesopotamian Marshes. This paper reviews the history of the Karkheh's agriculture and water development to the present day.

Iran is the gateway between Asia and the Middle East and has an intricate borderline with many countries. It covers an area of 1,648,000 square kilometers (km^2), and has a population of 70 million people, which is growing at an average rate of 1.1% per year. Turkmenistan, Afghanistan and Pakistan lie on its eastern frontiers, and the north is bounded by the Caspian Sea. There are small but culturally important borders with Turkey, Azerbaijan and Armenia in the northwest and the border with Iraq runs along the western side of the country, and also along the boundary of the Karkheh Basin. To the south, there is a long coastline along the Persian Gulf and Gulf of Oman.

Approximately 90% of Iran is arid or semi-arid and about two-thirds of the country receives less than 250 millimeters (mm) of annual rainfall. Rainfall ranges from less than 50 mm in deserts to more than 1,600 mm on the Caspian Plain (JICA-MOJA 2004). Iran is generally a water-short country, with less than 0.4% of the world's water available for 1% of the earth's population on slightly more than 1% of global land area. The country already uses 74% of its total renewable freshwater resources, which is well beyond the international norms that commend an upper limit of 40% (Keshavarz et al. 2005).

Agriculture plays an important but declining role in Iran's economy. It provided around 24% of the GDP from 1995 to 2000 and engaged 22% of the population (1996 census). By 2005, agriculture's share of GDP had fallen to 11.8% compared to 43.3% for industry and 44.9% for the service sector (CIA 2005). Only 8% of the country is arable land with only 1% under permanent crops, and 89% of the country is covered by mountains, deserts, rangelands and other land uses. Annual crops are mainly cereals, pulses and forage plants and perennial crops, including pistachio, grapes, citrus and dates. In 2002, 54% of cultivated area was under irrigation and the remainder was rainfed (JAMAB Consulting Engineers 2006a). The proportion of wheat demand that was grown locally decreased from 82.5% in 1994 to 58.5% in 1999 (JICA-MOJA 2004). During a severe drought from 1999 to 2001, Iran became the world's largest wheat importer, shipping in an average of 6 million tonnes annually, mostly from Canada, Australia, Argentina and France. But a bountiful harvest of 8.6 million tonnes in 2002, a 46% increase on the previous year, dramatically curbed Iran's wheat imports by around 50%. Domestic wheat production rose again the following year to 12 million tonnes and the country did not need to import grain at all in 2005, for the first time in decades. It is estimated to have imported an average of US$750 million worth of the crops per year since 1997. Bread is the staple food of the country's 70 million people and is heavily subsidized by the government. Local economic experts have predicted that self-sufficiency in wheat will help Iran save large sums in foreign currency, although this is not a significant number in terms of oil export revenue.

Most of the water abstracted is used for agriculture (93%), with 6% being used for domestic consumption and only 1% being taken by industry (Roostaei 2004). By 2020, the share allocated to agriculture must fall to 87% in order to satisfy rising demand in the industrial and domestic sectors (Keshavarz et al. 2005). The country's population of 68 million people consumes 7 billion cubic meters (BCM) out of the total annual volume of 92 BCM abstracted from surface water and groundwater (Freshwater-Iran 2004). Nationally, the quality of both surface water and groundwater is declining due to salinity and pollution although 85% of groundwater is potable (JAMAB Consulting Engineers 2006a, 2006b) and is the main source of drinking water at the moment. The current projections for 2020 estimate a total water use of 103 BCM out of an average renewable volume of 120-130 BCM, with a slight change in the balance of use of surface water and groundwater – surface water use is expected to rise from 46 to 54% of the total, with a corresponding decline in the share of groundwater (Freshwater-Iran 2004). Per capita water availability will fall to 900 cubic meters (m^3) by 2020, below the nominal value[1] where it becomes a constraint to life. It is believed that there is considerable potential to improve water use efficiency in farming, where water use is two to three times the world average (Keshavarz et al. 2005) and in domestic use. Sazeh Ab Shafagh Consulting Engineers (2003) notes that average per capita domestic consumption in the Karkheh Basin is 204 liters/day, which is high by regional standards[2], but falls far short of figures in the western United States (400-600 liters/per capita/per day).

The future prosperity of Iran will be heavily influenced by the availability and use of freshwater resources. Sustainable development will require considerable improvements in the economic and social productivity of water, even if the remaining renewable resources are exploited. The biggest potential for improvement lies in agriculture, but this will require investment, time and effort. The national irrigated area amounts to 7.65 million hectares (Mha) (Ministry of Jihad-e-Agriculture, unpublished statistical data).

The Karkheh River Basin (KRB), the focus area of this study, is one of the most productive areas in Iran. It contains 9% of the total irrigated area of Iran (0.6 Mha) and produces approximately 1 million tonnes of wheat per year, about 10-11% of the national total. The basin is considered to be “the food-basket of Iran” and it plays a key role in national food self-sufficiency, one that will become more important in the future, as it has relatively high potential in terms of land and water resources in comparison to other basins in the country. At the same time, the basin is highly vulnerable to overexploitation and poor management.

This paper discusses the historical evolution of the KRB with regard to agricultural development, water resources management, environmental sustainability, natural resources management and the development of urban and rural societies. The historical trajectory of agrarian and basin development provides insight into the current situation and should suggest a framework for evaluating future options in establishing sustainable land and water resources management.

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[1] Countries are characterized as water-stressed or water-scarce depending on the amount of renewable water available per capita of population. Water-stressed countries are defined as having less than 1,700 m^3/per capita/year and water may temporarily be unavailable at particular locations, and difficult choices may then have to be made between the use of water for personal consumption, agriculture or industry. Water-scarce countries have less than 1,000 m^3/per capita/year (see Falkenmark 1989). At this level, there may not be enough water to provide adequate food, economic development is hampered and severe environmental difficulties may develop.

[2] According to the World Resources Institute (WRI), average domestic water usage in 80 middle-income countries is 116 liters/per capita/day. The United Nations Population Fund (UNFPA) estimates a basic daily water requirement (BWR) of 50 liters per capita per day for the purposes of drinking, sanitation, bathing, cooking and kitchen needs. Consumption in excess of 100 liters per person per day would reflect additional needs such as agriculture, ecosystem protection and industry (WRI 2005).

CHARACTERIZATION OF THE KARKHEH RIVER BASIN

The Karkheh River Basin (KRB) is the third largest in Iran and has the third highest average annual flow after the Karoon and Dez rivers. It is located in western Iran, along the border with Iraq (Figure 1).

(a) (b)

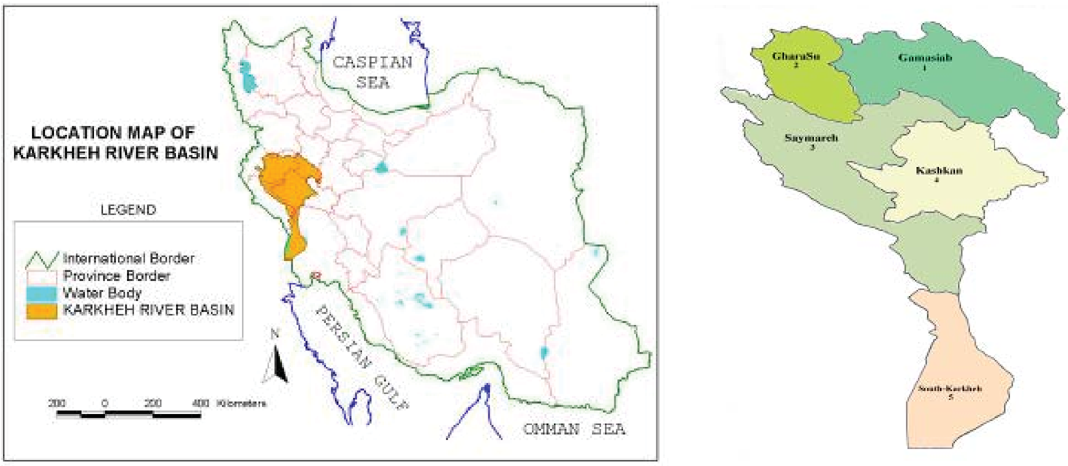


FIGURE 1. (a) Location of the Karkheh River Basin; and (b) its five subbasins.

The Karkheh River is 755 kilometers (km) long (Jafari 1997) and is typically 100 meters (m) across (Afshar Sistani 1994), reaching 400 m at its widest point. The basin covers an area of 51,324.85 km^2 (Sazeh Ab Shafagh Consulting Engineers 2003) and contains five subbasins: Gamasiab, Qarasu, Seymareh, Kashkan and South Karkheh (Figure 1). About 71% of the basin lies at elevations between 1,000 and 2,500 meters above sea level (masl) but only 1.9% soars beyond 2,500 masl. The lower basin is flat and close to sea level, with a sudden drop in elevation and slope at the southern end of the Seymareh subbasin (Figure 1) before the river drains into the Hawr-Al- Azim Swamp (Ashrafi et al. 2004).

The basin has experienced a rapid increase in population coupled with dramatic rates of urbanization. In 1969, 90% of the 1.5 million inhabitants lived in rural areas (Electro Consult 1969) and by 1976 there were 1.9 million, but only 65% lived in the countryside. The proportion of city dwellers had increased to 68% of a total population of 3 million by 1994. The corresponding average growth rates have been 5.5% per year in cities compared to only 0.3% in rural areas (JAMAB Consulting Engineers 1999). Much of the urban growth can be explained by massive displacement during the Iran-Iraq War, especially in the safer areas: the annual growth rate for Kermanshah in Qarasu reached 5.9%, whereas a mass exodus in the principle war zone in the Lower Karkheh saw an average decline of -0.7% (JAMAB Consulting Engineers 1999) and complete depopulation of some towns, such as Soosangerd.

The most recent census puts the basin population at 3.4 million in 2002, with 35% residing in rural areas, indicating some slight rebalancing in the post-war period. The historical populations and a projection for 2025 are summarized in Figure 2. The trend of urban migration is expected to continue, partly due to greater employment opportunities in the city, although many city dwellers maintain close connections with their land.

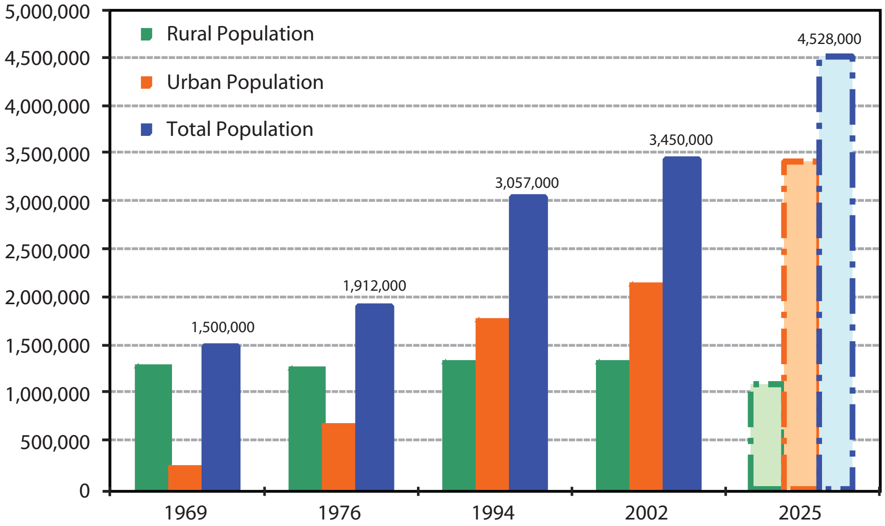


FIGURE 2. Population growth in KRB (*Sources:* JAMAB Consulting Engineers 1999; Ashrafi et al. 2004; Electro Consult 1969).

Karkheh is also strategically and economically important because of its vast oil and gas reserves. Cities such as Ahwaz are sprawling oil refineries and were the target of Saddam Hussein's aggression during the 1980s.

The climate of KRB is mainly semi-arid, with large differences in average annual precipitation, ranging from 150 mm in the south to 1,000 mm in the Upper Karkheh (Figure 3). Due to extremely

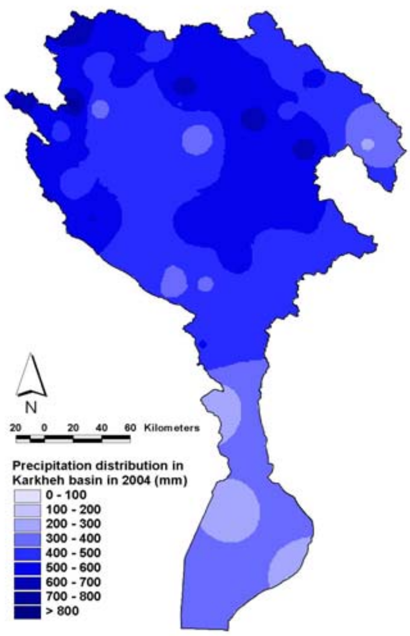


FIGURE 3. Rainfall distribution in KRB (*Source*: TAMAB[3] and IRMO[4] dataset)

[3] TAMAB stands for Iran Water Resources Management Co. under Ministry of Energy (www.wrm.ir)

[4] IRMO stands for Islamic Republic of Iran Meteorological Organization

high temperatures, a significant proportion of rainfall is evaporated directly from bare soils (Ashrafi et al. 2004). In the northern areas, summers are mild and winters are cold, whereas winters are mild and summers are extremely hot in the south. Average annual temperatures vary from 5 ÚC in the upper reaches to 25-30 ÚC in the southern plains.

Many weirs and water diversions have been built over millennia and now many dams are proposed for construction along the river and its tributaries. The Karkheh Dam was constructed in 2002 to provide irrigation to the dry, formerly barren, lowland plains. It filled for the first time in 2005 and is capable of storing more than 1.5 times the mean annual flow. The second dam is a proposed cascade under construction at Seymareh. By contrast, the upper basin is dominated by pasture and scattered and sparse forest, which has become increasingly degraded through overgrazing.

The average annual precipitation over the whole basin, using data for the last 40 years, is 22.5 BCM (TAMAB, unpublished consulting reports and data). There is debate about the amount that is evaporated without productive use, with estimates as high as 60-70% of precipitation, but clearly all dryland agriculture and pasture is supported by rainfall, and average annual renewable water resources (surface water and groundwater) have been assessed to be around 6.5 BCM (JAMAB Consulting Engineers 2006b). An estimated 3.2 BCM is diverted for irrigation, but net productive water use is calculated to be only 1.3 BCM, as a result of an overall estimated irrigation efficiency of 35% (Ashrafi et al. 2004).

The Karkheh River originates from Gamasiab Subbasin and is joined by many other streams. The Gamasiab River flows slowly through the Garri mountain valleys until it joins the Qarasu River, some 60 km southeast of Kermanshah city. The name of the river then changes to Seymareh, after the region through which it flows, and it receives water from the Ilam River as it meanders to the confluence with the Kashkan River. At this last canyon of the Koor Mountains, the river becomes the Karkheh and enters Khuzestan Province, terminating in the Hawr-Al-Azim swamp (Izadpanah 2005) (Figure 4).

No other water flows enter the basin apart from natural precipitation. Natural subbasin outflows have been defined at five points – Gamasiab (1,100 million cubic meters (MCM)/y); Qarasu (700 MCM/y); Kashkan (1,600 MCM/y); outflow from Seymareh into the Karkheh (5,600 MCM/y); and inflow to the Hawr-Al-Azim swamp (5,000 MCM/y). Apart from river inflows, there are considerable contributions from springs, and some groundwater interaction too.

HISTORY OF WATER USE IN THE KARKHEH BASIN BEFORE THE TWENTIETH CENTURY

The Karkheh region is an ancient cradle of civilization that was once rich and productive. It abounds with archeological sites that bear witness to the development of agriculture and cities. The river has been given many names. The names for its source, the Gamasiab River, have a colorful range of explanations: Gamasab means spring-head, or cave; the two parts of the word mean cow (Ga) and fish (Masab), in reference to mythical stories of two statues of a cow and a fish in ancient Nahavand City that were erected to ward off disease that plagued the region; in other texts, 'Ga' means big, 'Masi' is fish and 'Ab' is water – a river full of big fish; alternatively, 'Gamasi' means calm – calm water or calm river (Afshar Sistani 1994).

In 500 BC, the Karkheh was known as "Choaspes" and the derivation of Karkheh appears to be an arabicization of Charkheh, an ancient city in the Kingdom of Elam. Archaeological surveys have provided evidence of human presence in the region 15,000-25,000 years ago. The Elam Dynasty

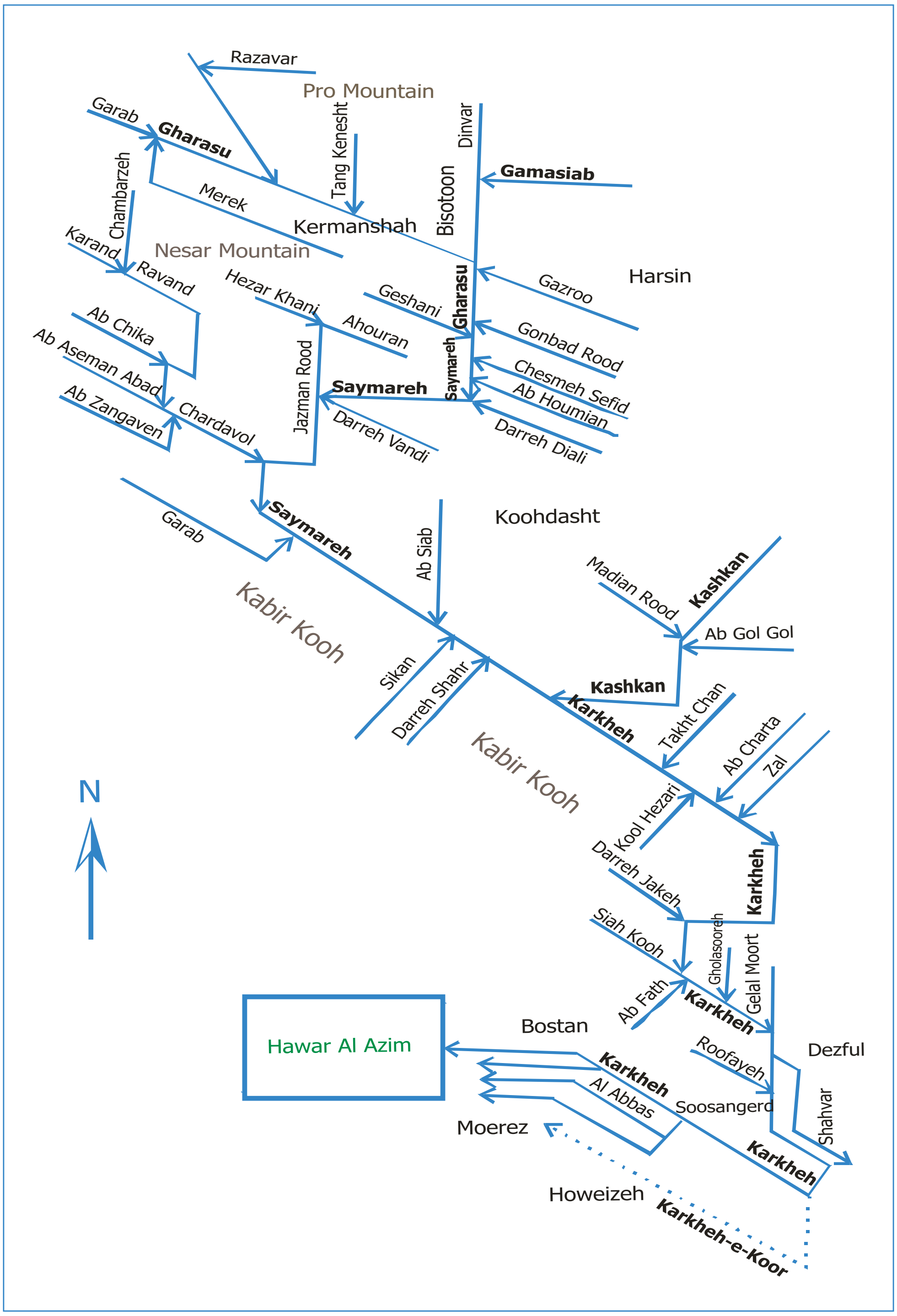


FIGURE 4. Schematic of the Karkheh River network (*Source:* Jafari 1997).

was the first identified government and organized society in the basin, starting around 4000 BC and is one of four recorded in ancient Sumerian texts. Three ancient tribes of Asian origin - Elamite, Medi and Kasi - settled in villages and undertook agriculture. Villages existed at Susa (now Shush, see cover picture) and Tiri. Settlements sprang up along the Lower Karkheh and Karoon rivers in 3000 BC and the Elam Dynasty ruled over almost all of what is now the Karkheh Basin (Afshar

Sistani 1994, 2002). It is hypothesized that cities emerged because of the security and productivity of agriculture (APERI-Royan Consulting Engineers 1993). Later, with the inward migration of Arab people, the villages and towns were named after the tribes living there, for example, Khafajieh (now Soosangerd).

Famous Achaemenid fire temples named after Nahid, the water goddess, were built in the catchment at Hamedan (near Gamasiab), Kangavar (Gamasiab) and Shush (Lower Karkheh). Other sacred places, such as the tomb of Daniel can be found close to the riverbank, and ancient bridges also functioned as diversion weirs, for example, Pol Dokhtar, built in the Sasanian era (Figure 5). The Karkheh River was considered sacred at this time. Several other important ancient cities, such as Nahavand in Gamasiab Subbasin, date from the Sassanid and pre-Islamic times.

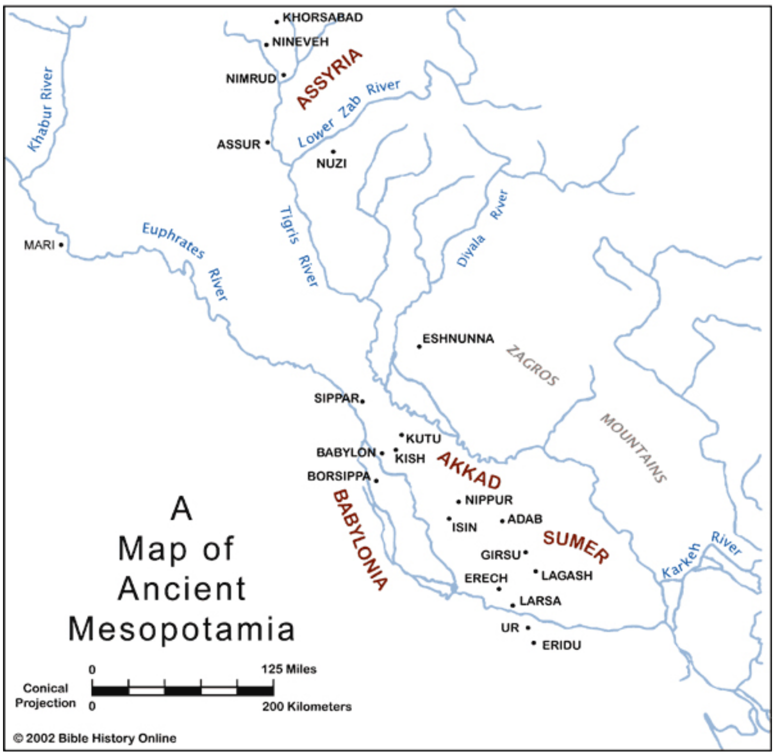


FIGURE 5. Ancient regions and cities of Mesopotamia - 4800 BC.

The Greeks knew Karkheh as “Khasep” and the Persians knew it as “Rood-e-Shush” (Shush River). Before the eleventh century AD, a branch of the Karkheh was called “Tiri” and then became Karkheh-e-Koor (Blind Karkheh) after a major influx of mud, which changed the hydrology of the region and prevented water from reaching the fields that previously lined the river. The river has been known as the Karkheh since the sixteenth century AD.

Some of the oldest examples of irrigated agriculture and earliest domestication of well-known fruits are traced to Mesopotamia and neighboring river basins. Large diversions could be made using brush weirs on larger rivers, and springs provided obvious natural opportunities, but other technologies played an important role, as discussed in Box 1.

Box 1. Qanats.

There is a long history of irrigation from springs and from an ingenious, ancient and indigenous technology – the Qanat or Karez. A Qanat is an underground channel or tunnel that is formed by digging a series of vertical shafts and joining them at the base (Figure 6). The underground channel intersects the water table where it is shallow, usually at the head of an alluvial fan. Water flows by gravity out into the lowland plain, at a point where the depth to the water table is too great for it to be tapped using dug wells. The gradient of the qanat must be carefully controlled—too shallow a gradient yields no flow and too steep a gradient will result in excessive erosion, collapsing the tunnel. Irrigation spread to Iran in the late Iron Age, but it was a long time until many qanats were dug east of Zagros Mountains in the sixth century BC. Qanats are found throughout Iran, Afghanistan and Western Pakistan, and are commonly thought to be a Persian technology, even if the word Qanat originates from Arabic. Indeed, it has been suggested that the rise of the Persian Empire, under Cyrus the Great, was built on irrigated agriculture and these enabling technologies. Herodotus, the Greek writer and historian, noted the importance of agriculture in the region and the fact that the Achaemenid Dynasty presented themselves as gardener-kings.

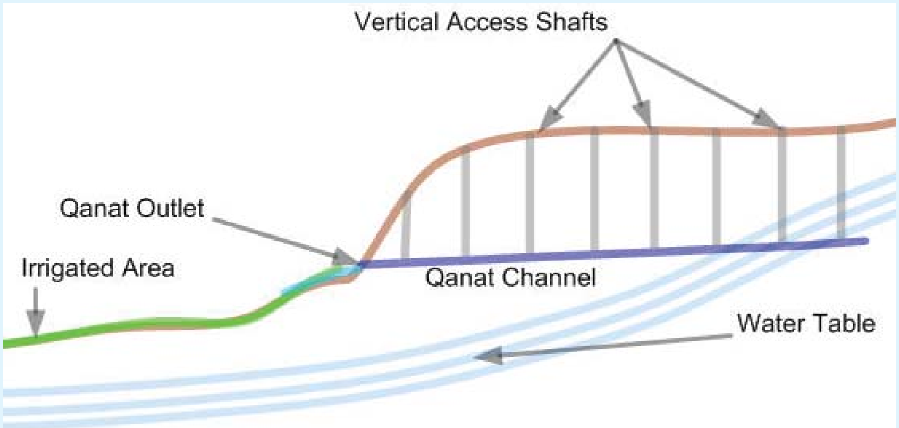


FIGURE 6. Qanat system (*Source:* Wikipedia).

Although the construction methods are simple, the making of a Qanat requires a detailed understanding of geology and a degree of engineering sophistication. Construction required both skills and a certain disregard for personal safety. In the twentieth century, it became increasingly difficult to find specialists with both sufficient skills and bravery to maintain them. The identification of suitable sites required skill, but there are also many colourful stories of confidence-men of the day trying to convince khans and farmers to put up money in advance where there was no hope of success. A skilled well digger would identify a suitable point to dig a trial well, perhaps up to 40 m deep, based on the stream lines and the nature of the alluvial fan where it emerges from the moutains. A watercourse alignment is marked on the hill-slope and the wells are dug and joined. From the air, one can see characteristic molehills with a dark eye at the center, marking each well as they march downslope towards the valley.

Since ancient times, there have always been conflicts between water users about their shares, rights and the reasons why they do not have enough. The boundaries of a well and the fair distribution of surface, well and floodwater have all been contested. Traditionally, land adjacent to a well or qanat is protected from encroachment, well drilling and other land use change, to safeguard the supply – the protected areas are known as "Harim". This tradition gradually broke down in the twentieth century, and the emergence of deep motorized tube wells has sounded the death knell for many qanats over the last 20 years. In Iran, the concept of Harim was introduced into formal law through Articles 136-139 of the Law on Property and Ownership (APERI-TAM Consulting Engineers 1997b). Apportionment of floodwater is important for direct use and for recharge of the aquifers that feed qanats – during a field survey in Lorestan, it was found that maintenance of downstream water rights was still a tense issue. However, in comparison with other basins, the density of qanats is low in KRB, and generally limited to smaller ones that provide domestic water supply, leaving irrigation to be traditionally supplied by springs and from the river. Nevertheless, the qanat has impressed a culture of cooperative water management and tradition in Iran that has extended to other sources.

In the same period (eleventh century AD), the Hawr-Al-Azim swamp came into existence in the western part of the Lower Karkheh on the site of the ancient Babylonian Kingdom. The swamp is part of the greater Mesopotamian Marshland, formed from three linked marshes: the Central, Al Hammer and Al Hawizeh (UNEP 2001). The 29% or so of Al Hawizeh that now sits within Iran is called the Hawr-Al-Azim in Persian. The Mesopotamian Marshland is situated on the extension of Bein Al Nahrein, which was the heart of Mesopotamia (APERI-Royan Consulting Engineers 1996b). The former courses of the ancient Euphrates (Purattu) and Tigris (Idiqlat) rivers and the former approximate extent of the Persian Gulf are denoted by short dashes in Figure 5, and it can be seen that the Karkheh once reached the sea. It was cut off by continuing deposition from the Tigris and Euphrates, which extended the delta into the Gulf of Persia.

It is believed that wheat was first cultivated anywhere in the world in western Khuzestan, in the Lower Karkheh Basin (Afshar Sistani 1994). The first evidence of settled agriculture dates from 8000-8500 BC (Afshar Sistani 2002; APERI-Royan Consulting Engineers 1993) and wheat and sugarcane are considered to be the most ancient crops of the region. Other important crops were barley, millet, sour oranges and rice. Horses, camels, buffalos, sheep and goats were preferred for animal husbandry. In the western part of the plain, people were mostly settled farmers who even built irrigation systems, compared to the east, where they were mostly pastoralists. A brief summary of this history is given in Table 1.

TABLE 1. Summary of the development of KRB prior to the twentieth century.

	Period	Year	KRB situation
Before Islam	Ashkanian Empire Sassanid Empire	247-224 BC 226 BC-642 AD	The region was calm, peaceful and stable. It was the time of powerful regional governments. Irrigation technology was developed and early versions of agricultural and dairy production took place. Orchards and agriculture were important (APER,1993). Houses were built from mud.
	Arab influence-Islam comes to Iran Saljoughian	642 AD 1045 AD	Animal husbandry dominant - cultivation of alfalfa became popular due to the importance of horses for Arabs. Rice cultivation (mainly in Hawr-Al-Azim) and palm plantation developed (APERI-TAM Consulting Engineers 1997b)
	Hasanouyeh Dynasty	C 10th AD	Agriculture was further developed and urbanization increased - the basin had high income
After Islam	Mongol invasion	1219 AD	The Mongol era was disastrous for the region as cities and villages were destroyed and agricultural activities were hampered. The Mongols valued and supported animal husbandry and nomadic life. In 1275 AD just one-tenth of Iran's arable lands were cultivated (APERI-TAM Consulting Engineers 1997b). One century later, the Khuzestan region began to improve and became productive; mainly wheat, sugarcane and cotton.
	Moshashayan Dynasty	1436 AD	Many Arab and non-Arab nomads migrated to Hawizeh (Lower Karkheh) from neighboring lands. They killed many existing settlers and neglected agriculture.
	300 years ago	C18th	Ordinary people were still living in a nomadic style and in tents, had a poorly developed agriculture, mainly cereals and grains (APERI-Royan Consulting Engineers 1993).

Period	Year	KRB situation
	200 years ago	Wheat, barley, alfalfa, rice, chickpea, lentil and orchards were grown mainly for home consumption. Cultivation of saffron and olives was replaced with sugarbeet, sun flower, soya and tobacco (APERI-Royan Consulting Engineers 1993).
	1779-1925	Ghajar era - only Khans and nomad leaders owned lands. From the middle of the Ghajar Dynasty land ownership and agricultural activities became more important - people start settling down in villages. In KRB, people settled down more in Kermanshah (Qarasu subbasin) and less in Kashkan and Lorestan due to fewer regional conflicts. Ghajar era - charcoal production development (APERI-Royan Consulting Engineers 1993)
	1890	Qarasu and Gamasiab subbasin were flourishing and was the center of settled life (APERI-Royan Consulting Engineers 1996a)
	1831	Plague outbreak (before this outbreak, Bostan and Soosangerd in Lower Karkheh were two important sources of tax revenue)
	1836	The Nahr-e-Hashem Dam failure made Dasht-e-Azadegan an arid and drought-prone plain (APERI-TAM Consulting Engineers 1997b)
Nineteenth century	1885	Shadrovan Shapoor Dam failure and Fatali Khan Bridge damage

The first village councils in the region were established around approximately 2000 BC. The village councils were mainly responsible for the water rights of village inhabitants for irrigation and other purposes. Each village was considered as a production unit known locally as “NASAGH”. This “Nasagh” was divided into smaller units called “Cow Pair”, reflecting the amount of labor and animal power available. In some regions, “Blocks” were formed by aggregating several Nasaghs, usually in a unit that was appropriate for managing local water resources and irrigated cultivation (APERI-Royan Consulting Engineers 1993). This system continued for centuries, but gradually people lost faith in cooperative systems of cultivation and due to mistrust of governmental systems and outsiders preference for private ownership and rainfed agriculture emerged in order to save water and money.

The main weirs in this catchment were constructed 1700 years ago during the Sassanid Era. For instance, the remains of the Pay Pol and Pol Dokhtar weirs in Lower Karkheh can still be seen today (Figure 7).

Howeizeh City in Lower Karkheh was built in 980 AD, after Islam spread to the region, and the first Arab tribe to establish itself in the Howeizeh region (Dasht-e-Azadegan) was the Bani-Asad in 1242 AD (APERI-TAM Consulting Engineers 1997b). Ancient “cities” of the region formed in areas of higher population density and became agricultural markets and centers of service provision. The ancient cities of KRB were also connecting points between two ancient civilizations (Beinol Nahrein and Byzantine) and the eastern world, and the famous ancient “Silk Road” also passed through this region (APERI-Royan Consulting Engineers 1993).

The cities built in Lower Karkheh over the last 100 years are Soosangerd, Bostan (formerly Basitin) and Hamidieh. Hamidieh, which was a village until 1956 with just 600 inhabitants and became a town in 1966 with 3,224 inhabitants. Sheikh Khazal (Head of the Bani-Taraf tribe and a powerful man of Khuzestan at the beginning of the century) built a castle there as well (APERI-TAM Consulting Engineers 1997b).

FIGURE 7. Remains of Pol Dokhtar Bridge on the Kashkan River, Khuzestan Province.

The changes in social setting affected crop patterns and natural resources in the region, for example, ancient olive cultivation disappeared from the Karkheh upper catchment when nomads re-established themselves about one hundred years ago.

THE KARKHEH RIVER BASIN IN THE TWENTIETH CENTURY

Molden et al. (2001) and Molle (2003) define three stages of river basin development: development; utilization; and allocation. In the development phase water use is limited, typically to rainfed agriculture and run-of-river-diversions. Dams are later constructed in the most convenient locations, either to produce energy or enable irrigation, while the supply for domestic purposes remains quantitatively negligible. Large-scale irrigation systems begin to appear where they are needed. Ecological systems and environmental functions are not significantly altered and water management tends to be based on demand, and conflicts rarely arise since the available resource is much greater than the demand.

In the utilization phase, water shortages begin to appear in the driest years and during unusually dry seasonal spells. Storage dams are added to the river as a safeguard against shortages from year to year, but good sites tend to be increasingly rare. Water quality problems and competition between irrigators also begin to manifest themselves and water management and conservation take on increasing importance. By the time the allocation phase is reached, all renewable water resources are fully utilized and sectoral water allocation becomes a point of tension. Water allocation to the most economically valuable uses then becomes the main target for water managers and policymakers (Molle 2003 and Courcier et al. 2005) and new institutions evolve to address intersectoral competition and manage river-basin resources in an integrated manner.

This classification has been applied to the Karkheh Basin in the context of development since 1900 AD. The synthesis has been divided into four eras:

1. Pre-development phase: 1900-1955
2. Development and utilization phase: 1955-1980

3. Groundwater exploitation phase and growing scarcity problems: 1980-2000
4. Overexploitation and emergence of the allocation phase; emerging trends and future prospects to 2025.

The main driver of water development has been the modernization of agriculture and associated policies to improve livelihoods and reduce poverty through farming, and in particular, the development of irrigation to overcome spatial and temporal uncertainty in agriculture.

The twentieth century was dramatic and dynamic for Iran – encompassing the "White Revolution" instigated by Shah Pahlevi, the Islamic Revolution that deposed him and the debilitating Iran-Iraq War. Before 1900, the extent of agriculture and water use was limited, due to the lack of motive power for pumping; uncertain governance; entrenched pastoral traditions; and a lack of capital for large-scale development and major civil works.

Pre-development Phase: 1900-1955

Before the Ghajar Dynasty (1779-1925 AD), only Khans and nomadic leaders possessed shelters and forts. From the middle of the Ghajar Dynasty, landownership and agricultural products became more important and people began to settle in villages in spite of conflicts and struggles between different tribes. A brief chronology from the tail of this period to the middle of the century is presented in Table 2, which mostly involved settlement of nomads and state-initiated agricultural development.

TABLE 2. Pre-development period in the Karkheh River Basin, 1900-1955.

Year	Event
1906-1911	Iran Constitutional Revolution: a widespread protest by clerics and merchants against the shah's mishandling of revenues and the foreign domination of Iranian assets leads to the Constitutional Revolution. The shah signs the new constitution in December, which effectively limits royal power and establishes an elected parliament, or Majlis
1915	The first well was dug in the basin at Asad Abad (Gamasiab). First groundwater exploitation using structures other than Qanats! (Sazeh Ab Shafagh Consulting Engineers 2003)
1920	The Central Government was stable; Sheikh Khazaal fomented resistance against it, and was in turn suppressed. From then on, Khuzestan was ruled by the Central Government with no significant local conflicts
1921	After World War I, Iran's Central Government became more stable - export of oil began and brought wealth to Iran. Railway construction encroached through nomads and khans' territory leading to efforts to settle and pacify. Changes in ownership regulations (APERI-TAM Consulting Engineers 1997b)
1920s	Cotton cultivation began in the upper catchment - decreased rice cultivation, banned due to malaria outbreaks and nomad settlement and substitution with cotton (APERI-Royan Consulting Engineers 1993). In Kashkan subbasin some good quality rice cultivation still remains
1932	Approval of the law to support settlement and grant land to Lor nomads in Lorestan. Focal point in land use change - converting forests and pastures (APERI-Royan Consulting Engineers 1993)
1935	The law of 1932 was further modified to allocate agricultural lands to individuals and local firms who were interested to irrigate land using pumps - 3 hectares (ha) to qualified individuals. Formation of Khafajieh (later called Soosangerd City), the center of the Bani Taraf tribe (APERI-TAM Consulting Engineers 1997b)
1937	"Country Division Law" was enacted - Iran divided into 10 provinces and 49 counties - Karkheh was part of the fifth (current Ilam, Kurdistan and Kermanshah) and sixth (current Khuzestan and Lorestan) provinces. The government subdivided the lands of Soosangerd (in Lower Karkheh near Hawr-Al-Azim) to farmers (1 ha) and Khans (20 ha)

1938-1941	Cotton Gin established in Khorram Abad (Kashkan subbasin) - Cotton Cultivation Development in Karkheh Upper Catchment until 1941 (APERI-Royan Consulting Engineers 1993)
1941	Iran administrative divisions changed (APERI-Royan Consulting Engineers 1993). The first water pump was installed for irrigation in Seyyed Ali Taleghani village (Lower Karkheh on river bank). Starting point for systematic surface water irrigated agriculture (between 1941 and 1952, 7 water pumps installed in Hamidieh and Soosangerd on the river bank (APERI-TAM Consulting Engineers 1997b))
1942	Starvation in Khuzestan and death of many people during World War II, due to lack of food and rainfall (APERI-TAM Consulting Engineers 1997b)
1946	In Dasht-e-Azadegan (Lower Karkheh), 65% of housing was still made of straw and 12% was made of tents (nomadic lifestyle was still dominant) (APERI-TAM Consulting Engineers 1997b)
1953	Nationalizaltion of oil

Charcoal production became popular in response to demand for hot water for bathing, for cooking and for factories. The Khans saw a good opportunity to obtain revenue from charcoal production in the forests and, therefore, encouraged its development. In the Alashtar region (in Kashkan subbasin), local tribes and nomads satisfied all charcoal demand of the neighboring regions like Nahavand in Gamasiab. The forests were more productive and dense in this period, but little now remains after the depletion as a result of charcoal production and encroachment by livestock and agriculture.

Traditional systems of barter were slowly eroded and replaced by monetary transactions from the middle of the Ghajar Dynasty (APERI-Royan Consulting Engineers 1993), due to a flourishing import and export trade, and the emergence of the ceramics and agricultural industries (APERI-TAM Consulting Engineers 1997a).

After World War I, the Central Government of Iran became more stable and powerful. The export of oil began and brought increasing wealth to Iran's economy. Western countries also took the opportunities offered in new markets for their products. With oil revenue, roads and railways were built, which increased travel to the areas traditionally controlled by nomads. The state promoted the settlement of nomads, allocated them land as an incentive, and sponsored irrigation development to make it productive. However, many people preferred their nomadic customs and lifestyle and continued to practice these well into the 1950s in the southern basin (Dasht-e-Azadegan). Dasht-e-Azadegan is 941 km from Tehran and was first called Bani-Taraf after the tribe living there. In 1935, it was named Dasht-e-Mishan, and then renamed as Dasht-e-Azadegan after the Islamic Revolution. This plain was under of the administration of Ahvaz City (center of Khuzestan) until 1944 and its residents were mainly Arab nomads. Further, state sponsored irrigation development followed with the construction of the Hamidieh Barrage in 1957 and accompanying laws and settlement programs. Following canal construction, there was a notable shift in population from the Hawr-Al-Azim to the newly developed plains of Dasht-e-Azadegan (APERI-TAM Consulting Engineers 1997b).

Agriculture and Water Use

The Ghajar Era was characterized by tribal feuding, which made settled agriculture difficult. Many new and established villages were ransacked and irrigation channels were systematically destroyed in such conflicts. Rice had always been irrigated, but as irrigation channels penetrated further into the plains, greater areas of wheat and barley were watered. There was a synergy between population growth and the modest level of industrialization, which increased demand and thus promoted further water development. The first motorized pump was installed on the river in Lower

Karkheh at Seyed Ali Taleghani village in 1941 (APERI-TAM Consulting Engineers 1997b), well after the first motorized well was developed in Gamasiab in 1915 (Sazeh Ab Shafagh Consulting Engineers 2003). Thereafter, modernization proceeded at an accelerating pace, with motorized pumps and cheap oil allowing flexibility in the abstraction of both surface water and groundwater. The average outflows from each subbasin, at the end of this era, are shown in Table 3, with reference to the map in Figure 8.

TABLE 3. Subbasin mean annual outflows, 1950-1955 (*Source*:TAMAB, based on unpublished original data starting from 1950).

#	Subbasin gauging station	Mean annual discharge (MCM/y)
1	Ghurbhagestan	900
2	Pol Cher	920
3	Pol Dokhtar	1,300
4	Pay Pol	4,400
5	Hamidieh	5,240

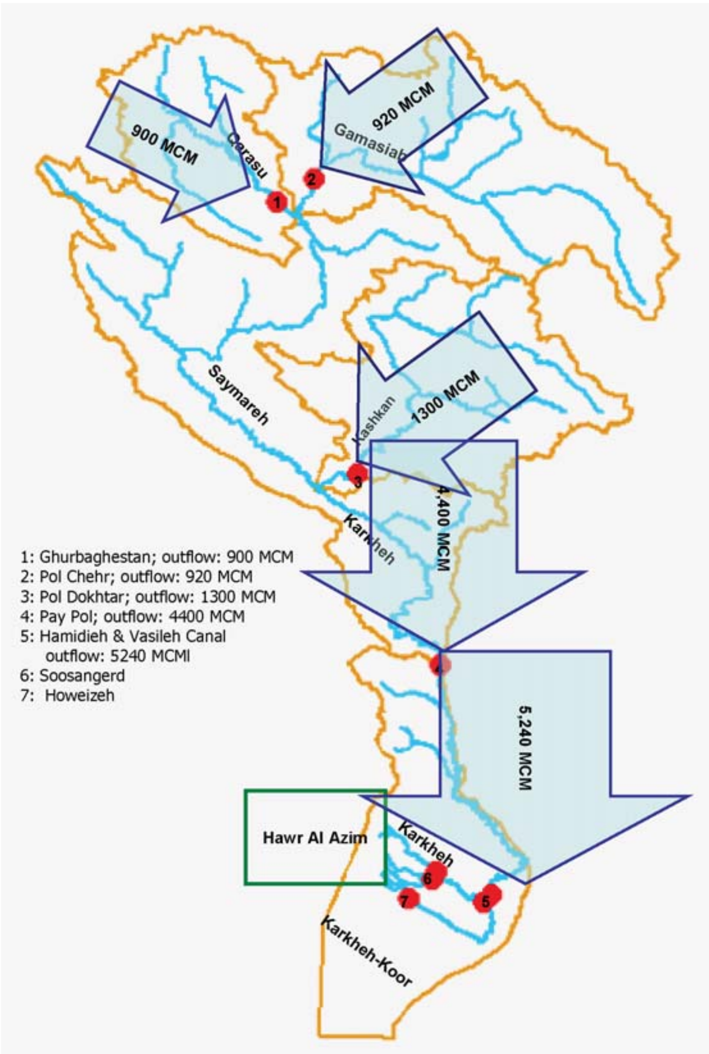


FIGURE 8. Outflow from KRB subbasins 1950-1955 (*Source:* TAMAB, unpublished dataset).

Water and Land Rights Policies

Before the "White Revolution" in the early 1960s, villages were mainly owned and administered by Khans. A feudal system governed with most of the area belonging to landlords, who leased to, or crop-shared with, peasants (APERI-Royan Consulting Engineers 1994; APERI-TAM Consulting Engineers 1997a). This was similar to the "Asiatic Production System"[5] with some key differences, such as having both small- and large-scale private ownership. There were two different contracts between landlords and peasants: sharecropping and leasing.

In sharecropping, five production elements were considered; land, animals, seeds, water and labor. Shares were attributed equally (in fifths) to whoever was responsible for the particular input. Normally, the master provided the first four factors and the sharecropper only contributed manual labor and received just 20% of the production. The exact breakdown of shares often varied, according to the relative power and circumstances of the landlord and the peasantry. In arid areas, the share for water was valued more highly than other inputs. Hereditary sharecropping was also common, known as Nassagh, often awarded after just one year of cultivation (APERI-Royan Consulting Engineers 1994) in units of 5-8 ha, equivalent to the area that could be cultivated with a pair of draft cattle.

Leases were contracted for one or two years at a fixed rate, determined by the quality of land and access to water. Hereditary leases were not offered and rental agreements were usually brokered by a mediator, typically someone from the middle class of village society. Although a fixed rent offered the tenant a good incentive to maximize production, they often experienced a shortage of capital and inputs, and tenanted land tended to degrade and lose productivity (APERI-Royan Consulting Engineers 1994).

A cooperative system evolved in irrigated farming, known as "Boneh". This system developed in arid and desert areas of Iran and was less common in the western and northern parts of Iran and in areas where nomadic lifestyles continued to be the norm (APERI-Royan Consulting Engineers 1994).

Rental agreements were overseen by a yeoman-peasant, known as a "Kad-Khoda". In return for rent-free land use, and occasionally for a salary, an experienced farmer was appointed by the village head to oversee the land use, land management and payment of dues. Between them, the Khan (landlord), the village leader and the Kad-Khoda were responsible for water administration, allocation and distribution, and related crop planning.

Transfer of public lands to local farmers began in 1931. In 1955, in accordance with the Law on "Sale of Public Land", areas known as "Khaleseh" were transferred to local farmers under a 20-year lease, with areas of roughly 10 ha for irrigated land or 15 ha for rainfed (APERI-Royan Consulting Engineers 1994). More widespread formal ownership of land thus began in this era. In 1932, the government approved a law to distribute free agricultural land in Lorestan to Lor nomads, who were eager to settle. In 1935, this law was further modified to allocate agricultural lands to individuals and commercial companies who were interested to irrigate lands using pumps (APERI-TAM Consulting Engineers 1997b) and introduce other technologies and investment.

[5] The "Asiatic Production System" had two important facets; provision of irrigation and the absence of private ownership. Irrigation facilities were generally provided by the government since, in arid and deserted areas, the costs were significant. Absence of private ownership clarifies that in eastern societies landownership was totally in the hands of the government and private ownership as found in the western world did not exist. In this, Iran's feudal system did not match the Asiatic system, since both small-scale and large-scale private ownership was the norm (APERI 1994).

In 1937, the country was divided into 10 provinces and 49 counties, but with some confusion over boundaries, leading to further subdivision in 1941, so that the fifth province became three – Ilam, Kurdistan and Kermanshah, and the sixth became Khuzestan and Lorestan. Prior to this, a law was passed in 1930 that defined the boundaries, rights and responsibilities of well and qanat owners. This legislation was supplemented soon after by a new law on the registration of water rights (Haghabeh).

In the 1950s, water was distributed to farms in three ways: 1) permanent flow, where water is supplied continuously to the village or farm delivery point with no time limit; 2) variable flows, where water shares for groups of farms were calculated by size, crop types and need, and were rotated accordingly; and 3) formal shares, such as traditional water rights owned by farmers at springs and qanats. Privately supplied water from pumps (surface water and groundwater) was normally charged the flow rate and duration of flow - based on a minimum unit of 25 liters per second (l/s) for 12 hours.

Development and Utilization Phase: 1955-1980

The chronology of events in the development and utilization period is summarized in Table 4.

TABLE 4. Development of the KRB during the development and utilization phase.

Year	Event
1955	Transfer of public ('Khaleseh') lands to local farmers; 10 ha irrigated or 15 ha rainfed on a 20-year loan (APERI-Royan Consulting Engineers 1994)
1956	Initial study of the Karkheh River Basin
1957	Hamidieh Barrage, initially supplying only 500 ha and reaching 1,500 ha by 1963 (APERI-TAM Consulting Engineers 1997b). This dam now conveys water for 185,000 ha via the Zamzam, Ghods and Hamidieh canal networks - starting point for the cultivation of summer crops of the region through irrigation canal (APERI-TAM Consulting Engineers 1997b) - the denser centers of population shifted from Hawr-Al-Azim to east of Dasht-e-Azadegan
1960-1963	White Revolution,i.e., changes in ownership regulations
1963	Yazd-e-Nou village construction - agriculture development in this region - wheat, barley and summer crops cultivation (APERI-TAM Consulting Engineers 1997b)
1964	Pumping water in the Kashkan and Seymareh rivers in upper Karkheh subbasins for irrigation of riparian lands and development of horticultural crops (e.g., melon) (APERI-Royan Consulting Engineers 1993)
1965	Establishment of Lorestan sugar cube factory - more development of sugarcane production in the region: sugarcane cultivation began in the region during the Reza Shah Pahlevi Era (APERI-Royan Consulting Engineers 1993)
1968	Establishment of "Oil Seeds Bureau" in the region - development of soya and sunflower cultivation. Soya is mainly cultivated in the Kashkan Subbasin and sunflower in the Qarasu Subbasin
	February 1968 - Flood in the basin. Reduction in cultivable area of arable lands due to flood and land acquisition in the areas to be served by Hamidieh Barrage (Ministry of Water and Power, KWPA 1971)
1975	The economy of Iran starts to takeoff - decrease of national agricultural production
1978	Islamic Revolution

The most important event in this period was the "White Revolution" (1960-63), which affected the region in a number of different ways. It was an ambitious set of economic and social reforms, introduced by Shah Raza Pahlevi, which included some radical themes such as giving voting rights to women. It included a massive programme for rural education with land reform and industrial modernization both seen as key elements intended to propel Iran on to the main stage of global affairs. The land reforms were also intended to empower farmers, establish clear titles and allow them to generate more wealth and stimulate greater productivity. As a result, 90% of sharecroppers became landowners, at least on paper. Water resources were also nationalized, principally to ensure protection of the nation's limited assets and to ensure equitable allocation through state sponsored projects.

However, the land reforms were bitterly opposed by the landed elite and the clergy, and in the fullness of time it became apparent that many former sharecroppers had neither the capital nor access to other input resources (such as water) to make their smallholdings viable. The entry of multi-national companies into the country to produce and export horticultural products also generated political resentment.

The country was developing rapidly and reached a point of economic "take-off" in 1975, fueled by high oil prices in the wake of the OPEC cartel price hike and the ensuing "oil crisis" of 1973. The price of oil increased from US$8 to US$36-39/barrel over this period, encouraging people to work in industry rather than agriculture. With increasing urbanization, more food was imported, and profit margins on the farm were slim and there were few incentives to produce surpluses. This led to a price collapse within the domestic market. In Kermanshah Province, for example, local chickpea could not be sold even for IRR 5 per kilogram (kg). Low prices and incomes and lingering failures of the land reform programme contributed strongly to rural dissatisfaction, and a desire for regime change. The "Islamic Revolution of Iran" began in 1979, but before the new regime was fully established some parts of the country witnessed some disorder and insecurity: some public and private lands were occupied by local people, and some problems remain today in contested ownership dating from the beginning of the revolution.

Agriculture and Water Use

Crop patterns and water use changed as a result of the White Revolution. For instance, in the Lower Karkheh, around 47% of the arable lands were dedicated to irrigated wheat and barley, 43% to rainfed wheat and barley, less than 9% to rice, and 2% percentage to summer crops (Figure 9). Over time, summer crops took over from rice cultivation, and rainfed wheat and barley cultivation shifted more towards irrigation (APERI-TAM Consulting Engineers 1997a). In the Upper Karkheh, around 1,964 farmers started pumping water from the Kashkan and Seymareh streams in the summer (APERI-Royan Consulting Engineers 1993), but wheat and barley remained the dominant crops over the KRB on the whole. Before the White Revolution, the average land area cultivated by each farm family was approximately 6-7 ha and this increased to 10 ha thereafter. Winter cereal cultivation was partly or fully mechanized, whereas summer crops (mostly horticultural products) were labor-intensive and traditionally tended.

During the early part of this period until after the White Revolution, most water abstraction was direct from the Karkheh River using traditional gravity diversion and sometimes rarely from groundwater via tube wells and deep wells (APERI-TAM Consulting Engineers 1997a). Of the water used, 93% was abstracted from surface sources. Farming was not mechanized and simple tools and livestock were used for tillage (APERI-TAM Consulting Engineers 1997a). Agriculture was, in most respects, a supplementary enterprise to livestock rearing until the advent of cheap and reliable pump sets (APERI-TAM Consulting Engineers 1997a). There was a steady increase in the number of motorized pump sets with a corresponding rise in the use of both surface water and groundwater towards the end of the period. Modernization of irrigation channels effectively began in 1957 with the construction and extension of the Hamidieh Barrage, which initially served

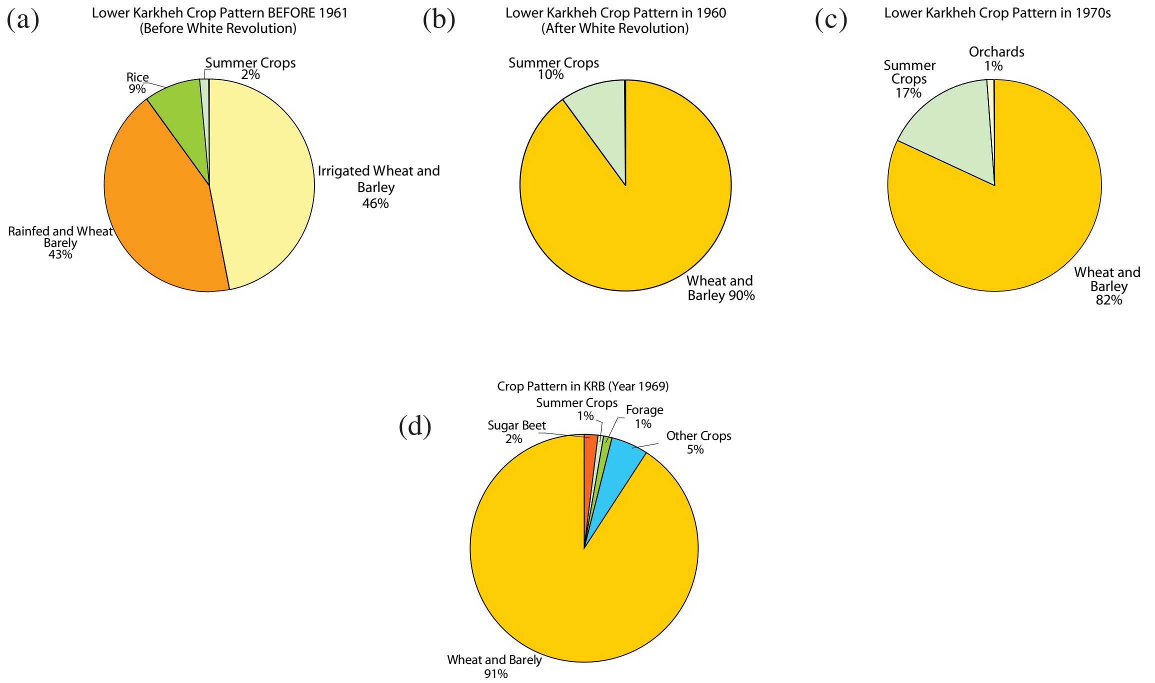


FIGURE 9. Crop pattern (a) in Lower Karkheh before 1961; (b) after the White Revolution; (c) in the 1970s[6] (APERI-TAM Consulting Engineers 1997b); and (d) in 1969 for the whole Karkheh, on an area of 700,000 ha (*Source*: Electro Consult 1969).

a tiny area (500 ha) that has eventually expanded to cover 185,000 ha. The increase in groundwater use, in terms of numbers of modern motorized pumps, is presented in Figure 10, and shows the slow but steady development of groundwater to the 1980s.

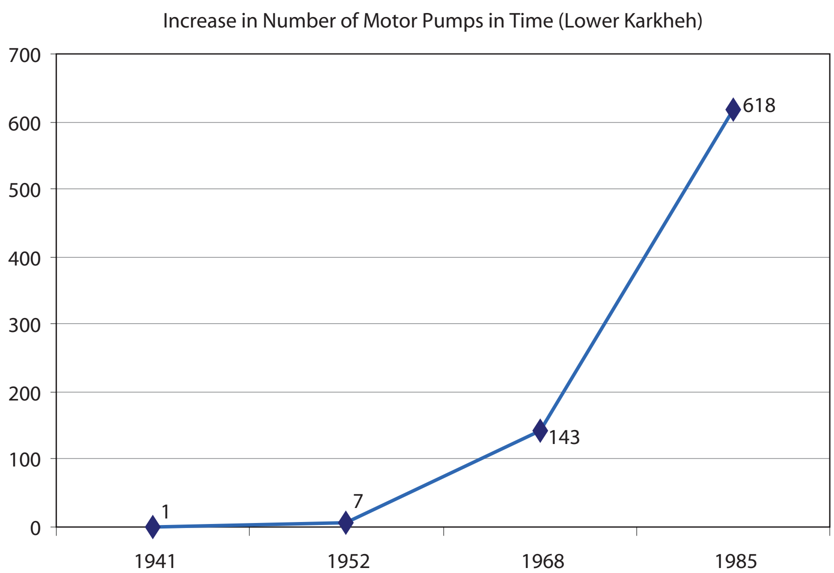


FIGURE 10. Motorized well installations in the Lower Karkheh Basin.

[6] No data was available to distinguish the amount of irrigated and rainfed wheat and barley, and no data was available for the whole Karkheh.

The average flows from each subbasin in this period were mostly higher than those recorded from 1955 to 1980 (Table 5) and are shown in Table 7, with reference to the locations shown in Figure 8. The outflow below Hamidieh declined in this period, reflecting the growing diversion of water for irrigation in the lower basin.

TABLE 5. Subbasin mean annual outflows, 1955-1980 (*Source:* TAMAB, unpublished dataset).

#	Subbasin gauging station	Mean annual discharge (MCM/y)
1	Ghurbhagestan	710
2	Pol Cher	1,150
3	Pol Dokhtar	1,500
4	Pay Pol	5,600
5	Hamidieh	5,000

The heaviest floods ever recorded in the history of the basin occurred in February 1968, and inundated significant areas of arable land causing the value of agricultural output to shrink by 5.7% in 1969. Land acquisition programs related to irrigation development from Hamidieh also contributed to this contraction in production (APERI-Royan Consulting Engineers 1996b; Sazeh Ab Shafagh Consulting Engineers 2003).

Water and Land Rights Policies

The White Revolution was intended to end the feudal system and reduce the power of the Khans. Redistribution of private and public land to the rural population had several goals: replacing low output subsistence with "beneficial agriculture"; increasing farmers' disposable income; developing real markets for industrial production in rural areas; and increasing agriculture productivity (APERI-Royan Consulting Engineers 1994).

Landlords did not disappear entirely and commercial/industrial agriculture was also introduced alongside small-scale farming. In the wake of the reforms, there were increases in settlement and cultivation in the valleys and along natural watercourses (APERI-Royan Consulting Engineers 1993).

Although the reform was not always implemented efficiently, it helped improve the lives of poor villagers to some extent. For instance, in the Kermanshah Province (Upper Karkheh), 629,292 ha of land was divided between 59,532 families, equivalent to 4.5 ha of land per household. Most of the lands were rainfed (approximately 90%) and the rest were irrigated (Electro Consult 1969). In contrast, in the Lower Karkheh, 110,728 ha of land was given to farmers, of which 71% was irrigated and 29% was rainfed, averaging 7.7 ha of rainfed and irrigated land per family (APERI-TAM Consulting Engineers 1997a). In roughly half of the cases, boundaries of lands stated in the deeds were smaller than the real area occupied by the farmer (APERI-TAM Consulting Engineers 1997a).

From this time on, there was private, public and common ownership of land but an unintended consequence of the reforms was land and water degradation – partly due to intensification and partly due to lower use of inputs. This built up pressure for the subsequent nationalization of strategic natural resources, such as water, forests and grazing land.

In 1963, "Rural Cooperative Organizations (RCOs)" were established to provide economic and commercial services to the farmers and substitute for the inputs provided by landlords under the feudal system. It was supposed to provide machinery and buy and market the products, but only to new landholders, and after the Islamic Revolution in 1979 it was extended to all farmers in the area. One of the most important functions of the RCO still is to distribute agricultural inputs including fertilizers, seeds and chemicals.

In 1968, a national water law was approved, based on the principle that water is a natural gift for all mankind, to be administered for the people by the state. The second article of the law nominated river basins as the natural unit of water management and administration. The law also recognized the existing and traditional rights (*Haghabeh*) of users to continue to enjoy the benefits of their water use. Forests and rangelands were also defined as national common property to be administered by the state.

The land reforms preceding, and conducted during, the White Revolution were successful in increasing the number of owners and establishing private rights, but in many ways failed to substitute for the loss of capital, direction and management skills of the feudal Khans. Land allocations were often too small to support the entire (extended) family, and overall production and productivity both fell (APERI-Royan Consulting Engineers 1996b). Although irrigated area began to increase, there were many impediments to the success of new smallholders.

New organizations, "Rural Production Cooperative Bureaus (RPCs)" were created from what were formerly known as "Agriculture Companies", and were first established in 1972. Their task was to improve the exploitation of water and soil resources to provide a broader rural development in some regions of Iran such as Kermanshah and Dasht-e-Azadegan, where they were quite successful in increasing yields: in 1973, average wheat and barley yields increased to 1,110 kg/ha (APERI-TAM Consulting Engineers 1997a). RPCs were established in order to promote mechanized agriculture, so they encouraged small farmers to exchange their lands for shares in the company. Gradually, the companies took over and many farmers lost their plots and effectively worked as agricultural laborers or emigrated in search of alternative employment (JICA-MOJA 2004).

With the expansion of pumped irrigation and public surface water and private groundwater development, grazing lands were converted to crop cultivation and the average size of arable holdings had increased to 9-10 ha by the 1970s. In 1979, the new Islamic Government placed higher value on private ownership and management and the RPC was temporarily abolished (JICA-MOJA 2004). By 1976, the landholdings in the Lower Karkheh were as follows: small subsistence farmers (< 10 ha) 37.5%; commercial private farmers (between 10-25 ha) 49.5%; and agri-business (more than 25 ha) 13% (APERI-TAM Consulting Engineers 1997a):

Groundwater Exploitation Phase and Growing Water Scarcity Problems: 1980-2000

Post-1980s, the story is dominated by the vicious and protracted Iran-Iraq War, whilst in the background, private groundwater use accelerated rapidly in the upper basin, as summarized briefly in Table 6.

TABLE 6. Key events in the KRB, 1980-2001.

Year	Event
1980-1988	Iran-Iraq War
1983	Law of Fair Water Distribution was enacted
1984	Water committee established under Jihad-e-Sazandegi
1992	Approximately 40,000 Marsh Arab refugees were living in Khuzestan near Hawr-Al-Azim
1999-2004	Drought period
2001	Karkheh Dam inauguration

An astonishing 2 million Iranians were killed during the Iran-Iraq War (1980-1988), with most of the fighting on or within the western borders (KRB) but with direct action as far away as in Tehran. The war clearly had a devastating impact on the Lower KRB, with the loss of 159 villages, and many others depopulated for years afterwards. Mines remain an enduring legacy to this war with an average of three incidents per day still bringing tragedy to the lives of peoples, more often than not those of pastoralists and nomads, and many parts of the Hawr-Al-Azim remain dangerous (APERI-TAM Consulting Engineers 1997a). Destruction of irrigation systems and degradation of arable lands ushered in a long period of poverty and economic stagnation in the region. Unemployment soared, with 13% of males in the KRB without jobs in 1991 (APERI-Royan Consulting Engineers 1996b). Unsurprisingly, this maintained or accelerated the pace of urban migration. The Central Government responded by ensuring comprehensive provision of electricity, clean drinking water and other services, even in the remotest hamlets.

Agriculture and Water Use

Groundwater use increased rapidly following government incentives and promotion of local water committees to develop well-based agriculture. These committees had been established under the Ministry of Jihad-e-Sazandegi (struggle) during the war, as part of a local stablization programme to improve local food self-sufficiency and support the military. Initially, the committees encouraged landowners to dig wells and irrigate whatever area they could, in preference to more precarious rainfed agriculture. As a result, the areas of summer maize and winter barley increased in the upper basin, notably around Kermanshah. The drought that began in 1999 increased farmer's reliance on groundwater, which was estimated to contribute more than 60% of regional crop water requirements (JAMAB Consulting Engineers 2006a). Of the current population of wells, 50% were installed between 1980 and 1995.

TABLE 7. Subbasin mean annual outflows, 1980-present (*Source:* JAMAB Consulting Engineers 2006a).

#	Subbasin gauging station	Mean annual discharge (MCM/y)
1	Ghurbhagestan	670
2	Pol Cher	1,060
3	Pol Dokhtar	1,600
4	Pay Pol	5,800
5	Hamidieh	5,100
6	Soosangerd	5,000
7	Hawizeh	355

Surface water development is more lumpy and capital intensive, requiring major investment. Construction of a massive storage, the Karkheh Dam, began in 2002 and the reservoir filled for the first time in 2005. The dam is designed to irrigate up to 300,000 ha, but the construction of the delivery network is a long way behind schedule. Flows from each of the main sub-catchments are presented in Table 7, with reference to Figure 8 and tables 3 and 5. It is clear that discharges to the Hawr-Al-Azim have fallen significantly, even though other flows have only fallen slightly compared to the previous period.

The total area under cropping has increased in tandem with irrigation development, but wheat and barley still remain the major crop choices and the proportions of each crop remain similar to previous times (Figure 11).

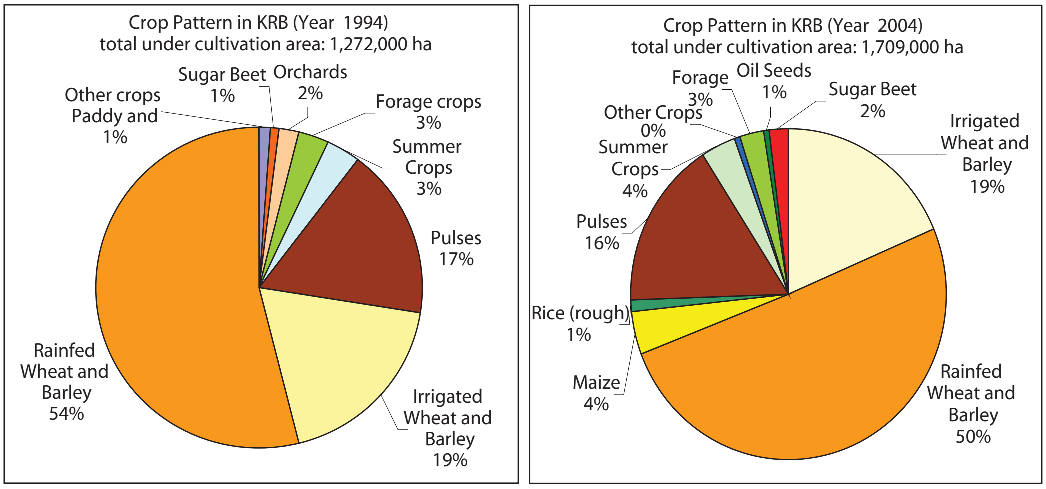


FIGURE 11. Crop pattern in KRB in (a) 1994 (*Source:* Ashrafi et al. 2004); and (b) 2004 (*Source:* Ministry of Jihad-e-Agriculture, unpublished dataset).

An extended drought from 1999 to 2004 reduced average wheat yields over the early years (Figure 12), but they rebounded with slight increases in rainfall from 2000 onwards. The irrigated areas which were maintained through extra groundwater pumping resulted in a significant drop in water table elevation.

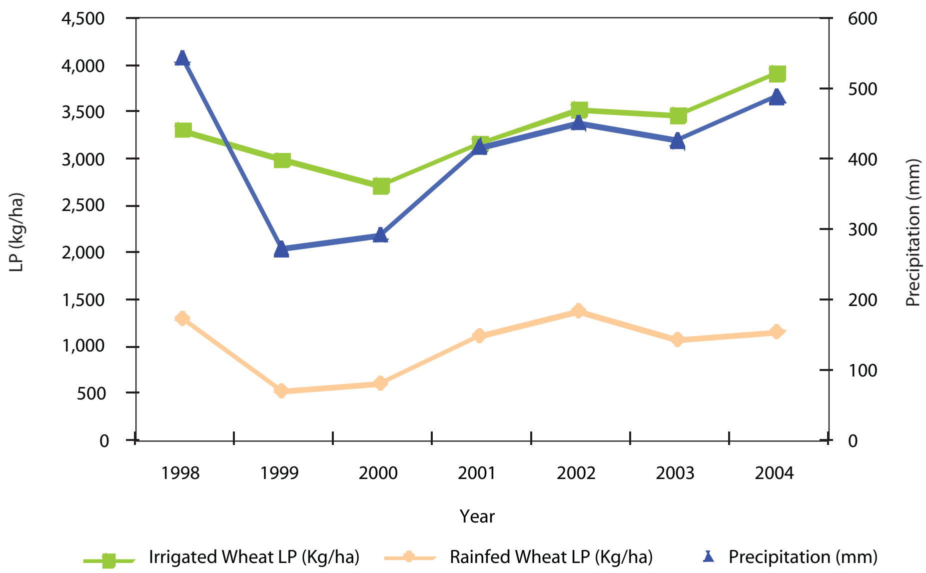


FIGURE 12. Relationship between wheat yield and precipitation during the drought from 1999-2004 (*Source:* Ministry of Jihad-e-Agriculture, unpublished dataset)[7].

[7] Approximately 270,000 ha of lands are under rainfed chickpea. Irrigated chickpea, cucumber and onion occupy only a small area in the region - irrigated chickpea 850 ha, cucumber 17,000 ha and onion 900 ha (Ministry of Jihad-e-Agriculture dataset-year 2000).

Waterlogging, soil salinization[8] and overgrazing emerged, as well as land and water management issues during this period. Due to limited grazing land (3% of cultivated land), but rising populations, and the land allocation programme, overstocking of rangelands has rapidly led to their deterioration, and encroachment of increasingly poor upland and foothill areas on the valley margins. Animal conditions and quality has also suffered, with the average weight of a marketed animal now 22% less than in the 1970s (APERI-TAM Consulting Engineers 1997a).

Water and Land Rights Policies

After 1979, the Islamic Revolution emphasized private ownership and RPCs were temporarily abolished. In 1989, the Ministry of Agriculture reestablished RPCs in various guises because it had become clear that such services were needed to support the larger numbers of small private landowners and also to improve national food security. Some of their duties include land consolidation, irrigation and water management, provision of agricultural machinery and farm inputs (JICA-MOJA 2004).

A land use known as "Temporary Occupation" also came into existence (APERI-TAM Consulting Engineers 1997a). In Karkheh, the Khans (tribal leaders and former landlords) had often managed to reassert their political and economic power and control over land through the provision of motorized pumping for irrigation. Some moved to Iraq after the 1979 revolution, and again after the Iran-Iraq War, so their lands were seized and redistributed by the government to smallholders. A "Central Headquarters of Land Transference" was established to oversee land redistribution in each administrative area, and so-called "7 person-committees" were set up in different cities to do the same thing. Land was transferred to those who satisfied the following criteria: landless, or those with very small holdings; those who had left their villages due to hardship; technical and agricultural graduates from colleges or university; and jobless with a keen interest in agriculture (APERI-Royan Consulting Engineers 1994). During this time, the average landholding size increased to 12 ha (APERI-TAM Consulting Engineers 1997a).

In the Upper Karkheh, almost all lands are privately owned (99%). The Qarasu subbasin has the highest level of joint-ownership (12%) as cooperatives or joint venture units, and the overall breakdown of ownership categories is: subsistence farms 42%; joint ownership – small farmers + companies (including RPC) 39%; small commercial holdings 10%; medium-sized commercial farms 5%; and large commercial farms 4%.

In commercial farming, there is generally a higher proportion of rainfed land, which results in lower average yields compared to smaller irrigated units. The highest productivity is typically seen on small commercial farms, with a high proportion of irrigated horticulture.

In 1983, the "Law of Fair Water Distribution" was introduced and all water resources of the country were declared to be government property (JICA-MOJA 2004; APERI-Royan Consulting Engineers 1996b). The Water Tariff Law (1991) set the procedure for water pricing as follows: The Ministry of Jihad-e-Agriculture (MOJA) should take responsibility for the collection of irrigation fees from the Ministry of Energy. The minimum penalty for illegal water use should be 1.5 times the water fee and the water fee is to be defined according to the gross income of farmers (JICA-MOJA 2004).

Groundwater and surface water management is the responsibility of the Ministry of Energy, through two local agencies – the Khuzestan Water and Power Authority (KWPA) for the lower

[8] Soil salinization occurred mainly in the Lower Karkheh due to construction of the Karkheh Dam, which stopped the seasonal flooding of the region (reducing leaching) and raised regional water tables.

basin and the West Regional Water Organization for the upper reaches. Irrigation system operation down to secondary outlet level is also under the control of the Ministry of Power, but further downstream (tertiary and quaternary) it is the responsibility of the Ministry of Jihad-e-Agriculture. The two agencies have been working together on irrigation management since 1996. At the time of writing, tertiary development is a long way behind the construction of the main system, which has slowed land development and limited production.

Overexploitation and Emergence of the Allocation Phase: Emerging Trends and Future Prospects to 2025

The extraction of non-renewable groundwater is excessive in many water scarce countries and regions, and groundwater use has exploded over the last two decades, causing depletion of aquifers at an alarming rate. Iran is one of the countries in Africa and Asia that has increasingly scarce renewable freshwater resources, which will fall below the threshold of 1,500 m^3/capita by the year 2030 (Hoekstra 2003). As water deficits increase, the need to import food rises, initially during droughts and years with poor harvests.

Iran, as a nation, and the KRB as an arid river basin, are on the cusp of entering a phase of water scarcity and intersectoral competition, as well as facing the challenge of trying to produce considerably more food with the same, or possibly declining, stocks of water. It is entering the "allocation phase" of water development. In this phase, many new and challenging issues need to be faced, in terms of: accounting for water use; dealing with hydrologic variability and declining security of supply; developing a detailed water rights system to support the accounting; enabling means of transferring water equitably to higher value uses, such as industry; and dealing with environmental water allocation to safeguard the natural resource base. Commodity trade is also important in terms of substituting imported grain for local water used to grow grains and other basic foodstuffs.

The estimated population in KRB will be 4.5 million in 2025, with 3.4 urban dwellers and 1.1 million in the countryside (see Figure 2). The figure reveals that the rural population has been quite stable over the last 40 years in terms of absolute numbers, with most of the growth being in the cities. Since most of the rural migrants are the young, the average age of those in the rural areas has steadily increased, whilst in the cities it has fallen.

Oil production remains the most important economic activity in the region, and this will continue. New developments will require a lot of space and encroach on agricultural lands in Dasht-e-Azadegan. Industry and agro-industry are increasing, but are dwarfed by Iran's center for oil production. In February 2004, INPEX (a Japanese oil company) entered into a service contract (a "buyback contract") with Iran's National Iranian Oil Company (NIOC) and its subsidiary, Naft-Iran Inter Trade Co. Ltd. (NICO) to further develop Azadegan Oil Field. INPEX was to have invested US$2 billion through two development stages, with a target output of 150,000 barrels (bbls) per day in the first stage. NICO was to hold 25% of the working capital and the rest was to be held by INPEX. The threat of international sanctions torpedoed the deal, and in the end the project was taken over by the Russian company YUKOS.

There is some political undercurrent that the region does not get a fair share of the revenues from its oil and that more could be done to reduce poverty in the basin, using some of this income.

Agriculture and Water Use

The Seymareh Dam in the Seymareh subbasin is under construction and is the first of four dams expected to be complete by 2025 on this section of the river. It is a double arch dam, 178 m high and with a crest 196 m long. The cascade of dams will regulate upstream flows, preserve the storage capacity of the Karkheh Dam through intercepting suspended bed load, provide some irrigation and generate 835 gigawatt hours (GWh) of electricity. The dams are part of a more ambitious cascade that reaches the upper catchment. They have been extensively studied, and their major economic benefits will be electricity generation and protection of downstream storage structures. There remain a number of questions about the hydrological assumptions and studies behind the design of the dam and, more recently, how they may be affected by the effects of climate change. Precipitation in Iran is predicted to fall, and evaporative demand will increase with higher mean temperatures, with likely, but little studied impacts on water availability. One of the major hydrological issues is with regards to the amount of water that will flow through to the Hawr-Al-Azim.

Other major water projects are on the horizon. A 540 km pipeline has been proposed to transfer water 0.76 MCM/day from the Karkheh Dam to Kuwait. Potable water supply will be sold to Kuwait at a price of US$1.5-2 per liter, a price similar to the cost of desalination. The project has not yet been completed, but the annual volume of water is significant, although less than 10% of recent annual average outflows to the Hawr-Al-Azim. It has a higher profile than irrigation water that has led to concerns about environmental flows, but the impacts of irrigation development are more far-reaching and severe.

The per capita domestic water use in the basin is also high (204 liters per capital per day (l/c/d)) and almost double the world's average. Most of this will continue to be sourced from groundwater, and local conflicts between agricultural and domestic use of groundwater are likely to emerge over the next 15-20 years, as much about quality and cost, as about quantity.

Necessary Rights and Policies

When a river basin faces water scarcity, there are three main responses: supply augmentation, conservation and reallocation (Molle 2003). Supply augmentation requires exploiting additional sources either within the basin or through inter-basin transfers. Conservation programmes concentrate on improving technology and management that reduce non-beneficial losses and allow real water savings to be made; however, conservation programmes need to make explicit provisions for the reallocation of saved water to do this. Reallocation involves transferring a defined and measurable quantity of water from one use to another, usually one with a higher economic or social value. Where the value of industry is much higher to society, this may involve large-scale transfers of water to the sector, offset by a corresponding increase in food imports.

Self-sufficiency in wheat and basic foods remains a priority for the Iranian Government. This sets up an immediate tension over the allocation of water between agriculture and other sectors, especially as basins like KRB approach full utilization. The government is also very responsive to rural needs, which include being able to make a reasonable living from farming, especially in the poorer areas of the country. A declining agricultural sector implies rising rural unemployment, which has historically resulted in disaffection and political change.

Therefore, technologies and policies that improve the productivity of water, in physical and economic terms, are required in response to increasing water scarcity. Apart from improved crop management, technologies and varieties, alternative sources, such as reuse of wastewater, can be considered in appropriate niches. Similarly, if potential productivity is limited by waterlogging and salinity, these stresses will have to be relieved to maximize crop and pasture productivity, for example, through improved drainage. River water quality is declining, but is still fit for agricultural use with an average electrical conductivity of 0.6 dS/m. Circumstantial evidence indicates that contamination due to the use of fertilizers and pesticides is increasing.

Trends in Transformation

Since ancient times, different races have lived in the Karkheh River Basin. Kurds mostly live in the Kermanshah Province, Lors live in Lorestan, Arabs live in the Khuzestan Province and there are still nomads living in and migrating across the basin. These races have their own languages (Kurdish, Lori and Arabic), cultures and customs. Each race has its own selection of tribes, some of which are historically famous, but no longer exist today, and others that still proudly bear their ancient names: Kakavand, Kalhor, Bakhtiari, Bani-Taraf, Sharfe, Niss, Aal Kassir, Savaed, Savari, Mazrae, Sorkheh and Bani Saleh (Afshar Sistani 1994; APERI-Royan Consulting Engineers 1993).

Historically, nomads were powerful and treated with care and respect by the Central Government. In recent centuries, most have been settled, or have settled on their own accord, in villages and cities. Those still committed to nomadic life have nevertheless become familiar with modern technologies, and may now transport their livestock instead of driving them to new pastures. Although nomads are traditionally associated with animal husbandry, many modern nomads also raise rainfed crops and families may typically have 4-5 ha. They continue to produce traditional handicrafts for themselves and for sale.

The livelihood strategies of the people living in the KRB can be divided into agriculture, animal husbandry, trading, labor, and tools and craftsman. From ancient times agriculture and orchards were complementary to animal husbandry and other livelihood activities, but following the advent of Islam, pastoralism took over and became more popular. Currently, both agriculture and settled animal husbandry are important sources of people's livelihoods (APERI-Royan Consulting Engineers 1993; APERI-TAM Consulting Engineers 1997b). Handicrafts include carpet and felt making, pottery, dried fruit processing, hunting and fur processing, collecting forest products and pharmaceutical plants from rangelands, charcoal production, and tool making. In ancient times, pottery was the most significant artistic endeavor (APERI-Royan Consulting Engineers 1993). Fishing also makes a significant contribution in the lower basin and, more recently, there has been considerable investment in fish farming throughout the basin.

Land Use Change

Over the past 40 years, the area under wheat cultivation has increased in tandem with irrigation investment, and yields have improved considerably since the 1960s. The minor crops in the crop pattern have changed over time: saffron used to be important and valuable, but has almost vanished from the region. Olives, once widespread, have also declined and sugarcane was much more widely planted centuries ago, and is now mainly grown by state-owned agribusinesses. Wetlands have been drained and encroached, as shown in Figure 13, on the margins of Hawr-Al-Azim.

FIGURE 13. Wetlands converted into wheat fields in lower KRB, February 2001 (*Source:* UNEP 2001).

Despite the continued dominance of wheat and barley in the cropping pattern, there has been an increase in crop diversity in the twentieth century, most notably since the 1980s, with irrigated and rainfed pulses proving popular across the basin – mostly chickpeas (Figure 14).

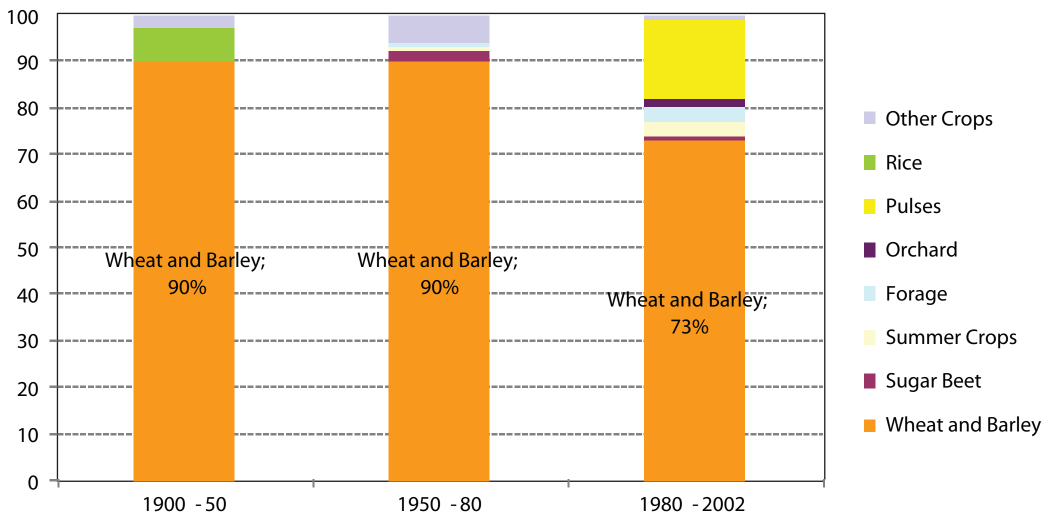


FIGURE 14. Changes in crop pattern in KRB, 1900-2000 (*Sources:* Electro Consult 1969; JAMAB Consulting Engineers 1999; Ashrafi et al. 2004).

Between 1950 and 1980, 95% of cultivation in the basin was rainfed. The current situation is significantly different due to the enormous scale of irrigation development throughout the country. Although the total irrigable area in the KRB amounts to a little over 700,000 ha, approximately 200,000 ha remain fallow every year (Ashrafi et al. 2004). The total cultivated area has grown from around 520,000 ha in the 1950s and 1960s to around 1 Mha in 2004 (the Ministry of Jihad-e-Agriculture[9] dataset; Electro Consult 1969). The expansion of area throughout the basin accelerated over the last 5 years (to 2004) but the proportions between irrigated and rainfed agriculture have remained at approximately 30:70 (Figure 15).

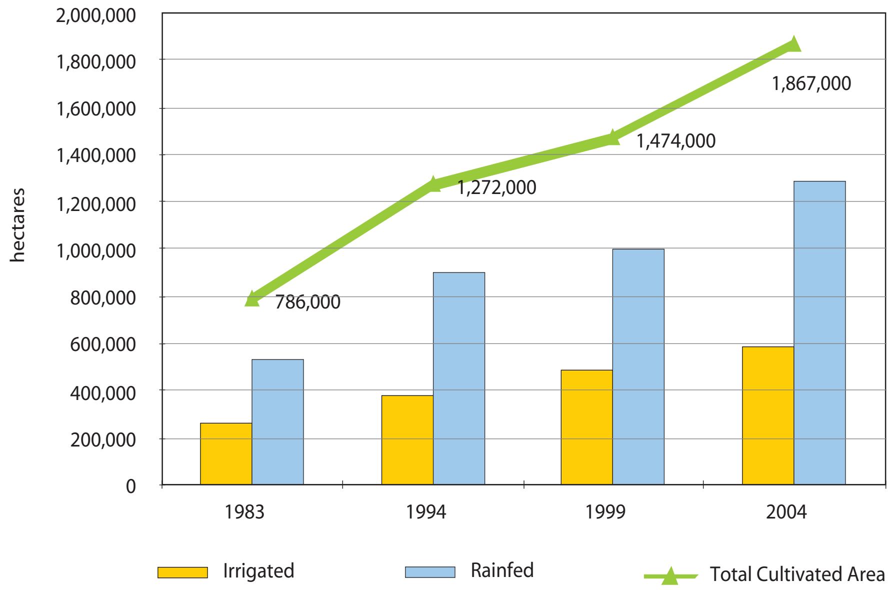


FIGURE 15. Areas under cultivation in KRB in the 1980-2000 period (*Sources:* Ashrafi et al. 2004; JAMAB Consulting Engineers 1999).

[9] The Ministry of Jihad-e-Agriculture is Iran Ministry of Agriculture (www.maj.ir)

WATER ACCOUNTING FOR THE KARKHEH RIVER BASIN

Water Depletion

Molden et al. 2001 define water depletion as a use or removal of water from a water basin that renders it unavailable for further use. He makes the important point that not all water diverted to a use is depleted, and return flows are often important sources of supply for downstream users. Conceptually, this is important as the abstractions made by upstream users affect water availability to those downstream. In the KRB, there are no provisions to protect downstream water availability, which has resulted in some conflict between upstream and downstream uses, for example, in the Nahavand Plain in Gamasiab subbasin.

A generalized schematic of the hydrologic system of a river basin is given in Figure 16, with typical long-term average annual volumes added for the Karkheh River Basin. Approximately 70% of all precipitation that falls in the basin is evaporated and the remainder flows to the Hawr-Al-Azim swamps.

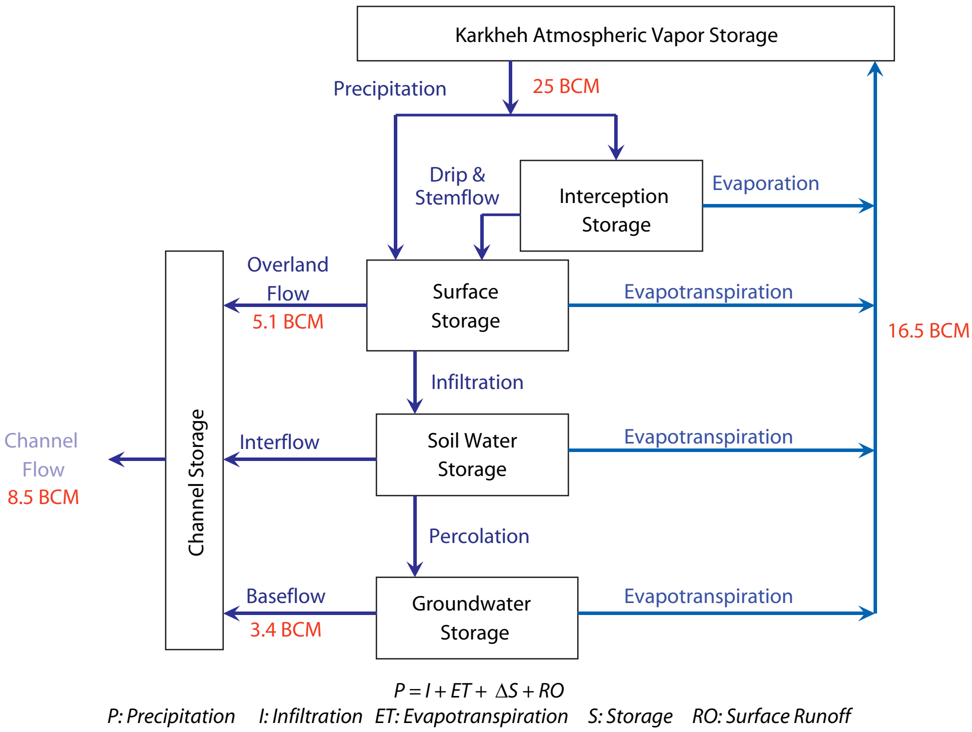


FIGURE 16. Karkheh Basin Water Balance (*Source:* Thompson 1999).

Prior to 1950, there was relatively little demand and the river's health was little affected either by abstraction or by human activities that might pollute it. The predominant sources of water for irrigation were springs and qanats, and wells were not used to exploit groundwater until combustion engines were available from 1915 onwards.

Water resources development accelerated from 1950 through to 1980 and witnessed a rapid increase in groundwater use, with well numbers rising from 150 to 3,000 over a brief period of 20 years, increasing total abstractions from 15 to 430 MCM/y. Some qanats fell into disuse through this era, and were replaced or displaced by private wells. The water account for 1969 (Figure 17) is considered typical of the period, which experienced a lower than average annual precipitation. The total depletion in the basin amounted to 88% of inflow, comprising 25% as beneficial, 28% as low beneficial and 35% as non-beneficial. Irrigated and rainfed agriculture accounted for only 6% and 10%, respectively, of the depletion of total water resources of the basin (860 MCM). Domestic and industrial consumption was negligible, estimated at less than 250 MCM per year.

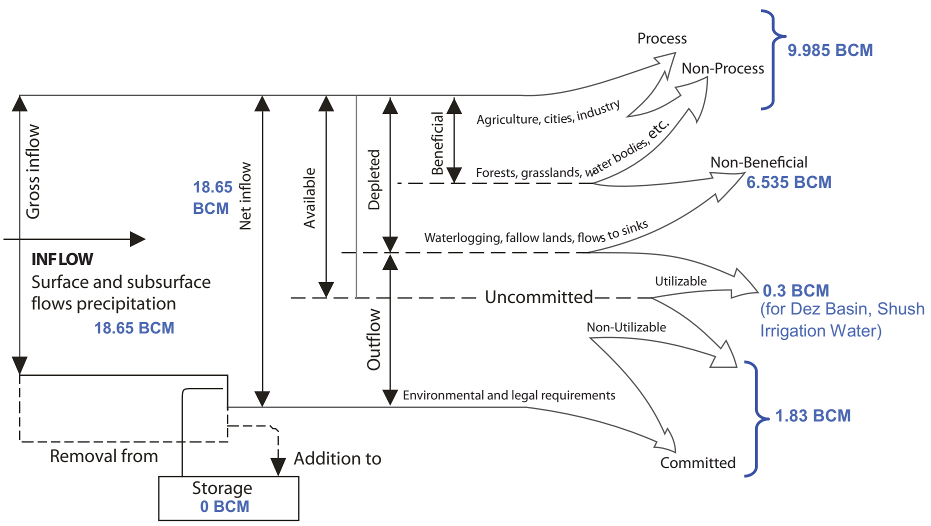


FIGURE 17. Water Accounting of KRB in the 1950-80 period (based on 1969 data, *Source:* Electro Consult 1969).

By 1984, there was an equal proportion of surface water and groundwater use for agriculture and other human benefits (JAMAB Consulting Engineers 1999). The period from 1980 to 2000 experienced an increase in annual precipitation, in line with the long-term average of 25 BCM. The corresponding water account from 1980 to 2000 is shown in Figure 18, with little increase in total depletion compared to the previous era (16.5 BCM), resulting in a larger outflow of 8.5 BCM/y (Ashrafi et al. 2004).

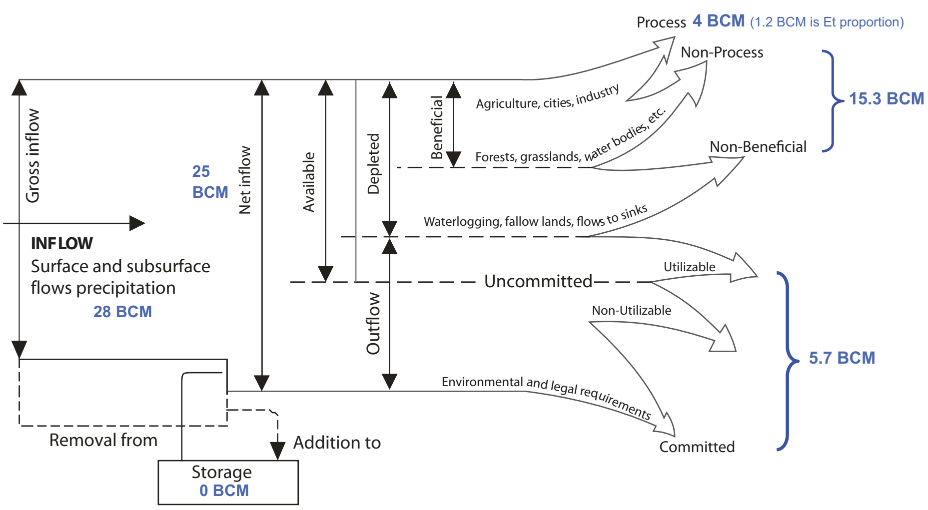


FIGURE 18. Water accounting for KRB in the 1980-2000 period for the reference year of 1994 (*Source:* Ashrafi et al. 2004).

The total volume depleted by irrigated agriculture is estimated to have risen to 1.2 BCM, out of a total water use by agriculture of 4 BCM/y. By far the largest volumes of water are depleted on rangelands, by natural vegetation and forests (11.3 BCM). About 50% of total depletion – from waterlogged and fallow lands - has minimal or no tangible monetary benefit, and is described as non-beneficial, although it ignores ecosystem values and possibly some limited direct economic gains from grazing and the use of natural products. About 3.4 BCM of outflow from the basin occurs in groundwater and around 5.1 BCM in surface flows: much of this is saline. The estimated diversions for irrigation amount to 3.7 BCM, but return flows and unproductive evaporation account for about 68% of this volume (Ashrafi et al. 2004). The proportion of basin inflows depleted by irrigation rose compared to the period up to 1980, but still represents only 7-8% of total precipitation (1.2 BCM), and municipal and industrial use remains minimal at 0.3 BCM/y, even though it is nearly three times the average use in the previous period: domestic water use accounts for about 8% of diversions, and industrial allocation remains tiny at 1% (Sazeh Ab Shafagh Consulting Engineers 2003; APERI-Royan Consulting Engineers 1996d; APERI-TAM Consulting Engineers 1997a).

Of the 4 BCM average annual diversions for human use, about 57% was sourced from groundwater (Sazeh Ab Shafagh Consulting Engineers 2003). This is about twice as much water that was abstracted per year between 1950 and 1980, with most of the increase being sourced from groundwater. Expansion of groundwater use was influenced by policies of the Ministry of Jihad-e-Sazandegi, which established water committees during the Iran-Iraq War in order to support and stabilize the population bear the battle zone. Groundwater recharge averaged 3.4 BCM per year and was greater than the total estimated abstraction of 2.3 BCM per year. This does not tally with empirical evidence of an average decline of 0.26 m per year in water table levels for the whole basin (Ministry of Energy, unpublished data; TAMAB, unpublished data 2002), but this level of decline represents a marginal loss of around 72 MCM per year from an aquifer equivalent area of 9,832 km^2. The links between surface water and groundwater systems are not clearly understood, and vary considerably across the basin.

The account shows that although only a small proportion of total water supply to the basin is diverted for human use, the renewable water resources in groundwater and surface water are coming under increasing pressure, and availability is, in turn, modified by harder to manage water use across rangelands, forests, fallow and waterlogged areas.

The drought from 1999 to 2004 further stimulated the development of groundwater – which peaked at 59% in 2001, and then settled at about 57% of total water abstraction thereafter. The dependency on groundwater is higher in the upper catchment, where rainfalls are normally higher, and is limited (almost non-existent) in the lower basin due to the salinity of the shallow aquifer (Figure 19).

Though the number of wells has increased between 2001 and 2004, the total abstractions have stabilized or decreased. A most likely reason for the decrease in groundwater pumping was the end of the drought coupled with the greater depth of pumping compared to 1990, which incurs higher costs. Water tables have fallen throughout the upper basin since 1990 and are up to 10 m deeper in Gamasiab, and 2 m deeper in Kashkan (TAMAB unpublished dataset 2002).

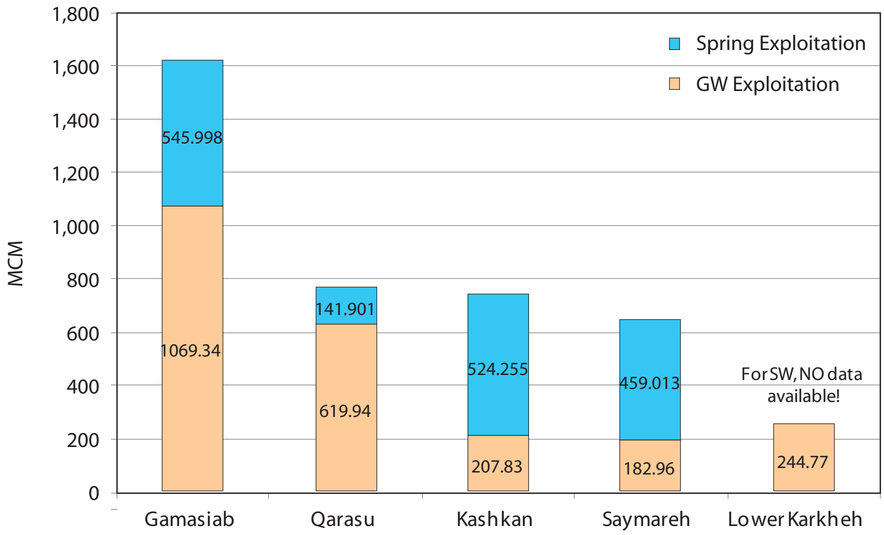


FIGURE 19. Share of surface water and groundwater exploitation in Karkheh Subbasins (*Source*: TAMAB, unpublished data 2002).

Trends in Streamflow

The long term mean annualized flow rate is 28 m³/s, measured upstream of Karkheh Dam. Peak flows occur in April, corresponding to the highest monthly rainfalls in the catchment. Minimum flows occur in October, which is also the driest month (Electro Consult 1969). There has been only one major flood event over the last 50 years, which occurred in 1968, causing mean flows to rise to close to 80 m³/s. However, smaller floods had a greater impact on the rural inhabitants, with the highest mortality during the period 1971-1972 and the greatest damage to farmland during the period 1994-1995 (Figure 20).

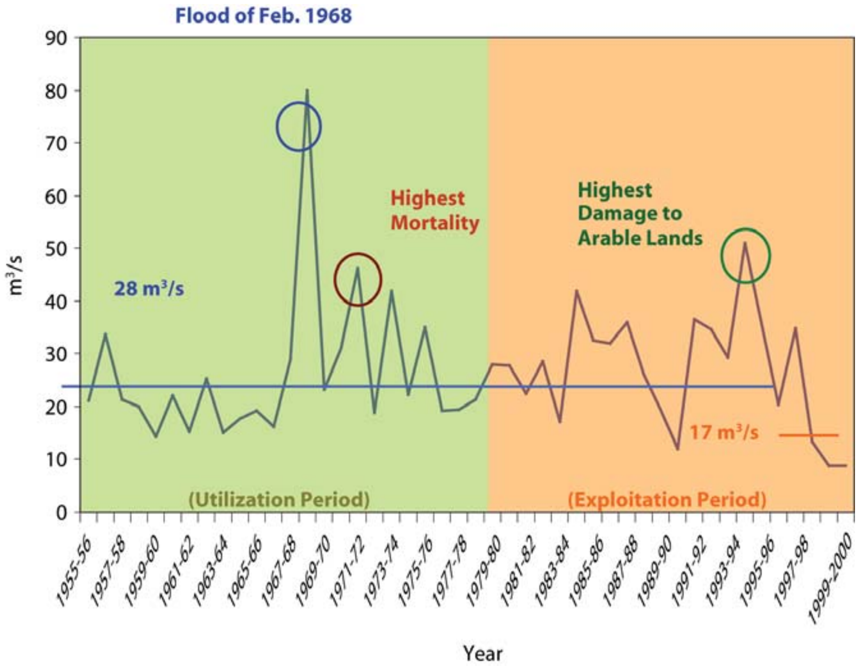


FIGURE 20. Karkheh River discharge in the past 50 years (*Source*: Sazeh Ab Shafagh Consulting Engineers 2003).

The impact of the drought on streamflows leaving each subbasin is summarized in Table 8, in comparison to average inflows over the pre-development period and over the period from 1955 to the onset of the drought. There is some indication of declining flows through the development period, but there was little change as a result of the drought. The flows in 2000 were much lower than the average for the whole drought period, with severe reductions in outflows in the upper basin.

TABLE 8. The impact of drought on long-term average streamflows out of each subbasin.

Subbasin	Average inflow 1950-1980 (m^3/s)	Average inflow 1955-1997 (m^3/s)	Average inflow 1997-2000 (m^3/s)	Average inflow 2000 (m^3/s)
Gamasiab	11.8	11	5	2.4
Qarasu	11.3	8.5	3.5	0.5
Kashkan	16.5	22	15.5	10
Seymareh	69.5	53.5	25.5	14.6
Lower Karkheh	131.4	180	108	52.4

A closer look at the variations in surface streamflows over the successive development periods show that there has been little change in the balance or average volumes of streamflow leaving each subbasin (Figure 21). The water balances presented above indicated that there was higher average rainfall after 1980 compared to the period before, which may, in part, explain the apparent lack of surface water and groundwater development having an effect on outflows up to the drought. These patterns also suggest that much of the increased groundwater use has had little impact on streamflow, which indicates that the connections between surface water and groundwater are limited.

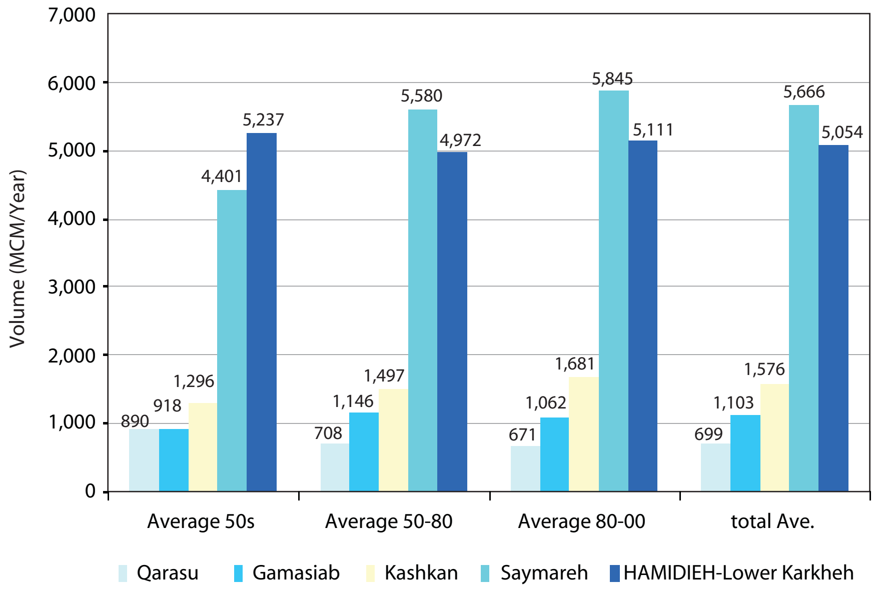


FIGURE 21. Annual outflows from different subbasins through successive development periods (*Source*: TAMAB, unpublished dataset).

Trends in Groundwater Use

By 2004, there were nearly 18,000 wells and qanats in the basin. The trends in the number of wells and qanats are presented in Figures 22 and 23, respectively.

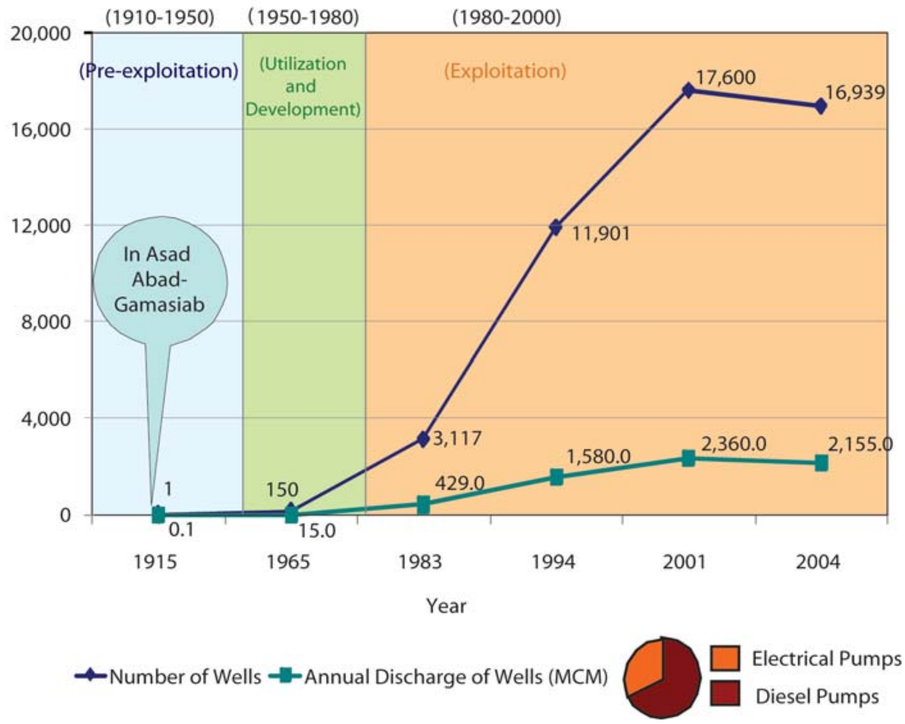


FIGURE 22. Growth in groundwater abstraction 1900-2004 (*Source*: Sazeh Ab Shafagh Consulting Engineers 2003; TAMAB, unpublished dataset 2006).

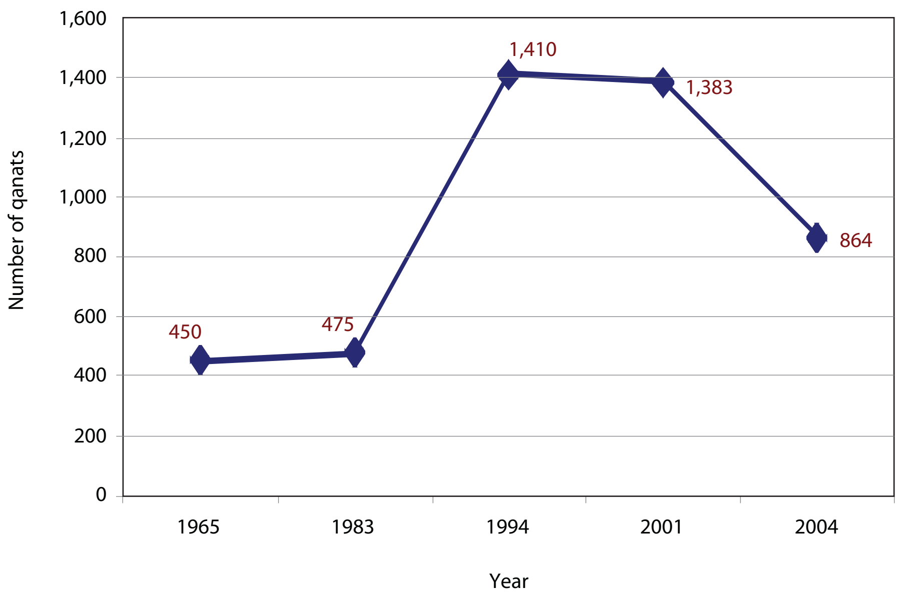


FIGURE 23. Changes in the numbers of qanats (*Sources:* Sazeh Ab Shafagh Consulting Engineers 2003; JAMAB Consulting Engineers 1999).

As water tables fell through the period of drought, qanats failed and deep wells took their place, probably increasing the likelihood of further failures of the traditional technology. Deep wells mainly powered by diesel pumps now account for more than 65% of the total volume of water abstracted and the abstraction from shallow wells and qanats had fallen dramatically (Figure 24).

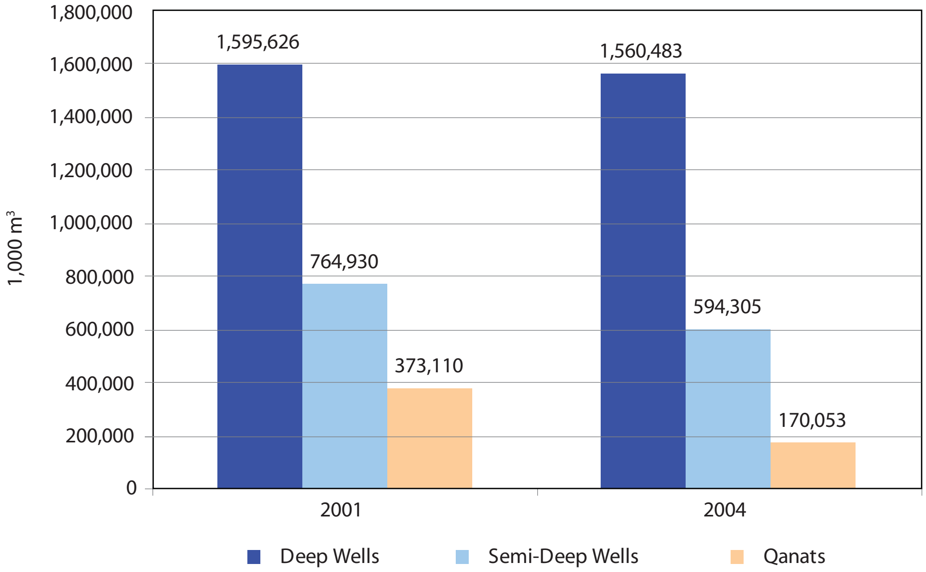


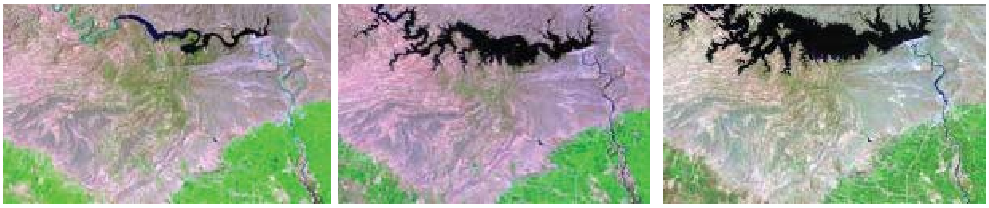
FIGURE 24. Abstraction from different groundwater sources, 2001 and 2004 (*Sources:* Sazeh Ab Shafagh Consulting Engineers 2003; TAMAB, unpublished dataset 2006).

Karkheh Dam

The Karkheh Dam (Figure 21) had long been mooted to irrigate large tracts of plain, to generate hydropower and to provide secure, good quality drinking water. Design studies for the Karkheh Dam were completed by foreign consultants in 1956 and again in 1966. Iranian consulting engineers conducted new feasibility studies from 1974 to 1979, and these were revisited and updated after the Islamic Revolution by Mahab-e-Qods in 1990, who selected the final site and alignment of the dam. Construction began on the core of the dam in 1991 but the powerhouse was not completed until 2003. The dam spilled for the first time towards the end of 2005 but, to date, only a small portion of the design command area is fully canalized. During the filling period (Figure 25), very little flow passed downstream to the Hawr-Al-Azim swamp.

The Karkheh Dam generates 934 GW of electricity annually and is planned to irrigate 320,000 ha of lands in the Ilam and Khuzestan provinces. The construction costs were equivalent to 1.91% of GNP and employed 76,030 people. The reservoir covers 166 km^2 and provides many recreational areas, some tourist resorts and new fish farming enterprises (Aftab-e Yazd Daily Newspaper, No. 346, Page 7 (www.aftab-yazd.com).

The dam is sensitive to loss of storage by silt deposition from sediments carried downstream from rangelands and cropland. Much of the proposed dam construction upstream is to minimize siltation in this strategically important storage. The negative impacts of the dam are anticipated to be progressive dessication of the Hawr-Al-Azim swamp and the loss of leaching and other ecosystem benefits of flooding in the plain.



2000 2001 2002

FIGURE 25. Karkheh Dam (above), and time series of reservoir filling (*Source:* Landsat Images (www.grid.unep.ch/activities/sustainable/tigris/2002_photo.php) and Iran Water and Power Development Co. (www.karkheh.com/index_en.asp)).

Provisions have been made for environmental releases to Hawr-Al-Azim swamp, but the details of volumes and release patterns are not widely known, and none have been made through the dam filling period (Figure 26). Streamflows and drainage flows were widely reported to have dwindled significantly by lowland producers, many of whom used to pump directly from these watercourses. The medium term changes and impacts on the hydrology of the lower basin are not properly understood yet or even discussed in public fora.

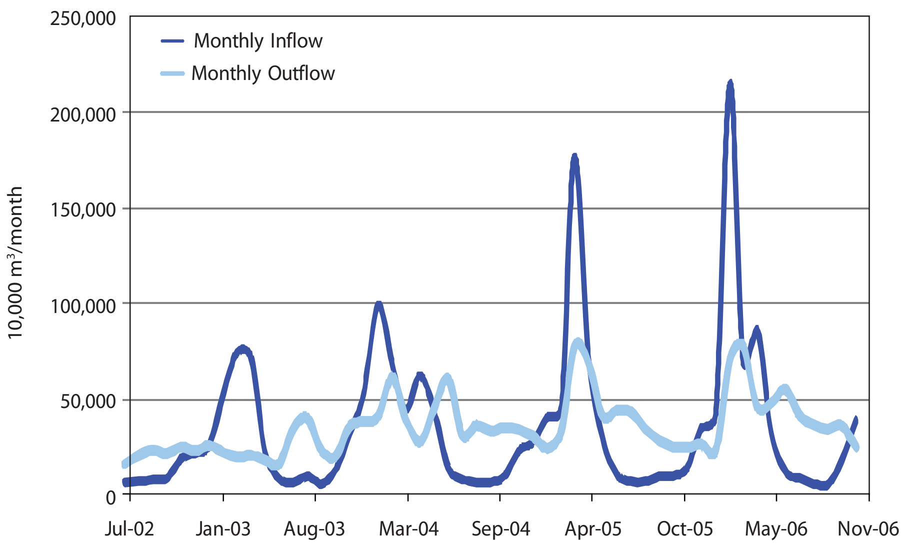


FIGURE 26. Inflow, outflow and reservoir storage of Karkheh Dam, 2002-2006 (*Source:* TAMAB, unpublished dataset); its useful reservoir capacity in 5,600 MCM (*Source:* Shadravan et al. 2004).

Hawr-Al-Azim Swamp – Degradation and Dessication of an Ancient Wetland

Three marshes combine to form the internationally famous Mesopotamian Wetlands. The Central, Al Hawizeh and Al Hammar wetlands are linked as shown in Figure 27. The Hawr-Al-Azim is the portion of Al Hawizeh that lies in Iranian territory (21% in 1973), and constitutes the heart of the marsh system. It has not been radically affected by the drainage of the marshes in Iraq, or by the upstream diversions on the Tigris and Euphrates rivers. Sadly, the surrounding marsh system has contracted dramatically in just 30 years, with the loss of 7,600 km^2 of primary wetlands, and their associate ecosystems, flora, fauna and services. As the surrounding marsh has shrunk, the proportion covered by Hawr-Al-Azim has risen to 29% in 2000, despite its area also decreasing by almost 50% (Table 9). The main fear now is that the remaining core of the marsh will shrink further due to water retention and diversion from the newly completed Karkheh Dam (UNEP 2001).

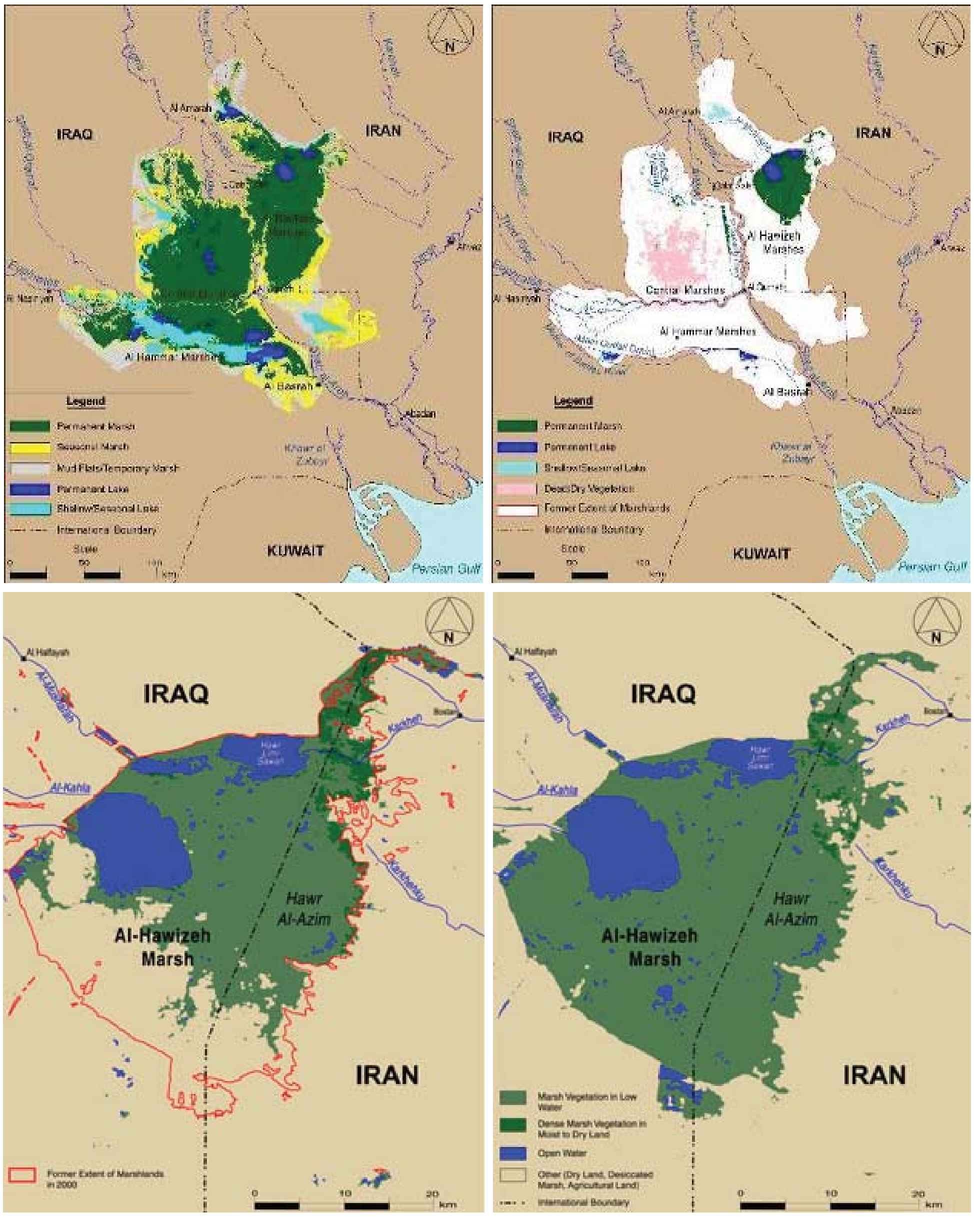


FIGURE 27. Mesopotamian Marshlands; 1973-76 and 2000 (left) and changes in the surface area of Hawr Al Azim, 2000–2002 (right) (*Source*: UNEP 2001).

TABLE 9. Area changes in Hawizeh (Hawr-Al-Azim) marshes in square kilometers (km^2), 1973-2000 (*Source:* UNEP 2001).

Hawr-Al-Azim	1973-1976 (a)	2000 (b)	Percentage change (b/a)
Permanent marshes	622.8	295.6	47.5
Permanent lakes	3.0	1.0	33.0
Seasonal/shallow lakes	15.4	0.3	2.0
Total	641.2	296.9	46.3

Analysis of Landsat satellite imagery shows that the surviving Mesopotamian marshlands contracted again by 30% from 1,084 km^2 in 2000 to only 759 km^2 in 2002. This coincides with a drought period but precedes the completion and filling of the Karkheh Dam. It was predicted that if losses continued at the same rate, the marshes would totally vanish by the year 2008 (UNEP 2001), but this has not happened, partly because, once the dam had filled, some Karkheh flows passed through to the marshes.

The main inhabitants of Iraqi and Iranian parts of the wetland are Marsh Arabs. They are a unique community that have lived in the area for 5,000 years, and who provide a living link between Iraqis and their Mesopotamian ancestry (UNEP 2001). Their population has declined dramatically from the 500,000 souls living there in the early 1970s; many were killed by Iraqi military action and many others fled to Iran after the Gulf War. About 40,000 settled in Khuzestan in the 1990s, in the Hawr-Al-Azim, but many returned later after the regime of Saddam Hussein was ousted.

CONCLUSION

The Karkheh Basin has a long and fascinating history, with some of the earliest examples of irrigation, agriculture and water engineering, not to mention cities, dating from the Mesopotamian Era. The basin has been at a physical and cultural crossroads, with nomadic pastoralism replacing settled agriculture for many hundreds of years up to the twentieth century.

The cultivated area has grown steadily since 1900, with a significant increase in population and urbanization. Pastoral lands were converted to rainfed agriculture in the upper basin, and rainfed lands have steadily been converted to irrigation, using surface water and groundwater, whilst new lowland areas have been serviced by dams and canals. The total cultivated area has doubled to 1.7 Mha in the last 20 years.

Groundwater has played a major role in recent irrigation development, and was given a major boost by the availability of cost-effective pumps and motors, stabilization policies in the Iran-Iraq War and the recent severe drought from 1999 to 2004. Although sponsored or incentivized by the state, most of the groundwater development has been private. The development of large-scale surface irrigation has been carried out by the government and has involved major costs. Emerging evidence indicates that groundwater is not closely connected to surface water in the upper basin and that, despite considerable reductions in average depth of the water table, there has been little impact on surface flows. The available flow data indicates minimal impacts and depletion of surface flows in the upper basin, but the recent completion of the Karkheh Dam, with a storage capacity in excess of mean annual flow, will significantly change the water balance downstream, with special concern now being raised on the potential impacts on the Hawr-Al-Azim swamp.

The development of the surface irrigation network to utilize much of the water stored in the Karkheh Dam is well behind schedule and, now that the reservoir has filled, it is likely that surface flows to the swamp will be partially restored. At the same time, existing irrigation has already exacerbated extensive waterlogging and salinity in the lowland plains. The marshes have long been saline but have nevertheless supported an established, but now largely vanished, agricultural community of Marsh Arabs.

The basin has leaped from a stage of relatively underdeveloped water use, to close to full commitment of available water resources in the space of 40 years – arguably simply through the completion of the Karkheh Dam. Concern over excessive groundwater use prompted regulatory restriction on licenses and pumped volume, but since the ordinances have not been enforced, groundwater mining continues.

River flows are measured by an impressive network of gauges but actual abstractions, particularly those from large pumps in the lower basin, are not fully accounted for. The basin is perhaps unusual in that the total volume of water resources (as a proportion of incoming rainfall) used for irrigation is very modest (1.2 BCM of evapotranspiration from 3 BCM of diverted water) and represents a small proportion of the total depletion (16-18 BCM). This depletion is a relatively large fraction of the total volume of rainfall of 18.5-25 BCM per year, since the area is relatively large, arid, and experiences extremely high summer temperatures with correspondingly high evaporative demand. There remains considerable potential to improve the efficiency and productivity of irrigation water use in the basin, which has an important bearing on the sustainable use of groundwater, and in minimizing waterlogging and salinity in the lowland areas. Although per-capita domestic water consumption is relatively high by world standards, it still accounts for less than 7% of abstractions and further demand could easily be sourced from savings in agricultural water consumption.

There is much concern over continuing land use change in the upper catchment, despite a static rural population: most of the net population growth in the region has taken place in the towns through a combination of migration and internal growth. However, many urban dwellers maintain close links with their villages and lands and continue part-time farming. Pressures on the uplands include loss of forest, conversion of marginal and steeper lands to grazing on the periphery of the valleys, and conversion of rangeland to rainfed agriculture. Stocking rates have risen considerably with the availability of bought-in feed and crop residues, but rangelands are thought to be increasingly overstocked and vulnerable to degradation.

However, erosion rates in the basin have always been high and mountainous areas contribute a significant portion of the bed load carried in the rivers. The future of large dams and irrigation systems is very dependent on avoiding sedimentation in channels and reservoirs. A major programme of dam construction has been proposed and is partly under way to protect the Karkheh Dam with a cascade of sediment trapping, hydroelectric dams.

The basin has a high strategic importance for Iran, as it is the home of almost 90% of its oil production and also accounts for the major part of natural gas resources. It contains a mix of cultures and nationalities, whose allegiance to central authority has only been cemented in the twentieth century. The region has suffered massively during the Iran-Iraq War and has, therefore, been of special political and development interest to Tehran.

The major challenges facing the basin are the sustainable use of groundwater, surface water and land resources to maintain rural incomes and contribute surpluses to national food security. Well thought-out policies on groundwater use are required and need to be implemented firmly and fairly. The Hawr-Al-Azim swamp is firmly in the international spotlight, and considerable work needs to be done to design and manage environmental allocations to maintain the swamp, coupled to the smart use of stored water, so that the irrigation it allows does not degrade and destroy the landscape through further waterlogging and salinity. Oil from the region generates a massive amount of national wealth, some of which has been used in large-scale infrastructure development projects throughout the basin. Although the rural population is not by any means the poorest in the country and benefits from a generous social security system, it is still slipping behind urban and industrial standards and this will increase political pressure to support and intervene in the region. The main solution that has been adopted is to provide more irrigation, but it remains to be seen whether this will deliver the required rural prosperity and avoid damaging the fragile ecosystem that supports farming in the region.

APPENDIX 1. WATER ACCOUNTING DEFINITIONS.

Gross inflow is the total amount of water flowing into the water-balance domain from precipitation and from surface and subsurface sources.

Net inflow is the gross inflow plus any changes in storage.

Water depletion is a use or removal of water from a water basin that renders it unavailable for further use. Water depletion is a key concept for water accounting, as interest is focused mostly on the productivity and the derived benefits per unit of water depleted. It is extremely important to distinguish water depletion from water diverted to a service or use, as not all water diverted to a use is depleted. Water is depleted by four generic processes:

> ***Evaporation:*** water is vaporized from surfaces or transpired by plants.
>
> ***Flows to sinks:*** water flows into a sea, saline groundwater or other location where it is not readily or economically recovered for reuse.
>
> ***Pollution:*** water quality gets degraded to an extent where it is unfit for certain uses.
>
> ***Incorporation into a product:*** through an industrial or agricultural process, such as bottling water or incorporation of water into plant tissues.

Process consumption is that amount of water diverted and depleted to produce an intended product.

Non-process depletion occurs when water is depleted, but not by the process for which it was intended.

Non-process depletion can be either ***beneficial*** or ***non-beneficial.***

Committed water is that part of the outflow from the water-balance domain that is committed to meet other uses, such as downstream environmental requirements or downstream water rights.

Uncommitted outflow is water that is not depleted or committed and is, therefore, available for a use within the domain, but flows out of the domain due to lack of storage or sufficient operational measures.

> Uncommitted outflow can be classified as ***utilizable*** or ***non-utilizable***. Outflow is utilizable if by improved management of existing facilities it could be used consumptively. Non-utilizable uncommitted outflow exists when the facilities are not sufficient to capture the otherwise utilizable outflow.

Available water is the net inflow minus both the amount of water set aside for committed uses and the non-utilizable uncommitted outflow. It represents the amount of water available for use at the basin, service or use levels. Available water includes process and non-process depletion plus utilizable outflows.

A ***closed basin*** is one where all available water is depleted.

An ***open basin*** is one where there is still some uncommitted utilizable outflow.

In a ***fully committed basin,*** there are no uncommitted outflows. All inflowing water is committed to various uses.

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ISSN 2012-5763
ISBN 978-92-9090-723-7