CGIAR Challenge Program on
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POLICIES, INSTITUTIONS AND ECONOMIES OF WATER RESOURCES AND MANAGEMENT IN THE KARKHEH RIVER BASIN OF IRAN

Editors: A. Keshavarz, H. Dehghanisanij, H. Asadi, T. Oweis, and A.M. Abdelwahab

Improving On-Farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF - PN8)

10

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Research Report no. 10

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Contents

Executive summary

This research report addresses researchers, farmers, decision and policy makers and public and private organizations involved in land and water development in the Karkheh River Basin (KRB) of Iran.

While the first chapter assesses the policies and institutional arrangements in the KRB, the second chapter focuses on the economic factors of on-farm water use efficiency in irrigated cereals in the lower part of the basin.

In 1982, a law on the Equitable Distribution of Water was enacted. It consists of five chapters, 52 articles and 27 notes. The main chapters are: (i) public and national ownership of water, (ii) groundwater resources, (iii) surface water resources, (iv) duties and authorities, (v) penalties and regulations. But despite this law, water management in the KRB is characterized by complex, overlapping, and sometimes competing networks of actors, rules, functions, and organizations which has caused delays in timely water delivery to farmers in the area. Even though several water policies, strategies, laws, and regulations exist, effective water resources development is yet to be achieved.

Reforms are needed to contribute to poverty reduction, environmental sustainability, gender inequity, and water pricing. These reforms should create a framework for the development of relationships among key governance actors, non-governmental organizations, civil society, the private sector and farmers to identify the most effective use of resources and methods of management. Because incentives failed to fully engage poor people in governing water resources, the state needs to practice its authority to enhance their voice and benefits.

Chapter two presents the study that was carried out in irrigated cereal fields in the Azadegan (DA) and Sorkheh (DS) plains in the lower Karkheh River Basin in 2006–2007. It was suggested that varieties tolerant to water shortages and salinity be developed and introduced to the region.

With regard to the low water productivity of various crops in this part of the KRB, it was recommended that optimized management of different inputs, particularly water, be extended in the area and the selection of exemplary farmers be based on high production and low water consumption.

Since the majority and the exemplary farmers believed that irrigation development would increase income and stabilize production, it is recommended that proper planning be designed for water development and increased water productivity.

Since farmers are receiving most of their information on optimal water management from the mass media, it is suggested that the national TV networks broadcast suitable programs on the advantages of optimum use of agricultural inputs and provide the needed information.

Extension agents should carry out more participatory projects with farmers and organize farmers' days to extend the best agricultural management practices, including the use of improved varieties and new irrigation methods

Chapter 1.

Assessing policies and institutional arrangements in the Karkheh River Basin of Iran

A. Keshavarz, H. Dehghanisanij, M.A. Ahmed and T. Oweis

Chapter 1. Assessing policies and institutional arrangements in the Karkheh River Basin of Iran

A. Keshavarz, H. Dehghanisanij, M.A. Ahmed and T. Oweis

1.1 Introduction

Due to increasing competition for water between different sectors, pressure to reduce agricultural water use is mounting, especially in arid and semi-arid regions. As opportunities for the development of new water resources are limited and costs are rising, increasing the productivity of existing water resources seems a realistic target. Improving agricultural water productivity is central to both economic and social development. When agriculture falters, sources of income are lost, social ties are disrupted and as a result, societies become more vulnerable.

The agricultural sector in Iran is one of the most important economic sectors in the country. According to the Forecast Update (2009), agriculture provides 18 per cent of GDP, 25 per cent of employment, 85 per cent of food production, 25 per cent of non-oil exports, and 90 per cent of raw materials used in industry. Because of the global rise in oil prices, agriculture's contribution to GDP decreased to 10.4 per cent in 2005 (National Report, 2005).

Future prosperity in Iran will also depend to a considerable extent on how well the country develops freshwater resources and how efficiently they are used. Despite water shortages, the overuse of water for irrigation is a major problem in many river basins of Iran. This situation is directly attributable to the low water-use efficiency of irrigation systems and poor water management at the farm and basin levels (Dehghanisanij *et al.,* 2006).

Since the 1960s, irrigated agriculture has played an important role in feeding the growing world population and this is expected to continue in future (Cai and Rosegrant, 2003). However, water availability for irrigation in developing countries (at present over 90 per cent of water resources are used for irrigation) must be reduced due to increasing demand for water from non-agricultural sectors. The situation in the KRB does not differ much from that in other parts of the world where about 93 per cent of total water withdrawals are used to meet agricultural requirements. Due to increased benefits from irrigated agriculture (average yields in irrigated areas are three times higher than in rainfed areas) more and more farmers are turning to irrigation to increase farm profits. In the absence of sufficient surface-water resources, groundwater use in the basin has increased many-fold over the last two decades (Dehghanisanij, 2008). The future of irrigated agriculture, which is responsible for more than 60 per cent of total grain production, is threatened by low crop yields, low water-use efficiency and increasing salinity and water-logging problems. Average water productivities of annual crops, such as wheat and barley, are 0.5 kg/m^3, which are far lower than the 0.9 kg/m^3 seen in neighboring Syria (Oweis and Hachum, 2003). This clearly demonstrates that there is ample scope for improvement in crop water productivity.

To harness the true potential of agricultural production in the KRB, equal attention must be given to rainfed production systems. This is because rainfed agriculture in the KRB accounts for half of the cultivated area and will remain the dominant source of crop production for the foreseeable future.

Average grain production in rainfed areas is rather low: 920 kg/ha for wheat, 950 kg/ha for barley and about 500 kg/ha for chickpea. Rain water productivity of rainfed land ranges from 0.3–0.5 kg/m^3, far lower than the average regional values of 0.7–0.8 kg/m^3 (Ashrafi and Keshavarz, 2004). This is the reason why, despite occupying 50 per cent of agricultural land, rainfed agriculture contributes only about 20 per cent of total food production in the KRB. Studies have suggested that low productivity in rainfed agriculture is due more to sub-optimal levels of management than to low physical potential (Rockstrom and Falkenmark, 2000; SIWI, 2001). This is also true for the KRB. This implies that improvements in productivity of rainfed agricultural systems in KRB can contribute significantly to meeting the food requirements of the country.

Karkheh reservoir and the Horolazim swamp are the main water bodies in the lower part of the basin. Agricultural activities and the development and construction of the irrigation and drainage network in the KRB, together with industrial development and rural and urban population growth are the main sources of environment contamination in the KRB. The establishment of Karkheh dam, flood controls, and the operation of irrigation and drainage projects, all influence environmental conditions in the KRB.

The problems of agriculture in the KRB are complex as the cultivable areas are almost exhausted and the possibility of increasing water resources is very limited. Therefore to meet the food demands of an increasing population, additional crop production will have to be accomplished mainly through increasing the productivity of the available water resources (Ashrafi and Keshavarz, 2004). The hypothesis of improved agricultural water productivity (WP) is that WP in the KRB could be substantially increased by improving on-farm irrigation management, introducing precision irrigation, introducing new crop varieties, adjusting cropping patterns, and integrating appropriate agronomic practices into the crop production system with suitable institutional setup and policies.

The objective of this study is to assess water use and related policies and institutions influencing water use in the KRB based on a review of the available policy documents as well as secondary and stakeholder survey data. In the next section of this report, we describe the farming systems of the KRB and their importance. Then we describe the natural resources of the basin. In the fourth section, we review water and water-related policies and institutions involved in water management in the KRB. The following section assesses water policies and the institutional environment, and it is followed by some conclusions and recommendations.

1.2 Karkheh River Basin

The Karkheh River Basin (KRB) is situated in the west of Iran. It is located between 30°53' and 34°57' N and 46° and 49° E (Figure 1.1). This basin is one of the most productive agricultural areas in the country. It accounts for 10 per cent of the total irrigated land and produces more than nine per cent of the total crop production of Iran (Marjanizadeh, 2008). The upper KRB is the main area for pulse production in Iran. Pulse production in KRB was 0.105 and 0.132 million tons in 1996 and 2005, constituting 37 per cent and 20.5 per cent, respectively, of pulse production in the country.

The climate in the KRB is mainly semi-arid with large variations in average

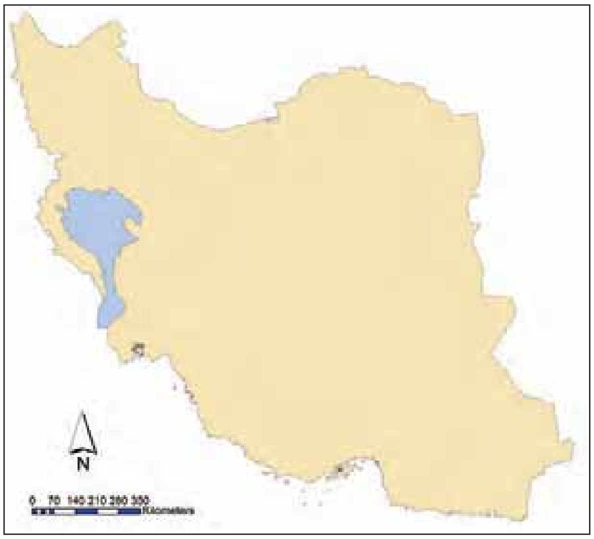


Fig. 1.1. Location of the Karkheh River Basin (KRB)

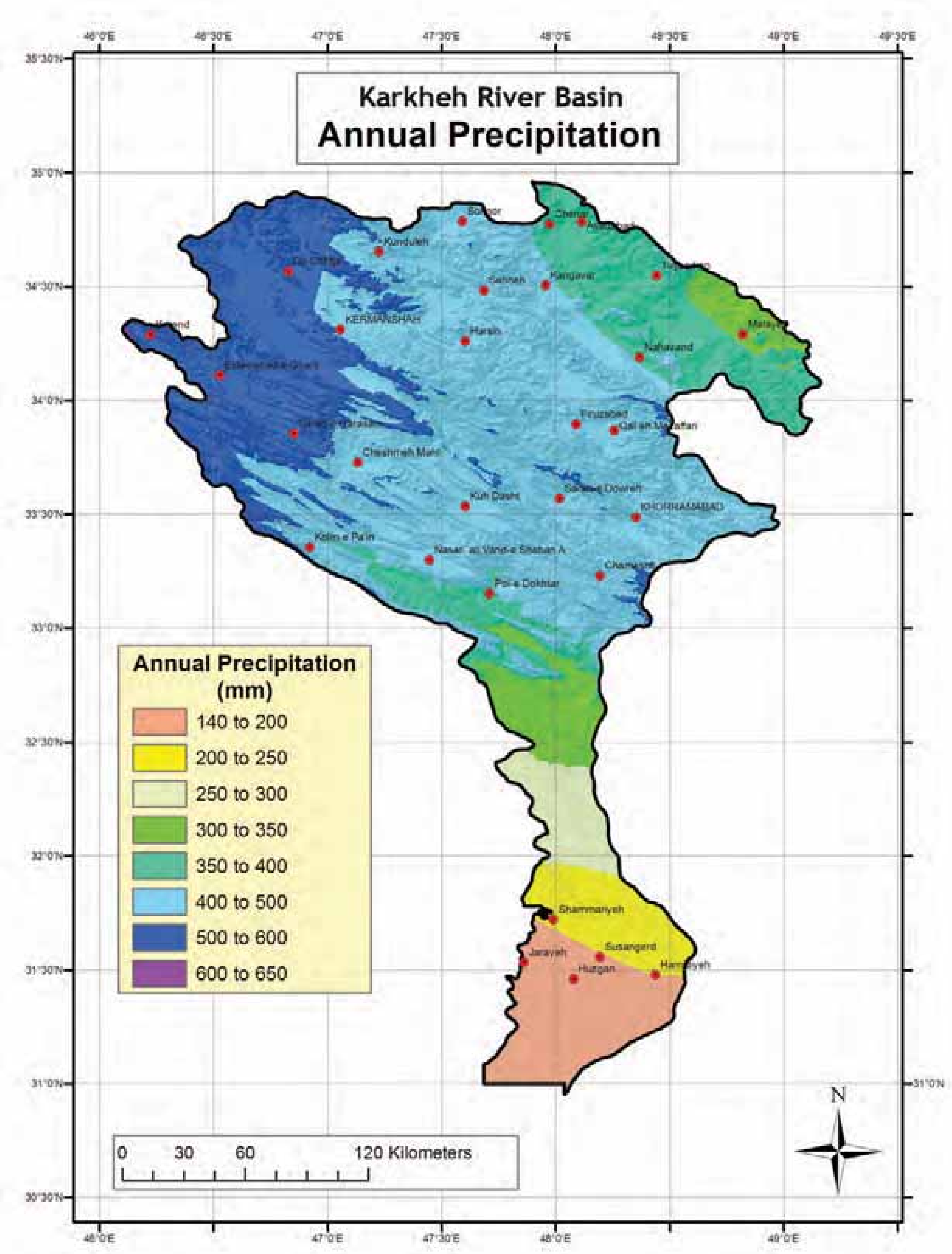
annual precipitation between the southern and northern areas. About 60 per cent of the KRB has a semi-arid climate, with most areas having a fairly warm climate (cool to mild winters with warm to very warm summers), however, 20 per cent of the basin is much cooler with cold winters. Irrigation is prominent in less than 10 per cent of the KRB. A considerable area (nine per cent) is also occupied by 'badlands'. In southern areas, average annual precipitation is about 150 mm whereas in the north it can be up to 750 mm (Figure 1.2). About 75 per cent of total rainfall falls in the first six months (January–June) of the year with over 50 per cent in just the three winter months (January–March). The remaining 25 per cent falls mainly in autumn (October–December) leaving the summer almost completely dry. Due to high temperatures in the southern areas of the KRB, about 65 per cent of the rainfall evaporates without being put to any beneficial use.

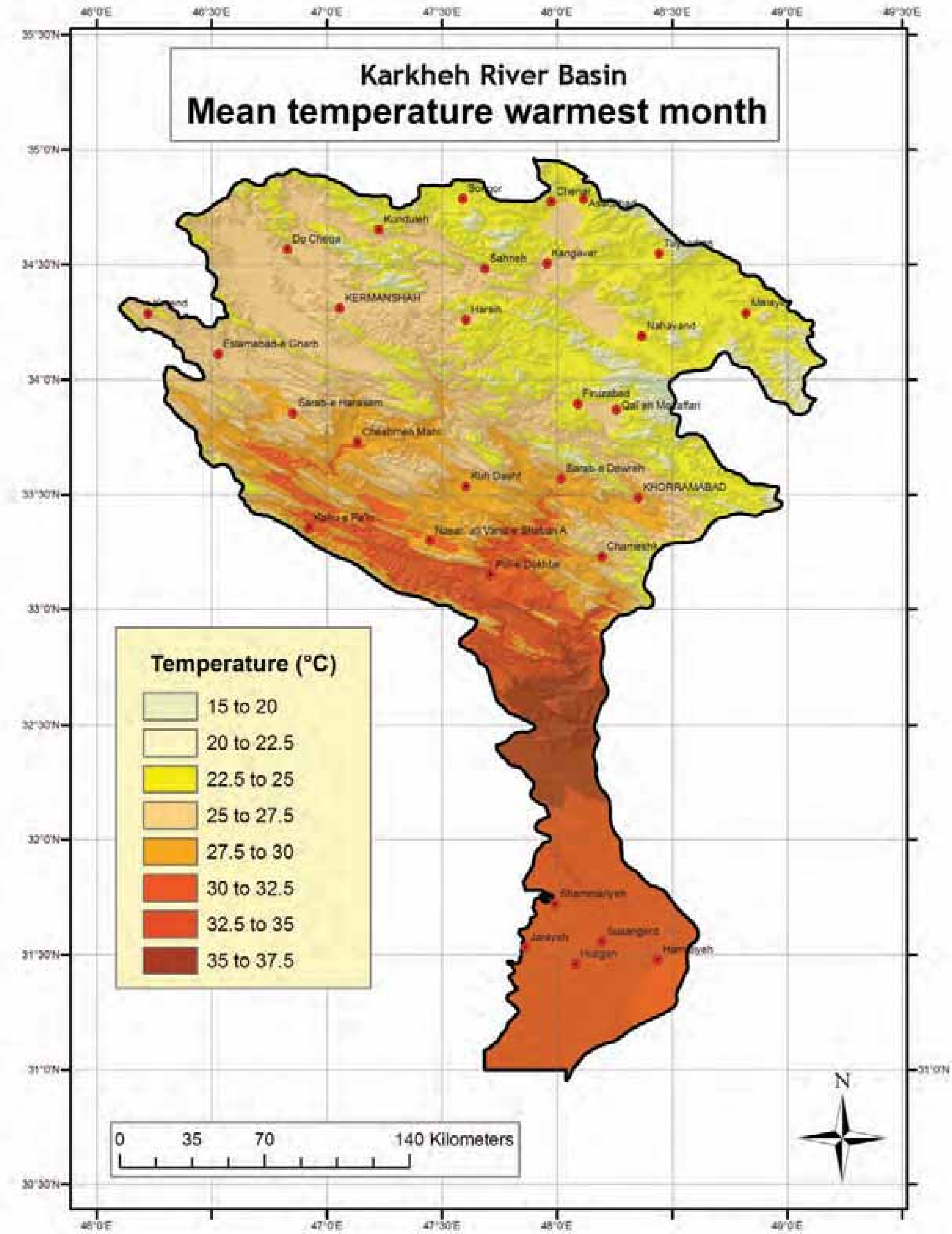
Evaporative demand of the KRB is very high. Class A pan evaporation in the basin ranges from 2000–3600 mm per year, of which 50 per cent occurs in just the three summer months. Therefore, on average, two cubic meters of water evaporate from one square meter of the reservoir surface.

The population of the KRB was about three million in 1996, increasing to 3.6 million in 2005. Maximum unemployment rate in the country in 1996 was 15.8 per cent and this was in the KRB. Total employment in the agricultural sector was 28 per cent in 1996 with no increase in 2005. The available water resources of the country are insufficient to support the increasing demand for food and competition for water by other sectors. The availability of freshwater resources is projected to decrease in the future.

KRB has now become an area of water shortage and the increasing incidence of drought has further compounded the problem. As a result, livelihoods in the rural communities are at stake especially in rainfed areas. Considering the present pace of deterioration, it is envisaged that the situation will worsen further in the near future.

To address these water shortages and low water productivity, the Government of Iran began construction of the Karkheh dam and the associated irrigation network in 1990. Irrigation systems management on farms downstream of the dam was improved by land leveling and developing furrow surface irrigation at the farm level. The Karkheh dam was completed in 1999 and became operational two years later. The Karkheh irrigation network (KIN) will cover an area of 343,260 ha in the lower KRB. Total investment in the Karkheh dam was US$410 million and total investment in the KIN is about US$347 million of which 66.5 per cent is supported by the flow and the rest (36.5 per cent) by the private sector. In the upper KRB, the decision was to expand pressurized irrigation systems, which now cover 27,000 ha of the agricultural area.


Karkheh River Basin
Annual Precipitation
Annual Precipitation (mm)
140 to 200
200 to 250
250 to 300
300 to 350
350 to 400
400 to 500
500 to 600
600 to 650
0 30 60 120 Kilometers
N
KERMANSHAH
KHORRAMABAD
Kunduleh
Kangavar
Harsin
Nahavand
Firuzabad
Chashmeh Mahi
Kuh Dasht
Kolm e Pa'in
Pol-e Dokhtar
Shamkhaniyeh
Susangerd
Jarayeh
Hutgan
Hamidiyeh
Songor
Sahneh
Malayer



Karkheh River Basin
Mean temperature warmest month
Temperature (°C)
15 to 20
20 to 22.5
22.5 to 25
25 to 27.5
27.5 to 30
30 to 32.5
32.5 to 35
35 to 37.5
0 35 70 140 Kilometers
N
KERMANSHAH
KHORRAMABAD

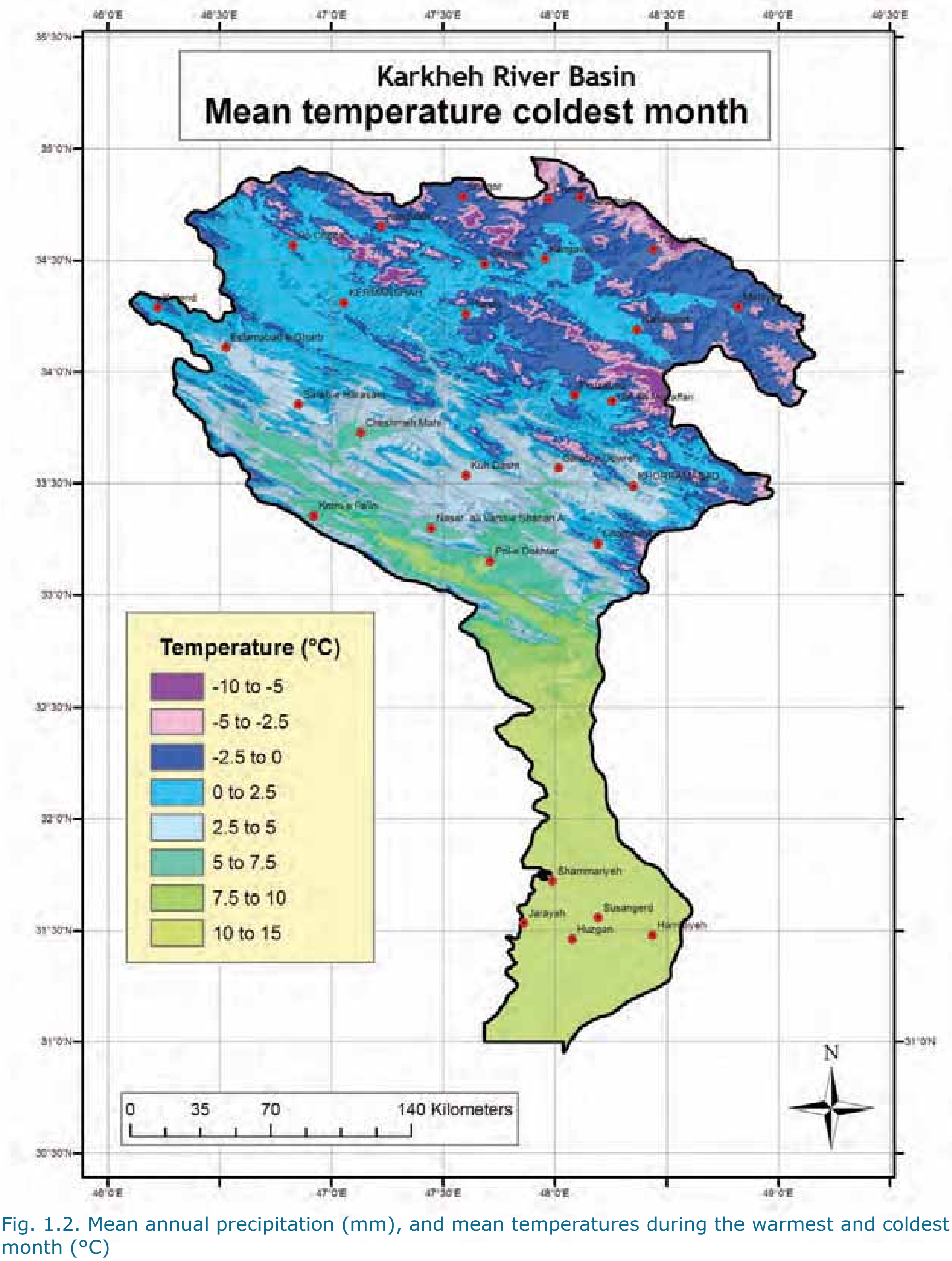


Fig. 1.2. Mean annual precipitation (mm), and mean temperatures during the warmest and coldest month (°C)

In the lower areas, two organizations were developed to control, manage, and allocate water coming from the Karkheh dam among the farmers and agro-industries in the upper and lower areas of the KIN. Here, the Ministry of Jihad-e-Agriculture established local agricultural offices to improve farming systems at the farm level for the entire irrigation network.

1.3 Farming systems in the KRB

Total annual crop production in Iran was about 39 million tons (M tons) in 1996, of which 1.5 M tons (3.7 per cent) was produced in the KRB. These figures increased to more than 70 M tons and about 3.3 M tons in 2005 (Figure 1.3). National wheat production was 10.0 and 14.3 M tons in 1996 and 2005, while barley production was 2.7 and 2.8 M tons (Ministry of Jihad-e-Agriculture, 2007). From the food security point of view, KRB wheat production was 0.84 M tons and 1.4 M tons in 1996 and 2005, contributing 12.2 per cent and 10.0 per cent to the national production. In the case of barley, KRB production contributed 11.0 per cent and 16.5 per cent to the national production in 1996 and 2005. In 2005, KRB produced 0.35 M tons of maize, which contributed 17.8 per cent to the national production of 1.99 M. tons. From 1998 to 2000, the country experienced a serious drought when average rainfall decreased to about 175 mm in contrast to the long-term average of about 252 mm. The impact of drought on the agricultural areas and production of annual crops during this period is shown in (Figure 1.3).

Two major agricultural production systems are present in the KRB. Dryland farming systems (rainfed) prevail upstream while fully irrigated systems are located mainly downstream. The areas under dryland farming systems are well established and occupy about 894,000 ha, while irrigated land currently occupies nearly 379,000 ha, that is expected to increase to 805,000 ha after new irrigation networks are completed and put into full operation. Total agricultural area and production in irrigated and dryland farming in the KRB are shown in (Figure 1.4). The total agricultural area (irrigated and dryland) has not changed much between 1995 and 2005. However, total production increased significantly after the three years of drought from 1998 to 2000, especially in irrigated agriculture. Increased production in the irrigated areas is attributed to the development of irrigation technology, mainly irrigation networks in the lower KRB.

1.3.1 Rainfed agricultural production systems

The upper catchments of the KRB are considered the most suitable zones in the country for dryland farming (rainfed) with an average annual precipitation of 350–500 mm. Most of the rainfall falls in winter, i.e. December to April. Average land holding is about four ha. The main cropping system is dryland with some irrigated farming. Irrigation is mainly from natural surface streams and groundwater. Irrigation development is slow as the KRB is not the priority region for the development of irrigation infrastructure. Wells are drilled at a depth of 50–100 m while the water table is around 20–25 m.

This cropping system covers nearly 894,000 ha. Most of the land is under dryland farming but some supplemental and full irrigation systems are also present. In the upper catchments, fully irrigated systems cover about 250,000 ha (JAMAB, 2000). In the northern sub-basins, more areas are coming under full

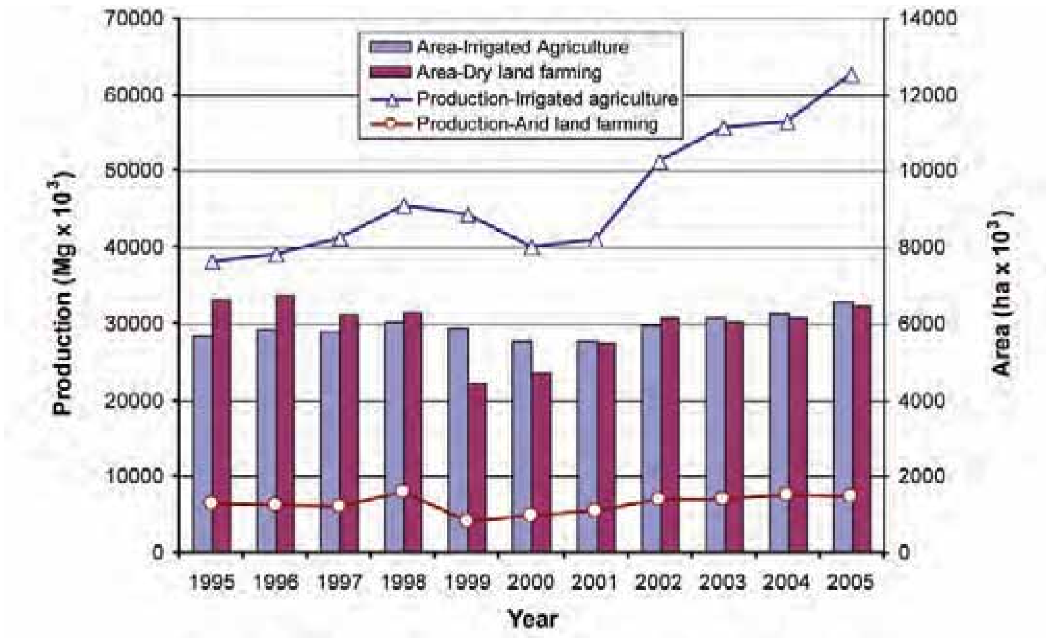


Fig. 1.3. Total agricultural area and production of annual crops in Iran from 1996–2005 for irrigated and dryland farming

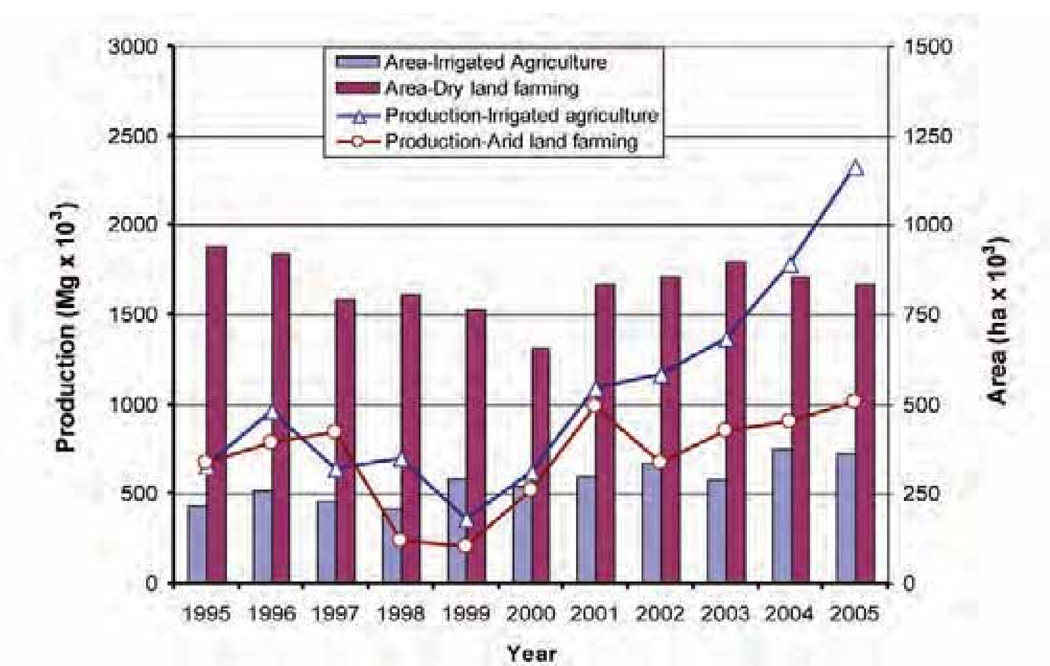


Fig. 1.4.Total agricultural area and production of annual crops in KRB from 1995–2005 for irrigated and dryland farming

and supplemental irrigation. Land and water productivity in the rainfed area is very low (0.4 kg/m^3). The major crops in these systems are cereals in rotation with pulses/legumes.

In rainfed areas, wheat is the dominant crop in rotation with barley and pulses (chickpea). In the irrigated land, wheat is also the dominant crop in rotation with maize, alfalfa, sugar beet and vegetables. Orchards are also important in the area with a marked dominance of olives, but they also include apples, nuts, pears, citrus, pomegranates, figs and grapes (Table 1.1). As agriculture in this area is susceptible to weather conditions especially rainfall, animal husbandry and livestock production is considered more reliable for rural livelihoods.

Wheat, barley, and pulses (mainly chickpea) occupy 47 per cent, 33 per cent and 18 per cent of the rainfed area, respectively (Table 1.1). Accordingly, wheat is the main crop in rainfed areas followed by barley and pulses. However, due to irregular precipitation and rainfall fluctuations between seasons, variations in agro-climatic conditions and lack of appropriate agro-management measures, productivity is below potential.

1.3.2 Irrigated agricultural production systems

The cultivated area under irrigated wheat in the KRB increased from 125,000 ha in 1996 to nearly 250,000 ha in 2005 (Figure 1.5). However maize and barley cultivation showed no noticeable increase. Expansion of the irrigated area is attributed mainly to irrigation network development and land leveling.

The area downstream of Karkheh dam, including the area under the Karkheh dam tunnel and the lower parts of the

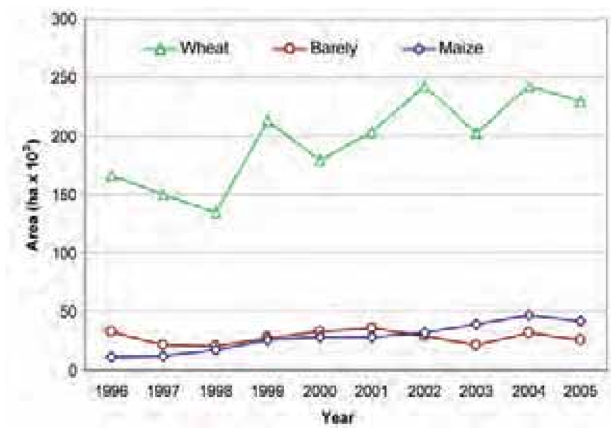


Fig. 1.5. Total area under cultivation with major crops in the KRB irrigated area from 1995–2005

Table 1.1. Cropping patterns in the upper KRB (2004).

Total area under cultivation		Area (x1000 ha)				Area (ha)	Cultivation system
		Rainfed agriculture		Irrigated agriculture			
(%)	(ha)	(%)	(ha)	(%)	(ha)		
52.8	574.8	47.4	407.0	72.5	167.8	Wheat	Main cropping pattern
27.6	300.7	33.5	287.0	5.9	13.7	Barley	
14.0	153.0	17.8	153.0	–	–	Pulses	
4.2	46.0	–	–	19.9	46.0	Maize	
0.4	4.0	–	–	1.7	4.0	Vegetables and summer crops	
1.0	11.1	1.3	11.1	–	–	Fallow	
100	**1089.6**	**100**	**858.1**	**100**	**231.5**	**Total**	

dam, is fully irrigated. The average annual rainfall in these areas ranges from 100 to 300 mm. The total irrigated area in the lower KRB is about 114,000 ha, which is expected to increase to 341,060 ha after completion of irrigation network development in Dasht Abbas, Evan, Dusaif, Ardyez, and the Bageh plains. This area is suitable for a wide range of crops. Presently, wheat, barley, maize, vegetables and summer crops are the most popular. Wheat, barley and maize are the three major crops in the KRB irrigated area (Table 1.2).

field application. As a result, irrigation efficiencies are low and land and water resources are at risk of quality degradation. Overall irrigation efficiency of the traditional networks in Dasht-Azadegan (southern KRB) ranges from 14 to 23 per cent (Ashrafi and Keshavarz, 2004) as compared to the neighboring Dez basin where irrigation efficiencies are from 32 to 37 per cent (Fatemi *et al.,* 1994). Water productivities for annual crops such as wheat and barley are less than 0.5 kg/m^3. The major reasons for these low efficiencies are inadequate

Table 1.2. Cropping patterns in the lower KRB.

Total area under cultivation		**Area (ha)**				**Crops**	**Cultivation system**
		Rainfed agriculture		**Irrigated agriculture**			
(%)	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**		
65.9	76,104	93.3	1400	65.5	74,704	Wheat	Main cropping pattern
15.5	17,930	6.7	100	15.6	17,830	Barley	
0.5	524	–	–	0.5	524	Maize	
4.2	4855	–	–	4.3	4855	Vegetables and summer crops	
0.2	235	–	–	0.2	235	Gardens	
13.7	15,846	–	–	13.9	15,846	Fallow	
100	**115,494**	**100**	**1500**	**100**	**113,994**	**Total**	

Due to the increasing availability of water in this area, annual cropping intensities have increased to about 120 per cent. Field sizes range from one to four hectares. Farmers are still applying irrigation using basin/border irrigation methods. Most fields are not very well leveled, which is causing patches of low and high infiltration within the same field. This in turn affects overall productivity and results in poor water-use efficiency. As a result, the area experiences high groundwater abstraction.

In the lower KRB, some irrigation water is lost during conveyance and

water delivery systems and inefficient on-farm water management practices. This not only reduces water availability for other crops in the region but also creates drainage and associated salinity problems. If the present irrigation management practices continue, resource degradation threats are expected to increase in future with wider impacts.

1.3.3 Socioeconomic characteristics of the KRB

KRB is located in the west of the country; all parts of the basin south of the Karkheh dam to the Horolazim swamp, border Iraq, as does a small area north of the dam. The western boundary of the basin is also near the border.

Consequently, the region experienced outmigration during the war between Iraq and Iran. Residents gradually returned to the area after the cease-fire, and so variations in the population in most parts of the KRB do not show a constant trend from both the number or constitution point of view.

Population studies in the basin must take into account these effects of war and migration. The population of the lower KRB was the most affected. The population growth rate in the area does not show the normal trend, for instance, a total population of 295,000 in 1996 increased to 403,000 in 2003. The total population of the basin reached about 4 million after the war as residents returned to their home towns. Of the total population, 47 per cent live in urban areas and 53 per cent in rural areas (nationally, 38 per cent live in rural areas). This could be due to the economic lag and people's relationship with agriculture. It should be noted that urban population growth has been higher than that in rural areas over 1996–2003.

The percentage of literate people in rural and urban areas varies according to age and gender. More than 92 per cent of the urban population between 6 and 24 years old are literate. However, in rural areas, about 89 per cent of men and less than 60 per cent of women are literate. The number of literate men is more than 60 per cent in the over 25 year age group, while for women of the same age this percentage is less than 30 per cent. This rate in rural areas is more than 50 per cent and less than 12 per cent, respectively.

Employment

The average unemployment rate in the basin was about 16 per cent (five per cent higher than the country average), about 17 per cent and 15 per cent for urban and rural areas, respectively. The unemployment rate for men and women ranged from 13–20 per cent and 14–45 per cent in different areas of the basin. The higher rate for women is due to social and cultural reasons. Consequently, there were more opportunities for men to be employed in the region. However, this rate is less for tribal women and they are always busy and active.

The employment rate in the agricultural sector is about 45 per cent, in the service sector, 43 per cent and in industry, 10 per cent. The national average employment rate in the agricultural sector is 23 per cent. The high employment rate in the agricultural sector in the KRB shows that the KRB has not yet developed adequately.

Horticulture has not developed in the region and more than 91 per cent of agricultural production is mainly field crops. Animal husbandry and livestock production is limited to sheep and cows. The number of animals per rural family is about 30 sheep and five cows.

Quality of life

Most villages have road access (tarmac or dirt road). More than 92 per cent of families have access to electricity and tap drinking water is available for about 82 per cent of the villages. Due to the small population in many of the villages, the establishment of health centers has not been considered economical. However, they have been established in the larger villages. For instance, there are nine centers in Azadegan and two in Dehloran.

There is a health center in five per cent of villages with a population of more than 100.

Land ownership and income per capita

The average area of agricultural landholding is not the same in different areas of the KRB and there are also variations between irrigated and rainfed areas. For instance, in the irrigated areas of the lower KRB, land ownership area varies between 6.5 and 100 ha, while in the north, it is 1.6 and 6.2 ha for irrigated and rainfed land. The annual average family income was US$ 3515, US$ 3368, US$ 4585, US$ 4290, and US$ 1534 for the five years 1998–2002. In 2002 there was a big drop in income due to the drought.

Women

The role of women in employment has already been discussed. Their ownership of land is very limited and in our study only involved about 35 women. They are treated as equal to men in water allocation. There is no council or specific organization for women. They are regarded the same as men from the civil rights point of view and for public services. Women are not active as members of rural councils or other civil organizations because of cultural poverty. For instance, even though they have the right to vote, no woman has ever been nominated for a rural council. Since the KRB has a high potential for agricultural development and women have some knowledge of family health, healthy food and technical expertise, improving women's knowledge and occupational training could be helpful in improving living standards and protecting the environment.

1.4 Natural resources profile and management in the KRB

1.4.1 Land

The surface area of KRB is about 51,000 km^2, of which 55 per cent is comprised of mountains and 45 per cent of plains. Mountainous regions are mostly located in the central and eastern parts, while plains stretch over the northern and southern parts of the basin. The KRB covers 47 agricultural plains and seven provinces – Hamedan, Kermanshah, Lorestan, Ilam, Markazi, Kordestan, and Khuzestan. (Figure 1.6). However, more than 98 per cent of the area is covered by five provinces as Kordestan and Markazi Provinces cover less than two per cent of the total area of the KRB (Ashrafi and Keshavarz, 2004).

The upper catchments of the KRB (about 70 per cent of the KRB area) are located at an elevation of 1000 to 2500 m with the highest point reaching some 3600 m above mean sea level. As a result, these parts of the basin are very cold during winter (December–February) with heavy snow fall. The remaining parts of the KRB slope suddenly towards the south, passing through the Khuzestan plain and finally end in the Horolazim swamp, which extends partly into neighboring Iraq. According to the 1:1,000,000 digitized soil map of Iran, developed in 1996, the KRB is classified in three categories based on soil temperature and moisture regimes (Vesan Consultancy Company, 1996). In most of the upper and central KRB the soil is limestone and the climate is the main factor accounting for changes in soil characteristics. In the upper KRB the soil moisture regime is xeric, with average annual temperatures of 8–15°C. This soil moisture regime is typical of regions with high precipitation during

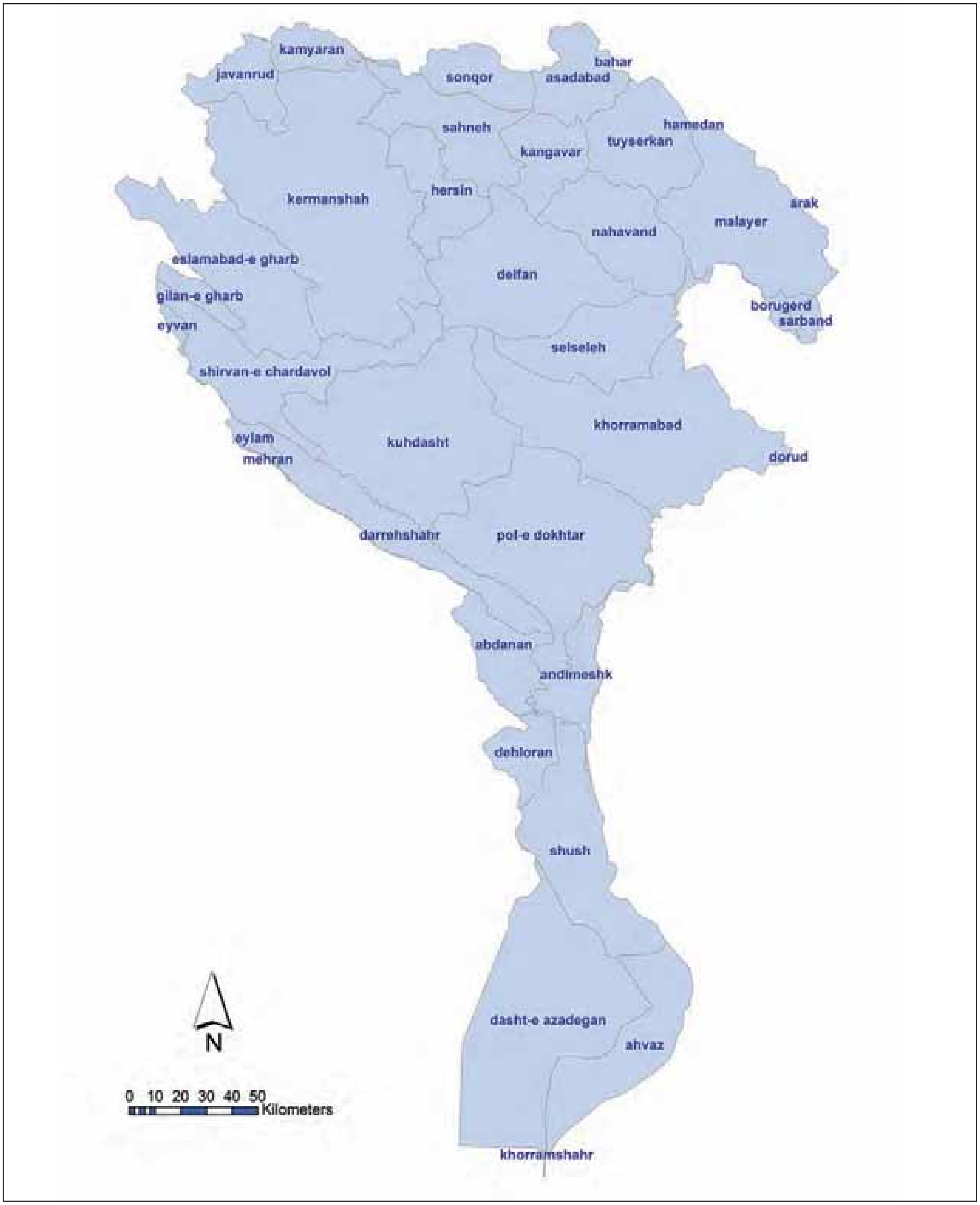


Fig. 1.6. Map of the KRB with district boundaries

winter and a dry summer. These areas are suitable for dryland farming of crops compatible with colder regions, i.e. wheat, barley, chickpea. Due to climatic conditions, oak trees cover the higher land and mountain areas where soil fertility is quite high, especially in the surface soil layers. Surface flows carry the lime from the soil surface layer to the central KRB. Accordingly, soils in these areas are mainly classified as Calcixeralls or Calcixerepts. The area is suitable for animal husbandry, but over-pasturing and non-technical harvesting of trees has led to increased soil erosion. In some areas, the fertile soil layer has been completely removed and the second layer, which is light and lime, is exposed. The Karkheh River carries an average of 32.86 million tons/year of alluvial material, and is the second river in the country in terms of sediment load. Sediment discharge of the KRB, composed of 10 per cent sand, 80 per cent silt and 10 per cent clay, is about 770 tons/year/km, with a concentration of 59.3 g/l.

The central KRB is located between the cold climate of the north and warm climate of the south and the soil has a rustic moisture regime. In these regions, dryland farming is also practical and higher yields may be expected due to the lower precipitation and favorable temperatures. Due to the vegetation cover, which is still obvious in some areas, the soils in these areas are mainly classified as Calciustolls or Calcixerepts. Soils are subject to heavy erosion due to rainstorms and heavy showers together with improper agricultural land management.

The lands of the lower KRB are part of the Khuzestan plateau. Soils are alluvial in nature, formed originally by river flooding. These alluvial areas are flat and soil permeability is low with little slope and poor natural drainage. The soil has an aridic moisture regime typical of regions with an annual precipitation less than evapo-transpiration. Soils are mostly young river deposits of fine texture with little profile development and medium to low infiltration capacity. Surface salinity of these soils fluctuates during the season and generally increases towards south. The soils of these areas are mainly classified as Haplosalids or Torrifluvents.

The downstream area of the Karkheh Basin stretches from the Karkheh dam in the north for more than 100 km southward, where the Karkheh River discharges into the marshlands of Horolazim. The command area of lower Karkheh includes Dasht Abbas, Evan, Dusaleg, Arayez, and Bageh. Agriculture in this sub-basin is largely irrigated, with annual rainfall ranging from 300 mm in the north to 100 mm in the south. About 300,000 ha are further planned to be irrigated through newly extended irrigation and drainage networks.

The large amount of water loss during conveyance and field application has created drainage and associated salinity problems in the downstream sub-basins and lowland areas. The groundwater table is within one to three meters of the soil surface and as a result, soil salinity is increasing. This has created water-logging problems in many areas. An estimate of the total salt-affected soils exceeds 225,000 ha. Salinization has occurred chiefly in the upper soil layers and is mainly of the chloride type. River banks and elevated areas are relatively less saline. Large accumulations of salt are observed in depressions far from the river because of the seepage of river water. Due to degraded land and water quality, crop water productivity and irrigation efficiencies are low and land and water resources are at risk of quality degradation. In the Dasht-e Azadegan (DA) plain, the problem of soil salinity is magnified due the farmers' lack of knowledge and skills and the unavailability of new and improved farming practices. Because of the shortage of water only 70,000 ha of the total of 340,000 ha of the DA area are under cultivation. Based on a semi-detailed soil study in DA, out of a total area of 95,000 ha in DA, 6500 ha are in Class II, 26,800 ha in Class III, 1500 ha in Class IV, and 34,800 ha in Class V; the remainder being in Class VI.

The natural resources of the upper catchments are severely degraded leading to poor vegetation cover, degraded physical and chemical soil properties and a disturbed water balance. About 70 per cent of the forests and 90 per cent of the rangelands are degraded. Consequently, there is widespread erosion and a high sediment load carried downstream (average sediment yield is 920 tons/km^2/year). The major causes of land degradation are conversion of natural pastures to rainfed agriculture, overgrazing and poor drainage of roads.

1.4.2 Water resources

Actual and potential water resources

The Karkheh River emerges from Kermanshah, Lorestan and Kordestan in the Zagros mountain ranges and originates in the karstic springs of Gamasiab and Gharesu and from the Kashkan and Saymareh Rivers. The Kashkan and Saymareh Rivers join together to form the Karkheh River that passes through stony and mountainous paths to reach the Paye Pole station south of Andimeshk. In the central and northern parts of the basin, the river meanders constantly, but from Paye Pole, the entrance to the Khuzestan Plain, it contains alluvium sediments.

The Karkheh River has the highest annual flow of water in Iran, after the Karoun and Dez Rivers. The water resources of the KRB consist of both surface water and groundwater. Average annual rainfall in the basin is 24.9 billion cubic meters (bcm), out of which 5.1 bcm is flood and surface water, 3.4 bcm infiltrates into the groundwater and the remaining 16.4 bcm evaporates directly into the atmosphere. The quality of river (surface) water is generally good, though it varies both seasonally and along the path downstream, reaching up to three dS/m near the final outlet.

The Karkheh Basin has five major sub-basins – Gamasiab, Gharasu, Saymareh, Kashkan, and South Karkheh – as shown in Figure 1.7. These are further divided into147 smaller sub-basins. A brief introduction to the five major sub-basins and their contribution to the total annual inflow to the KRB is given below:

Gamasiab sub-basin includes the northern and north-eastern parts of the basin. This sub-basin includes the branches of the Gamasiab, NahEvand, Mlayer, Toyserkan, Khorram-roud and Dirineh-roud Rivers. The total area of this sub-basin is 11,459 km^2 and agricultural land is highly productive. The average discharge of the Gamasiab River is 34.6 m^3/s, with maximum of 110 m^3/s in March and a minimum of 3.41 m^3/s in September.

Gharasu sub-basin includes the western parts of the basin and the Gharasu is the main river of this sub-basin, although the Razavar, Khersabad and Merk Rivers also contribute to the sub-basin. The area of this sub-basin is 5350 km^2. The average annual discharge of the Gharasu River is 23.3 m^3/s, with a maximum of 73.7 m^3/s in March and a minimum of 4.25 m^3/s in September.

Saymareh sub-basin covers the central and southern parts of the basin and the Saymareh is the main river of this basin. Other streams, such as the Jazman, Abchenar, ChamrEvand, Darredozdan,

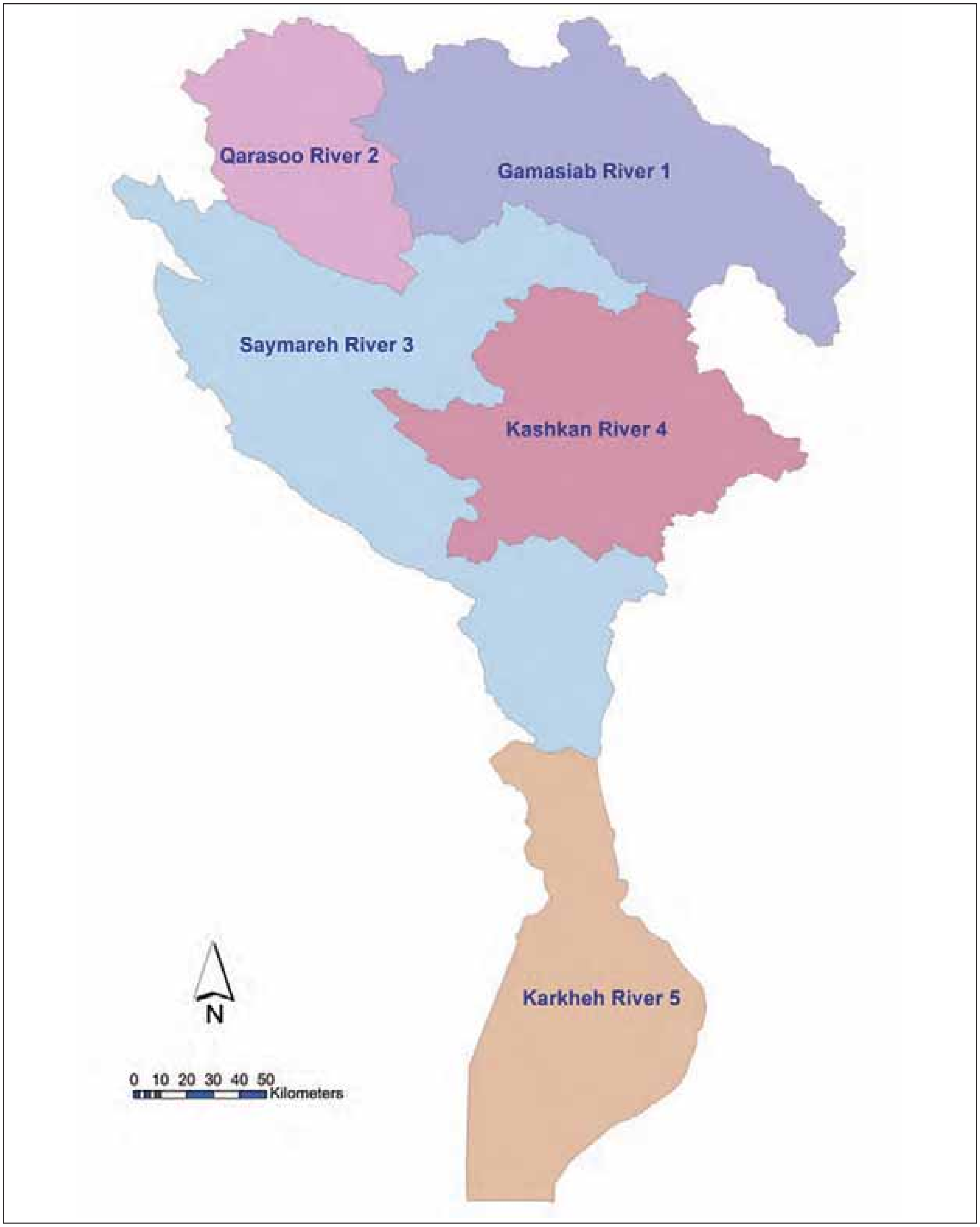


Fig. 1.7. Five major sub-basins of the Karkheh River Basin

and Zal also join the Saymareh River on its way. The total area of this basin is 16,411 km^2. The Karkheh River is formed where the Kashkan River join the Saymareh. The average annual discharge of the Saymareh River at the Paye Pole station is 73.8 m^3/s.

Kashkan sub-basin covers the central and eastern parts of the basin. The main river of this sub-basin is the Kashkan, which is supplemented by the Haroud, Doabo-shotor, Khorram-roud and Madian-roud Rivers. The area of this sub-basin is 8955 km^2. The average annual discharge of the Kashkan River measured at the Pole Dokhtar station is 132.29 m^3/s in March with a minimum of 15.1 m^3/s in September.

The main river of the *South Karkheh Basin* is the Karkheh, which is formed by the joining of Saymareh and Kashkan Rivers. Most of the irrigable and arable lands of the KRB are located in this sub-basin. The total area of this sub-basin is 8589 km^2 and it is the flattest sub-basin of all. The Horolazim swamp is located at the lower end of the sub basin and the newly constructed Karkheh dam is located at its upper end in the north.

Historically, the use of groundwater for agriculture has been popular in the region. Groundwater exploitation in the KRB was started as early as 1915 when the first well was dug in the Asadabad area (Marjanizadeh, 2008). However, during the last three decades, groundwater exploitation in KRB has taken a quantum leap. In recent years, increasing water scarcity has prompted more and more farmers to extract groundwater to meet their irrigation requirements. Presently, groundwater accounts for nearly half of urban and agricultural water supply in the KRB. Total exploitation of groundwater in the KRB is about 3856 million cubic meters (mcm) per year. This groundwater is exploited with the help of over 17,000 wells and 2677 springs (JAMAB, 2000). Tube wells are installed at different locations in the KRB with a discharge capacity of 7–44 l/s. About 87 per cent of the extracted groundwater is used for agriculture, 12 per cent for drinking purposes and about one per cent is consumed by industry. There are about 15 suitable aquifers used to extract groundwater for agriculture. Most of these aquifers are located in the northern part of the KRB. The central part of the basin is mostly mountainous and in the southern part the groundwater is saline and considered unfit for irrigation.

The pollution of surface and groundwater poses a serious threat to human health and the environment in the KRB. Much of the groundwater is vulnerable to contamination by pollutants originating from point and non-point sources. The pollution of surface and groundwater from diffuse sources, such as agriculturally-derived nitrates can pose risks to human health and the environment and it is estimated that in the Karkheh Basin over 70 per cent of nitrates in natural waters are derived from agricultural land. Recent studies conducted by JAMAB (2000) have shown that only two per cent of the extracted groundwater is fully fit for agriculture. About 61 per cent is rated as relatively good and the remaining 27.5 per cent is only suitable for selected crops. Excessive use of fertilizers/pesticides, because of low prices and lack of knowledge has caused over the past two decades deterioration in groundwater quality, which in turn, has affected crop production in the area. Therefore, poor farmers have become poorer and unsustainable agriculture is the inevitable result of this action.

Water development plan

In the KRB, three dams are in operation, four are under construction, and 12 are under study (Table 1.3). The total

Table 1.3. Irrigation networks in the KRB

Name of the dam	Name of the irrigation network	Capacity of the irrigation network (ha)			
		In operation	Under construction	Under study	Total
Karkheh	Dashteh Azadegan (unit 1 and 2)	26,056	4228	–	30,284
	Dashteh Azadegan (unit 3)	–	–	13,290	13,290
	Dashteh Azadegan (unit 4)	–	–	23,000	23,000
	Extension of Dashteh Azadegan	–	–	52,976	52,976
	Shahid Chamran	–	–	13,200	13,200
	Extension of Shahid Chamran	–	–	63,300	63,300
	Kosar	14,150	–	–	14,150
	Hamidieh, Gods and Zamzam	15,800	–	–	15,800
	Evan	10,985	–	–	10,985
	Dosaleg	9500	6500	–	16,000
	Arayez	–	–	27,938	27,938
	Bageh	–	–	7637	7637
Karkheh	Dashteh Abbas	10,600	11400	–	22,000
	Einekhosh and Fakeh	–	10780	19,720	30,500
Jozman	Jozman	–	–	1800	1800
Chenareh	Chenareh	–	–	12,500	12,500
Sikan	Sikan	–	–	4950	4950
Gheshlaghe Olya	Gheshlagh e Olya	–	–	7929	7929
Shiyan	Shiyan	–	–	3600	3600
Gavmishan	Gavmishan	–	–	7600	7600
Anahita	Anahita	–	–	3200	3200
Sarabe Talkh	Sarabe Talkh	–	–	1800	1800
Makhmalkoh	Makhmalkoh	–	–	6000	6000
Kaka Sharaf	Kaka Sharaf	–	–	4200	4200
Tong Paryan	Tong Paryan	–	–	2200	2200
Iushan	Iushan	–	–	4800	4800
Sarabi Toisirkan	Sarabi	–	–	–	–
Nemat Abad	Nemat Abad	–	–	1600	1600
Kalan e Malayer	Kalan e Malayer	–	–	1800	1800
Gerin	Gerin	–	–	15,300	15,300
Total		87,091	32,908	300,340	420,339

irrigation network under these dams will be 420,339 ha, of which 87,091 ha are already operational, 32,908 ha under construction, and 300,340 ha under study. There are also five hydro-electric power dams planned for construction in the upper KRB at Tange-mashoreh, Seymareh, Pa-alam, Koran and Bozan Choman. Karkheh dam is the biggest dam in the KRB and it was constructed both for hydro-electric power and as a reservoir. Karkheh dam serves 341,060 ha of modern and 23,684 ha of traditional irrigation networks (Khuzestan Water and Energy Organization, 2006).

Karkheh dam construction was completed in 1999 and became operational in 2001. The main objectives of the dam are to produce hydro-electric power (934 GW/h/year), flood water control, and regulate the flow for the irrigation of more than 340,000 ha of land downstream of the dam. These arable lands are located in different plains situated in the lower parts of the KRB (Mahab-Ghodss, 2007a). Irrigated areas are mainly present downstream of Karkheh dam where the average annual rainfall ranges between 100–300 mm. The total irrigated area in the lower KRB is about 111,000 ha, which is planned to increase to 300,000 ha after the extension of the irrigation network to the Paye Pole plains including Evan, Arayez, Dosaleg, Bageh, and the plains northwest and west of Khuzestan including Hamidieh, Ghods, Dashteh Azadegan, Dasht Abbas, Fakeh, and Ein-e-Khosh (Mahab-Ghodss, 2007a; 2007b).

The Govmishan dam is located at km 25 on the Kamyaran-Sanadaj road in Kordestan Province. Construction was completed in 2007 and the associated irrigation network is still under construction. The main objectives of the dam are (i) to transfer water from the Goveh-roud River basin to the Ghareso River Basin, one of the branches of Karkheh River, (ii) to supply a regulated flow for irrigation (110 mcm/year) to more than 30,000 ha of land downstream of the dam including Kamyaran, Bilvar and Miyan Darband, (iii) to cater for urban and industrial water needs in Kermanshah city (90 mcm), (iv) for environmental purposes, and (v) for the Ghareso River ecosystem (Mahab-Ghodss, 2007a; 2007b).

Changes in groundwater table levels and the problem of water logging

In the upper KRB, the groundwater table level has declined on average by 12.5 m during the last two decades, 5.8 m of which occurred over the last five years (2003–2007). The maximum decline is reported from the Kermanshah region with an average of 1.8 m/year from 2003–2007. In the Merek region (selected site for the upper KRB), the groundwater level varied from 1390 m to about 1380 m above sea level over the period 1997–2005 (Figure 1.9).

In Dashteh Evan, in the north of the lower KRB, annual water withdrawal from groundwater is more than 70 mcm while annual return is about 76.915 mcm. There are 172 active wells in Dashteh Evan covering a total area of about 12,062 ha. The wells' discharge rate ranges from 5–95 l/s. The water table level in this region ranges from 7–47 m where the soil water flux is from the highlands to the northwest, west and southwest of the plain to the center and the east. Since 1999, the depth of the water table has increased due to water delivery from the Karkheh dam (Figure 1.8).

In the lower KRB, the groundwater level in non-arable land (or specific locations that were not cultivated during the period 1979–1989) varies between four and seven m while on cultivated land it is about 1.2–3.0 m. This difference shows the impact of agricultural return flow on

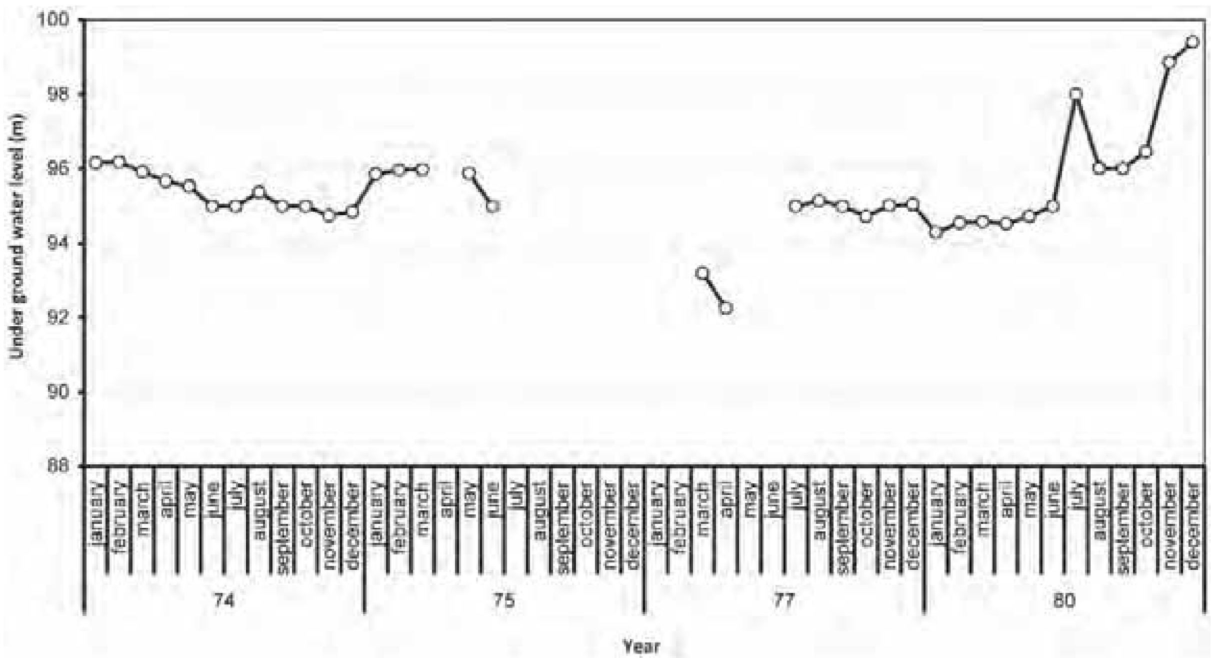


Fig. 1.8. Fluctuations in the level of the water table in the Evan region

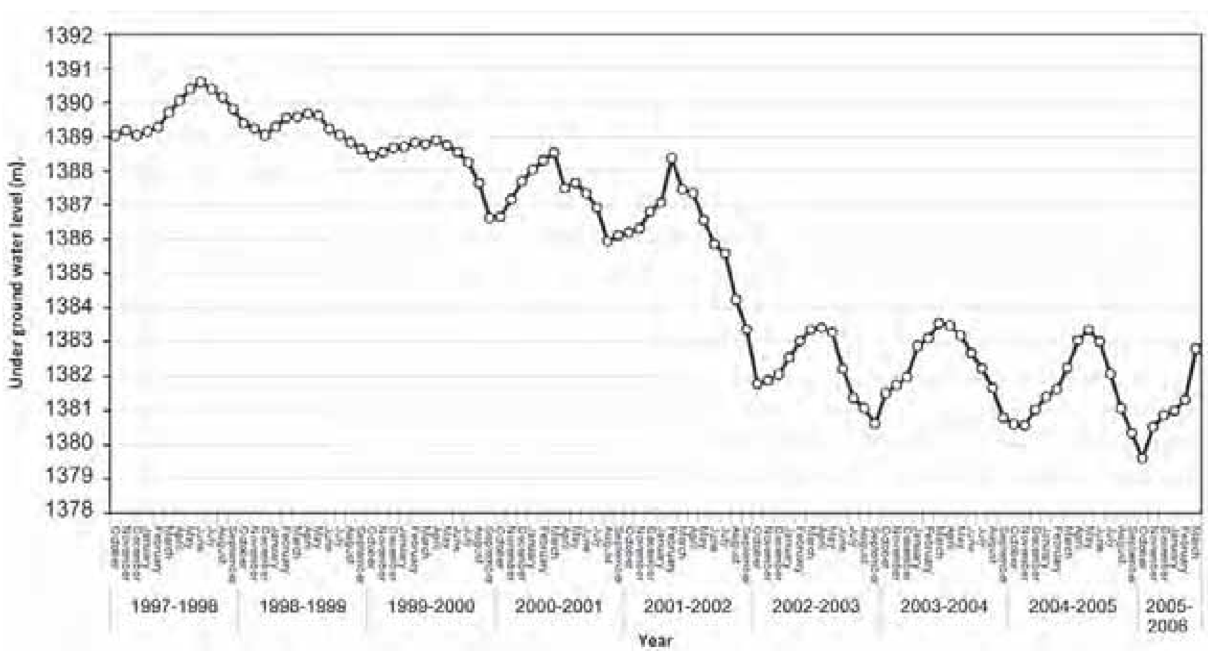


Fig. 1.9. Fluctuations in the level of the water table in the Merek region

the water table. The main problem facing agriculture in this area is water logging and salinity. Water logging followed by soil salinity happens during certain periods. For example, under wheat cultivation early November is the planting date in DA. Late November is the first irrigation for land preparation and the harvest is in late May. Deep percolation losses of irrigation water during this period cause the water table to rise, peaking in February. The major causes of salinity and water logging are high water tables, high evaporative demand, and salt-containing soil horizons. The construction of Karkheh dam has helped to minimize flood damage but has made salinity a bigger problem. Before the construction of the dam, seasonal floods were the greatest source of water for leaching salts.

The salinity (EC) of groundwater and irrigation water in this area is six–nine dS/m and three dS/m, while soil salinity is highly variable ranging from about two dS/m to well over 100 dS/m. The main drains have recently (in 2003) begun operation with an outlet in the Hor-al Azim wetlands (Mahab-Ghodss, 2007c). At present, despite the construction and operation of the main drains in the area, in some places the system is still not functioning properly. This is mainly due to technical and excavation problems, i.e., inadequate slope of the drain lines and also problems connected with the outlet (based on regional agricultural organization experts and authorities and information gathered during local visits in 2004). Gravity drainage to the outlet is not possible in practice and pumping is required.

1.4.3 Technical progress, adoption and productivity

Different technologies have an impact on cropping patterns, yields, production and their variation. These include seed varieties, mechanization, agronomic practices, irrigation, etc. Evaluation of the impact of different technologies over time requires a wide-ranging study. Here, we are mentioning only a few technologies that have had the greatest impact on agricultural development and increased agricultural production.

In the lower KRB (downstream), irrigated wheat varieties with appropriate attributes such as drought resistance or resistance to epidemic diseases (such as yellow rust) have been introduced over the last 15 years. These varieties; Falat, Chenab, Chamran, and Darab II, have a high-yield potential and have resulted in significant production increases at the site. The main constraints to agricultural production in these areas are high groundwater levels and high levels of salinity over a wide area. For instance, the Azadegan plain with an area of 220,000 ha is facing salinity and water logging problems that limit agricultural production. This issue has been aggravated since construction of the dam has prevented flooding. Drainage has priority over water supply in this area.

The introduction of high-yielding hybrid maize seed with characteristics suitable for planting as a second crop after wheat has resulted in an expansion of maize cultivation in the area, where the level of the water table is low. The introduction of high-yielding sugar beet varieties (55 tons/ha) as a winter crop has also played an important role in agricultural development in the area. However, sugar beet cultivation has declined recently because of the closure of the sugar factory. Barley cultivation has not expanded in the lower KRB because of pricing and lack of adaptable varieties. Rainfed agriculture is not important on the downstream farms, but it is more common in the upper KRB (upstream).

In the framework of the long-term prospects for rainfed agriculture in Iran, newly adopted technologies (agronomic practices and seed varieties) have recently been introduced in the area, but they are not widespread.

The adopted technologies include new varieties of wheat, barley and chickpea, and mechanized cultivation of chickpea or the 'delayed' germination system. However, yield and production of rainfed crops are mainly subject to environmental conditions.

Well-adapted wheat and barley varieties have been introduced for irrigated agriculture in the temperate zone. New varieties together with agronomic practices have significantly increased yields and production. Maize cultivation has also expanded in these areas following the introduction of hybrid varieties, for example, variety 704 was introduced for growing as a second crop after wheat. As a result, the upstream areas of the KRB are now in third place in maize production in the country.

The technologies needed for the 'cultivation plan' are now almost all available. For instance, maize and sugar beet are grown using row planting machinery, weeds in wheat and barley fields are properly controlled, and adopted maize and sugar beet seed and certified wheat seed are being used.

In the lower KRB (downstream), as well as in other parts of Khuzestan Province, only surface irrigation is used. Despite governmental support for the development of pressurized irrigation systems, this type of system is not-prevalent in this part of the basin and in large irrigation projects.

In the Azadegan plain, the most common irrigation method is border irrigation. The plots are next to each other and about 400 m long. Wheat yield is about 1.5 tons/ha in these fields. In agricultural land without salinity and water logging, border irrigation is common. On level fields, row planting and furrow irrigation is used. However, the irrigation water applied is more than the crop water requirements (about 30 per cent) mainly due to social and technical issues such as incorrect field size, lack of knowledge on irrigation and field management, and a sub-optimal water allocation system in the irrigation network.

Although surface irrigation is the adopted system in most irrigated lands, irrigation technology upstream is more advanced. Surface irrigation is performed by furrow irrigation with a proper plot size. Development of sprinkler irrigation systems has long been requested by farmers and recently large-scale micro-irrigation has been introduced for row crops such as maize. This shows that farmers have a tendency to adopt irrigation systems that are more efficient and productive.

The total production of major dryland crops in KRB from 1996–2005 is shown in (Figures 1.10–1.12). Wheat yields under rainfed and irrigated conditions are 900–1300 kg/ha and 3500 kg/ha, respectively (Figure 1.10). Barley yields are generally similar to those for wheat. Chickpea is grown under rainfed conditions with average yields of around 500–600 kg/ha. These levels of production produce an income of less than US$50 per ha, which is the major reason for poverty in the rural areas of the KRB. Despite governmental support, supplemental irrigation technology has not been successful in these areas due to water shortages during the growing season. The other important issue is lack of attention to drainage and surface water discharge, resulting in depletion of production during heavy rainfall on the gently sloping plains.

Major reasons for low yields are shallow soil depths and relatively low soil fertility. Farms are not adequately mechanized and limitations in irrigation development restrict the introduction of profitable cropping patterns in this area. Unlined irrigation channels are poorly maintained causing considerable conveyance losses and low field-scale efficiencies. Moreover, this region faced serious drought from 1998–2000 (Figure 1.10). Since dryland farming is mainly precipitation dependent, yields and consequently total production decreased significantly during the drought.

As a result of the adoption of the new technologies discussed, total production and land productivity increased significantly in irrigated agriculture, especially for wheat and maize (Figures 1.11 and 1.12). Yields of wheat and maize increased to about 4000 and 8500 kg/ha, respectively.

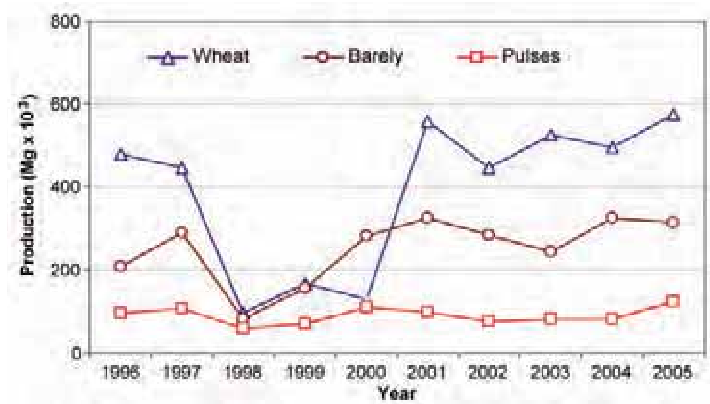


Fig. 1.10. Production of major crops under dryland farming in the KRB (1996–2005)

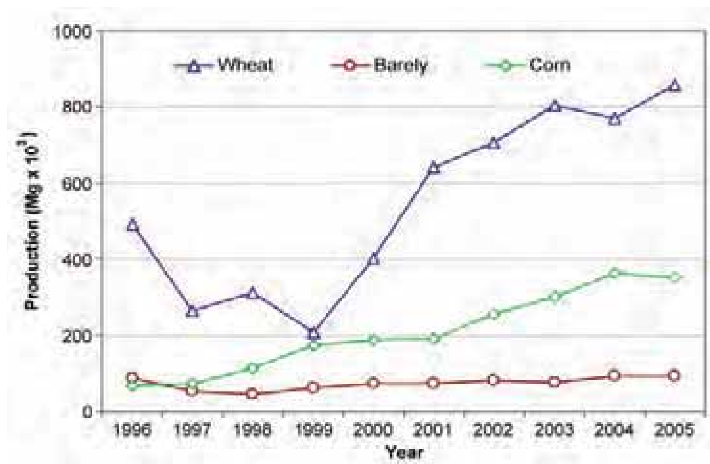


Fig. 1.11. Production of major crops under irrigated agriculture in the KRB (1995–2005)

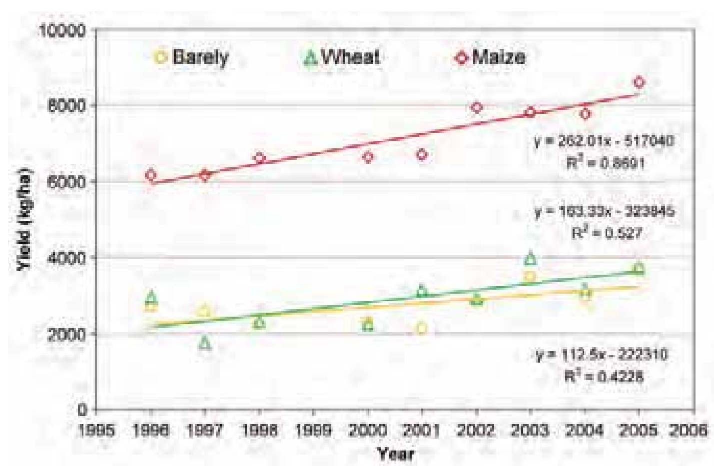


Fig. 1.12. Yields of major crops under irrigated agriculture in the KRB (1995–2005)

1.5 Water and water-related policies and institutions

1.5.1 Water legislation at the national level

The constitution of the Islamic Republic of Iran considers water resources as a public property and their management is devolved to the Government. Even before the Iranian revolution, these resources had been treated as public property based on the existing laws. Therefore, to implement Government control over these resources, separate

duties and authorities have been assigned to four different ministries for many years. Consequently, the organization of new ministries as well as the laws and regulations related to water need to be studied.
Since 1900, more than 120 specific and general laws have been approved by the Government and the Parliament related to different aspects of water management in Iran (Loh Hagh, 2007). It is evident that some of them have been approved for a specific aim and cannot now be applied, or might have been rescinded by Government or Parliament. The most significant laws approved since 1900 are as follows:

- the qanats law (approved in 1930)
- trans-boundary surface water resources and supervision of the Government on the seas (1934)
- permission for the establishment of an Independent Irrigation Agency (1943)
- modification of the law on an Independent Irrigation Agency (1955)
- the manual, the Water and Power organization (1960)
- bill for the establishment of the Ministry of Power (1963)
- constitution of the Water and Power Organization (1960)
- conservation of groundwater resources (1966)
- water charges by organizations and companies under the Ministry of Power (1967)
- water law and the method for its nationalization (1968)
- constitution of the water boards of the Fars, Tehran, Khuzestan, Northern Provinces, Esfahan, Southeast, and Azerbaijan Provinces (1968)
- equitable distribution of water (1982)
- water charging from curable land in Zabol town (1987)
- fixing agricultural water fees (1990)
- formation of waste water companies (1990)
- establishment of rural water and waste water companies (1995)
- establishment of the Ministry of Jihad-e-Agriculture (2000)
- investment in water plans of the country (2000)
- transformation of Provincial Central Water Office to Regional Water Office and transformation of Regional Water Office which cover more than one province to the Provincial Regional Water Organization.

These laws dealt with the main aspects of water management including:

- study, research, planning, and allocation of resources
- operation of water resources and water structures
- conservation of resources and control and regulation of water withdrawn and consumed
- coordination of the activities related to water resources management

In addition to these laws, some articles related to water resources were also included in the five National Development Plans1 since 1989:

According to the second National Development Plan (NDP), the Ministry of Energy is authorized to allocate water in the irrigation networks or well systems volumetrically for optimal utilization of water. The main purpose is to increase water savings and improve agricultural water productivity (Loh Hagh, 2007).

The third NDP deals with the absorption of financial resources for investing in and promoting water supply and agricultural projects, such as irrigation and drainage networks. In this plan, execution of the

[1] The five-year National Development Plan is a strategy decided by the country since 1989 for cultural, economic and social development.

water-saving policy, motivation of water users to optimize water use, and the formation of water users' associations are emphasized. The plan also emphasizes development of water resources and the agricultural sector, improvement of irrigation efficiency, water-use efficiency and economic productivity in the country, construction of small and large dams, and construction of the network and water diversion structures for border waters. The government is also allowed to allocate and charge water prices based on the National Water Documents in the irrigation networks and pumping stations (deep or semi-deep wells), and to apply water-saving policies and guidance to agricultural water users for better use of water resources.

The fourth NDP confirmed that water is the focal point for sustainable development in the country. This plan is a continuation of the third national development plan emphasizing the development and promotion of irrigation management to improve agricultural water productivity at least by 25 per cent. The plan also emphasizes investment in water plans with priority to irrigation and drainage networks, attention to water supply projects and completion of irrigation and drainage networks, improvement in human capacity development, and consideration of stakeholders' rights and sustainable development in inter-basin water transfer projects.

1.5.2 Government objectives and policies

According to the latest approvals by the Iranian Assembly of Experts and Expediency Council and the current laws and regulations, Government objectives and policies based on a long-term vision for the agricultural water sector can be summarized as follows:

- sustainable development and land-use planning in river basins
- improvement in water productivity and political value of water in exploitation, allocation, conservation, and consumption of water
- enhancement of water exploitation and minimization of all natural and non-natural losses of water in the country
- comprehensive planning in different water projects including dams, watersheds and aquifer management, irrigation networks, on-farm improvement activities, land leveling, conservation of water quality, drought management, flood control, water reuse, use of marginal waters, enhancement of knowledge and technology, and enhancement of the role of stakeholders in exploitation and operation of water plans
- priority to the consumption of common border waters.

Improvement of agricultural water productivity is the main objective of agricultural water policy. Focus on water and its impact on the environment should receive more attention. The value of water has economic, social and environmental dimensions. Water supply, reduction of water losses and re-use of water are among the most important policy objectives of the Government. Provision of domestic water is the duty of the Government and has especial importance and priority. The consumption policies support optimal consumption and set logical limits for water users

One of the principles that regulate this objective is the 'Equitable Distribution of Water Law' (EDWL). The EDWL is one of the most important national acts on water policy in Iran after the Islamic Revolution and was approved by Parliament in 1982 and slightly modified later. The law consists of five chapters, 52 articles and 27 notes.

The most important policies laid down by the EDWL emphasize that authority and responsibility for conservation, permission and oversight of the use of water resources rest with the Government, authority for supervision and regulation of water pollution is given to the Environment Conservation Organization, control and oversight of the use of groundwater resources is under the authority and responsibility of the Ministry of Energy (MoE). The EDWL policies also consider improvements in water demand and allocation regulations, water consumption optimization with emphasis on agricultural water consumption, water pricing for different consumption purposes and water fees collection, and operation and maintenance (O&M) of irrigation and drainage networks.

Improving water supply and water productivity programs has been one of the most important Government policies over the past 22 years. In this regard, different rules have been set and furthermore, different technical infrastructures (including executive, research and consultative bodies), in both public and private sectors, have been developed. This attention, in addition to the establishment of special laws and regulations, is also reflected in the content of the National Development Programs.

In 2002, based on studies conducted in the 'Comprehensive Plan for Water Resources', the Ministry of Energy provided some suggestions and scenarios for the management of water resources in Iran. These scenarios were as follows:

- Supply-based management
- Demand-based management
- Conjunctive supply and demand-based management
- Socioeconomic, technical, and policy-based scenarios

Following these scenarios, MoE suggested an initial plan entitled 'Long-term development strategies for Iran's water resources'. Comments from different ministries relevant to water (especially the Ministry of Agriculture) were added to the suggestions and finally, by virtue of Principle no. 138 of the Iranian Constitution, the cabinet approved it in 2003 as the 'Long-term development strategies for Iran's water resources'.

The 'Long-term development strategies for Iran's water resources' aims to be a suitable guide to compiling medium- and short-term plans for national water management, resulting in the optimal exploitation of national water resources by uniting all areas of water management.

The long-term strategy emphasizes the importance of coordination among various sectors, monitoring water resources capacity on the basis of the principles of sustainable development and meeting land-use planning policies in regional and joint basins, reform of water consumption patterns taking into account the economic and environmental value of water, water resources pollution management and control, reasonable pricing of water, observing national goods and citizens' natural and social rights in water, transferring projects between basins and water exchange, risk management (drought and floods) and public awareness programs, equipping and completing water gauging networks, and operating historical water structures.

The document approved by the cabinet is regarded as a pioneering measure for international policies. In accordance with the decisions made by world leaders at the summit on sustainable development in Johannesburg in September 2002, all countries are obliged to compile their integrated water management plans by 2005. Iran is the only country in the region that has so far compiled and approved this plan.

1.5.3 Participatory irrigation management

Iranian rural communities have a history of accumulated knowledge and experience on water management. Many centuries ago, there was no water resource management legislation, but un-written norms were accepted by local communities. Hence, there were enough reasons for farmers to adapt themselves to such by-laws for proper management and efficient water use especially under *qanats* and traditional river systems. In other words, there was no recurrent dilemma between the farmers' compliance to local by-laws and social context versus the implementation of the necessary managerial changes imposed by local elders or leaders.

On the other hand, under accepted definitions of local land attribution and water distribution, there are traditional water control and measurement structures. It should be noted that there was no appreciable conflict or struggle in water distribution and irrigation systems' maintenance. Farmers could manage their own traditional irrigation system even in periods of water shortage during drought years.

The land reform of 1962 changed the local social structure of water management and gradually disrupted the traditional cooperation and social cohesion. Governmental organizations and the relevant agencies became the active external players in the economic and social life of the village. The local community became passive in decision-making governing the major part of their daily lives. Therefore, the gradual weakening of traditional cooperation began in rural areas.

These interventions have been represented by the Government that has developed dam construction and irrigation networks, and the gap between the authorities responsible for water resource management and the local communities has widened. Further to such planning and development revolution in water resource management, which has emphasized the 'top-down' approach, the entire management of irrigation networks was tackled by the Government, with very limited involvement of the farmers.

Out of 37 million hectares of potential land for agriculture, about 7.8 million hectares is under irrigation. Completed irrigation networks cover only 0.7 million hectares. However, due to limitations in budget, continuous increasing financial burden led to the inability of the Government to fully provide the operational and maintenance costs and development as well. Moreover, inappropriate management of irrigation has contributed to environmental problems and operational and maintenance constraints, thereby causing social problems and physical deterioration.

Consequently, the concept of participation became the most important pre-condition for the development plans to improve operations and management. However, farmers' participation in irrigation management was not possible as it is understood that the Government should take the full authorities for developing, operating and managing irrigation networks.

Two decades ago, i.e. 1990, Iran initiated the first five-year National Development Plan for economic, social and cultural development. During the past decade, the

Government also initiated management reforms in modern irrigation systems.

The general trend of the NDPs has been towards privatization. Irrigation network development was a part of this plan, but more focused on budget sharing. According to the NDP policy, farmers had to pay the majority of the irrigation networks' (sub-main canal) construction costs. Bureaucratic constraints and inadequate maintenance of irrigation systems led the Government to divest itself of most of its responsibility transferring it to the private sector. In this context, three groups of events could be identified:

Privatization of the operation of modern irrigation systems

In 1991, the Government of Iran decided to transfer most of the operation and maintenance tasks involved in the management of the irrigation networks to the private sector and decided to establish a new private company called the Operation and Maintenance of Irrigation Networks Company (OMIC), as an autonomous body under the MOE. In the same year, an agreement between the Ministry of Jihad-e-Agriculture (MoJA), MoE, and Management and Planning Organization (MPO) was signed. With the establishment of OMIC, the operation, maintenance and administration of the irrigation network (INET) were gradually transferred to local communities, each OMIC concession performing Operation and Management (Q & M), in the associated INET.

The New Irrigation Management policy enacted in 1991 rationalizes the O&M responsibility, which is assigned to three administrative levels (central, provincial, and local) with the designation of responsibility to OMIC for the Irrigation Management Transfer (IMT) program in Iran.

In early 1992, about 20 OMICs were registered but not operating. Their main tasks were improving O&M, increasing irrigation efficiency and management, and improving water fee collection. At the beginning, OMIC's shares were divided between water users (51 per cent) and government organizations (49 per cent for MoJA & MOE). In practice, this kind of shared stock was not applicable resulting in the deterioration of irrigation networks and the reluctance of farmers to take responsibility of these tasks. In reality, 100 per cent of ownership was shared between government organizations.

Although in most of the INET the quality of O&M and communications improved, the provincial government body became stronger and water users' management structures became weaker. In addition, most of the initial objectives were forgotten.

There were acceptable incentives to transfer responsibilities of the government organizations to OMIC, but there were inadequate incentives for local communities to take over these responsibilities, unclear by-laws for transferring the required authorities to water users, insufficient capacity in the local communities, and inadequate structures to perform such responsibilities. Hence, water users could not take initiatives and fulfill their roles in O&M and administrative affairs as well. Looking for solutions to these constraints put extra pressure on the OMICs.

Supportive laws and intensive policies for optimized use of agricultural water

There are two main supportive laws as background to these policies: (i) the second 5YDP (1995 to 1999), where the Government emphasizes Optimized Use of Agricultural Water (OUAW) and that provincial organizations of MoJA should establish water users' groups, (ii) the third 5YDP (2000 to 2004), where the Government emphasizes participation of farmers in water resources management.

Based on the supportive laws and detailed regulations discussed, water users' groups should be organized by the provincial offices of MoJA with the participation of the provincial bodies of MOE and the Ministry of Cooperatives (MOC). Water users' groups (WUGs) are a formal type of community-based organization (CBO), but in the form of cooperative agencies. These CBOs appeared in the Iranian water management literature for the first time in 1996.

According to the NDP and the law of optimized use of agricultural water, the MoJA was supposed to set up the WUGs within two years and for each intake of a secondary canal introduce the representative of each WUG to the OMIC, as the water-master responsible for water distribution among the water users of each tertiary unit. In this regard, Ghazvin Irrigation network was established in 1997 with 50,000 hectares under cultivation. It is located in the northwest of Tehran. From the beginning of the operation of the network, farmers had their own managerial structure to distribute water among themselves, but to solve some of the constraints on O&M, irrigation management reforms needed to be performed.

The local department of MoJA was not interested in the constitutions of Water Users' Cooperatives (WUCs), especially because they had their own different model (Rural Producers' Cooperatives, RPC) and had little interest in a new model. Accordingly, WUCs were not active until 1999.

In response to the suggestion of MOE, in order to find a solution for the establishment of WUCs by-laws, a committee including representatives of MOE, MoJA and MOC was formed. The committee held several meetings and had several outputs. The first by-law for establishment of WUCs was the most important one. This by-law was approved by MOC and was sent to the provinces to establish WUCs as quickly as possible.

In accordance with these by-laws, many WUCs were established, but most of them never succeeded. The main constraints were lack of sufficient incentives, lack of a defined position for WUCs on decision-making, and WUCs' institutional weakness to support their roles.

As well as WUCs, the RPCs could also not find enough institutional capacity to perform OUAW law and played basic roles during the 1990s. Experiences in Gillan Province are a good example to illustrate this.

In early 2002, the OUAW by-laws committee suggested to Gillan's OMIC to transfer part of its O&M responsibilities (e.g. fee collection) to rural consumers' cooperatives (RCC) and RPCs. Over the next five years, results were negative.

In some irrigation networks establishment of WUCs was not on the agenda. These OMICs chose a different strategy and carried out improved traditional management. Varamin irrigation network (VINet)'s experience in the late 1990s was a good example. From the beginning of the network's operation farmers had their own management model. In this model, representatives of WUCs in each secondary unit were responsible for operation and maintenance of the lower part of the main canals with developed cooperation. During the drought years and water shortages such cooperation was enhanced.

In the third NDP (2000 to 2005) landowners' and water users groups' participation in soil and water resources management were highlighted again. In addition, more attention was paid to formally-structured socioeconomic farmers' business groups and marketing. In this law, MoJA had a mission for a maximum of six months to provide the constitution of agricultural activities. In the preliminary draft, WUA has a position at the core of all agricultural constitutions. At the moment, this model for agricultural activities is under the test in the Ghazvin irrigation network.

As a summary to this section, it can be said that much effort has been devoted to agricultural constitutions and some valuable lessons have been learned, but the strategies have not yet been approved. Most of the articles in the third and the fourth NDP are not yet officially implemented.

Distraction of financial support in irrigation projects (national and international)

A joint project agreement for irrigation development was signed between the Government of Iran and the World Bank (1991). This project was based on the MoE's irrigation program. One of the main concerns of the World Bank (WB) prior to providing financial support was to understand the legal position of the WUGs in the irrigation systems. The project was approved and started in four irrigation networks – Moghan (MINet), Behbahan (BINet), Tajan, and Zarrine-rud – in 2000. Project performance was acceptable in terms of physical improvement (MINet and BINet), but of little value in terms of irrigation management improvement (IMI). MINet and BINet have been performed and Tajan is under construction. In spite of common activities and efforts and technical and financial support by the MoE and MoJA in these regions, the Water Users' Association could not continue its activities successfully.

1.5.4 Policy generation process

The compilation of water policies in Iran can be categorized in three periods. From 1981–1988, there was no uniform plan among the different sectors of water users. Each sector, including different ministries, defined policies based on their own evaluation and internal decisions. These policies were submitted annually to the Planning and Budget Organization through the action work plans for approval and financial support.

In 1988, with the commencing of the NDP, necessary arrangements were made to develop a policy in cooperation with different sectors. Accordingly, various Programming Councils were set up to develop a policy for related activities under the responsibility of one ministry but with members from other ministries. The Agricultural Water Council (AWC) was set up with members from the Ministries of Agriculture, Energy and Jihad, and the Planning and Management Organization, together with a number of senior experts and NGO representatives. Agricultural and water policies at the national level were investigated, discussed, and finalized in the council. Then, the recommended policies, objectives, and action plans were submitted to Parliament for finalization, approval, and for enactment in the national long-term plan (first, second, third and fourth). In other words, the Islamic Parliament is the ultimate reference for finalizing policies for the national long-term plan. Each policy counts as a sequence in the plan. Since 2005, all policies, objectives, and action plans have been based on the Long-Term Vision (LTV). The LTV is a set of long-term strategic policies for 2035 that, after evaluation and introduction by the Iranian Assembly of Experts and Expediency Council, has been approved and notified by the Supreme Leader. In addition to the LTV, overall specific water policies (mentioned in Section 6.2. 'Government objectives and policies') have been issued by the Supreme Leader by this process.

During this period, the High Council on Water was established for policy making on supply, distribution, and water consumption. This council comprises members including a number of ministers, heads of organizations and senior experts, chaired by the head of the council.

It should be noted that since 2005, policies that must be considered in the NDP have been proposed by the Iranian Assembly by Experts and Expediency Council and approved by the Supreme Leader for the consideration of Government and Parliament.

1.5.5 Current policy on the environment

Public investment

Investment in water infrastructure can be classified into different activities such as reservoir dams, diversion structures and irrigation and drainage networks, specific drainage projects, pumping stations, and development of modern irrigation technologies (e.g. pressurized irrigation systems). The associated water infrastructure is considered and approved through the national budget law (in the water and agriculture section).

Decision support, study, design, construction and operation of reservoir dams, water diversion structures, and main irrigation and drainage networks are supported by public funding when water use covers a group of water users.

The study and design of sub-main irrigation and drainage networks or specific drainage projects have so far also been supported by the public budget. However, the establishment of sub-main irrigation and drainage networks is based on partial funding and cost-sharing by the users. The percentage of cost sharing in sub-main irrigation networks was almost fixed until 1997 at 50 per cent from the public budget and 50 per cent from users. Since then, the water users' share was reduced to 30 per cent.

The proportion of the Government and users' share in the costs for the study, design and implementation of on-farm improvements and land leveling and consolidation are defined in the annual national budget. In general, until 1999, contributions to this kind of activity were 30 per cent by government and 70 per cent by users. Later, contributions became the same, i.e. 50 per cent for each. From 2001 until 2006, Government's contribution increased compared to that of users. For example, the Government's share was set at 85 per cent for 2006, while users paid just 15 per cent.

For the development of modern irrigation technology, the regulations mostly focused on investment by the users (about 90 per cent) with Government's share just covering about 10 per cent of the cost of irrigation systems in terms of design and installation. The Government's share increased to 50 per cent in 2008, due to the inability of users (farmers) to provide the required financial support. Furthermore, such investment is of a long-term nature (5–15 years), where the Government considers the budget needed based on the projects planned for each year. These budgets are called 'controlled budgets' and are transferred to the Agriculture Bank or other project agencies by Government warrant to be invested in the approved projects. The Government share is defined in the annual budget regulations and would be allocated.

Regulations

Water rights: After being established by Parliament in Iran in 1920, water rights have been preserved and closely adhered to.

In the first comprehensive law before the revolution entitled 'Water law and methods for its nationalization', surface and groundwater resources were declared as national wealth and the Ministry of Water and Power became responsible for their protection and development. In EDWL, water is recognized as an intersectional commodity where the protection, allocation, and conservation of all water resources are governmental responsibilities.

Water rights form a well-known regulation for water resources (surface and groundwater) in Iran, defined as the right to water use which has been approved in notebooks, ownership documents, court orders, or any other official document, before the approval of the EDWL. The cooperation of each owner in shared or common wells and *qanats* is based on the agreement or paid share for digging wells and *qanats*. The owner of a water use license is allowed to use the water in lands other than his/her own.

Consequently, in any water development project or investment leading to new or higher water resources potential, the water rights of existing water users have been recognized and they have priority for water allocation in any new operational system (network).

The Ministry of Energy is responsible for evaluation of the related documents and for issuing licenses of water rights or water use from surface and groundwater in cooperation with the Ministry of Jihad-e-Agriculture. The amount of water allocated to each license depends on the water resource availability. The permission to use water is a 'right for reasonable and beneficial use of water based on anticipated regulations and committed to users (actual and legal persons) by issuing license'.

Iran has historical experience in agricultural and groundwater use by delivering water using a gravity system (*qanats*). Owners or users of *qanats* have had mutual local agreements on water rights for about 2500 years. Currently, 35.000 *qanats* deliver an annual volume of eight bcm water that is about nine per cent of the total water resources in the country. In the past, a similar sharing procedure was commonly practiced for springs in Iran.

Water allocation: Before the revolution, the Independent Irrigation Agency (established in 1955) was responsible for all irrigation management activities based on the conventional water rights in each location and for defining and registering the amount of water for each owner based on the total allocated land. At the same time, in Khuzestan Province, an important area for water resources – the Khuzestan Water and Power Authority - was responsible for improving and establishing new irrigation networks and recommending cropping patterns and calendars. These activities were the first steps in legalizing water allocation and irrigation improvement at the farm level. In addition, under the nationalized water law (1968), the issue of an Efficient Water Use License (EWUL) was based on cultivated area, location of consumption, distribution system between the farms, and water quality. This law was the first law on agricultural water management, but there is no specific information on its enforcement.

The main national legislation on water allocation and management is the EDWL and subsequent amendments. Accordingly, the Ministry of Energy is responsible for improvements in water allocation and management by equipping wells with volumetric water meters and issuing licenses for appropriate water consumption in accordance with the EWUL.

The MoE is also responsible for water allocation and granting permission for water use by different sectors as well as for issuing water use licenses based on technical information provided by the Ministry of Agriculture for crop water consumption in cultivated areas of a given location. The Ministry of Agriculture is responsible for collecting water fees and oversight of the charging regulations.

Under this law, the owner of a water use and operation license must avoid improper consumption and water loss, and the Ministries of Agriculture and Energy are responsible for evaluating and controlling water consumption and for providing technical guidelines for users. Ministries of Agriculture and Energy together are responsible for documenting the operating manual for the EDWL.

Due to the importance of improvements in agricultural water use and the applicable water allocation mechanism for agriculture, the topic has been repeatedly stressed by long-term development plans over the past two decades.
According to the second National Development Plan, an operating manual on appropriate irrigation management for each crop in a given location has been provided jointly by the Ministries of Agriculture and Energy and approved by the cabinet. This manual, the National Water Document (NWD), was published in 1999.

The NWD includes cropping patterns, cropping calendars, and the water requirements of field crop and orchards for each of the 609 agricultural plains in the country. In the NWD, crop water requirements are based on the Penman-Monteith model suggested by FAO (Allen *et al.,* 1998), using a long-term (20 years) weather factors database including temperature, humidity, wind velocity, solar radiation, and daylight hours. The crop coefficient in this calculation was obtained from local research studies. The crop coefficient suggested by FAO was modified for each field crop and orchard at a given location where local research study had not been conducted or completed. The cropping calendar, humidity percentage and wind velocity at each location were used to modify the crop coefficient. This document was published in 28 volumes, one for each province, covering all agricultural plains in each province and the pattern of cultivated crops and orchards.

Groundwater utilization

The first groundwater law was approved in May 1966. Under this law control and preservation of groundwater resources and authority for conservation, permission and oversight for water use rests with the Government and supervision is authorized by the Ministry of Energy. This ministry is responsible for controlling groundwater levels and for prohibiting use in some areas where the water table level is dropping significantly. MoE is responsible for recharging groundwater resources and issuing licenses for any withdrawal depending on the groundwater capacity. One of the main sections of this law stipulates the necessity to equip wells and *qanats* with water meters and water level recorders to monitor the amount of water used and variations in groundwater levels. Also, some mechanism is required for artesian wells to control excessive out-flow.

In 'Water law and methods for its nationalization' there is some mechanism for water use from groundwater. Some other subjects are also included under this law: the Ministry of Energy is authorized to name those plains where water withdrawal is prohibited and to block un-authorized wells by judicial power. Owners of licensed wells are responsible for withdrawing water based on the amount specified in their license.

The regulations in the EDWL on the operation and prohibition of groundwater use are somehow different from those in 'Water law and methods for its nationalization', but are more comprehensive in context subject matters. For example, the owners of wells or *qanats* are responsible for preventing water pollution and they must inform the environmental conservation office if they are unable to control it. The Ministry of Energy is authorized to buy extra amounts of water from owners of licensed wells at an equitable price. The Ministry of Energy can prevent the mixing of fresh water with saline or polluted water by informing the owners. The topic of controlling over-withdrawal from artesian wells and the use of equipment to monitor groundwater levels and water withdrawal is emphasized.

Water use and energy: The energy required for water withdrawal from wells (more than 440,000 wells) and pumping stations for pressurized irrigation systems (the total agricultural area under pressurized irrigation is about 700,000 ha) has been provided mostly from fossil fuels. Since 1999, the Government has provided technical and financial support to replace diesel engines with electric engines under the 'electrical engines development law' approved on 5 May 1999. Energy costs for agriculture have benefited significantly from a subsidy before and after 1999. Total agricultural energy subsidies including fuel for tractors and agricultural machines ranged between US$1115.2 and US$6465.7 million per year from 2001–2005 (Table 1.4). The cost of producing one kilowatt of energy per hour is about 70 cents, while the charge to the agricultural sector is only 2.5 cents. Subsidies for electric engines just cover the energy consumption specified in the operation license and for higher consumption the cost increases significantly.

Irrigation management regulations: According to the latest regulations and policies, irrigation management activities can be described as:

- The study, design and establishment of diversion reservoir dams, water structures and main irrigation and drainage networks when water users are more than one, since development of such structures is supported by public funding.
- The study and design of sub-main irrigation and drainage networks or specific drainage projects that, until now, have been supported by public budgets.
- The regulation of the establishment of sub-main irrigation and drainage networks, based on cooperation and cost-sharing by users. The cost-sharing rate has been almost fixed. In 1987, the share was 50 per cent each from the public budget and users.
- The regulation of the study, design and conducting of on-farm improvements and land consolidation, are defined in the annual national budget. The proportion paid by Government and users is defined in this regulation. In general, financial contributions for such activities were

Table 1.4. Total agricultural energy (fuel and electricity) subsidies for 2001–2005.

Source of energy	2001	2002	2003	2004	2005
Fossil fuels (million dollar)	3684.7	463.5	646.1	894.3	1537.7
Electrical (million dollar)	2781.0	651.7	510.0	631.3	1385.0
Total (million dollar)	**6465.7**	**1115.2**	**1156.1**	**1525.6**	**2922.7**

30 per cent from Government and 70 per cent from users, until 1999. After 1999, contributions from both were equal, 50 per cent from each. From 2001 until 2006, the Government's contribution increased in favor of the user. For example, the Government's contribution in 2006 was 85 per cent, leaving just 15 per cent for users.

- The regulation of the development of pressurized irrigation systems, concentrating mainly on investment by users (about 90 per cent), with Government contributions covering only 10 per cent of systems design and installation. The Government share increased to 50 per cent in 2008, but this has not yet been applied in practice.
- Since users (farmers) are unable to meet such financial obligations to support these activities and the return of investment is long (5–15years), Government will consider the budget required based on the planned project for each year. These budgets are called 'controlled budgets' and are transferred to the Agriculture Bank or other project agencies by Government warrant to be invested in approved projects. The Government's share is defined in yearly budget regulations and would be allocated.

1.5.6 Pricing policies

Subsidies in Iran exist in production, consumption and services, where subsidies for consumption are usually higher. Indirect subsidies for inputs in the agricultural sector include fertilizers, pesticides, seeds, agricultural machinery, agricultural production insurance, and the expenses of the base price of agricultural commodities (APERI, 2007). Governmental goals in the agricultural sector are very diverse; they include the efficient supply and demand for agricultural production, the control of market prices, increasing farmers' income, extension of the use of special inputs or restriction of some inputs, supporting agricultural exports, and supporting sustainable rural development.

Polices include provision of low interest rate loans and other credits, establishment and development of agricultural product insurance, distribution of inputs at low prices, extension and education of research findings and new technologies, tax exemptions, base prices, reduction in custom tariffs, and increases in import custom tariffs for agricultural products. The subsidies for agricultural productions from 2002–2005 was based on the base price in 2005, and its contribution to GDP are presented in (Table 1.5).

Based on the results in (Table 1.6), agriculture's contribution to GDP was about 14 per cent, while agricultural production subsidies from GDP increased from 0.5 per cent to 1.2 per cent from 2002 to 2005 and decreased to 0.8 per cent in 2006. Consumption subsidies from GDP increased more than 80 per cent from 2002–2006 compared to 2002. This shows that supporting policies for consumption costs more than that for production.

Table 1.5. Subsidies for agricultural production for 2002–2005.

	2002	2003	2004	2005	2006
Increased value based on fixed prices in 2005 (million dollar)	32,762	35,359	36,241	39,682	41,535
Total GDP (million dollar)	238,614	255,498	268,562	280,245	297,523
Agricultural contribution to GDP (%)	13.7	13.8	13.4	14.1	13.9
Agricultural production's subsidy from GDP (%)	0.5	0.6	0.8	1.2	0.8
Consumption subsidies from GDP (%)	1.7	1.9	2.2	3.2	3.1

Table 1.6. Subsidized credits for the development of electric-powered wells by the Ministry of Energy.

Year	1999	2000	2001	2002	2003	2004	Total
Total credits (million dollar)	112.42	104.4	106.32	23.1	41.65	16.05	**400**

Energy subsidy

Until 1990, more than 90 per cent of total energy consumption in the agricultural sector was from fossil fuels. In an attempt to improve energy consumption management, to economize on foreign exchange and to replace fossil fuel energy, the share of electrical energy use increased gradually by about 12, 13, and 15 per cent each year over the period 1997–1999.

To provide fuel for wells and reduce the cost of energy, taking into account the lower cost of amortization of electric-powered wells, the higher efficiency of electric engines, compared to diesel engines, the improved water withdrawal control, and the decrease in the fossil fuel subsidy (decreased import of fuels), the electrical engines development law was approved in 1990. The total number of wells in the country is about 440,000. After the introduction of this law, electrical energy consumption increased to about 30 per cent of the total energy consumed in the agricultural sector (in 2006). To apply this law, the Ministry of Energy supported the development of electric engines for wells by a non-returnable subsidy during 1999–2005 (Tables 1.6 and 1.7).

By subsidizing credit, a total number of 47,757 diesel engines were replaced by electric engines by the end of 2006. The Ministry of Jihad-e-Agriculture also provided credits for electric wells in 1999, 2000 and 2005 through subsidy and non-returnable credit support, resulting in 4581 wells being equipped with electric engines.

In total by 2006, 52,338 wells (12 per cent of the total wells in the country) were operating using electric engines as a result of the allocation of 431.5 million dollars. The total subsidy allocated to

Table 1.7. Subsidized credits for the development of electric-powered wells by the Ministry of Jihad-e-Agriculture.

Year	2000	2001	2005
Total credits (million dollar)	31.5	35.1	41.03

energy in agriculture during 2001–2005 is presented in (Table 1.8).

Water prices

Water pricing policy in Iran dates back to 1925, when the law 'ownership of land and quadrupeds (livestock)' was approved to define a tax on income from *qanats* which were used for drinking-water purposes. The tax rate was equal to five per cent of income. Under this law, people who restore current *qanats* or establish new ones will be exempt from tax for five years.

The second local regulation was applied by the Khuzestan Water and Power Authority on water withdrawal from the Dez River in 1960. Under this the policy, (i) those who had water rights from the Dez river could draw water free of charge, and (ii) those who requested more water than what was covered by their water rights, in addition to new users, had to pay for the water requested (five per cent).

The first national water pricing policy was initiated in 1968. Under this policy, the final price was calculated based on the operational cost and the rate of interest on investment for water supply. To support the agricultural sector, the water price was based only on the operational cost for 10 years and for farmers who had water rights the policy recommended a 30 per cent discount. The water price for the industrial and urban sectors was based on investment rates of six per cent and three per cent, respectively.

After the revolution, in the first comprehensive water policy at national level (1982), some new policies were included. Under this policy, those who supplied water by private investment had to pay for government supervision. Discounts were considered for low-income families in the cities. For government supervision of private water supplies, the price for each water supply unit was between 0.25 to 1.0 per cent (0.2 cent per m^3 on average) of total value of agricultural crop production. This policy was later cancelled following complaints by farmers.

As an incentive for poor farmers, a specific policy (1987) for water prices in the Zabol district (a poor farming area on the border with Afghanistan) was initiated. It recommends that farmers pay only 2.2 cents per hectare for irrigated land.

The most important policy for the agricultural water sector is 'Fixing the Agricultural Water Price' and has been running since 1990. Under this policy, a priority discount is allowed on the water price for land cultivated with the main agricultural crops (such as wheat, barley, rice, etc.) as follows:

Table 1.8. Total subsidy for energy in agriculture for 2001–2005.

	2001	2002	2003	2004	2005
Fossil fuels (million dollar)	2568.0	589.0	646.0	894.3	1537.6
Electricity (million dollar)	2780.0	664.2	509.0	631.2	1384.8
Replacement of fossil fuel engines by electric engines (million dollar)	139.9	23.1	41.6	17.0	41.03
Total (million dollar)	**5487.9**	**1276.3**	**1196.6**	**1542.5**	**2963.4**

1. The water price for irrigated agriculture under regulating dams and modern irrigation networks is three per cent of the price of the crop produced. This rate has increased to four per cent after 10 years.
2. For irrigated land under conjunction systems, the water price is two per cent of the price of the crop produced.
3. Farmers who use traditional irrigation systems have to pay only one per cent of the price of the crop produced.

For increasing water-use efficiency by the farmers, the 'Fixing the Agricultural Water Price' policy recommended that farmers who produce a yield of 50–100 per cent more than the average yield would benefit from a 50 per cent discount on the water price. Furthermore, the policy recommended that water be free of charge for those who produce more than double the average yield.

However, if this policy is not applicable, farmers are charged US$23 per hectare for water. Consequently, under a new dam and new irrigation network, where the final water price is about 82 cents/m^3, farmers are only charged 0.025 cents/m^3.

Crop pricing policy

The first crop pricing policy was approved in 1983 as the 'base-price policy' (BPP) to support production of the main agricultural crops and to provide farmers with a minimum income. Under this policy, the Government is responsible for approving and announcing the base-price of each crop before the planting season and guarantees to buy excess production those farmers are unable to sell on the open market. The crops included in the first phase of the law included wheat, barley, rice, sugar beet, maize, cotton, oilseeds, tea, potato, onion, and pulses. Other crops also included in this policy are raisins, dates, apples, pomegranates, citrus, and figs. Other products mentioned in the BPP are animal husbandry production and cocoons (approved in 1993). The BPP does not cover all crop varieties and cropping systems. For example, for rice, the base price is set for high-yielding varieties to encourage farmers to adopt these varieties.

The BPP in the agricultural sector is sometimes used as a fixed price for industrial crops when the customers are specified. For instance, sugar beet, cotton and oilseeds should be sold directly to the associated processing factory. In this case, the BPP would be called the 'fixed price'.

To implement this policy, the Government has an interest in buying wheat as well as industrial crops. Wheat in Iran is mostly purchased by the Government because provision and supply of bread in the country is highly subsidized. There is a special prescription for quality control in this regard.

There is no policy for pricing by the Government for a wide range of other agricultural products such as animal products, vegetables, wood, fisheries, eggs, medicinal crops, and fruit. The price of these products is usually determined by supply and demand.

Pricing for chemicals and seeds

Prior to the revolution, all chemical inputs in the agricultural sector were supplied and distributed by private companies. After the revolution, this has been carried out by a government company who is responsible for the supply and distribution of most agricultural inputs, including fertilizers and pesticides (insecticides, fungicides and herbicides). To increase agricultural production, the price of these chemicals is kept below market price. The company receives a subsidy from the Government to balance their expenditure. In early 1990, the Government tried to supply inputs based on the actual market price, but this policy was not successful because of political unrest and complaints by farmers. Since 2003, insecticides have been supplied and distributed by the private sector based on the market price.

Since 1959, the Government has been responsible for the control, supervision and certification of all imported and domestically produced seeds and, since 2003, an independent institute has been established for seed certification issues.

Seed prices for most crops produced by local farmers are generally based on supply and demand without the intervention of Government or other organizations. Prices of imported seeds, mostly for summer crops (potato and onion), are based on supply and demand and free prices. Crops for which the seeds are research-based and commercial varieties introduced and supplied by research organizations are categorized as principal crops for food security and include wheat and barley. For these crops, seed prices are subsidized. The seeds are certified by research organizations and include 30 per cent of the seeds needed for irrigated wheat, 10 per cent of rainfed wheat and 16 per cent for irrigated barley. Even though the price of certified seeds is 25 per cent higher than the crop base price, the cost of monitoring the farms, transportation, disinfection, and winnowing, which is more than 25 per cent of the value of the seeds, is paid by the Government through subsidies.

Crop seeds of which the preliminary seed (foundation seed, parent lines and breeder seed) is released through on-going research activities at public research stations use public facilities and funding. Production is proportional to demand at country level. Consequently, the Government also pays a subsidy to research centers for parent lines seed production. The parent lines seed cost is much higher than the sale price of wheat and barley by research organizations. The total amount of chemical fertilizer, agricultural pesticide and seed and subsidies for 2002–2006 are presented in (Table 1.9). Government’s contribution to agricultural insurance increased noticeably, which stimulated the development of the insurance business in agriculture. In addition, government has also paid producers’ insurance damages (Table 1.9).

Export subsidies

Support to agricultural production, as well as to industry and services, has been one of the long-term objectives and policies of the Government over the last two decades. One of the main policies supporting export commodities is that they are free of any currency agreement and local domestic demand and market control has no restriction or effect on export products, except for genetic resource materials. The cabinet must provide for the required annual budgets to encourage the export of agricultural products. These budgets must have clear objectives in that regard.

Export commodities and services are exempt from any tax. In addition, export incentives - a type of subsidy payment- have been granted, especially for agricultural products. Consequently, to support local production in international markets, subsidies have been paid from time to time.

Recently, export subsidies have been granted for eggs, chicken, potato,

Table 1.9. Total amounts (thousand t) and value (million US$) of chemical fertilizer, agricultural pesticide and seed subsidies for 2002–2006.

	2002		2003		2004		2005		2006	
	Amount[1]	Value[2]	Amount	Value	Amount	Value	Amount	Value	Amount	Value
Chemical fertilizers	2831	1057	3021	1525	3632	2833	3751	4865	–	4844
Pesticides and seeds	24	501	25	427	27	435	26	512	–	508
Insurance subsidies	–	62	–	150	–	682	–	732	–	946
Damage paid	–	319	–	633	–	1132	–	1672	–	1930

[1]thousand t; [2]million US$

onion, tea, raisins, and breeding shrimp. However, the export subsidy actually paid was 30 per cent less than the anticipated values, which could be attributed to difficulties with subsidy payments. The government paid export subsidies and awards from 2001–2004, but has only paid export awards in 2005–06 (Table 1.10).

Most agricultural commodity export policies balance excess production with domestic price control, and most are cash crops (fruit, vegetables, shrimp, and caviar). To compete in international market, export fruit and vegetables are well irrigated and of a better quality. Consequently, more water is used to produce these crops compared to crops produced for domestic markets.

1.5.7 Institutions involved in water policy implementation

Ministry of Agriculture

Prior to 1943, various organizations in the country, such as the Ministry of Agriculture, the Ministry of Finance and the Agricultural Bank, were responsible for water and irrigation management. These responsibilities included *qanats* development, supervision of the distribution of water-rights and responding to users' complaints. The scattered and diverse activities and overlap of responsibilities were the main obstacles to the coordination and advancement of the programs. To overcome these issues, in 1943 the law establishing the Independent Agency

Table 1.10. Total export subsidies and awards (million US$) for agricultural commodities for 2001–06.

Agricultural commodity	Years					
	2001	2002	2003	2004	2005	2006
Eggs and poultry	11.96	–	0.70	6.19	–	–
Raisins	5.12	9.41	7.19	0.65	–	–
Tea	6.03	–	1.78	7.73	–	–
Potatoes	–	–	–	3.31	–	–
Shrimp	–	1.23	2.7	10.67	–	–
Total	**23.11**	**10.64**	**12.37**	**28.55**	**26.7**	**15.2**

of Irrigation was approved under the supervision of the Ministry of Agriculture, to be responsible for water management in the country. In 1955, its technical responsibilities were expanded to include issues such as comprehensive studies of water resources, the design of dams and irrigation networks and the construction of some dams and irrigation and drainage networks, establishing investment companies in cooperation with the owners of agricultural land in different regions, determining and collecting water fees, and other responsibilities.

The activities of the Independent Agency of Irrigation were very effective and useful. Some of its important activities included:

- Establishing hydrometric stations for 35 rivers
- Establishing new meteorological stations
- *Qanats* development
- Constructing some diversion dams and various irrigation networks
- Establishing the Soil Institute (presently the Soil and Water Research Institute).

On the establishment of the Ministry of Water and Electricity in 1963, the Independent Agency of Irrigation became affiliated to this Ministry.

In 1955, the Agricultural Engineering Office was established in affiliation to the Ministry of Agriculture with the aim of promoting the conservation and suitable use of water and soil resources. The main responsibility of this office was to offer consultation and technical support to the development of new irrigation systems and implementation of pilot irrigation and mechanization projects in different agricultural areas.

In 1991, the Ministry of Agriculture established a new 'Deputy Ministry of Technical and Infrastructure' for the development of water and irrigation. Consequently, the Agricultural Engineering Office was divided into three new independent offices (i) Land consolidation and leveling and increasing irrigation efficiency office, (ii) pressurized irrigation systems development office, and (iii) irrigation network development office. In 2001, land consolidation and leveling and increasing irrigation efficiency, and Irrigation network development were merged. Finally, in 2007, the title of the Deputy Ministry changed to the Water, Soil and Industries.

Currently, soil and water issues are part of the responsibilities of different organizations within MoJA (Annex 1)

Ministry of Energy

The first water resources management and development agency in Iran was established in 1943 and it was affiliated to the Ministry of Agriculture until 1963. The Khuzestan Water and Power Organization was established and became active as an independent organization before the establishment of the Ministry of Water and Power in 1963. Subsequently, irrigation development agencies as well as the Khuzestan Water and Power Organization and associated authorities at the provincial level were merged with this new ministry.

By increasing water-related work and the development and construction of dams, irrigation and drainage networks, and pumping stations, much provincial infrastructure as well as Municipal and Waste Water Companies have been established and now cover the whole country. The Ministry's title was changed to the Ministry of Energy in 1974.

The Ministry is responsible for water resources and management in the country. In addition to the Ministry of Energy, the Ministry of Jihad-e-Agriculture and some other ministries and organizations are also responsible for some water-related work.

According to the latest structural diagram of the Ministry of Energy, out of five Deputies, one is responsible for water resources, municipal water and waste water. This Deputy is responsible for the macro-programming of municipal and waste water, standardization for the technical, social and environmental engineering aspects of water, improvement and development of water supply projects, water resources development, rivers, and costal engineering. The main headquarters are at the ministerial level and more than 121 regional water companies in different areas are responsible for water supply and allocation to users (agriculture, urban and rural areas, industry, and the environment). The Ministry is also responsible for monitoring groundwater levels and allocation. It carries out research and educational programs through five regional centers, one central institute, and one independent college, which provide opportunities for research on water resources management issues and developing human resource capacity.

1.6 Assessment of water-related policies and institutions

To assess the institutional arrangements and policies in KRB a focused study was conducted at selected sites in the upper and lower KRB. The study aimed to assess the impact of institutions and policy implementation on food safety, economic growth, social equity, poverty reduction, and environmental conservation.

A questionnaire was designed based on the project objectives, and selected farmers and administrators were interviewed. The questionnaire included issues on:

1. Agriculture in irrigated regions and related policies – cropping patterns, production, marketing.
2. Economic and socioeconomic policies – population, occupation and education, land ownership.
3. Related policies on poverty and justice – water allocation, drinking water, gender issues.
4. Sustainability and the environment – land fertility, water quality, land degradation.
5. Irrigation technology development.
6. Water allocation policies – water consumption, water rights, water allocation mechanisms.
7. Water pricing and investment policies.
8. Institutional – water management, environment, agricultural water,

Benchmark selected sites are an essential component of an integrated natural resources management (INRM) approach to agricultural research. We selected two benchmark sites based on (De Pauw *et al*., 2008): Sorkheh in the lower KRB and Merek in the upper KRB (Figure 1.13). They are relatively small areas, used to develop, test, adapt, and evaluate improved genetic and natural resources management practices and technologies under farmer and community practices and not on research stations (Oweis *et al.,* 2009). To allow a meaningful extrapolation of the research conducted at these benchmark sites, they have to be representative of the larger target areas of the research, meaning that they should resemble the broader agro-ecological zone(s) of interest in terms of the major agricultural, environmental, and human elements.

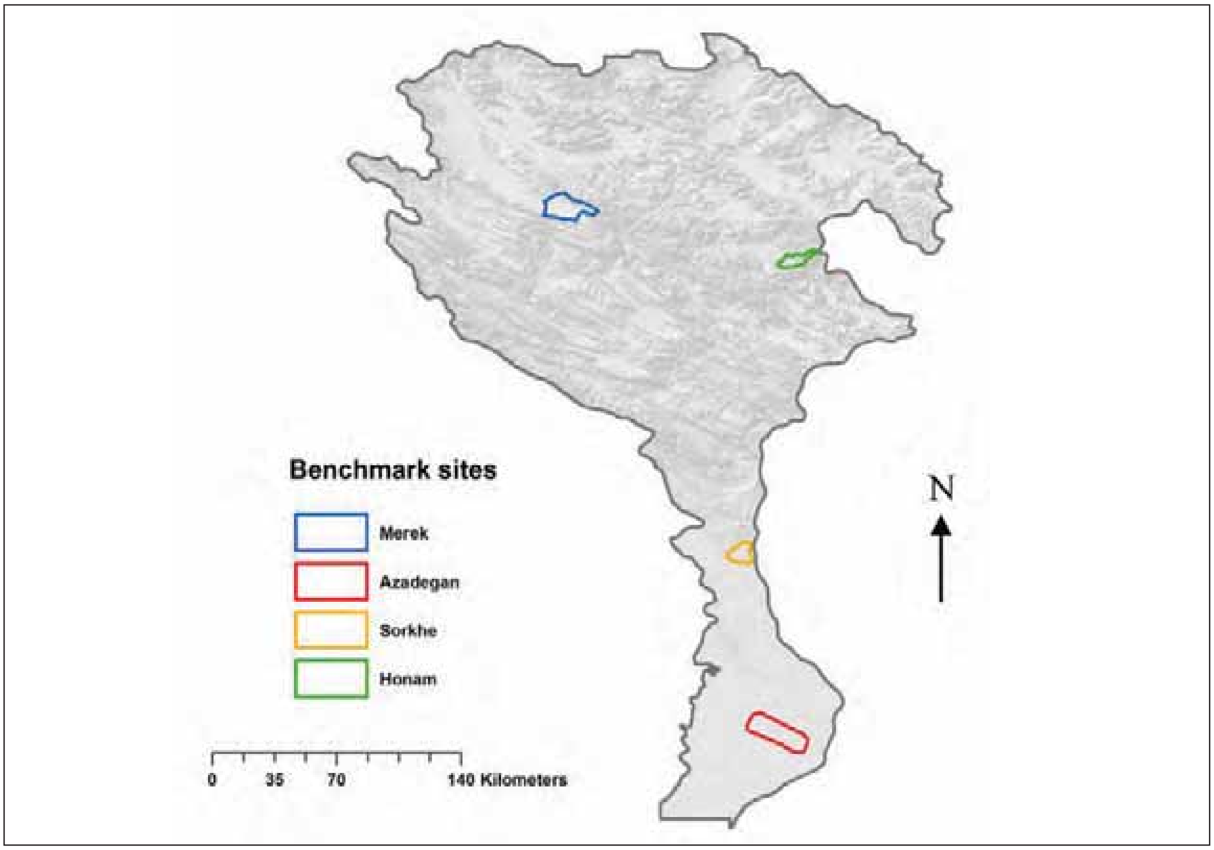


Fig. 1.13. Location of the benchmark sites in KRB.

Based on (De Pauw *et al.,* 2008), the benchmark sites were selected by extraction from the KRB-level maps of Agro-ecological Zones (AEZ), landforms (A1.17), and land use/land cover and soils.

Sorkheh is located in the irrigated plains and has the same arid climate with mild winters and warm to very warm summers. Merek is in a broad valley with a rather narrow piedmont and mountain slopes. In terms of land use/land cover, it is diversified, containing irrigated and rainfed crops, rangelands and bare rock outcrops. Merek is the only benchmark site with some open forest areas.

Precipitation and temperature data for the benchmark sites, obtained by extraction from the relevant climate sources, are summarized in (Table 1.11) and (Figure 1.14).

The AEZ present at the benchmark sites occupy most of the KRB, hence on this criterion the benchmark sites are highly representative, even though some of the AEZ may occupy only a small area at the benchmark sites.

1.6.1 Appropriateness of irrigation water management technologies

Appropriate irrigation technologies are different in the upper and lower KRB. In the lower basin (downstream), irrigation experience goes back to more than 45

Table 1.11. Summary of precipitation and temperature data for the benchmark sites.

Benchmark site	Factor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Merek	Precipitation, mean (mm)	69.8	69.5	98.7	55.6	30.1	1.0	0.4	0.1	0.3	25.4	62.0	76.3
	Precipitation, SD (mm)	1.2	2.4	1.9	2.7	2.0	0.1	0.2	0.1	0.1	0.6	1.4	0.5
	Temperature, mean (°C)	0.7	2.3	6.2	11.6	16.2	21.5	25.4	24.9	20.6	14.9	8.7	4.0
	Temperature, SD (°C)	1.1	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.9	1.0
Sorkheh	Precipitation, mean (mm)	76.1	54.2	53.9	25.9	6.0	0.0	0.0	0.0	0.0	8.6	32.5	68.8
	Precipitation, SD (mm)	1.7	0.8	2.1	0.4	0.1	0.0	0.0	0.0	0.0	0.2	0.7	2.1
	Temperature, mean (°C)	10.8	13.1	16.5	22.2	29.0	33.6	35.4	35.0	31.8	25.4	18.6	13.4
	Temperature, SD (°C)	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0

SD = standard deviation

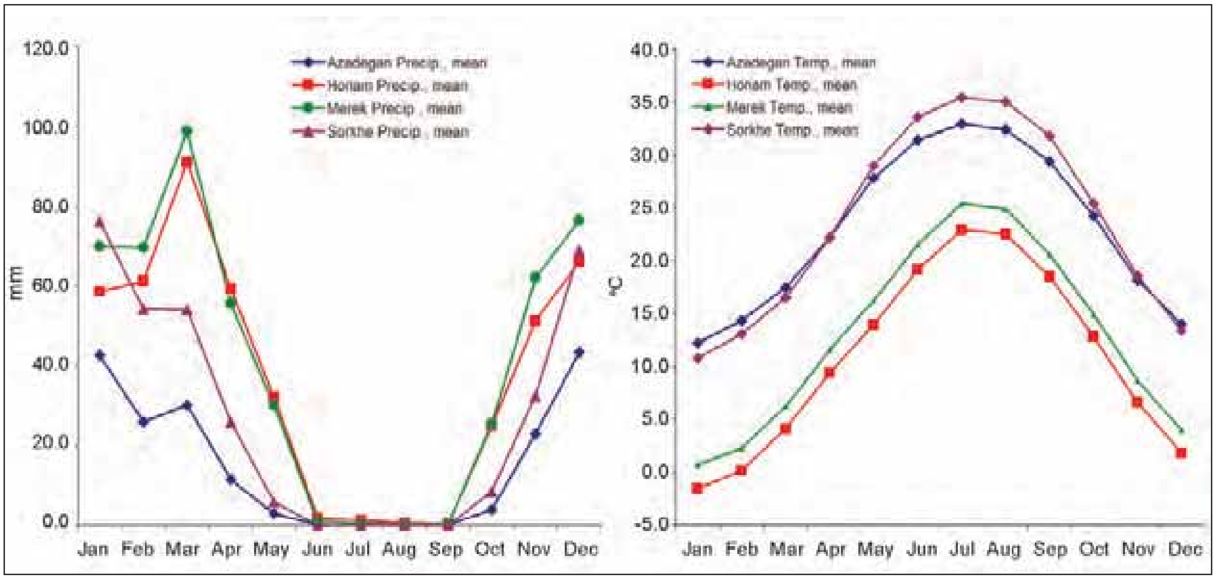


Fig. 1.14. Mean monthly precipitation (left) and temperature (right) at the benchmark sites

years before the irrigation and drainage network was developed. Most of the agricultural area is irrigated by surface irrigation. Some successful experience with advanced irrigation systems, such as sprinkler irrigation in citrus orchards, marks the beginning of the development of modern irrigation systems in this area.

In the lower basin, border irrigation was popular, but farmers shifted to furrow irrigation with time. Here, the irrigation borders in some fields reach about 400 m. In this system, plots in border irrigation systems follow each other and a large amount of water is applied to the first plot, which then runs on to the next. Water loss in the first plot is very high due to deep percolation in the plots closer to the canal.

Future plans for the lower KRB and the Karkheh dam irrigation and drainage network have suggested 259,000 ha of surface irrigation for heavy textured soils and 61,200 ha, including 40 per cent sprinkler irrigation, 12 per cent drip irrigation and 48 per cent surface irrigation, for light textured soils. An evaluation of border irrigation in this area has shown that with the correct border length, a 37 per cent water saving could be achieved. This means that water productivity of wheat could be increased from 0.6 to 1.4 kg/m^3.

When conducted on maize, the same study showed that with a suitable surface irrigation system, 30 per cent of water could be saved and water productivity could be increased by 50–100 per cent from 0.53 to 0.60 kg/m^3. These results show that the new irrigation technology is compatible with the area and could be effective in improving irrigation management in the future.

More than two decades ago, border irrigation was widely used. Currently, surface irrigation is common and used for wheat, barley and sugar beet.

For increasing agricultural production, implementation of numerous soil and water projects, modified irrigation systems, and new technologies in agricultural area, through the governmental policy support, bring the resulted of 168,000 ha of wheat and 46,000 ha of maize being irrigating by furrow irrigation.

These areas had practical sprinkler irrigation systems 40 years ago and since the third long-term NDP (1991), pressurized irrigation systems have been widely accepted. Based on the latest report, in the upper KRB, 25,000 ha of agricultural land is under sprinkler irrigation and 2000 ha is under drip irrigation. The application of pressurized irrigation systems saves about 30 per cent of water compared to surface irrigation. It should be noted that one type of sprinkler irrigation system (gun system) was not acceptable in this area and was almost collected from the field after a few years.

Another example of irrigation systems acceptable to farmers is drip tape. Farmers have suggested some changes in current institutional policy regarding the drip tape system so that they could apply the system on their farm with less bureaucracy. Over recent years, drip tape irrigation was applied to row crops resulting in 40 per cent water saving compared to sprinkler irrigation with a 45 per cent increase in production. Extension of pressurized irrigation systems and mobilization and rehabilitation for optimization of agricultural land together with the provision of surface drainage systems to discharge surface runoff are suggested technologies for these areas.

1.6.2 Conflicts, institutional responsibilities and policy

The structure of the Khuzestan Water and Energy Organization (KWEO) has already been discussed. KWEO is a provincial water organization. It includes two operating companies for surface and subsurface water resources. Due to the size of the irrigation network in Khuzestan Province, the operating company for surface water resources is divided into two branches, one for the North and the other for the East of Khuzestan.

The Operating Company for East Khuzestan is responsible for the operation, maintenance and management of irrigation networks in the lower KRB, while the Operating Company for North Khuzestan is responsible for the Dez irrigation network and the upper Karkheh River irrigation network, where the Sorkheh site is located.

These companies are also responsible for water allocation based on field size and cropping patterns, water pricing, agreement between water users and the company, drawing up budgets for irrigation network maintenance, and reporting on operations and construction to KWES. The Operating Company for North Khuzestan (NOP) is divided into two branches: the Dez irrigation network under Dez dam, and the western part of the Karkheh irrigation network, where Ghods village and the Sorkheh site are located.

Until 2006, the management of water allocation at the Sorkheh site (West Karkheh) was under NOP control and users had to contact NOP directly. However, the bureaucracy was such that each network had to have its own office in NOP which forced users to contact two separate bodies regarding agreements on water allocation amounts and delivery times. However, for licenses concerning water withdrawal from groundwater and issues related to the pumping stations, users had to contact NOP directly.

As discussed earlier, there is a Jihad-e-Agriculture organization in the provincial directorate office in each county which is covered by an Agricultural Service Center (ASC).

The Sorkheh site has an ASC which is responsible for:

- supporting farmers on agricultural issues related to agricultural machinery, animal husbandry, subsidies, infrastructure operation, etc.
- extension and education services
- supplying agricultural materials
- renewing governmental budgets for land leveling, well drilling, optimization of agriculture machinery, replacing diesel engines for wells with electric engines, etc.
- facilitating agreements between the Government and farmers for the main cropping patterns (wheat, maize, canola)
- developing agriculture and animal husbandry at the site
- offering education for women.

The ASC annual plan is usually coordinated with the provincial agricultural organization. There is no particular bureaucracy in the ASC, but there are some difficulties in the county agricultural organization mainly regarding financial support through the bank. The other local institutions at the Sorkheh site are the rural cooperative, the rural production cooperative, the participatory land committee, the rural Islamic council, partner groups and a farmers' community system (*baneh*).The rural production cooperation is part of the land-use system policy set up by the government for agricultural development and receives governmental support on technical matters. Partner groups were formed when there was some agricultural land with no owner. They have governmental support for agricultural activities. The farmers' community system (*baneh*) existed at the site before the irrigation network was established. *Baneh* developed independently, without government support, between farmers, villages and tribes.

There has been some conflict over water and agricultural inputs. Inadequate loan and bank facilities are some of the main issues raised by farmers. They need to have bank-acceptable guarantees to obtain a loan or other bank facilities. So, farmers who do not have collateral acceptable by the bank are not able to receive financial support to improve their agricultural situation. However, due to bureaucracy, even though most farmers are interested in using new technology and land leveling and wish to accelerate construction of the irrigation network, they are unable to exploit bank facilities for irrigation network construction, well equipment, land leveling.

There are other issues related to water delivery at the irrigation network gates. The West Karkheh office delivers water to the gate but accepts no responsibility beyond that point, even though there are sometimes 20 users for a given irrigation gate. In this situation, fields located near the gate usually receive more water than those far away from the gate due to factors like water losses during conveyance, non-existence of accurate facilities for volumetric control of water, improper gate management, etc. The West Karkheh Water Management office accepts to deliver water to the farmer's representative and water is shared among farmers upon agreement. However, farmers refuse to accept this due to technical issues in water delivery system in the irrigation network and pumping station. Furthermore, farmers do not receive any compensation for reductions in yield due to delays in water delivery.

1.6.3 Weaknesses and gaps

Unfortunately, over the last decade no water has been allocated to protect the ecosystem and the environment. Accordingly, some valuable ecosystems in the region have been affected by KRB irrigation development plans. As mentioned earlier, construction of the Karkheh dam controlled flooding in the lower KRB. Consequently, the quality of most agricultural land changed and salinity increased. As a result, a large area of the Azadegan plain is now not arable due to salinity.

The results of semi-detailed studies indicate that approximately 80 per cent of farmlands in the Dasht-e-Azadegan area have both low or high salinity and alkalinity. Overall, out of 91,470 ha in the Dasht-e-Azadegan region, the following can be observed:

- 1 per cent or 70 ha have no salinity and sodicity limitations
- 16 per cent or 14,599 ha have moderate salinity and sodicity
- 27.4 per cent or 25,040 ha have high salinity and sodicity
- 2.2 per cent or 2040 ha have varying rates of salinity and sodicity.

Increasing soil salinity and poor agronomic practices in these regions are among the causes of the very low rates of agricultural production. Irrigated agriculture in these regions faces many issues. For instance, field size, irrigation scheduling, water allocation systems, irrigation systems, surface drainage systems, etc., are all problematic and result in low germination rates and low crop production which intensify soil salinity and water logging.

Irrigation network development in the lower KRB has caused the water table level to rise. Since 1999, the water level has increased by about 1.4 m – this is a recharge of about 9.33 mcm to the aquifer.

chemical fertilizers are usually recommended by the local ASC based on soil analysis. Recently, fertilizer application and management has been monitored of experts employed by farmers and under the authority of the Engineering Statute Organization. Farmers have recently been prevented from burning crop residues to protect the environment and the ecosystem, but some still continue doing so, which calls for further regulation in this area. More than 82 per cent of families have access to tap water. Due to the low population, a water treatment center and health center have not yet been established in many villages.

1.6.4 Distortions caused by pricing policies

Irrigation water is almost free and there is no control on the amount and quality consumed. As mentioned earlier, water allocation is based on the land area and crop. However, in practice at the Sorkheh site, water allocation is about 1.0 l/sec/ha during winter and 2.0–2.5 l/sec/ha during summer. This amount varies according to the soil type and the distance from the gate, irrespective of the cropping pattern. So, if water pricing is based on the average production at the site and the farm area, there is no advantage for farmers who achieve high levels of production with their water.

Farmers who receive water from the network are discontent with the payment system because water delivery is not punctual and their crop is therefore usually damaged. This is an unfair situation considering that agricultural authorities give prizes to farmers who achieve higher productivity.
Water pricing at (upstream and downstream) sites are based on the guidelines approved by government (discussed in Section 6.6. 'Pricing Policies'). At the Sorkheh site, farmers sign a contract with NOP on water costs. In these contracts, the monthly allocation is decided based on cropping patterns and field size.

Under this contract farmers have to pay 50 per cent of the water cost in advance and the rest after the harvest. At the Sorkheh site, farmers have to pay the NOP for pumping water from the main channel to the secondary channel, while since 2005; farmers who have a pumping station to draw underground water have to cover electricity or gasoline costs.

1.6.5 Effectiveness in addressing food security and water-use efficiency

Food security

The area under wheat in Iran is about 6.6 million ha (2.2 million ha irrigated and 4.4 million ha rainfed) and covers nearly 50 per cent of the total cultivated area under annual crops. National wheat production was 10.0 and 14.3 million tons in 1996 and 2005. An adequate supply of bread in the country at a low price is one of Iran's food security policies, and is mainly related to wheat production.

From the food security point of view, total wheat production in the KRB (rainfed and irrigated) was about 1.433 million tons in 2005. Of this; 856.9 thousand tons were produced from irrigated land and the rest in rainfed areas. Considering the population of the KRB in 2005, which was about 3.6 million, and assuming wheat consumption of 170 kg per capita, the total amount of wheat required for food security in the KRB is about 0.612 million tons, i.e. about 43 per cent of the total wheat produced in the basin. Therefore, about 57 per cent of total amount of wheat produced in the KRB plays an important part in the food security of the country.

The other main crops in the KRB are barley and maize with a total production of 0.408 and 0.353 million tons, respectively. During the expansion plan for maize production in the country during 2005, the KRB contributed 17.8 per cent of the total national production of 1.99 million tons.

The upper KRB is the main area for pulse production in Iran. Pulse production in the KRB was 0.105 and 0.132 million tons in 1996 and 2005, respectively, constituting 37 per cent and 20.5 per cent of total pulse production in the country.

Water-use efficiency (WUE)

In the irrigation network, water allocation is based on an agreement between the ME or network office and the farmers. As mentioned earlier, the water allocation rate for each unit of land is almost constant and in the agreement is based on each farmer's total land area. This is in spite of the availability of information regarding the water requirements of different crops in the National Water Document. This information has been disseminated officially to all water organizations in the country including those located in the KRB. However, water organizations are still following their traditional procedures for water allocation. They allocate water based on the available water. It may be less than the amount agreed in the contract during drought. In other words, there will be deficit irrigation in the entire lower KRB irrigation network when the basin faces drought or water scarcity. However, improper management and allocation in the irrigation network may impact on yields depending on the field's location in the network.

Under conditions of water scarcity, farms near the gate receive more water than those far from the gate. The water level in the network also varies depending on the distance from the main gate in the main channel. Therefore, the contract is not a policy to improve water productivity but to oblige farmers to make water payments. However, water allocation could be more effective and water productivity improved, if it is managed properly.

Farmers who have a well usually draw water from underground when needed. There is no serious control on well pumping stations but water productivity in fields with well water resources is usually better than in fields relying on the irrigation network. This may be because these farmers have better control over their water and their crops do not experience water stress during growth.

1.6.6 Other issues

There is no council or specific organization for women. From the civil rights' point of view, women are equal to men; they may even receive better support on official matters related to public services. Women are not active as members of rural councils or other civil organizations because of cultural poverty. There is no organization to improve cultural attitudes especially for women. The regions have a huge potential for development. NGOs could have an impact on the improvement of women's knowledge, their free-time occupations, protection of the ecosystem, village health, and improving rural livelihoods.

1.7 Conclusions and recommendations

This study was conducted to review the policies and institutional arrangements on irrigation water use and to assess the consequences for water allocation and productivity in the selected sites of Sorkheh and Azadegan in the lower KRB and Merek in the rainfed area of the upper basin. The method used is based on a review of the available policy documents, as well as secondary and stakeholder survey data, to assess water and water-related policies and institutions influencing water use in the KRB.

The Ministries of Energy (MoE) and Jihad-e-Agriculture (MoJA) are the main institutions responsible for managing water in Iran. The MoE is responsible for the storage, supply and allocation of water to different consumer sectors, while the MoJA is responsible for improvements in water productivity and the development of irrigation systems technologies. In Iran, there are 49 research and/or educational institutes related to water, 14 institutes focusing specifically on water research, 25 societies concerned with water or agriculture, 47 consulting engineering firms specialized in water, and 178 manufacturing and/or design companies in irrigation (especially in pressurized irrigation systems).

Water management in the KRB is characterized by complex, overlapping, and sometimes competing networks of actors, rules, functions, and organizations. Multiple actors and organizations involved in water-related decision-making at different levels have caused delays in water delivery, such that farmers do not receive water at the right time and in the amounts.

The law of the Equitable Distribution of Water is one of several important pieces of national legislation on water policy in Iran, first approved by Parliament in 1982 and slightly modified later. It consists of five chapters, 52 articles and 27 notes. The main chapters are: (i) public and national ownership of water, (ii) groundwater resources, (iii) surface water resources, (iv) duties and authorities, and (v) penalties and regulations. Even though several water policies, strategies, laws, and regulations exist, effective water resource development is yet to be achieved.

Examples of deficiencies include:

- Few development projects for water resources, especially for secondary canals, despite high investment
- Low water productivity at both national (0.9 kg/m^3) and KRB (0.54 kg/m^3) levels
- Depletion of groundwater and negative water balance in some basins
- Simultaneous soil and water resources degradation
- Rising groundwater levels in a large area downstream of Karkheh dam, resulting in increased soil salinity and a decrease in the cultivated area and yields. Agricultural development in this area has almost stopped
- Deterioration in socioeconomic conditions and the use of cropping patterns without cash crops have led to a situation where farmers' incomes in the lower KRB are less than in other parts of the country
- The natural resources of upper catchments are severely degraded, which results in poor vegetation cover, degraded physical and chemical soil properties, and disturbed water balance
- Achievement of the goals of the first three NDPs on water allocation,

productivity, and water resources management was less than expected.

Reforms are needed to contribute to poverty reduction, environmental sustainability, gender equity, and water pricing. These reforms should create a framework for the development of relationships among the key government actors, non-governmental organizations, civil society, the private sector, and farmers to identify the most effective use of resources and methods of management. Because incentives are lacking to engage poor people in governing water resources, the state needs to use its authority to enhance their voice and benefits.

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Chapter 2.

Economic Factors of On-Farm Water Use Efficiency in Irrigated Cereals in the Lower KRB, Iran

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Chapter 2. Economic Factors of On-Farm Water Use Efficiency in Irrigated Cereals in the Lower KRB, Iran

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2.1 Introduction

Planning for optimal use of water resources is of vital importance in Iran since the supply of water is limited while water demand is continuously increasing associated with population growth and the expansion of economic activities. Consequently, the use of proper criteria and mechanisms to allocate and exploit water resources is crucial for the realization of national development programs. Generally, there are three types or combination of mechanisms for water allocation (Soltani, and Zibai, 1996):

- Political/administrative-based allocation system
- Technically-based allocation system
- Economically-based allocation system.

In Iran, the economic value of water is higher than the prevailing price. Therefore, water allocation should be based on economic mechanisms. Following this method, water is a valuable input and should be economized (Asadi, 1997). Water pricing impacts water allocation among different consumers, water conservation and investment motivation. It also impacts the partial coverage of costs, cropping patterns, income distribution and efficient water and environment management practices. The most appropriate price for water is one which reflects the share of water in increasing production levels and this is called the 'efficient price' (Soltani, 1995). Increasing demand for food in developing countries with limited water resources necessitates irrigation research to determine the optimal water requirement for maximum production per unit of land and/or water. Since the supply of water in Iran has always been limited and the level of demand has been increasing with population growth, planning for optimal use of water resources has a specific importance. The amount of irrigation water used for agricultural crops is high in Iran compared with many other countries. For example, while water use for wheat is generally from 4500–6500 m^3/ha and for maize from 5000–8000 m^3/ha, the corresponding means in Iran are 8000 m^3/ha for wheat and 10,000–12,000 m^3/ha for maize. About 93 per cent of the renewable water resources of the country are used in agriculture (Keshavarz and Heydari, 2004; Keshavarz and Heydari, 2005).

The present study was carried out in two plains, Dasht Azadegan (DA) and Dasht Sorkheh (DS) in the Karkheh River Basin (KRB) in Iran. This basin is in the west and south of the country – west of the Zagros ranges and located between 56°34′ and 58°30 North and 46°06′ to 49°10′ East. The area of the basin is 50,764 km^2, of which 27,645 km^2 are mountainous and 23,119 km^2 plains and hills. The mountainous areas of the basin are mostly in the eastern and central parts. The plains are mostly in the northern and southern parts and cover almost 45 per cent of the basin area. Water in the KRB is limited and becoming scarcer as population and demand increase. The productivity of rainfed agriculture is low, conventional irrigation management is poor, cropping systems are sub-optimal, and policies and institutions are weak. However, Iran's agricultural strategy identifies water productivity improvement as a top priority. The KRB reflects in many ways the problems of water management in other basins in the region. In the Khuzestan Province, the average volume of water delivered to cereals is 7910 m^3 and the average price of irrigation water and pumping costs, e.g. in irrigation networks of the Evan plain, are 0.30 US cent/m^3 and 0.125 US cent/m^3, respectively (Ministry of Energy, 2003., Keshavarz *et al.,* 2005).

The purposes of this study were to investigate the:

- Socioeconomic characteristics of the target regions
- Different water uses and water price for cereals in the target regions
- Situation of irrigated cereals in the Azadegan and Sorkheh plains
- Socioeconomic characteristics between sample farmers
- Profitability in irrigated cereal production between sample farmers (costs and benefits, gross margin, cost ratio and return on sales)
- Average water-use efficiency in irrigated cereals between sample farmers
- Production value in irrigated cereals for one Rial of water use in the Azadegan and Sorkheh plains
- Effects of economic factors on average water-use efficiency and its comparison in areas with different salinities (Azadegan plain) and other areas (Sorkheh plain)
- Reaction of sample farmers to some quality characteristics.

2.1.1 Climate and socioeconomics of the study sites

Climate of DA and DS plains is warm and semi-arid. Based on 2003 data, average annual rainfalls of DA and DS plain were 219.6 and 335.2 mm respectively. There is no rain during June-September. The rain occurs mainly during December-March. Average annual temperature of the region is 22.9 ^{0}C with the maximum absolute annual temperature of 51.8 ^{0}C. Average annual relative humidity and evaporation are 47 per cent and 3099 mm, respectively.

Population of DA and DS plains are 112945 and 6126, respectively. About 57800 people (51.2 per cent) of the total population of the DA and DS plains live in the urban areas and the rest i.e. 48.8 per cent, live in rural areas, respectively. The socioeconomic characteristics of the DA and DS plains are shown in Table 2.1. The coefficient of mechanization in Khuzestan Province and the DA plain

Table 2.1. Population, literacy, and landholdings in the DA and DS plains in the lower KRB.

Total population (%)			Literacy rate (%)		Average size of land holdings (ha)			Employed population (%)
DA		DS	DA	DS	DA			DA
Urban	Rural	Rural			Rustic	Mechanized	Segments	
57,795 (51.2%)	55,150 (48.8%)	6126	64.4	60.9	17.6	9.8	2	19,283 (25.8%)

Sources: 1-Agricultural Planning and Economic Research Institute, Ministry of Jihad-e-Agriculture, 2003.
2-Statistics Center of Iran, 2003.

are 0.63 and 0.56 hp/ha, respectively. Information on the amount of agricultural equipment and machinery in DA and DS are given in (Table 2.2).

According to information from the target regions (2004), the area under irrigated wheat in the DA and DS plains as percentages of the total area under irrigated wheat in Khuzestan was 50,050 ha (15.1 per cent) and 5000 ha (1.5 per cent), respectively. Irrigated wheat production in the DA and DS plains as percentages of total irrigated wheat production in Khuzestan was 135,135 tons (11.8 per cent) and 18,000 ton (1.6 per cent), respectively. Average yields of irrigated wheat in the DA and DS plains are 2700 and 3600 kg/ha, respectively. Information on planting area, yield and total production of common cereals in the DA and DS plains is provided in (Table 2.3).

The source of surface water in the DA plain is the Karkheh River. Irrigation is by a combination of traditional and modern systems. In the DA plain, based on the cropping pattern of the irrigated area, water requirements are estimated to be 831.21 mcm per year. Currently water consumption in the area is 742.7 mcm per year (89 per cent). The rate of water consumption from pumps, the network and groundwater are 490.6, 245.1, and 7 mcm per year, respectively.

The irrigation method in the DA plain for wheat and barley is a combination of furrow and border irrigation and for maize it is furrow irrigation. The share of water among the consuming

Table 2.2. Agricultural equipment and machinery in the DA and DS plains.

The number of pieces of agricultural equipment and machinery										
DA plain						DS plain				
Disk and plow	Fertilizer sprayers	Tractor-mounted sprayers	Threshers	Cereal planting equipment	Other	Disk and plow	Fertilizer sprayers	Tractor-mounted sprayers	Threshers	Other
1800	530	400	257	117	916	356	195	96	17	781

Source: 1-Management of Jihad-e-Agriculture in the DA Plain, 2003.
2-Extension and Agriculture Services in the DS Plain, 2004.

Table 2.3. Planting area, production and yield of irrigated cereals in the DA and DS plains compared to Khuzestan Province and the country.

Target regions	Planting area (ha)			Production (tons)			Yield (kg/ha)		
	Wheat	Barley	Maize	Wheat	Barley	Maize	Wheat	Barley	Maize
DA plain	50,050	5020	120	135,135	8534	624	2700	1700	5200
DS plain	5000	88	2541	18,000	176	19,820	3600	2000	7800
Khuzestan	331,335	27,646	59,207	1,149,239	51,435	396,697	3469	1860	6700
National	2,547,632	597,494	273,903	9,750,305	1,935,013	1,924,128	3827	3239	7025

Source: 1-Management of Jihad-e-Agriculture in DA plain, 2003.
2-Extension and Agriculture Services in DS plain, 2004.

sectors in the DA plain for agriculture, drinking, green spaces, industry, and fish production is estimated to be 742.7, 19.1, 1.22, 1.37, and 6.1 mcm per year, respectively. Based on local information (Sources: Agricultural Planning and Economic Research Institute, Ministry of Jihad-e Agriculture, 2003; Khuzestan Water and Power Authority, Ministry of Energy, 2003) the net, gross and total volume of water required for the 72,105 ha of planted area in DA are 3458.3 m^3/ha^{-1}, 11,527.8 m^3/ha, 831.21 m^3/ha, and 30 million m^3/ha^{-1}, respectively. The Evan plain is one of the plains in the lower KRB and the irrigation networks are well established there. Because of the availability of data and the similarity of this plain to the DA and DS plains, information on allocated water, prices and tariffs for irrigation water in this plain are provided in (Table 2.4) (Irrigation Network of Karkheh and Shavour, 2005).

Table 2.4. Water rates for airrigated cereals in irrigation and sanitation networks of Evan plain in the lower KRB (2004–2005).

Agricultural products	Volume of allocated water (m^3/ha)	Modern network		Average tariff ground water (Rials/m^{-3})
		Average price of irrigation water (Rials/m^{-3})	River pumping costs (Rials/m^{-3})	
Wheat	6463	37	14.4	3
Barley	5366	23	17.4	3.5
Maize	11,902	26	7.8	4.1
Mean	7910.3	28.7	13.2	3.5

2.1.2 Review of similar studies

In a study of on-farm water-use efficiency in Syria, a total of 80 farmers from 24 villages were sampled. On average, farmers had 16 years of irrigation experience and most of them (91 per cent) were full-time operators. Nearly 94 per cent of farmers indicated that their cropping pattern was mainly determined by market conditions, while 6.3 per cent were influenced by agricultural policies. Also, 39 per cent of farmers believed that water supply was limited and 78.8 per cent of them used groundwater for irrigation. Total farm size averaged 14.79 ha, while the average areas for wheat, barley and cotton were 5.21, 3.27 and 4.35 ha, respectively. The average amount of water applied to a farm was 19,831 m^3 and average water application by crop was 4833, 3770 and 15,385 m^3 for wheat, barley and cotton, respectively, with corresponding yields of 3391, 2245 and 3636 kg/ha. In that study, the dependent variable was irrigation water use for each crop and the independent variables were irrigated area for each crop (ha), output price[2] (SL/kg), total water available to the farm (m^3), experience in irrigation (years), water price (SL/ha/year), price of variable inputs, and qualitative variables including dummy variables on distance between the source of water and the farm, soil type, soil salinity, soil depth, crop irrigation technology, water application, and water management practices. Results showed that water productivity for wheat, barley and cotton was 0.9, 0.56 and 0.57 kg/m^3, respectively, with the corresponding value of the adjusted coefficient of determination (R^2) equal to 0.65, 0.53 and 0.93. Output prices appeared to be a strong determinant of short-run decisions on water allocation among

[2] In Syrian pounds (Lira) per kilo (SL/kg)

competing crops. Own-price variables for wheat, barley and cotton were positive and significant in explaining water use. An increase in the wheat price by 1 SL/kg, holding other variables constant, would increase water use for wheat by 198 m^3. Similarly, a 1 SL/kg increase in the cotton price would increase water demand for cotton by 1240 m^3. An increase in the cotton price by 1 SL/kg will reduce the amount of water allocated to wheat by 102 m^3, whereas a 1 SL/kg increase in the wheat price will induce a 216 m^3 reduction in water use for cotton. On-farm water-use efficiency (FWUE) in wheat, barley and cotton was 0.61, 0.45 and 0.76, indicating that actual water use exceeded the water requirement by about 39 per cent, 55 per cent and 24 per cent (Shideed *et al.,* 2005)

In another study of on-farm water-use efficiency in Iraq, 100 farmers were sampled .On average, the farmers had 11 years of irrigation experience and most of them (69 per cent) indicated that water supply was limited. The cropping pattern was mainly determined by market conditions and agricultural policies. Total farm size averaged 37.02 ha and average irrigated areas for wheat, potato, sugar beet, and tomato were 25.35, 8.92, 3.48 and 4.83 ha, respectively. The average amount of water available to the whole farm for winter cropping was 448,006 m^3 and average water application by crop was 5424, 75,216 and 40,289 m^3 for wheat, potato and sugar beet, respectively. For summer cropping, water available to each farm was 210,970 m^3, on average, of which 70,763 m^3 was used for tomato. Annual rainfall for the study area during the 1997–1998 season was 292.8 mm, with a standard deviation of 89 mm. Crop yield was 2184 , 16,311, 14,091 and 12,761 kg/ha for wheat, potato, sugar beet and tomato, respectively. Water productivity defined in technical terms as kg of output per m^3 of water, was highest for potato, i.e. 1.44 kg/m^3 (each additional m^3 of water gave 1.44 kg of potato tubers). Water productivity for wheat, sugar beet and tomato was 0.7, 0.97 and 0.73 kg/m^3. Among the 100 sampled farmers, 53 farmers grew wheat under rainfed conditions and 47 farmers used supplemental irrigation (SI). The average grain yield was 2360 kg/ha for wheat under SI and 1360 kg/ha for rainfed wheat. Results showed own-crop area and price appear to be the most important two variables explaining the farmers' water use decisions when irrigating potato, sugar beet and tomato. The estimated coefficients of these two variables are positive and highly significant in each water-use equation for the three crops. The water constraint variable is positive in the water-use equation of the four crops, but it is significant in the wheat and tomato equations. Average on-farm water-use efficiency (FWUE)[3] in wheat, potato, sugar beet, and tomato was 0.34, 0.45, 0.32 and 0.68. (Oweis *et al.,* 1999).

In a similar study of on-farm water-use efficiency in Jordan, 70 farms were sampled. Results showed that, water productivity under irrigated conditions for tomato, potato, wheat, and onion was 1.706, 2.854 and 0.172 and 0.63 kg/ m^3, respectively. The value[4] of water productivity was estimated at 16.89 JD/m^3 (US$24) for tomato, 17.84 JD/m^3 (US$25.3) for potato and 4.81 JD/ m^3 (US$6.83) for onion. Average area for tomato, potato, wheat and onion was 1.13, 1.93, 0.6 and 0.53 ha, respectively. Actual water used for tomato, potato, wheat and onion was 4038, 2212, 2160 and 2770 m^3, respectively. The water needed for tomato, potato, wheat and onion was estimated 4014, 2222, 1684 and 2809 m^3, respectively (Shideed *et al.,* 2005).

[3] Defined as 'the ratio of the required amount of irrigation water to produce a specific output level to the actual amount of water applied by farmers'.
[4] In Jordanian Dinars (JD)

2.2 Materials and methods

2.2.1 Theory

The relationship between irrigation water and crop production is defined as follows:

$Yi=F\ (Wi/Ai,Fi)$
where, Yi is the production of crop i, Wi is applied water for crop i, Ai is the cultivated area for crop i, and Fi are the inputs for crop i.

If water input was the only limited factor, then, profit can be estimated from the following equations:

$\Pi=TR-TC,\ TR=Py.Y,\ TC=W.Pw$
where, Π is the profit, TR is gross income, TC is total cost, Py is the price of the crop, and Pw is water price.

Then:
$\Pi=Py.Y-W.Pw$

By taking derivative with respect to the water price variable, we get:

$\partial \pi/\partial W=dY/dW.Py-Pw=0$

Optimum consumption of water is when the marginal value of water equals the water price.

$dY/dW=MPw$ » $MPw.Py-Pw=0$ » $MPw.Py=VMPw=Pw$

*Water productivity (WP) is defined as the ratio of yield (kg) to total water supply (m^3).

This concept is average production (y/w). If so, Average Product (AP) is maximum, then AP equals the marginal product (MP).

If AP=max » $AP=MP$=WP
*This concept reflects the technical measure of efficiency and thus is not sufficient to assess the economic level of water-use efficiency.

*The economically efficient amount of water use depends on the relative prices of water, the prices of inputs, the marginal products of inputs, the amount of inputs, and the prices of crops.

The concept of on-farm water-use efficiency (FWUE) is defined as the ratio of the amount of irrigation water required (Wr) to produce a specific output level to the actual amount of water applied by farmers (Wa).

$FWUE=(Wr/Wa).100$

If FWUE <1, the actual amount of water applied (Wa) is greater than the required amount of water (Wr), implying that farmers are over-irrigating their crops.

If FWUE>1, Wa is less than Wr, implying that farmers are under-irrigating their crops, i.e. in this situation, water is limited.

If FWUE=1, it means that farmers are fully efficient in using irrigation water because Wa and Wr are equal.

In order to determine the effect of economic factors on water productivity, the following three models are considered (Shideed *et al.,* 2005; Moore *et al.,* 1994):

1. Variable input method
2. Fixed-allocatable input model
3. Behavioral model.

In the variable input model, based on the application of Hotelling's lemma:
The first-order partial derivative of the restricted profit function with respect to the water price variable gives the water demand function.

The demand function for water is:

$Wi = \partial \pi \, (Pi, r, rw, ni : x) / \partial rw$

Thus:

$Wi = \alpha i + \beta i \, Pi + \Sigma \, \gamma i \, r + \gamma irw + \theta ini + \Sigma \, \dot{\eta} si \, X \, s$

where, Pi = price of the crop *i*, *r* = variable input prices other than water, *rw* = the price of water, *Wi* = water allocated to the crop *i*,
x = variables taken as given in the short run (e.g. irrigation technology), and
ni = land allocated to the crop *i*

The demand function for water in the fixed-allocatable input model is:

$\text{Max} \; \Sigma \, \pi i \, (Pi, r, ni, wi : x) / \Sigma \, wi = W$

where, *w* is farm-level quantity of water.

The general form of the behavioral model is:

$wi = wi(ni : x)$

Microsoft Excel was used to solve the models. In this program, in the main menu of the water model:

The first step is defining the dependent variables (the dependent variable is total amount of water applied to the crop studied), we insert a star (*) in the related row for that column, which is labeled as dependent variable.

The next step is defining the independent variables:

* For the variable input model, independent variables are: output price, planted area of crops, price of inputs, water price/or cost and other exogenous variables (irrigation technology).
* For the fixed-allocatable input model, independent variables are: output price, planted area of crops, price of inputs, farm-level water use (instead of water price) and other exogenous variables (irrigation technology).

* For the behavioral model, independent variables are: planted areas and other exogenous variables (irrigation technology).

*Meanwhile, we define the rainfall variable to calculate the actual water use, because, actual water use is the sum of the amount of irrigation water applied to a crop and the amount of rainfall.

2.2.2 Efficiency and productivity analysis

There are two common approaches in the literature for estimating technical efficiency. One approach is based on non-parametric, non-stochastic, linear programming. The second approach uses econometrics to estimate a stochastic frontier function and to estimate the inefficiency component of the error term. The stochastic frontier model assumes an error term with two additive components, an asymmetric component which accounts for pure random factors (v_i) and a one-sided component which affects the inefficiency relative to the stochastic frontier (u_i). The random factor (v) is independently and identically distributed with $N\,(0, \sigma_V^2)$ while the technical inefficiency effect, (u), is often assumed to have a half normal distribution $IN(0, \sigma_V^2)$. The Battese and Coelli (1995) model specification may be expressed as:

$Yi = Xi \, \beta + (v_i - u_i)^*$

where *Yi* is the production or the logarithm of the production of the i^{th} farm

Xi is a *K**1 vector of input quantities of the i^{th} farm

β is a vector of unknown parameters v_i are random variables which are assumed to be i.i.d. $N(0,\sigma_V^2)$, and independent of the u_i which are non-negative random variables which are assumed to account for technical inefficiency in production and are assumed to be independently distributed as truncations at zero of the $N(m_i, \sigma_u^2)$, distribution where: $m_i = z_i \varphi$

where z_i is a p*1 vector of variables which may influence the efficiency of a farm and φ is a 1*p vector of parameters to be estimated.

Variance parameters expressed as:

$$\sigma^2 = \sigma_V^2 + \sigma_u^2 \quad \gamma = \sigma_u^2 / (\sigma_V^2 + \sigma_u^2)$$

The parameter, γ, has a value between zero and one such that the value of zero is associated with the traditional response function, for which the non-negative random variable, u_i, is absent from the model. Thus, this model specification is non-nested and hence no set of restrictions can be defined to permit a test of one specification versus the other.

In this specification, the parameters β, σ, σ_u and γ can be estimated by the maximum likelihood method, using the computer program, Frontier Version 4.1. This computer program also computes estimates of efficiency.

Maximum likelihood was estimated using the Cobb-Douglas stochastic production frontier for determination of TE of farmers in wheat and barley production.

2.2.3 Cost function

All of the above specification has been expressed in terms of a production function with the u_i interpreted as technical inefficiency effects, which cause the farm to operate below the stochastic production frontier. If we wish to specify a stochastic frontier cost function, we simply alter the error term specification from $(v_i - u_i)$ to $(v_i + u_i)$; this substitution would transform the production function into the cost function:

$$C_i = Xi\,\beta + (v_i + u_i)^*$$

where C_i is the logarithm of the cost of production of the i^{th} farm,

Xi is a K*1 vector of input prices and output of the i^{th} farm, and

β is an vector of unknown parameters.

In this cost function, the u_i now defines how far the farm operates above the cost frontier. If allocative efficiency is assumed, the u_i is closely related to the cost of technical inefficiency. If this assumption is not made, the interpretation of the u_i in a cost function is less clear, with both technical and allocative inefficiencies possibly involved. Thus, we shall refer to efficiencies measured relative to a cost frontier as cost efficiencies in the remainder of this document. The exact interpretation of these cost efficiencies will depend upon the particular application.

2.2.4 Efficiency predictions

The computer program calculates predictions of individual farm's technical efficiencies from the estimated stochastic production frontiers, and predictions of individual farm cost efficiencies from estimated stochastic cost frontiers. The measures of technical efficiency relative to the production frontier and of cost efficiency relative to the cost frontier are defined as:

$$EFF_i = E(Yi^*\ U_i, Xi)/E(Yi^*\ U_i{,}{=}0, Xi)$$

where Yi* is the production cost of the i^{th} farm, which will be equal to Yi when the dependent variable is in original units and will be equal to exp(*Yi*) when the dependent variable is in logs. In the case of a production frontier, EFF_i, will take a value between zero and one, while it will take a value between one and infinity in the cost function case. (Ahmed *et al.,* 2002). The efficiency measures can be shown to be defined as:

Cost or production	Logged dependent variable	Efficiency (EFF_i)
Production	Yes	$\exp(-u_i)$
Cost	Yes	$\exp(u_i)$
Production	No	$(x_i \beta - U_i) / (x_i \beta)$
Cost	No	$(x_i \beta + U_i) / (x_i \beta)$

The above four expressions for EFF_i all rely upon the value of the unobservable U_i being predicted. This is achieved by deriving expressions for the conditional expressions of these functions of the U_i, conditional upon the observed value of $(V_i - U_i)$.

2.2.5 Research methods

The present study was implemented in the DA and DS plains in Khuzestan Province for cereal crops (wheat, barley and maize) during 2006–2007. Data were collected using two methods. In the first step, library studies were conducted to collect basic information and previous research on the subject. Later, the total number of farmers was determined by stratified random sampling as follows:

$$n = \frac{\Sigma (Ni^2 . Vi / Wi)}{N^2 D + \Sigma (Ni.Vi)} \qquad i=1, 2$$

$$Wi=Ni / N \qquad D=B^2 /4 \qquad ni=n (Ni/N)$$

where:
i = (1-Azadegan plain, 2-Sorkheh plain)
n: sample size
N: number of population of farmers in regions (Azadegan and Sorkheh plain)
Vi: variance of land area in stratum i
Ni: number of farmers in stratum i
Wi: fraction of observation allocated to stratum i
D: bound of error
ni: number of sample size in stratum i

Out of the total sample of 166 farmers, 136 farmers were selected from the Azadegan plain (20.6 per cent) from Shahid Chamran Agricultural Service Center (ASC), 14 per cent from Shahid Alamolhoda ASC, 14 per cent from Hovizeh ASC, 14 per cent from Bostan ASC, 12.5 per cent from Rafi ASC, 11 per cent from Allaho Akbar ASC, 8.8 per cent from Valfajer ASC, 5.1 per cent from Sableh ASC), and 30 farmers from the Sorkheh plain (23 per cent from the village of Salar Shahidan, 23 per cent from the village of Fath, 13 per cent from the village of Shahid Fallahi, 13 per cent from the village of Mohagerin,, 13 per cent from the village of Esteglal, and 13 per cent from the village of Gods). The required data was collected by questionnaire.

The survey also included questions and information on issues such as: farmer's general characteristics; land use (cropping pattern) by type of land tenure; soil characteristics; water resources; cropping system (including method of irrigation, land preparation and planting methods and their costs, fertilizer use, pesticide and herbicide application and their costs, and method of harvesting and its cost); agricultural inputs (except water) and their costs, water inputs (including the total area irrigated, water rights, irrigation scheduling (interval) and timing, and irrigation costs); competition for and shortages of water; agricultural crop yields and price outputs; socioeconomic conditions; and other related factors. Overall, the questionnaire dealt with information under the following headings:

- Location of the farm
- Farmer's general characteristics
- Land use (cropping pattern) by type of land tenure
- Soil characteristics
- Water resources
- Cropping systems
- Agricultural inputs and costs (except water)
- Water inputs
- Agricultural crop yields and price outputs
- Socioeconomic conditions and other factors.

In this study, average water productivity was equal to total production divided by water use. Profitability index was determined by using Microsoft Excel. To estimate the average water productivity cost ratio and return on sales, the following equations were used:

WP = Total product / water use
Cost ratio = (Total cost / Gross income) * 100
Return on sales = (Net profit / Gross income) * 100.

2.2.6 Variables in the frontier production function

In this study, crop outputs (yield in kg/ha) depend on purchased inputs such as seeding rate, fertilizer (urea rate, phosphate rate in kg/ha) and water consumption (m^3/ha), plus dummy variables including land tenure (private (1) and rented (0)), water limitations (yes (1) and no (0)), soil salinity (low (1), otherwise (0)), soil texture (light (1) and otherwise(0)), irrigation technology (sprinkler (1), others (0)). The dependent variable in the model is the amount of output (yield) per hectare including only grains.

In this study, co-linearity was diagnosed by using Variance Inflation Factors (VIF) (Shideed *et al.,* 2005).

$$VIF_i = 1/ (1- R^2_i)$$

R-square tells us how predictable our independent variables are from the set of other independent variables. It tells us about the linear dependence of one independent variable on all the other independent variables. Big values for the Variance Inflation Factor (VIF) are problematic. It has been suggested by some, to seek values of 10 or larger, but, there is no certain number that can be deemed fatal. When *R*-square is large, Variance Inflation Factor (VIF) will be large.

Small values of tolerance (close to zero) are also trouble.

$$\text{Tolerance} = 1- R^2_i = 1/VIF_i$$

2.2.7 Variables in the technical efficiency (TE) model

Variables including land size (ha), water price (Rial/m^3), seed rate (kg/ha), urea rate (kg/ha), phosphate rate (kg/ha), price of crop (Rial/kg), technology, and cropping area explain water productivity (WP).

Dummy variables including land tenure (private (1) and rented (0)) ,water limitations (yes (1) and no (0)), soil salinity (low (1), otherwise (0)), soil texture (light (1), otherwise(0)), irrigation technology (sprinkler (1),otherwise (0)), method of irrigation, method of land preparation, and water quality explain inefficiency. The dependent variable is the technical inefficiency measure determined together with the frontier function and estimated using Frontier 4.1.

2.3 Results and discussion

2.3.1 Socioeconomic characteristics of the sampled farmers in the DA and DS plains

Using stratified random sampling, 166 farmers were selected: 136 farmers from the Azadegan plain (28 from Shahid Chamran Agricultural Service Center (ASC), 19 from Shahid Alamolhoda ASC, 19 from Hovizeh ASC, 19 from Bostan ASC, 17 from Rafi ASC, 15 from Allaho Akbar ASC, 12 from Valfajer ASC, and seven farmers from Sableh), and 30 farmers from the Sorkheh plain (seven from Salar Shahidan village, seven from Fath village, four each from Shahid Fallahi village, Mohajerin village, and Esteghlal village, and five from Ghods village) (Table 2.5).

(Table 2.6) presents some socioeconomic information gathered by interviewing the sampled farmers. As can be seen, for most characteristics, the average values for farmers in the two plains are close. However, the number of active children working on the farm in DS is almost twice that of DA. Also, the contribution of irrigated crops to household income is 20 per cent higher in DS compared to DA.

The average land area by type of ownership under wheat, barley and maize was 18.55, 9.00 and 13.27 ha, respectively. According to the total results obtained in both plains, the number of farmers who planted wheat, barley and maize on their own land was 36.7 per cent, 64.5 per cent and 100 per cent, respectively. Further information on land tenure in the two plains is shown in (Table 2.7).

The contribution of irrigated crop production to household income was estimated at 81.63 per cent. The contribution of off-farm and on-farm sources to household income was 9.6 and 90.4 per cent, respectively (Table 2.8).

All wheat farmers in the study used a disk for land preparation. Seed drills and rotary machines were used for planting by 15.7 per cent and 84.3 per cent of wheat farmers, respectively. Fertilizer

Table 2.5. Number of sampled farmers from different Agricultural Service Centers (ASC) at the study sites.

Azadegan plain								Sorkheh plain
Shahid Chamran ASC	**Shahid Alamolhoda ASC**	**Hovizeh ASC**	**Bostan ASC**	**Rafi ASC**	**Allaho Akbar ASC**	**Valfajer ASC**	**Sableh ASC**	**Sorkheh ASC**
28	19	19	19	17	15	12	7	30

Source: Research data.

Table 2.6. Some socioeconomic characteristics of sampled farmers in the DA and DS plains

Characteristics	**Mean**		**Max**		**Min**	
	Azadegan plain	**Sorkheh plain**	**Azadegan plain**	**Sorkheh plain**	**Azadegan plain**	**Sorkheh plain**
Age (years)	44.7	45.1	75	70	23	32
Number of children	6.1	5.1	18	10	0	1
Number of children active on the farm	1	1.9	11	4	0	0
Experience in agriculture (years)	24.3	24.9	60	50	3	10
Land size (ha)	20.8	22	100	65	1.5	4

Source: Research data.

Table 2.7. Land use by type of land tenure in the target regions

Crops	**Owned**			**Rented**			**Total**
	Average area (ha)	**% of total area**	**% of sampled farmers**	**Average area (ha)**	**% of total area**	**% of sampled farmers**	**Average area (ha)**
Wheat	18.55	42.5	36.7	46.5	57.5	63.3	40.5
Barley	9	64.7	64.5	14.25	35.3	35.5	10.38
Maize	13.27	100	100	-	-	-	13.27

Source: Research data.

Table 2.8. Income sources and their share in the total household income (average of the two sites).

Source of income		**% Share in total income**
Off-farm		9.60
On-farm	Irrigated production	81.63
	Rainfed production	8.64
	Livestock production	0.12
	Others	0.01
	Sub-total	90.40
Grand total		**100.00**

Source: Research data of the present study was applied application using a drill by 95.2 per cent of the farmers, while 4.8 per cent applied it manually. Herbicide application was carried out manually by 94.6 per cent of wheat farmers, while the rest used a sprayer (Table 2.9).

In both plains, the area under wheat is far larger than the areas under barley and maize. However, consumption of inputs, such as water and fertilizer, is much higher in maize compared with the other two crops. More details about cultivated areas and consumption of some inputs in DA and DS are given in (Tables 2.10 and 2.11).

Table 2.9. Type of equipment used for land preparation, planting, and fertilizer and herbicide treatment by sample wheat farmers at the study sites.

Methods	% of wheat farmers
Land preparation:	
- disk	100
Planting:	
- seed drill	15.7
- rotary seeder	84.3
Fertilizer application:	
- manual	4.8
- drill	95.2
Herbicide application:	
- manual	5.4
- sprayer	94.6

Source: Research data

Price of inputs showed some variation between the two plains and depended mainly on the availability of the input and crop type, particularly for water charges. More details are presented in (Table 2.12).

In this study, 89 per cent of farmers planted irrigated wheat, 5.9 per cent planted irrigated barley, and 5.1 per cent planted irrigated maize (Table 2.13). Maize was grown mainly as a second crop after wheat.

2.3.2 Determination of profitability of irrigated cereals among sample farmers

In the Sorkheh plain, mean production costs for wheat were about 3.8 million Rials/ha, consisting of land preparation – 16.9 per cent (0.64 million Rials/ha), planting – 20.9 per cent (789,375 Rials/

Table 2.10. Average size of cultivated land and input consumption in irrigated cereal production by sample farmers in the DA and DS plains.

Farm size and type of inputs	Azadegan plain		Sorkheh plain	
	Wheat	Barley	Wheat	Maize
Average planting area (ha)	18.6	9	19.1	13.3
Average number of plots per farmer	2.4	1.2	3	1.8
Seed rate (kg/ha)	283.1	208.8	255	25.2
Urea rate (kg/ha)	215.3	180.3	323.3	470.4
Phosphate rate (kg/ha)	121.4	109.3	158.3	168.5
Potassium fertilizer rate (kg/ha)	–	–	81.5	88
Amount of water used (m^3/ha)	6569.5	5463.5	7322.3	14888.8

Source: Research data

Table 2.11. Overall average of input use by sample farmers in DA and DS.

Inputs	Wheat		Barley		Maize	
	Mean	SD	Mean	SD	Mean	SD
Seed (kg/ha)	278	34.32	208.8	29.69	25.19	1.34
Urea (kg/ha)	234.82	96.47	180.2	89.82	470.4	99.36
Phosphate (kg/ha)	128.07	54.24	109.3	34.35	168.52	69.66
Potash (kg/ha)	81.48	32.56	–	–	88	42.1
Herbicide – Tajik (l/ha)	1.084	0.242	1.084	0.242	–	–
Herbicide – 2,4-D (l/ha)	1.86	0.295	1.86	0.295	–	–
Herbicide –Range Star (g/ha)	25.24	7.585	25.24	7.585	–	–
Herbicide –Eradikan (l/ha)	–	–	–	–	5	–
Water applied (m^3/ha)	6705.53	517.02	5463.5	158.85	14888.8	1225.1

Source: Research data SD = standard deviation

Table 2.12. Price of inputs per crops (averaged over the two sites).

Inputs	Wheat		Barley		Maize	
	Mean	SD	Mean	SD	Mean	SD
Seed (Rial/kg)	2849.4	321.7	1997.4	320.04	13450	0
Urea (Rial/kg)	544.8	113.3	544.8	113.3	544.8	113.3
Phosphate (Rial/kg)	724.1	133.85	724.1	133.85	724.1	133.85
Potash (Rial/kg)	568.8	63.23	568.8	63.23	568.8	63.23
Herbicide –Tajik(Rial/l)	61,391	20785	–	–	–	–
Herbicide – 2,4-D (Rial/l)	11,842	3797.5	–	–	–	–
Herbicide –Range Star (Rial/g)	676.88	113.6	–	–	–	–
Herbicide –Eradikan (Rial/l)	–	–	–	–	2798.2	1165.8
Water (Rial/m^3)	128.94	53.98	123.73	24.17	28.57	3.09
Insurance (Rial/ha)	81,925.6	10,670.3	84,642.9	7239.5	11,2273	22,230.7

Source: Research data
SD = standard deviation

Table 2.13. Average size of irrigated area by crops in the target areas.

Crops	Area (ha)	% of farmers
Wheat	6061	89
Barley	403	5.9
Maize	345	5.1
Total	**6809**	**100**

Source: Research data

ha), crop husbandry, excluding water costs – 28.5 per cent (1.08 million Rials/ha), harvesting – 6.3 per cent (0.24 million Rials/ha), transportation – 3.8 per cent (144 404 Rials/ha), and insurance – 2.1 per cent (79 667.3 Rials/ha) (Tables 2.14 and 2.15). Mean water use and irrigation for wheat was 0.8 million Rials/ha, while the mean irrigation water price was 53 Rials/m^3. Mean production costs

Table 2.14. Means production costs for irrigated cereals for sample farmers in the Azadegan and Sorkheh plain (x1000 Rials /ha).

Cost items	Azadegan Plain		Sorkheh Plain	
	Wheat	Barley	Wheat	Maize
Land preparation	366	336	640	720
Planting	876	462	789	778
Fertilizers, herbicides,	1005	1034	1079	1055
Irrigation labor	1280	980	811	1108
Price of water (Rials/m^3)	146	124	53	29
Harvesting	251	231	240	476
Transportation	187	143	144	206
Insurance	84	85	80	127
Total costs	**4051**	**3221**	**3783**	**4470**

Source: Research data

Table 2.15. Crop yields and prices of irrigated cereals in the DA and DS Plains.

Crops	Yield		Price output	
	Mean	SD	Mean	SD
Wheat	2877.21	1069.01	2044.45	59.03
Barley	1855.9	503.09	1869.44	156.42
Maize	5711.1	1161.26	1620	0

Source: Research data

SD = standard deviation

for maize were about 4.5 million Rials/ha, consisting of land preparation – 16.1 per cent (0.7 million Rials/ha), planting – 17.4 per cent (0.8 million Rials/ha), crop husbandry, excluding water costs – 23.65 per cent (1,054,610.7 Rials/ha), harvesting – 10.6 per cent (475,833.3 Rials/ha), transportation – 4.6 per cent (0.2 million Rials/ha), and insurance – 2.8 per cent (127,272.8 Rials/ha). Mean water use and irrigation for maize was 1.1 million Rials/ha, while the mean irrigation water price was 28.6 Rials/m^3. Similar data for wheat and barley in the Azadegan Plain are shown in the two tables.

In the Sorkheh plain, mean wheat yield was 4246.7 kg/ha (Table 2.16). Therefore, with a guaranteed price of 2050 Rials/kg, mean gross income from wheat was about 8.7 million Rials/ha, while the mean net profit was 4.92 million Rials/ha. Results showed that 43.5 per cent of the gross income from wheat was spent on fixed and variable production costs (cost ratio = 43.5 per cent). For maize, the cost ratio and return on sale are shown in (Table 2.16), based on a guaranteed price of 1620 Rials/kg.

Results obtained for wheat and barley in the Azadegan plain are also shown in the same table. From the table, it is clear that the saline conditions in this plane had a drastic negative effect on the economics of crop production. For example, the net profit from wheat in DS is more than four times greater than that in DA. Lower crop yields and higher production costs are the main reasons for this difference. Overall, the maximum return on sale was obtained from wheat in Sorkheh (56.5 per cent), while barley production in Dasht Azadegan gave the minimum return of (4.5 per cent).

Table 2.16. Mean net profit and profitability of irrigated cereals for sample farmers in the Azadegan and Sorkheh plains.

Parameter	Azadegan plain (DA)		Sorkheh plain (DS)	
	Wheat	Barley	Wheat	Maize
Yield (kg/ha)	2575.1	1855.9	4146.7	5711.1
Gross income (x1000 Rials/ha)	5237.7	3372.2	8705.7	9252.0
Total costs (x1000 Rials/ha)	4051.0	3221.0	3783.2	4469.6
Net profit (x1000 Rials/ha)	1186.8	151.3	4922.6	4782.4
Cost ratio (%)	77.3	95.5	43.5	48.3
Return (%)	22.7	4.5	56.5	51.7

Source: Research data

2.3.3 Water-use efficiency and gross income

Among sample farmers in the Sorkheh plain, mean water productivity for wheat and maize was 0.58 and 0.38 kg/m^3, respectively, while the corresponding production values for one Rial of water used were 10.7 and 8.3 Rials (Table 2.17). The water cost ratio showed that about 10 and 12% per cent of gross income from wheat and maize, respectively, were spent on water.

Table 2.17. Average water productivity and value of production for one Rial of water use in irrigated cereals in the Azadegan and Sorkheh plains.

Economical Index	Azadegan plain		Sorkheh plain	
	Wheat	Barley	Wheat	Maize
Average water productivity	0.39	0.34	0.58	0.38
Value of production for one Rial of water use (Rials/ha)	4.1	3.44	10.74	8.35
Water cost ratio	0.24	0.29	0.10	0.12

Source: Research data

Among sample farmers in the Azadegan Plain, mean water productivity for wheat and barley was 0.39 and 0.34 kg/m^3, respectively. The production value of these crops for one Rial of water use was 4.1 and 3.4 Rials, respectively. The water cost ratio showed that that about 24 and 29 per cent of gross income from wheat and barley, respectively, was spent on water.

2.3.4 Effects of economic factors on the average water-use efficiency

Determination of efficiency and inefficiency

The maximum likelihood method was used to estimate the parameters in the stochastic frontier and inefficiency model. According to the results, for wheat in the target areas variables including water price (t-ratio = -4.7), seed rate (t-ratio = + 2.14), urea rate (t-ratio = + 4.4), phosphate rate (t-ratio = + 3.27) had significant effects on water productivity (WP).

The relationship between land area under wheat and water productivity[5] was negative, i.e. WP was low in large fields.

[5] Defined as the amount of output produced (kg) to the amount of water applied (m^3)

Water productivity was also low when the water price was high, but it increased with an increase in the rates of seeding and fertilizer use (urea and ammonium phosphate) and with higher wheat prices (Table 2.18).

Different levels of inefficiency for wheat can be explained by land tenure (t-ratio = - 3.25), water limitation (t-ratio = + 8.51), soil salinity (t-ratio = - 2.61), and soil texture (t-ratio = + 2.53). These variables had significant effects on technical inefficiency.

Wheat farmers who owned the land had a low technical inefficiency in water use, i.e. their TE in water use was high. However, the TE of wheat farmers with water limitations or soil salinity was lower than for other farmers.

The relationship between soil texture and technical inefficiency in water use was positive. Sigma-squared and gamma were estimated at 0.598 and 0.841, respectively. Log likelihood function was -0.129. For wheat, the mean TE of the sample farmers in water use was 0.88 (Table 2.19).

For wheat, estimated model:

$$WP_w = -4.61 WP^{-0.172} SR^{0.324} UR^{0.219} PR^{0.161}$$

$$U_w = 0.183 - 0.187\,LT + 0.136\,WL - 0.126\,SS + 0.084\,ST$$

Log Likelihood = - 1.29

$\sigma^2 = 0.084$ $\gamma = 0.0084$

Table 2.18. Estimates of the variables affecting water productivity (WP) in wheat.

Variable	**Parameters**	**Estimated coefficient**	**Standard error**	**t-ratio**
Intercept	B_0	- 4.61	1.83	- 2.52
Land size	B_1	- 0.0139	0.0219	- 0.64
Water price	B_2	- 0.172	0.037	- 4.68
Seed rate	B_3	0.324	0.152	2.14
Urea rate	B_4	0.219	0.0498	4.4
Phosphate rate	B_5	0.161	0.0492	3.27
Wheat price	B_6	0.121	0.143	0.85

Source: Research data

Table 2.19. Estimates of the variables explaining inefficiency in wheat.

Variable	**Parameters**	**Estimated coefficient**	**Standard error**	**t-ratio**
Intercept	Φ_0	0.183	0.0618	2.96
Land tenure (LT)	Φ_1	-0.187	0.058	-3.25
Water limitation (WL)	Φ_2	0.136	0.016	8.51
Soil salinity (SS)	Φ_3	-0.126	0.048	-2.61
Soil texture (ST)	Φ_4	0.0836	0.0331	2.53
Sigma-squared	σ^2	0.0598	0.0062	9.62
Gamma	γ	0.0084	0.0415	0.202
Log of likelihood function	L	-1.29	–	–

Source: Research data

For barley, the water price (t-ratio = 2.6) was significant, but application rates of urea (t-ratio = 1.22) and ammonium phosphate (t-ratio = - 1.33) were insignificant. The relationship between land area under barley and water productivity was negative, i.e. water productivity was low in large barley fields. However, WP was high when the price of water and barley and/or rate of urea were high and it was low when seeding and phosphate application rates were high (Table 2.20).

water use was 0.897 (Table 2.21).

For barley, estimated model:

$$WP_b = -2.97 WP^{0.656}\, SR^{-0.494}\, UR^{0.094}\, PR^{-0.155}$$

$$U_b = -\,0.0987 + 0.427 WL - 0.062\, SS - 0.113\, ST$$

Log Likelihood = 14.7

$\sigma^2 = 0.0377$ $\gamma = 0.048$

According to the results, 60.4 per cent of wheat farmers had a TE in water use

Table 2.20. Estimates of the variables explaining water productivity (WP) in barley.

Variable	Parameters	Estimated coefficient	Standard error	t-ratio
Intercept	B_0	- 2.97	0.989	- 2.3
Land size	B_1	- 0.0042	0.049	-0.86
Water price	B_2	0.656	0.249	2.63
Seed rate	B_3	-0.494	0.734	-0.67
Urea rate	B_4	0.0935	0.0765	1.22
Phosphate rate	B_5	-0.155	0.116	-1.33
Barley price	B_6	0.223	0.361	0.62

Source: Research data

According to the results for barley at the study sites, the different levels of inefficiency can be explained by water limitations (t-ratio = + 3.8). This variable had a significant effect on technical inefficiency. Barley farmers who owned the land had low technical inefficiency in water use, i.e. their TE in water use was high. Technical efficiency of barley farmers with water limitations was lower than for other farmers. The relationship between soil texture and technical inefficiency in water use is negative.

Sigma-squared and gamma estimates were 0.038 and 0.048, respectively. Log likelihood function was 14.7. For barley, the mean TE of the sample farmers in over 90 per cent, 25 per cent had a TE between >=80 per cent <90 per cent, 9.1 per cent had a TE between >=70 per cent <80 per cent, and 5.5 per cent had a TE between >=60 per cent <70 per cent. The mean TE in water use of wheat farmers was 88 per cent with maximum and minimum values of 99.6 per cent and 66.8 per cent. About 46.2 per cent of barley farmers had a TE in water use over 90 per cent, 41 per cent had a TE between >=80 per cent <90 per cent, and 12.8 per cent had a TE between >=70 per cent <80 per cent. The mean TE in water use of barley farmers was 89.7 per cent, with maximum and minimum values of 100 per cent and 76.7 per cent (Table 2.22).

Table 2.21. Estimates of the variables explain inefficiency for barley crop.

Variable	Parameters	Estimated coefficient	Standard error	t-ratio
Intercept	Φ_0	-0.0987	0.281	-0.35
Land tenure	Φ_1	-0.0751	0.136	-0.55
Water limitation	Φ_2	0.427	0.113	3.77
Soil salinity	Φ_3	-0.062	0.276	-0.225
Soil texture	Φ_4	-0.113	0.227	-0.498
Sigma-squared	Б^2	0.0377	0.0029	12.9
Gamma	ɣ	0.048	0.0075	6.41
Log of likelihood function	L	14.7	–	–

Source: Research data

Table 2.22. Technical efficiency of sample farmers in water productivity (wheat and barley).

Efficiency (%)	Wheat farmers		Barley farmers	
	No. of farmers	%	No. of farmers	%
>= 90	99	60.4	18	46.2
>= 80<90	41	25	16	41
>= 70<80	15	9.1	5	12.8
>= 60<70	9	5.5	-	-
Mean	88.04%		89.7%	
Max	99.6%		100%	
Min	66.8%		76.7%	

Source: Research data

The stochastic frontier function

According to the results, for wheat in the target regions, the dependent variable was log of output per hectare. All the coefficients are significant. Variables of water consumption (t-ratio = 5.38), seed rate (t-ratio = 1.43), urea rate (t-ratio = 4.1), phosphate rate (t-ratio = 2.44) had significant effects on yield.

The relationship between seed rate of wheat and output was positive. Increasing seed rate, urea rate, phosphate rate and water consumption led to increased output (Table 2.23).

For wheat, the different levels of inefficiency can be explained by land tenure (t-ratio = -3.77), water limitations (t-ratio = 2.75), and soil salinity (t-ratio= -3.9).These variables had significant effects on technical inefficiency, but soil texture (t-ratio = 1.02) was insignificant. Wheat farmers who owned the land had a low technical inefficiency in wheat production. Technical efficiency of wheat farmers with water limitations is lower than for other farmers. Wheat farmers with soil salinity had a lower TE than other farmers. The relationship between soil texture and technical inefficiency in production is positive. Sigma-squared

Table 2.23. Estimates of the Cobb-Douglas stochastic production frontier for wheat.

Variable	Parameters	Estimated coefficient	Standard error	t-ratio
Intercept	B_0	- 7.178	2.476	- 2.9
Seed rate	B_1	0.257	0.18	1.43
Urea rate	B_2	0.241	0.059	4.1
Phosphate rate	B_3	0.157	0.0644	2.44
Water consumption	B_4	1.33	0.248	5.38

Source: Research data

and gamma were 0.064 and 0.003, respectively. Log likelihood function was -8.74. For wheat, the mean TE of sample farmers was 86.1% per cent (Table 2.24).

$$WP_w = -7.178\ SR^{0.257} UR^{0.241}\ PR^{0.157}\ WC^{1.33}$$
$$U_W = 0.243 - 0.194LT + 0.144WL - 0.162\ SS + 0.06\ ST$$
Log Likelihood = - 8.74
$\sigma^2 = 0.0641 \qquad \gamma = 0.003$

For barley in the target regions, the dependent variable was log of output per hectare. Variables of water consumption (t-ratio = 1.34), seed rate (t-ratio = -0.26), urea rate (t-ratio = 0.48), and phosphate rate (t-ratio = -1.35) had no significant effect on yield (Table 2.25).

For barley, the different levels of inefficiency can be explained by land tenure (t-ratio = - 0.9), water limitations (t-ratio = 0.09), soil salinity (t-ratio = -0.06), and soil texture (t-ratio = -0.13). Coefficient of Sigma-squared and gamma were estimated 0.045 and 0.006, respectively. Log likelihood function was 5.35. For barley, the mean TE of the sample farmers was estimated at 85.6 per cent (Table 2.26).

$$WP_b = 4.345SR^{-0.311} UR^{0.227}\ PR^{-0.159}\ WC^{0.529}$$
$$U_b = 0.221 - 0.109LT + 0.17WL - 0.131\ SS - 0.082\ ST$$
Log Likelihood = 5.35
$\sigma^2 = 0.045 \qquad \gamma = 0.006$

Table 2.24. Estimates of the parameters of the technical inefficiency model for wheat.

Variable	Parameters	Estimated coefficient	Standard error	t-ratio
Intercept	Φ_0	0.243	0.0689	3.52
Land tenure	Φ_1	-0.194	0.0514	-3.77
Water limitation	Φ_2	0.144	0.0524	2.75
Soil salinity	Φ_3	-0.162	0.0415	-3.91
Soil texture	Φ_4	0.06	0.0592	1.01
Sigma-squared	σ^2	0.0641	0.0064	10.07
Gamma	γ	0.003	0.0252	0.12
Log of likelihood function	L	-8.74	-	-

Source: Research data

Table 2.25. Estimates of the Cobb-Douglas stochastic production frontier for barley.

Variable	Name of parameters	Estimated coefficient	Standard error	t-ratio
Intercept	B_0	4.345	10.68	0.407
Water consumption	B_1	0.529	0.395	1.34
Seed rate	B_2	-0.311	1.214	-0.26
Urea rate	B_3	0.227	0.477	0.477
Phosphate rate	B_4	-0.159	0.118	-1.35

Source: Research data

Table 2.26. Estimates of the parameters of technical inefficiency model for barley.

Variable	Parameters	Estimated coefficient	Standard error	t-ratio
Intercept	Φ_0	0.212	0.134	1.58
Land tenure	Φ_1	-0.109	0.1197	-0.91
Water limitation	Φ_2	0.17	1.92	0.088
Soil salinity	Φ_3	-0.132	2.036	-0.065
Soil texture	Φ_4	-0.082	0.616	-0.13
Sigma-squared	Б^2	0.045	0.018	2.501
Gamma	ﻻ	0.006	1.18	0.0052
Log of likelihood function	L	5.35	–	–

Source: Research data

According to the results, 37.3 per cent of wheat farmers had a TE over 90 per cent in wheat production, 27.7 per cent had a TE between >=80 per cent <90 per cent, 28.9 per cent had a TE between >=70 per cent <80 per cent, and 6.1 per cent had a TE between >=60 per cent <70 per cent. The mean TE of wheat farmers in wheat production was 86.1 per cent, with maximum and minimum of 99.7 per cent and 63.9 per cent. About 31.7 per cent of barley farmers had a TE over 90 per cent in barley production, 43.9 per cent had a TE between >=80 per cent <90 per cent, and 24.4 per cent had a TE between >=70 per cent <80 per cent. The mean TE of barley farmers in barley production was estimated at 85.6 per cent, with maximum and minimum of 99.8 per cent and 74 per cent (Table 2.27).

Estimation of coefficients and co-linearity statistics of variables

According to the results of ordinary least squares (OLS) estimated in the target regions, variables of age, experience, total land, land preparation, irrigation cost, harvested cost, water quantity, soil salinity, and rainfall had significant effects on the income of the farmers. Large values of VIF are not good. In this study, the VIF estimate was lower than 10, thus there is not co-linearity between the independent variables (Table 2.28).

Reaction of sample farmers to some of the characteristic indices

In response to questions regarding the factors determining cropping patterns,

Table 2.27. Technical efficiency of sample farmers in wheat and barley production using stochastic maximum likelihood method.

Efficiency (%)	Wheat farmers		Barley farmers	
	No. of farmers	%	No. of farmers	%
>= 90	62	37.3	13	31.7
>= 80<90	46	27.7	18	43.9
>= 70<80	48	28.9	10	24.4
>= 60<70	10	6.1	–	–
Mean	86.1%		85.6%	
Max	99.7%		99.8%	
Min	63.9%		74.04%	

Source: Research data

Table 2.28. OLS estimation of coefficients and co-linearity statistics of variables.

Variables	Coefficients	t-statistics	Co-linearity statistics	
	Un-standardized		Tolerance	VIF*
Constant	-8705952	-3.25		
Distance to village	-1438.6	-0.03	0.656	1.524
Age	-48641.7	-2.01	0.266	3.765
Education	88818.3	0.76	0.515	1.94
Experience	54012	2.3	0.298	3.372
Total land	-6370.2	-1.46	0.502	1.991
Land preparation cost	0.363	0.32	0.365	2.736
Planting cost	.089	0.16	0.754	1.326
Protection cost	-0.125	-0.23	0.642	1.558
Irrigation cost	0.005	0.01	0.392	2.552
Harvest cost	13.59	3.15	0.387	2.587
Transportation	15.11	7.4	0.649	1.54
Insurance	-2.71	-0.52	0.89	1.124
Water quantity	-20.13	-0.06	0.409	2.448
Seed rate	5119.1	1.2	0.645	1.549
Urea rate	4051.5	2.78	0.642	1.557
Phosphate rate	-1627	-0.69	0.759	1.318
Land tenure	973330.5	2.25	0.715	1.399
Soil salinity	-168101.6	-0.45	0.46	2.173
Soil texture	-1050390	-1.91	0.626	1.597
Rainfall	32834.9	5.85	0.186	5.362

Source: Research data
* The dependent variable is income of farmers * VIF is variance inflation factor

12.1 per cent of farmers mentioned market conditions, 13.8 per cent water requirement, 4.8 per cent agricultural policies. 45.8 per cent of farmers mentioned water requirement, market conditions, and agricultural policies, 18.1 per cent water requirement and agricultural policies, 1.8 per cent length of growth season, and about 3.6 per cent did not answer this question (Table 2.29).

As to the existence of an informal water market, 53.3% per cent of farmers interviewed in DS and 73.5 per cent in DA, responded negatively. Responses to some other questions raised in the interviews are presented in (Tables 2.30 through 2.41). Some examples of their answers are given here.

In response to the question on changes in the irrigated area of their farms in Sorkheh (DS), 46.7 per cent said it had increased while 6.6 per cent said it had

Table 2.29. Frequency distribution of farmers' responses to the question on factors affecting cropping patterns.

Factors affecting cropping pattern	**Sorkheh plain**		**Azadegan plain**		**Total**	
	No. of farmers	**%**	**No. of farmers**	**%**	**No. of farmers**	**%**
Market conditions	11	36.7	9	6.6	20	12.1
Agricultural policies	6	20	2	1.5	8	4.8
Water requirements	11	36.7	12	8.8	23	13.8
No answer	2	6.6	4	2.9	6	3.6
Water requirements, Market conditions, Agricultural policies	–	–	76	55.9	76	45.8
Water requirements, Agricultural policies	–	–	30	22.1	30	18.1
Length of growth season	–	–	3	2.2	3	1.8
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

Table 2.30. Frequency distribution of farmers' responses to questions on some socioeconomic characteristics in the Sorkheh plain.

Question	**No. of farmers**			**%**		
	Yes	**No**	**No answer**	**Yes**	**No**	**No answer**
Are there any informal water markets?	13	16	1	43.3	53.3	3.4
Are drainage systems available?	24	6	–	80	20	–
Has the irrigated area changed on your farm?	18	11	1	54.3	33.3	13.4
Is the amount of water limited to your farm?	16	10	4	60	36.7	3.3
Have you ever heard about optimal water use?	28	2	–	93.3	6.7	–
Have women taken any role in irrigated farming?	12	18	–	40	60	–
Do you use saved seed?	11	15	4	36.7	50	13.3
Are there any proper water systems?	15	15	–	50	50	–

Source: Research data

decreased and the rest did not answer. Asked the same question, 24 per cent of farmers in DA said they had increased the irrigated area, while 2.2 per cent of farmers had decreased and 73.5 per cent of farmers did not answer the question.

When asked about how they determine their irrigation interval and timing of irrigation, the majority of farmers said that soil moisture was their main criteria. As to irrigation water quality, 70 per cent of sample farmers said that their water was fresh, 13.9 per cent said it was saline and 13.2 per cent thought that their water was ‘semi-saline’.

In response to a question on their changes in water management when water becomes scarce, 27 per cent said that they would decrease the number of irrigations, while nearly 48 per cent gave no answer. In regard to sources of information needed for irrigation water management, 63.9 per cent of the interviewed farmers mentioned extension and the public media.

In regard to the management of crop residues, about 20.5% of farmers collect them for farm animals, and 62 per cent of farmers both collect them and use them for grazing for farm animals (Table 2.40).

Table 2.31. Frequency distribution of farmers’ responses to questions on some socioeconomic characteristics in the Azadegan plain.

Question	**No. of farmers**			**%**		
	Yes	**No**	**No answer**	**Yes**	**No**	**No answer**
Are there any informal water markets?	29	100	7	21.3	73.5	5.2
Are drainage systems available?	28	103	5	20.6	75.7	3.7
Has the irrigated area changed on your farm?	37	92	7	46.3	48.5	5.2
Is the amount of water limited to your farm?	63	66	7	27.2	67.6	5.2
Have you ever heard about optimal water use?	127	7	2	93.4	5.2	1.4
Have women taken any role in irrigated farming?	88	43	5	64.7	31.6	3.7
Do you use saved seed?	26	78	32	19.1	57.4	23.5
Are there any proper water systems?	30	102	4	22.1	75	2.9

Source: Research data

Table 2.32. Responses of farmers to the question regarding changes in the irrigated area of their farms.

Response	**Sorkheh plain**		**Azadegan plain**		**Total**	
	No of farmers	**%**	**No of farmers**	**%**	**No of farmers**	**%**
Increasing	14	46.7	33	24.3	47	28.3
Decreasing	2	6.6	3	2.2	5	68.7
No answer	14	46.7	100	73.5	114	3
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

Table 2.33. Response of farmers to the question concerning their water management strategy if water becomes scarce/

Response	Sorkheh plain		Azadegan plain		Total	
	No. of farmers	%	No. of farmers	%	No. of farmers	%
Reduce number of irrigations in the same area	11	36.7	34	25	45	27.1
Introduce new crops	1	3.3	–	–	1	0.6
Dig a new well	13	43.3	–	–	13	7.8
Optimum irrigation	–	–	28	20.6	28	16.9
No answer	5	16.7	74	54.4	79	47.6
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

Table 2.34. Responses of farmers to the question on how they classify the importance of the following factors in determining number of irrigation and the timing of each one in the Sorkheh plain.

Factors	High		Moderate		Low		No answer	
	No. of farmers	%	No. of farmers	%	No. of farmers	%	No. of farmers	%
Soil moisture	27	90	2	6.7	-	-	1	3.3
Wilting of the plant	20	66.7	9	30	-	-	1	3.3
Shortage of rainfall	22	73.3	7	23.3	-	-	1	3.3
High temperatures	18	60	7	23.3	4	13.3	1	3.3
Water costs	22	73.3	1	3.3	5	16.7	2	6.7
Recommendation by extension	20	66.7	6	20	3	10	1	3.3
Farmer’s experience	19	63.3	6	20	4	13.3	1	3.3

Source: Research data

Table 2.35. Responses of farmers to the question on how they classify the importance of the following factors in determining number of irrigation and the timing of each one in the Azadegan plain.

Factors	High		Moderate		Low		No answer	
	No. of farmers	%	No. of farmers	%	No. of farmers	%	No. of farmers	%
Soil moisture	76	55.9	9	6.6	7	5.1	44	22.3
Wilting of the plant	49	36	42	30.9	5	3.7	40	29.4
Shortage of rainfall	62	45.6	23	16.9	8	5.9	43	31
High temperatures	63	46.3	27	19.9	7	5.1	39	28.7
Water costs	19	14	22	16.1	35	25.7	60	44.5
Recommendation by extension	86	63.2	9	6.6	1	0.7	40	29.4
Farmer’s experience	88	64.7	9	6.6	–	–	39	28.7

Source: Research data

Table 2.36. Responses of farmers to the question on the quality of their water resources.

Response	Sorkheh plain		Azadegan plain		Total	
	No. of farmers	%	No. of farmers	%	No. of farmers	%
Fresh	20	66.7	96	70.6	116	69.9
Saline	2	6.7	21	15.4	23	13.9
Semi-saline	5	16.6	17	12.5	22	13.2
No answer	3	10	2	1.5	5	3
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

Table 2.37. Responses of farmers to the question on how they classify the importance of the following factors in determining added water quantities.

Response	Sorkheh plain		Azadegan plain		Total	
	No. of farmers	%	No. of farmers	%	No. of farmers	%
Price of crop	–	–	7	5.1	7	4.2
Recommendation by extension	3	–	33	24.3	36	21.7
Area planted to each crop	5	10	6	4.4	11	6.6
Water availability	13	16.7	22	16.2	35	21.1
Price of water, area planted, price of crop		–	48	35.3	48	28.9
No answer	9	43.3	20	14.7	29	17.5
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

Table 2.38. Responses of farmers to the question on their sources of information on optimal water use.

Response	Sorkheh plain		Azadegan plain		Total	
	No. of farmers	%	No. of farmers	%	No. of farmers	%
Agricultural extension	14	46.7	24	17.6	38	22.9
Public media	7	23.3	1	0.7	8	4.8
Other farmers	7	23.3	–	–	7	4.2
Extension, Public media	–	–	92	67.6	92	55.5
Extension, Other farmers	–	–	10	7.5	10	6
No answer	2	6.7	9	6.6	11	6.6
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

Table 2.39. Responses of farmers to the question on how they describe the effects of irrigation development on household livelihoods.

Response	Sorkheh plain		Azadegan plain		Total	
	No. of farmers	%	No. of farmers	%	No. of farmers	%
Income increasing	1	3.3	23	16.9	24	14.5
Income decreasing	2	6.7	–	–	2	1.2
No effect	2	6.7	–	–	2	1.2
Increase and stability of the production	21	70	107	78.7	128	77.1
No answer	4	13.3	6	4.4	10	6
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

Table 2.40. Responses of farmers to the question on the management of crop residues

Response	Sorkheh plain		Azadegan plain		Total	
	No. of farmers	%	No. of farmers	%	No. of farmers	%
Collected for farm animals	18	60	16	11.8	34	20.5
Burn	4	13.3	4	2.9	8	4.8
Collected and sold	5	16.7	4	2.9	9	5.4
Grazing	2	6.7	6	4.4	8	4.8
Collected for animals and Grazing	–	–	103	75.7	103	62
No answer	1	3.3	3	2.3	4	2.5
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

Table 2.41. Responses of farmers to the question regarding their sources of information on irrigation water management.

Response	Sorkheh plain		Azadegan plain		Total	
	No. of farmers	%	No. of farmers	%	No. of farmers	%
Agricultural extension	15	50	20	14.7	35	21.1
Own experience	4	13.3	7	5.1	11	6.6
Relatives	2	6.7		–	2	1.2
Other farmers	1	3.3	1	0.7	2	1.2
Public media	8	26.7		–	8	4.8
Extension, Public media	–	–	106	78	106	63.9
No answer	–	–	2	1.5	2	1.2
Total	**30**	**100**	**136**	**100**	**166**	**100**

Source: Research data

2.4 Conclusions

The total results from both plains show that the number of farmers who planted wheat, barley and maize on their own land was 36.7, 64.5 and 100% per cent, respectively. The contribution of irrigated crop production to household income was estimated at 81.6 per cent. The contribution of off-farm and on-farm activities to the household income was 9.6 and 90.4 per cent, respectively.

All wheat farmers in the study used a disk for land preparation. Seed drills and rotary machines were used for planting by 15.7 per cent and 84.3 per cent, respectively, of wheat farmers.

Most wheat farmers, 95.2 per cent, applied fertilizer by drill while 4.8 per cent applied it manually, and most, 94.6 per cent, applied herbicides manually, while the rest used a sprayer.

In the Azadegan Plain, average seeding rates for irrigated wheat and barley were 283 kg/ha and 209 kg/ha, respectively. The corresponding rates of fertilizer application were 215.3 kg/ha and 180.3 kg/ha of urea and 121.4 and 109.3 kg/ha of diammonium phosphate. Average water use for the two crops were 6569 and 5463 m^3/ha. The mean net profit from irrigated wheat was 1.2 million Rials/ha with a cost ratio of 77.3 per cent – the gross value of the crop could cover 77.3 per cent of the costs. Returns from wheat were 22.7 per cent in this area.

In the Sorkheh Plain, average seeding rates for irrigated wheat and maize were 255 and 25.2 kg/ha, respectively. The corresponding rates of fertilizer application were 323.3 and 470.4 kg/ha of urea, 158.3 and 168.5 kg/ha of diammonium phosphate, and 81.5 and 88 kg/ha of potassium fertilizer. Average water use for the two crops were 7322 and 14,888 m^3/ha. The mean net profits from irrigated wheat and maize were 4.9 million Rials/ha and 4.8 million Rials/ha with a cost ratio of 43.5 per cent and 48.3 per cent, respectively. Returns were 56.5 per cent for wheat and 51.7 per cent of maize.

Estimates of the production function of wheat over the entire region showed that variables including water price, seed rate, and the application rate of urea and phosphate had significant effects on water productivity (WP)[6]. The relationship between the size of the wheat field and WP was negative, i.e. water productivity is low in large wheat fields. Also, since farmers' reaction to higher water prices was not reflected in their irrigation practices, the relation between water productivity and higher water prices was negative. However, when seed, urea, phosphate rate and wheat price were high, WP increased. The different levels of inefficiency for wheat can be explained by land tenure, water limitations, soil salinity, and soil texture, which had significant effects on technical inefficiency. Wheat farmers that own their land have a high TE in water use. Technical efficiency of wheat farmers with water limitations and/or soil salinity is lower than for other farmers. The relationship between soil texture and technical inefficiency in water use is positive. In other words, lower efficiencies are associated with heavier soil textures. For wheat, the estimated mean TE of the best exemplary farmers in water use was 0.88.

For barley WP, the effect of water price was significant, but, urea and phosphate rates were insignificant. Water productivity was high when water prices and rate of urea applications were high. Water productivity was low when seed

[6] WP defined as the ratio of output produced (kg) to the water applied (m^3)

rate and P-fertilizer application rates were high. Water productivity is high, when urea rate and barley price is high. Water limitation had significant negative effect on technical inefficiency.

Barley farmers who owned their land had a high TE in water use, but those with water limitations had lower TE than other farmers. For barley, the mean TE of the best exemplary farmers in water use was 0.897.

Technical efficiency of wheat farmers in water use varied greatly: for 60.4 per cent of the farmers it was over 90 per cent, for 25 per cent the range was >=80 per cent <90 per cent, for 9.1 per cent the range was >=70<80 per cent, and 5.5 per cent of wheat farmers had a TE in the range of >=60 per cent <70 per cent. The mean TE of wheat farmers in water use was estimated at 88.04 per cent, with maximum and minimum values of 99.6 per cent and 66.8 per cent. About 46 per cent of barley farmers had a TE in water use over 90 per cent, 41 per cent between >=80 per cent <90 per cent, and 12.8 per cent between >=70 per cent <80 per cent. The mean TE of barley farmers was 89.7 per cent in water use, with maximum and minimum values of 100 per cent and 79.7 per cent.

Among wheat farmers, 37.3 per cent had a TE in wheat production over 90 per cent, 27.7 per cent between >=80 per cent <90 per cent, 28.9 per cent between >=70 per cent <80 per cent and 6.1 per cent between >=60 per cent <70 per cent. The mean TE of wheat farmers was 86.1 per cent in wheat production, with maximum and minimum values of 99.7 per cent and 63.9 per cent. About 31.7 per cent of barley farmers had a TE over 90 per cent in barley production, 43.9 per cent between >=80 per cent <90 per cent, and 24.4 per cent between >=70 per cent <80 per cent. The mean TE of barley farmers was 85.6 per cent in barley production, with maximum and minimum values of 99.8 per cent and 74 per cent.

In the Sorkheh Plain, in response to a question on the factors affecting cropping pattern, 43 per cent of farmers mentioned market conditions. Also, 53 per cent said that there was no informal water market in the region. About 70 per cent of the farmers believed that irrigation development could improve household livelihoods and would stabilize production. In Azadegan Plain, 67.6 per cent of the sample farmers had heard information on optimum water consumption from extension agents and public media. In regard to management of crop residues, about 75.7 per cent of farmers collect them for farm animals, selling and grazing. About 27.2 per cent of farmers said that the amount of irrigation water was limited in their region and recommended reduced number of irrigations, use of new varieties tolerant to deficit irrigation, and appropriate irrigation methods. About 78.7 per cent of farmers believed that irrigation development would increase household income and stabilize production.

It was suggested that varieties tolerant to water shortages and salinity be developed and introduced to the region.

With regard to the low water productivity of various crops in this part of the KRB, it was recommended that optimized management of different inputs, particularly water, be extended in the area and the selection of exemplary farmers be based on high production and low water consumption.

Since the majority and the exemplary farmers believed that irrigation development would increase income and stabilize production, it is recommended that proper planning be designed for water development and increased water productivity.

Since farmers are receiving most of their information on optimal water management from the mass media, it is suggested that the national TV networks broadcast suitable programs on the advantages of optimum use of agricultural inputs and provide the needed information.

Extension agents should carry out more participatory projects with farmers and organize farmers' days to extend the best agricultural management practices, including the use of improved varieties and new irrigation methods.

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Annex 1.

Organizations responsible of soil and water issues within MoJA

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Deputy of Water, Soil and Industries

This Deputy has three central offices at national and provincial levels. It is responsible for short, middle and long-term objectives, plans and policies for soil and water development, introduction and extension support for the development of new irrigation technologies, soil drainage and reclamation and irrigation networks, revising/preparing drafts of rules and regulations related to the management, maintenance and operation of water and irrigation systems; developing procedures for the implementation of water law; and the revision of procedures and regulations for governmental investment as well as private sector in irrigation development.

Forests, Rangelands and Watershed Management Organization (Executive Organization)

This independent and national organization is affiliated to the MoJA. At the national level, watersheds are managed by a Central Deputy. Natural resources (forests, rangelands and watersheds) have vital importance in arid and semi-arid countries. Therefore, this organization has an executive division in all provinces called the Natural Resources Office, of which the Deputy of watershed management is responsible for the study, implementation and management of watersheds.

Bureau of Environment and Sustainable Development of Agriculture

This central office is under the supervision of the Ministry and is mainly responsible for the control and supervision of agricultural-sector activities based on sustainable development via the conservation of natural resources, optimum chemical (fertilizer, pesticides, etc) consumption, support for biological organism development and application for insects control and soil fertility, study of environmental criteria and standards, agricultural sewage, and the development of new national laws and regulations.

Agricultural Research, Education, and Extension Organization (AREEO)

The Agricultural Research and Education and Extension Organization was established in 1974. Presently, all agricultural research institutes, education, and extension centers are affiliated to AREEO, managed by a board of trustees with a staff of scientists. Institutes under AREEO include the Soil and Water Research Institute, the Agricultural Engineering Research Institute, and the Research Center for Soil Conservation and Watershed Management.

Soil and Water Research Institute (SWRI)

This is a major institute and one of the oldest, established in 1952. SWRI is affiliated to the AREEO and fulfills its mandate through nine research departments.

The institute's responsibility in the area of water is mainly related to the soil, water and plant relationship. Research projects cover all the main agricultural crops to identify how much water is needed and an appropriate irrigation schedule. The institute has published technical irrigation bulletins and annual research reports and set out demonstration fields. It should be noted that this institute has comprehensive responsibility for soil resources (soil survey and classification, soil fertility, crop nutrient, fertigation, land evaluation, and soil microbiology).

Agricultural Engineering Research Institute (AERI)

This institute, established in 1988, is also one of the main institutes of AREEO in the area of agricultural engineering. This institute is mainly responsible for carrying out all agricultural engineering research, including irrigation and drainage. It carries out much research on irrigation and drainage networks, irrigation systems, drainage, advanced irrigation systems, greenhouse production, and irrigation water management. The institute also has research branches in more than 15 provinces and attempts to address research problems in the main irrigated areas. AERI also publishes many technical reports in its specialized areas. One of the main outcomes is that this institute was one of the main contributors to the National Water Document, which includes 32 volumes containing information on crops’ water requirement. The institute is also responsible for research in agricultural machinery and mechanization and food processing.

Research Center for Soil Conservation and Watershed Management

This center was established in 1994 to conduct research on soil conservation and watershed management. It carries out research on weather, climate, water, earth sciences, vegetation, social and economic problems, soil conservation, and watershed management.

CGIAR Challenge Program on
WATER & FOOD

Benchmark river basins

The CP Water & Food is a research, extension and capacity building program aims at increasing the productivity of water used for agriculture. The CP Water & Food is managed by an 18-member consortium, composed of five CGIAR/Future Harvest Centres, six National Agricultural Research and Extension Systems (NARES) institutions, four Advanced Research Institutes (ARIs) and three international NGOs. The project is implemented at nine river basins (shown above) across the developing world. The Karkheh River Basin (KRB) in western Iran is one of the selected basins. The program's interlocking goals are to allow more food to be produced with the same amount of water that is used in agriculture today, as populations expand over the coming twenty years. And, do this in a way that decreases malnourishment and rural poverty, improves people's health and maintains environmental sustainability.

Improving On-farm Agricultural Water Productivity in the Karkheh River Basin Project (CPWF PN 8)
Strengthening Livelihood Resilience in Upper Catchments of Dry Areas by Integrated NRM (CPWF PN 24)

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