Chapter 1.

Present status of salt-affected and waterlogged soils in Dasht-e-Azadegan and management strategies for their sustainable utilization

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Introduction

Salt-prone land and water resources are major impediments to the optimal utilization of crop production systems in many arid and semi-arid regions of the world, including Iran (Alizadeh et al. 2004; Moghaddam and Koocheki 2004). The salinization of land and water resources has been the consequence of both anthropogenic activities (causing human-induced or secondary salinity and/or sodicity) and naturally occurring phenomena (causing primary fossil salinity and/or sodicity) (Ghassemi et al. 1995). The main cropping systems in the country are based on irrigated agriculture where at least 50% area (4.1 Mha) fall under different types of salt-affected soils (Cheraghi 2004). Therefore, the dependency on irrigated agriculture is at stake in areas where salt-prone land and degradation of water resources has increased over time.

Human-induced salinization of land and water resources has occurred mostly in unique topographic conditions of semi-closed or closed intermountain basins where irrigated agriculture has been practiced for centuries. The slightly and moderately salt-affected soils are mostly formed on the piedmonts at the foot of the Elburz (Alborz) Mountains in the northern part of the country. The soils with severe to extreme salinity are mostly located in the Central plateau, the Khuzestan and southern coastal plains, and the Caspian coastal plain (Koocheki and Moghaddam 2004). The extent and characteristics of salt-affected soils in Iran has been investigated by several researchers (Dewan and Famouri 1964; Mahjoory 1979; Abtahi et al. 1979; Matsumoto and Cho 1985; Banie 2001).

Owing to abundant water resources, fertile lands and sufficient extraterrestrial energy, Khuzestan province in southwest Iran is potentially one of the most suitable regions for agricultural production. However, salinization of land and water resources has become a serious threat to efficient use of these invaluable resources. It is estimated that out of the total 6.7 Mha of the province, 1.2-1.5 Mha (18-22% of total area) are faced with the dual problems of soil salinization and water logging (Anonymous 2000).

The Karkheh river basin (KRB) is one of the major river basins in the Khuzestan province, consisting of two main sub-basins namely Karkheh Olia (upstream) and Karkheh Sofla (downstream). The KRB is, most notably, the eastern flank of the ‘cradle of civilization’ (ancient Mesopotamia) and a boundary between the Arab and Persian cultures. This major river system of western Iran has unique agricultural and hydrological aspects; but also much in common with other catchments around the world, e.g. rural poverty and land degradation, low water and agricultural productivity, a dry climate, and growing upstream-downstream competition for water. Agriculture in the upstream basin is mainly rain fed, while the downstream basin is mostly irrigated. The drainage outlet of the KRB, which also is a basin outlet, is the Hoor-Al-Azim swamp in southwest Iran and on the Iran-Iraq border (Fig. 1.1). At present, there are very limited modern irrigation and drainage networks under operation within the KRB and agriculture is yet to be fully developed. However, the government has started constructing irrigation and drainage networks with the goal of improving the traditional irrigation systems, e.g. in the Dasht-e-Azadegan (DA) plain in southern parts of the lower KRB (LKRB). It is in this area where this project was carried out. This chapter describes this area (Dasht-e-Azadegan) in terms of its geology, soils, climate, and

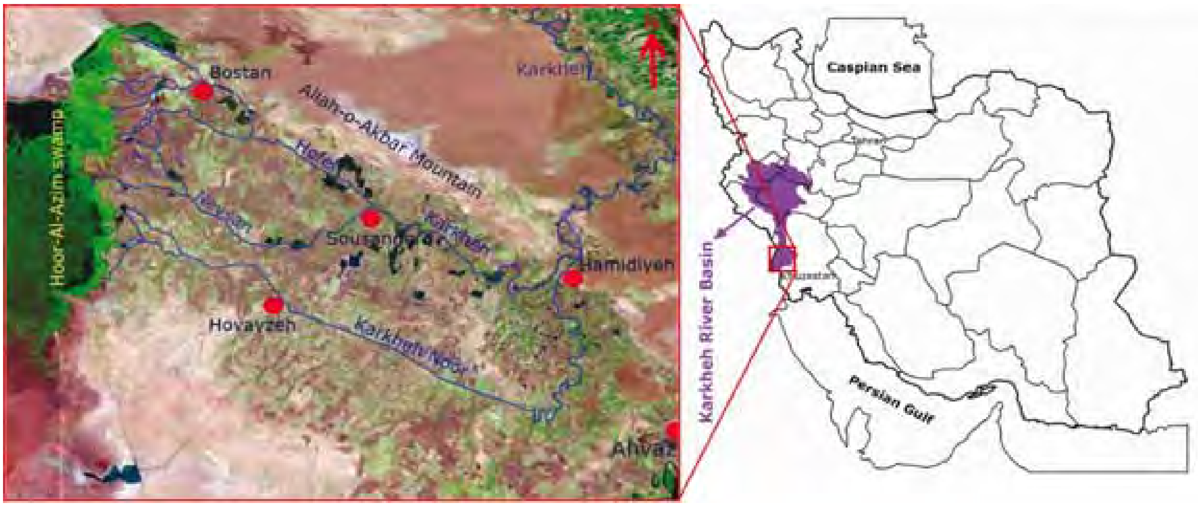

Fig. 1.1. Karkheh River Basin (KRB) and Dasht-e-Azadegan (DA) region

water resources. It also reviews salinity and waterlogging problems based on previous studies carried out in the region. Lastly, general recommendations for effective use of soil and water resources for crop production and environmental are given.

Geology

Azadegan plain is a deep structural hole covered by Quaternary sediments. The deepest part of this cavern is in the west and northwest of the region and around Hoor-Al-Azim. The outer edge of the plain is in the east and northeast, where the bedrocks have been uplifted to form the Mishodagh and Allaoakbar mountains. The deepest layers of the plain are composed of the Kachsaran, Mishan, and Aghajari (Fars group) formation, from deep to shallow. These formations were overlain by conglomerate rocks (Bakhtiari formation). The semi-deep portion of the hole was filled by recent sediment, which covers Bakhtiari conglomerates.

The whole of sedimentary deposits in the Azadegan plain were laid down during the Quaternary period. Sediment ranges in thickness from zero at the foot of the mountains to 100 m in the west and northern west of the plain in the vicinity of Hoor-al-Azim. Information about the upper strata of plain reveals that there are many varieties and diverse features as compared to the deeper part of plain. There, it can be seen that thin lens-like sand features in a clay-silty background appear on a limited scale. These features are accompanied by transverse layers, indicative of a different deltaic formation. These events show that the river tributary beds have undergone frequent changes of position at times near the Holocene epoch. Furthermore, fine sediments such as silt and clay particles and to a lesser extent chemical sediments, organic matter, and vegetative material provide evidence of vast Quaternary marshes in the plain, particularly on the west side of the plain, where marshes along the western border of Iran can be seen. Sedimentary deposits of the Holocene epoch covering the surface of the plain include alluvial, fluvial, and aeolian sediments. The alluvial and fluvial sediments of plain are products of the geodynamic action of the Karkheh river tributaries.

Soils

The soils of the area are alluvial soils formed originally by the floods of the river. These alluvial areas are flat and soil permeability is low, with little slope and poor natural drainage. Azadegan plain is a flood plain with very weak topography. The maximum elevation of 12 m a.s.l. is around Sosangerd and the Sosangerd-Hoveizeh highway. The lowest elevation is on the northwest side of the plain; adjacent to Hoor-Al-Azim (3-4 m a.s.l.). Azadegan plain is the terminal basin and all of tributaries of the Karkheh river end in this plain. Therefore, the plain is the scene of constant accumulation of the river sediment.

The low precipitation has developed the aridic soil moisture regime throughout the region. The moisture control section, in normal years, is dry in all parts for more than half of the cumulative days per year, when the soil temperature at a depth of 50 cm from the soil surface is above 5°C; and it is moist in some or all parts for less than 90 consecutive days when the soil temperature at a depth of 50 cm is above 8°C. These conditions cause low availability of water for cropping and as a result, soils are classified only in the Aridisol and Entisol orders based on development status of diagnostic horizons (Soil Survey Staff 2003).

As a result of the hot climate, the mean annual soil temperature is 22°C or higher, and the difference between mean summer and mean winter soil temperatures is more than 6°C, either at a depth of 50 cm from the soil surface or at a densic, lithic, or paralithic contact, whichever is shallower, so the soil temperature regime is considered to be hyperthermic in all series.

The carbonatic nature of the parent material, in addition to the low precipitation of the region has enhanced accumulation of secondary lime minerals in the soil mineralogy control section so that the carbonatic or mixed (calcareous) mineralogy classes are common in the region. Based on the USDA Soil Taxonomy (Soil Survey Staff 2003), soils are mainly classified as orders of the Entisols and Aridisols. The young (recently formed) Entisols of the region belong to two suborders. Fluvents are characterized by either 0.2% or more organic carbon of the Holocene age at a depth of 125 cm below the mineral soil surface or an irregular decrease in content of organic carbon from a depth of 25 cm to a depth of 125 cm, or to a densic, lithic, or paralithic contact if shallower. These soils have wide distribution in the region so that seven soil series belong to this suborder. The Kout soil series, which is classified as Salorthidic Torrifluvents, is a typical Solonchak profile. Fluvaquents also are identified in the lowland physiographic region of the plain. Redoximorphic features (brown mottling in a pale green soil matrix) in Fluvaquents (Sarhangiyeh, Shahatt-e-Abbas and Machriyeh series) represent hydric conditions (seasonally saturated) in young, flood plain soils. The coarse-textured soils are extended around rivers in Susangerd city so the Psaments can be identified just in this region. Psaments, which occur only in the Susangerd soil series of the region, have good drainage and have less than 35% (by volume) rock fragments and a texture of loamy fine sand or coarser in all layers.

Medium- to coarse-textured soils exist in areas around the Karkheh river and its tributaries, which have experienced frequent flooding in previous times. Soil series in this area show a distinct stratification, including sequences of different-size textured ranges from coarse to medium textured and in these areas the slope is gently perpendicular to the river (natural levees). For Aridisols also just two suborders of cambids and salids had been identified in the region. Cambids, which are Aridisols with cambic diagnostic horizons, formed under submerged conditions in this region and so they belong to the Aquicambids that cover Fenikhi, Yazd-e-No and Luliyeh series. In this sub-order, the soil profile is either irrigated and has aquic conditions for some time in normal years in one or more layers within 100 cm of the soil surface; or is saturated with water in one or more layers within 100 cm of the soil surface for 1 month or more in normal years. Aridisols with the Salic diagnostic horizon that have a upper boundary of horizon within 100 cm of soil surface are classified as Salids. These soils are identified in Jarahyeh and Abohomayzeh soil series. Table 1.1 gives a classification of the main soil series in Dasht-e-Azadegan (Mahab-e-Ghods 1992).

Climate

The existing statistics indicate that the weather is hot in summer with a mild and short winter. Annual mean temperature of the region is 23.1ºC. The maximum daily temperature in the warmest months of the year (July and August) is 43.02ºC and the minimum daily temperature in the coldest month of the year (January) is 5ºC. The average precipitation in the area is 175 mm according to statistics of the past 10 years. The wettest month of the year is October, with 44.1 mm and the driest months are May to late September when there is almost no precipitation. Annual mean evaporation in this area is 2004.9 mm. The maximum evaporation of 303.6 mm is in July and the minimum of 42.7 mm occurs in January. Based on the climate data for the last 10 years at Sosangerd and Howeyzeh stations, as well as the bioclimatic map of the Mediterranean region, and despite the existent of 260 dry days in a year, Dasht-e-Azadegan has not been classified as Accentuated Sub-Desertic Area. The total rainfall in Sosangerd and Bostan is 180 and 200 mm, respectively. There is a weather station in Bostan. The agricultural services centers also are equipped with rain gauges. In Table 1.2 some of the factors influential in climate and evaporation of the Dasht-e-Azadegan region are presented (Mahab-e-Ghods, 1992).

Crops

Current crops in Dasht-e-Azadegan include cereals such as wheat, barley, rice, and ground cereals; vegetables such as melon, watermelon, tomato, cucumber, eggplant, okra, lettuce, cabbage, carrot, radish, onion, etc; grains such as beans; plants used as fodder for livestock such as alfalfa, barely, corn, and sudan grass. More than 78% of agricultural production in Dasht-e-Azadegan region is dominated by grains (Table 1.3), mainly wheat and barley (Mahab-e-Ghods, 1992).

Water resources

The only source of water for the Dasht-e-Azadegan is the Karkheh river with its tributaries. The river originates from Zagross mountain ranges and is fed by snow melt. The average monthly discharge of the river for the period of 1987 to 1998 is shown in Fig. 1.2 (Mahab-e-Ghods 1992). There is a distinct flood period during winter and early spring. As explained later these floods are the main cause of salinity and waterlogging in the region, because large quantities of salts are deposited in the soils as pure water is evaporated during the hot summers. Since the construction of the Karkheh reservoir dam, the adverse effects of these floods

Table 1.1. Classification of the main soil series of Dasht-e-Azadegan (Mahab-e-Ghods1992)

Physiography	Soil series	Area		USDA soil taxonomy		
		ha	**% of total**	**Family**	**Sub group**	**Order**
River alluvial plain	Hofel	1460	1.6	Coarse loamy, carbonatic, hyperthermic	Typic Torrifluvents	Entisols
	Karami	15760	18.2	Fine loamy, mixed (calcareous), hyper-thermic	Typic Torrifluvents	Entisols
	Fenikhi	10640	11.6	Fine, mixed, hyperthermic	Fluventic Aquicambids	Aridisols
	Yazd-e-Now	8100	8.9	Fine loamy, mixed, hyperthermic	Fluventic Aquicambids	Aridisols
	Abu-Homayzeh	7990	8.7	Fine loamy, carbonatic, hyperthermic	Typic Haplosalids	Aridisols
	Ahmad-Abad	17440	19.1	Fine, mixed (calcareous), hyperthermic	Typic Torrifluvents	Entisols
	Kout	1290	1.4	Fine, mixed (calcareous), hyperthermic	Salortidic Torrifluvents	Entisols
	Sousangerd	170	0.2	Mixed, hyperthermic	Typic Torripsamments	Entisols
	Karkheh	7730	8.5	Fine, mixed, hyperthermic	Typic Solorcthids	Aridisols
	Golbahar	810	0.9	Coarse, loamy, mixed, hyperthermic	Typic Salorthids	Aridisols
	Hovayzeh	3490	3.8	Fine loamy mixed (calcareous), hyper-thermic	Typic Torrifluvents	Entisols
	Sariyeh	2300	2.5	Fine mixed (calcareous), hyperthermic	Vertic Torrifluvents	Entisols
	Hamidiyeh	1080	1.2	Fine loamy mixed (calcareous), hyper-thermic	Typic Torrifluvents	Entisols
Lowland	Sarhangiyeh	4100	4.5	Fine, mixed (calcareous), hyperthermic	Typic Fluvaquents	Entisols
	Shat-e-Abbas	380	0.4	Coarse loamy, carbonatic, hyperthermic	Typic Fluvaquents	Entisols
	Machriyeh	1950	2.1	Fine loamy, mixed (calcareous), hyper-thermic	Typic Fluvaquents	Entisols
	Jarrahiyeh	2890	3.2	Fine loamy, mixed, hyperthermic	Typic Haplosalids	Aridisols
	Louliyeh	1620	1.8	Fine, mixed, hyperthermic	Fluventic Aquicambids	Aridisols
Plateaux	Kout	230	0.2	Fine, mixed (calcareous), hyperthermic	Typic Fluvaquents	Entisols
	Sum	**89430**	**97.8**			
	Miscellaneous	2040	2.2			
	Total	91470	100	Fine, mixed, hyperthermic		

Table 1.2. Metrological parameters of Dasht-e-Azadegan plain (Hamidiyeh station)

Month	Temperature (°C)			Precipitation (mm)	ET (mm)
	Average Min.	Average Max.	Average		
January	5	16.4	10.7	41.3	42.7
February	6.9	19.7	13.3	24.1	62.5
March	11	24.8	17.9	23.3	105
April	15.2	30	22.6	17.7	150
May	19.6	36.6	28.1	6.5	234
June	22	41.8	31.9	0.0	299.2
July	23.7	43.2	33.5	0.2	303.6
August	22.8	43.2	33	0.0	279.8
September	19.2	41.2	30.2	0.7	235
October	14.8	35.1	25	4.2	155.5
November	10.1	26.6	18.3	11.5	88.1
December	6.7	19.1	12.9	45.5	49.5
Average	14.8	31.5	23.1	175	2004.9

Table 1.3. Agricultural production in Dasht-e-Azadegan plain (cropping season 2003-2004)

Crop	Planted area		Yield (kg/ha)
	ha	%	
Cereal	67417	90.25	2682
Pulses	626	0.84	1856
Industrial crops	1149	1.54	757
Vegetable	1218	1.63	38266
Summer crops	2836	3.80	28812
Forages	1456	1.94	26540
Total	**74702**	**100**	-

Table 1.4. Karkheh river water quality.

EC_{iw} dS/m	pH	meq/L							SAR	RSC meq/L
		HCO^{3-}	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+		
1.48	7.95	2.51	6.49	4.33	4.25	3.3	6.51	0.13	3.35	1.23

have been reduced considerably. The dam was completed on the Karkheh river in 1999 and became operational in 2001. The main objectives of the dam are to produce hydropower energy (1000 GW/h/year), flood water control, and

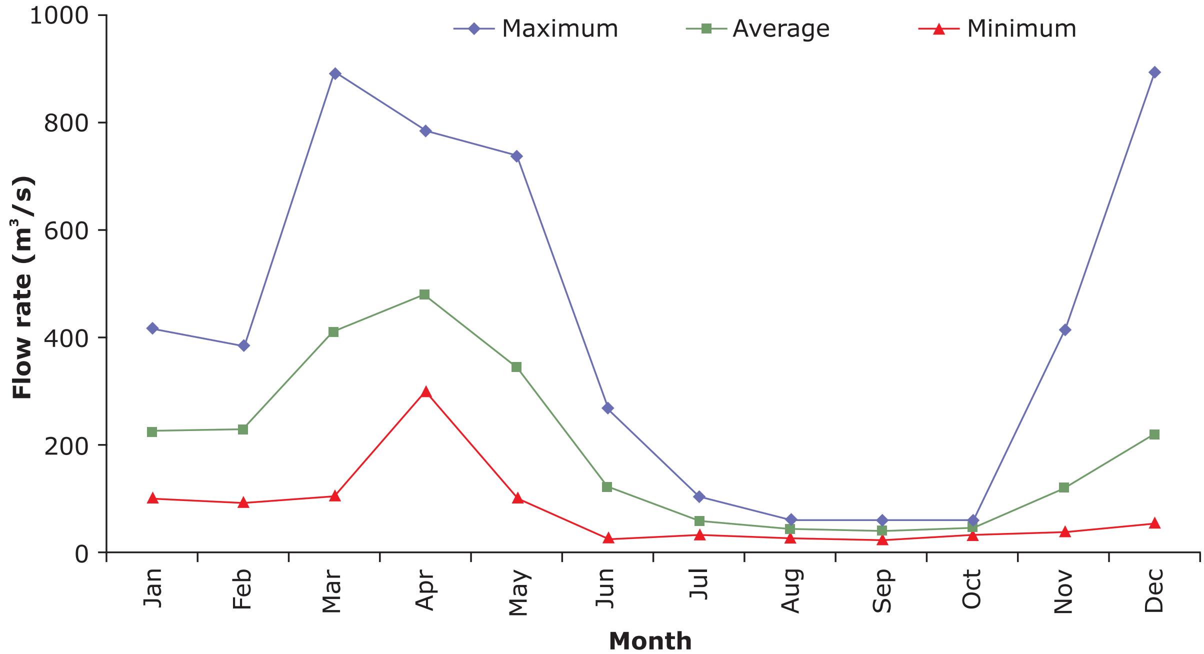

Fig. 1.2. Karkheh river monthly discharge at Hamidiyeh gauging station, 1987-1998

a regulated flow of water for irrigation of more than 340,000 ha of land downstream. These arable lands are located in different plains situated in the lower parts of the KRB (Mahab-e-Ghods 1992). The quality of Karkheh river water, as a surface resource, is generally good (Table 1.4), though it varies seasonally and also along the river towards to the outlet (Fig. 1.3), which reaches up to 2.4 dS/m near the Hoor-Al-Azim swamp.

There are limited irrigation networks in the region (mainly pumping from river to the canal). The main canals and drains are constructed or under completion (main irrigation and drainage canals in Kout and Hamoodi are under construction). But unfortunately there are no secondary or tertiary canals or lateral drains. At present, despite the construction and operation of main drains, the system is not functioning properly in all areas. This is mainly due to technical and excavation problems (i.e. improper slope of drainage lines) and also due to problems concerning the outlets. Gravitational drainage to outlet is not feasible and pumping is required.

Salinity and waterlogging

The main problems limiting agricultural production in this region are waterlogging and salinity. As indicated before, saline-sodic soils constitute a vast area of Dasht-e-Azadegan. Soil studies show that around 99% of the area of the region has been faced with either high or low salinity or sodicity for a long time (Table 1.5). Generally, natural and man-made factors are involved in the soil quality of the region.

Based on the field studies, the soils of the Dasht-e-Azadegan region are divided into two types of saline soils and saline-sodic soils. The smaller portion of the region, referring to the Fenikhi soil

Fig. 1.3. Water quality changes along the main branches of the Karkheh river

series, is covered by saline soils with electrical conductivity (EC) > 4 dS/m, exchangeable sodium percentage (ESP) < 15% and pH of less than 8.5. In contrast, most of the DA region has saline-sodic soils with EC > 4 dS/m, ESP > 15% and pH of less than 8.5. The Abu-Homayzeh, Ahmad Abad, Karkheh, Karami and Yazd-e-Now soil series belong to the saline-sodic soil class. It is expected that the high values of sodium to calcium plus magnesium ratio would be relatively dominant. The sodium absorption ration (SAR) values varied from 6 to 66 and more, out of which most of the samples had an SAR of more than 13. Table 1.5 shows the extent of saline lands with salinity and alkalinity rates (Mahab-e-Ghods 1993).

Saline-sodic soils have some different properties from both saline and sodic soils. If attempts are made to leach out the soluble salts of saline-sodic soils with good quality water, the exchangeable Na+ levels and also pH would increase and therefore, the soil would take on the adverse characteristics of sodic soils. Therefore, attention must first be given to reducing the levels of exchangeable Na+ ions and then to the problem of excess soluble salts.

The situation in Dasht-e-Azadegan seems to be different. Based on the results of leaching experiments and a number of other observations, it is unlikely that the problem of sodicity will be encountered in leaching of these soils without any other treatment. The result of a leaching experiment in the Hofel soil series is given in Table 1.6. Soil salinity and sodicity of the profile to a depth of 150 cm before leaching (zero depth of application) and with application of water in 0.25-m depth increments up to 1 m is given (Mahab-e-Ghods 1993). After leaching, soil salinity and SAR are both reduced. A regular practice by the farmers is that after the fallow period during summer, the soil is leached generously with one or two applications of water to reduce the accumulated salt in the seed bed. If there were a danger of sodic soil development, this regular practice would result in such soils, but they are not actually observed. Also, as shown by the data in Table 1.4, the SAR of irrigation water is low, which is favorable for leaching these soils.

Leaching experiments of the Karkheh soil series show an interesting feature (Table 1.7). Soil salinity in the lower depths (below 50 cm) remains the same even after 75 cm of water is applied, indicating that water is not moving through these layers and bypass flow is occurring due to deep cracks. This may have great

Table 1.5. Extent of saline lands with salinity and alkalinity classes (Mahab-e-Ghods 1993)

Soil series	**S0**[1]	**S1**[2]	**S1A13**	**S2**[4]	**S2A1**[5]	**S2A2**[6]	**S3A2**[7]	**S3A3**[8]	**S3A2 / S2A2**[9]	**S4A3**[10]	**S4A4**[11]
Hofel	-	-						1460 (1.6)			
Karami		3289 (3.6)	276 (0.3)			5816 (6.4)	5988 (6.5)		391 (0.4)		
Fenikhi		2450 (2.7)				4830 (5.3)	3360 (3.6)				
Yazd-e-Now						2240 (2.5)	5860 (6.4)				
Abu-Homayzeh										1180 (1.3)	6810 (7.4)
Ahmad-Abad		568 (0.6)	2002 (2.2)		2491 (2.7)	4659 (5.1)	2917 (3.2)	4803 (5.3)			
Kout											1290 (1.4)
Sousangerd	70 (0.1)	100 (0.1)									
Karkheh										7610 (8.4)	120 (0.1)
Golbahar										810 (0.9)	
Hovayzeh		429 (0.5)	427 (0.5)		49 (0.1)	986 (1.0)	142 (0.2)	1457 (1.5)			
Sariyeh		449 (0.5)	31 (0.0)			1037 (1.1)	783 (0.9)				
Hamidiyeh			193 (0.2)			887 (1.0)					
Sarhangiyeh		4100 (4.5)									

Table 1.5. (continued)

Soil series	S0[1]	S1[2]	S1A13	S2[4]	S2A1[5]	S2A2[6]	S3A2[7]	S3A3[8]	S3A2 / S2A2[9]	S4A3[10]	S4A4[11]
Shat-e-Abbas						380 (0.4)					
Machriyeh		285 (0.3)		1150 (1.3)	515 (0.5)						
Jarrahiyeh											2890 (3.2)
Louliyeh							1620 (1.8)				
Kout											230 (0.2)
Sum	70 (0.1)	11670 (12.8)	2929 (3.2)	1150 (1.3)	3055 (3.3)	20835 (22.8)	20670 (22.6)	7720 (8.4)	391 (0.4)	9600 (10.6)	11340 (12.3
Miscellaneous Total	*Electrical conductivities (EC) are in dS/m, ESP is exchangeable sodium percentage, and numbers on the parenthesis are areas in percent										

1- EC<4, ESP<10
2- EC=4-8, ESP<10
3- EC=4-8, ESP=10-15
4- EC=8-16, ESP<10
5- EC=8-16, ESP=10-15
6- EC=8-16, ESP=15-30
7- EC=16-32, ESP=15-30
8- EC=16-32, ESP=30-50
9- EC=8-32, ESP=15-30
10- EC>32, ESP=30-50
11- EC>50, ESP>50

implications in terms of water loss during irrigation episodes, where inefficient surface irrigation is practiced in the area. Improvement of leaching efficiency and irrigation application efficiency should require further research in these soils.

Major causes of soil salinity

Major factors causing soil salinization in the lower Karkheh basin can be classified as follows (Ghobadian 1969; Cheraghi et al. 2008):

- High groundwater table
- Salt-containing layers
- Inadequate drainage facilities
- High evaporation
- Salt intrusion by wind
- Sediment transport during flood periods.

High groundwater level

High water tables are the major factor in soil salinization in Khuzestan province. The salt concentration in groundwater is extremely high, exceeding 100 g/L in many cases. It should be mentioned that groundwater could cause salinity in cases where its level is higher than a certain depth. This specific depth of groundwater is called the critical depth, which varies between 2.5 and 3.5m. It means that soil salinization due to capillaries and its accumulation in the plow layer will be expected if the distance between the soil surface and

*Table 1.6. Soil analyses before and after salt leaching from the Hofel soil series (Mahab-e-Ghods 1993)**

Applied water (cm)	Soil depth (cm)	EC_e (dS/m)	SAR
0	0-25 25-50 50-75 75-100 100-150	28 25.5 24.2 24.2 26.4	23.4 16.6 21.5 16.8 15.5
25	0-25 25-50 50-75 75-100 100-150	18.5 25.3 23.6 22.9 7.3	17.2 - 15.6 16.5 18.4
50	0-25 25-50 50-75 75-100 100-150	8.3 15.8 22.9 26.4 5.1	9.9 - 17.2 19.3 19.9
75	0-25 25-50 50-75 75-100 100-150	7.6 10.8 24.5 24.8 8.9	5.8 9.2 17.6 20.9 20.8
100	0-25 25-50 50-75 75-100 100-150	8.3 10.1 11.1 19.3 -	12 11.6 14.5 13.5 19.3

*Characteristics of the soil profile: soil texture, silty loam; soil salinity-sodicity class, S3A2; water table depth, 0.5 m; hydraulic conductivity (K), 0.98 m/d; depth of impermeable layer, > 4 m; salinity class of applied water, C3S1 (EC=1.75 dS/m, SAR= 1.8 , pH= 7.6)

the water table is smaller than the above-mentioned depth. In arid and semi-arid regions such as the Khuzestan province, where upward water flux due to high evaporation is considerable, even fresh groundwater causes soil salinization because of high groundwater levels. Investigations have shown that in most parts of Khuzestan, the groundwater level is higher than the critical depth. This case is especially true for the regions where extended agriculture has developed. It is observed that in non-arable lands, the groundwater level is usually deeper than the critical depth, but near villages where agricultural practices are more intensified, the problem is more severe. In LKRB, the groundwater level in non-arable land (or specific locations which had not been cultivated during the Iran-Iraq war 1979-1989) varies between 4 and 7 m, while its level is about 1.2-3.0 m in cultivated land. This difference shows the significance of agricultural return flow effects.

A high groundwater level for extended periods, especially in the hot season, causes specific morphological characteristics in the soil profile, which

Table 1.7. Result of soil analyses before and after salt leaching in the Karkheh soil series (Mahab-e-Ghods 1993).

Applied water (cm)	Soil depth (cm)	EC_e (dS/m)	SAR
0	0-25 25-50 50-75 75-100 100-150	61 59 54 56 52	66 53 50 60 61
25	0-25 25-50 50-75 75-100 100-150	9 22 58 62 64	62 51 58 53 54
50	0-25 25-50 50-75 75-100 100-150	3.4 19 55 65 64	6 31 50 44 36
75	0-25 25-50 50-75 75-100 100-150	3 10 54 61 58	8 23 42 48 45
100	0-5 0-25 25-50 50-75 75-100 100-150	3 3 5 54 59 47	7 4 10 41 37 36

are the results of periodic oxidation-reduction conditions due to variations in the groundwater level. These specific symptoms are more pronounced in the presence of organic carbon and sesquioxides. One of the most popular signs of this kind is mottling (segregation of subdominant color different from surrounding region's color). In the Ahmadabad soil series (west of Dasht-e-Azadegan), which is heavy textured and has a hard massive structure, gley spots are observed in some profiles below 1m depth. In the Abohomayzeh soil series, weak gley spots and mottling can be observed. West of the Bostan-Pol-e-Ramazam road and near Shatt-e-Abbas, with Machriyeh, Jarrahieh, and Lulieh soil series, which are generally flooded during early winter up to late spring, the soil is usually waterlogged half of the year. Therefore, the soil moisture regime at the moisture control section of these profiles is aquic with diagnostic symptoms of mottling and gley spots.

Salt-containing layers

A salt containing layer is a horizon or a layer of geological material in which salt content is not only high but also higher than the rest of the soil profile. If these layers are located at a depth less than

0.5m below the soil surface, especially in heavy textured soils, topsoil salinization occurs, as in the case of Khuzestan.

In the Dasht-e-Azadegan plain, despite the high calcium carbonate and calcium sulfate content of the soil, no calcic or gypsic diagnostic horizons were identified. However, accumulation of hygroscopic salts such as $CaCl_2$, $MgCl_2$, $MgSO_4$ and KCl in combination with NaCl can be observed on both sides of the river banks. High temperature differences between river, lateral canals and irrigated land cause moisture diffusion and evaporation that in turn leaves huge amounts of salt on the soil surface. Salic diagnostic horizons have been identified only in Abohomayzeh, Kout and Jarahyeh soil series. In Abohomayzeh and Jarahyeh series, soil surface is highly dispersed.

Inadequate drainage facilities

Most of Khuzestan's soils are heavy textured and have a slight slope and therefore, the importance of adequate drainage facilities is obvious. However, in many cases little attention has been paid to this problem. Drains, which had been dogged, are generally the main drains and are deep. Although these drains can partly absorb the drainage water of the surrounding area, their effective radius is small. Natural drains, which discharge to the main outlet of the region (Hoor-Al-Azim), are not functioning well due to technical and environmental problems and due to the very low slope of land. Problems associated with inadequate drainage are more serious in low lands and areas with low slope.

The west side of Dasht-e-Azadegan is usually flooded during winter and spring. During summer, salts, which have been leached into the sub-soil, tend to rise and accumulate on the soil surface due to the high evaporation. The surface of these soils is often cracked during the hot and dry season, which is related to the high clay content of these soils. As a result, infiltration rates are low.

High evaporation

One of the factors that accelerates soil salinization under high groundwater conditions is high evaporative demand, which causes upward flux of salt-containing water to the topsoil continuously, or at least in the warm season. The critical depth of the groundwater table that will cause soil salinization is highly dependent on evaporation rate as well as the soil type. For example in Khuzestan such depth had been reported to be range between 2.5 and 3.5 m, based on soil type and evaporation demand. Periods of 260 dry days in Hamidiyeh, and 290 dry days in Ahvaz, are climatic characteristics of the region. In Hamidiyeh, annual precipitation is 245 mm, while annual evaporation is 2205 mm, or an evaporation to precipitation ratio exceeding nine. Surface evaporation is one of the most important meteorological factors in the region significantly affecting the soil genesis processes. High evaporation leads to a capillary rise of soluble salts and their accumulation at the soil surface.

Salt intrusion by wind

The dominant directions of winds in this region are west, northwest, and southeast, which occur as dust storms. They carry huge quantities of sediments that are mostly deposited on the surface of the plains. It has been estimated that in each storm event 5-50 kg salts/ha are deposited on the soil surface, which accumulates to 200-1000 kg/ha annually. It is suggested that the deposited salts originate from the coastal lands of both sides of the Persian Gulf and of the Gulf of Oman. They represent salt intrusion by wind erosion. These salt deposits are translocated within the region. It has been estimated for Khuzestan province that 10-50 t salts/ha are translocated from one point to another. It should be mentioned that the risk of accumulation of these salts is more serious around the villages (Ghobadian 1969).

Sediment transport in the flood periods

The origin of most of the soil series in Dasht-e-Azadegan derives from the sediments of Karkheh river and its tributaries, except for the lowlands. Hence, the salt content of sediments from Karkheh river affects the salinity and sodicity of these soils. After flood periods, a large part of the region is submerged. During the dry season, water drawing back from land of higher elevation leads to the formation of small swamps (hour) and permanent ponds in the lowlands. Typical examples are the small swamps around the Hour-Al-Hoveyzeh. In 1968, about 3000-4000 km^2 of Khuzestan province were covered with floodwater. The sediment deposited about 1.5 million tonnes of salt on the soil surface (Ghobadian 1969).

Amelioration and management strategies

Availability of drainage facilities is fundamental to improve the quality of salt-affected soils. It reduces the adverse effects of shallow water tables and waterlogging, and hence, improves crop production. There is no doubt that one of most important needs for the study area is to complete an adequate drainage network for the entire irrigated area. Encouraging efforts has been initiated, but the drainage system is incomplete. Lateral connections are lacking, and the drainage system covers only a limited area under irrigation. It is noted that agricultural management practices cannot serve as a substitute for adequate drainage of salt-affected and waterlogged soils. Most efforts in improved management to reduce the impact of salinity are suggested to have a rather temporary effect. To avoid the further salinization of agricultural soils, the communities and agricultural agencies are called to apply sound management practices until adequate drainage is installed.

One of the most important pre-requisites to enable permanent crop production in this region is the development of a network to monitor the effect of different management practices on the salt content of groundwater, as well as the salt and water balance of the root zone. These regular measurements will provide the data basis required to suggest the best methods to prevent restoration of salinity in the root zone and groundwater. On the other hand, water and salt balance studies on the watershed scale will increase our ability to predict the role of any hydrological unit in the fate and behavior of catchments. Cheraghi (2008) monitored salinity and depth to a shallow water table with observation wells during November 2003 to April 2004 in Dasht-e-Azadegan. There was a large variation in salinity of groundwater ranging between 4 and 100 dS/m. No trend was found in the way in which salinity changed throughout the study area. Salinity variation could be partly explained because of variation in soil textures. Salinity of groundwater in light-textured soils was less than that of heavier textured soils. Salinity was also lower in the vicinity of the river tributary rather than further away from the river. The depth to water table was lowest in April as a result of deep percolation from winter rain, over-irrigation of fields, river flooding, and seepage from earth channels. The depth to water table reached its maximum in September due to high evaporation during the hot dry summer. This pattern seems to repeat itself throughout the years, hence accumulating salt in the soil.

Appropriate irrigation schedules based on soil-moisture depletion or climatic data would prevent excess losses of irrigation water into the subsoil or groundwater. Land leveling could improve water distribution and limit waterlogging problems. Further attention should be paid to the irrigation system. To increase the efficiency of water use the irrigation water must be applied uniformly. Some of these issues were tested in the field as part of this project and the results are given in Chapter III.

Generally speaking, the agricultural cropping systems and practices in the subject area are suboptimal and should be improved. At present, the crop varieties used by farmers are not adapted to the prevailing soil conditions. Significant improvements in production could be realized by introducing salt-tolerant varieties. As was discussed earlier, 90% of the cultivated area is allocated to wheat. The two varieties grown, Chamran and Verinak, give average yields of 2 t/ha. Testing high-yielding varieties, available in the country, in the area may introduce a more suitable variety for the area. Some varieties that are bred for salinity tolerance such as Kavir, Bam, Sistan, etc. were tested as part the CPWF projects for improving water productivity in the area and the results are presented in Chapters IV and V of this report.

Another important factor limiting crop production is the accumulation of salt in the top soil that mainly occurs during the fallow period when the soil is uncultivated. Leaching of salts before sowing can reduce the adverse effects of salt on crop establishment. Other suitable practices are trash mulching and suitable crop rotations.

Conclusions

KRB is one of the major river basins in the Khuzestan province consisting of two main sub-basins namely Karkheh Olia (upstream) and Karkheh Sofla (downstream). Agriculture in the upstream basin is mainly rain fed, while the downstream basin is mostly irrigated. Dasht-e-Azadegan plain is the terminal basin of the Karkheh river so all of its tributaries end in this basin. The main problems limiting agricultural production in this region are salinity and waterlogging. Saline-sodic soils constitute a vast area of Dasht-e-Azadegan. About 99% of the area of the region has been faced with salinity or sodicity for a long time. The salinization of land and water resources has been the consequence of both anthropogenic activities (causing human-induced or secondary salinity and/or sodicity) and naturally occurring phenomena (causing primary fossil salinity and/or sodicity). Major factors causing soil salinization in the lower Karkheh basin are the high groundwater table, salt-containing layers, inadequate drainage facilities, high evaporation, salt intrusion by wind and sediment transport during flood periods.

The management strategies for sustainable utilization of salt-affected soils in Dasht-e-Azadegan should consider: installation of a drainage network for the entire irrigated area, leaching of salts to reduce the adverse effects of salt on crop establishment, appropriate irrigation scheduling and water distribution systems, introduction and use of salt tolerant crops, improvement of the agricultural cropping systems and practices, and development of a network for monitoring the effect of different management practices on the salt content of groundwater as well as salt and water balance of the root zone.

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