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International Water Management Institute

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Executive Summary

Sustainability of irrigated agriculture in Iran is threatened by the salinization of land and water resources. These problems are the result of seepage from unlined canals, inadequate provision of surface and subsurface drainage, poor water management, and cultural practices and use of saline water for irrigation. Approximately, half of the irrigated area falls under different types of salt-affected soils and average yield losses may be as high as 50 percent. The annual economic losses due to salinity are estimated to be more than US$ 1 billion. The problems of salinity and water logging are not just agricultural problems, but they do affect the country as a whole and ultimately the social fabric of Iranian society. Salt-prone land and water resources have very adverse social and economic effects on communities, causing poor living standards in affected areas and health problems for humans and animals. This situation has forced the local population to abandon their lands and migrate to other areas to earn their living.

Despite these huge challenges, there is no national strategic plan available that directs research on salinity and water logging assessment and management. In addition, no comprehensive database is available to evaluate the extent and characterization of salt-prone land and water resources. Furthermore, there are large differences in various studies conducted for the quantification of salt-prone land and water resources, which raise serious concerns about the reliability of data.

The review of fragmented database reveals that the problems of salinity/ sodicity and water logging are spread over a range of landscapes, including irrigated lands, rainfed dryland farming areas and rangelands. Since most investigations have been carried out on selected soil profiles or on soil samples collected from potentially salt-affected soils, it is not possible to categorize these soils in terms of relative distribution of different types. As a general assessment, slightly and moderately salt-affected soils are mostly found on the piedmonts at the foot of the Elburz (Alborz) Mountains in the northern part of the country. The soils having severe to extreme salinity are predominantly located in the Central Plateau, the Khuzestan and Southern Coastal Plains and the Caspian Coastal Plain.

Natural leaching of salts from agricultural fields is not possible as rainfall is generally insufficient. The process of salinization of the surface water resources is mainly due to natural conditions, and to a lesser extent, to the discharge of drainage water into the river systems. Estimates show that about 6.7 km^3 of brackish water flow annually through 12 major rivers. Some large-scale projects have been carried out on the management of saline water resources.

Over the last three decades, several approaches have been used to ameliorate salt-affected soils in Iran to enhance their productivity. These include leaching practices to remove excess salts from the root zone, use of chemical amendments, application of higher rates of fertilizers to mitigate salinity effects, growing of salt-tolerant plant species, and improvement in genotypes of commonly grown field crops. Although some improvements have been observed in isolated places, little has been translated to a larger scale. Despite all these efforts, problems of soil degradation still persist in vast tracts of irrigated areas because farmers generally lack knowledge of important aspects of proper management of saline soils and irrigation waters of different quality.

The recent trends and future projections suggest that the need to produce more food and fiber for the expanding Iranian population will lead to an increase in the use of salt-prone water and land resources for crop production systems. Therefore, an assessment of the impact such use will have on the environment and crop productivity will inevitably have to be made through a holistic approach.

There is no straightforward solution to the complex problems of salt-induced soil and water resources degradation in Iran. The approaches addressing the management of these resources need to be multidimensional and must take into account the biophysical and environmental conditions of the target area as well as livelihood aspects of the associated communities. The following priorities are likely to add value to the existing and future strategies of Iranian policy makers, researchers, extension workers and farmers: (1) development of salinity preparedness programs for salinity management, databases and maps of salinity hotspots, awareness programs for policy makers and researchers, and potential markets for the agricultural produce from salt-prone areas; (2) use of innovative applications of indigenous and advanced knowledge for salinity management; (3) introduction of conservation initiatives for field crops such as wheat, barley, and cotton as well as halophytic plant species capable of growing and producing on salt-affected lands; (4) improved management of saline drainage water in areas where these waters predominate and their disposal options are limited; (5) community-based management of salt-prone land and water resources that would help in strengthening linkages among researchers, farm advisors, and farmers as well as minimize the chances of developing secondary salinization.

INTRODUCTION

With a total area of 1.65 million km² (land: 1.64 million km² and water: 0.012 million km²), the Islamic Republic of Iran is located in southwestern Asia. About 53 percent of Iran consists of mountains and deserts and some 16 percent of the country has an elevation of more than 2000 m above sea level. Approximately, 90 percent of the country is arid and semi-arid. The summer is extremely hot with temperatures in the interior reaching as high as 55°C. In winter, temperatures in the minus range are common in many places, reaching as low as–30°C in the north-west. The average annual rainfall ranges from less than 50 mm in the Central Plateau to more than 1600 mm on the Caspian Coastal Plain, with an average of about 250 mm. The average annual potential evaporation of the country is very high, ranging from less than 700 mm along the Caspian Sea shore to over 4000 mm in the deserts and the south-western part of the Khuzestan.

Estimates based on long-term (1977-2001) historical databases suggest that about 97.3 km^3 of surface water is produced internally in Iran every year (Keshaverz et al. 2002). This figure includes the average annual flow of rivers generated from endogenous precipitation and base flow generated by the aquifers. The annual groundwater recharge amounts to 49.3 km^3, of which 12.7 km^3 is obtained from infiltration in the river bed. The overlap shared by groundwater and surface water is 18.1 km^3. Taking into account this overlap, the annual total internal renewable water resources are 128.5 km^3 (FAO 2002; Earth Trends 2003). The annual per capita water availability is 1775 m^3. About 93 percent of the total water resources is used for irrigation, followed by the small shares for domestic (5 percent) and industrial (2 percent) sectors. The use of water in industrial and domestic sectors produces about 3 km^3 of wastewater, which is reused in irrigation in treated, partly treated, or diluted forms.

Recent estimates of cultivated area amount to 18.2 million ha, including both arable land (16.1 million ha) and area under permanent crops (2.1 million ha). There has been an increase of about 6 percent in total cultivated area since late 1990s, but it still only constitutes about 11 percent of the total land area of Iran. Of the total cultivated land, about 8.1 million ha are under irrigated agriculture (ICID 2002). Surface irrigation techniques are used on 98.7 percent of the area equipped for irrigation and 1.3 percent benefits from pressurized irrigation systems. About 50 percent of the irrigated area depends directly or indirectly on groundwater, including spring water.

Major crop production systems in Iran are based on irrigated agriculture, where about 50 percent of the area falls under different types of salt-affected soils (Cheraghi 2004). The largest tract of salt-prone soils exists in Central Iran. Salt-prone land and water resources are major impediments to productive agriculture. Therefore, the dependence on irrigated agriculture is at stake in areas where land and water resources degradation has increased over time. It is estimated that in areas where salinity is present, average yield losses may be as high as 50 percent (Siadat et al. 1997).

Despite heavy risks of soil salinization, no comprehensive database exists to determine the true extent and characterization of salt-prone land and water resources in Iran. In order to develop workable strategies, it is inevitable to do in-depth review of existing information on the approaches used so far for the management and improvement of salt-prone soil and water resources. This information is also needed to develop recommendations for future research in this field. This report synthesizes the information on the extent, characterization and implications of salt-prone land and water resources in Iran. In addition, the report evaluates the management practices used for salt-affected soils and their potential for crop production systems in the foreseeable future.

SOURCES OF SALTS IN IRANIAN SOILS

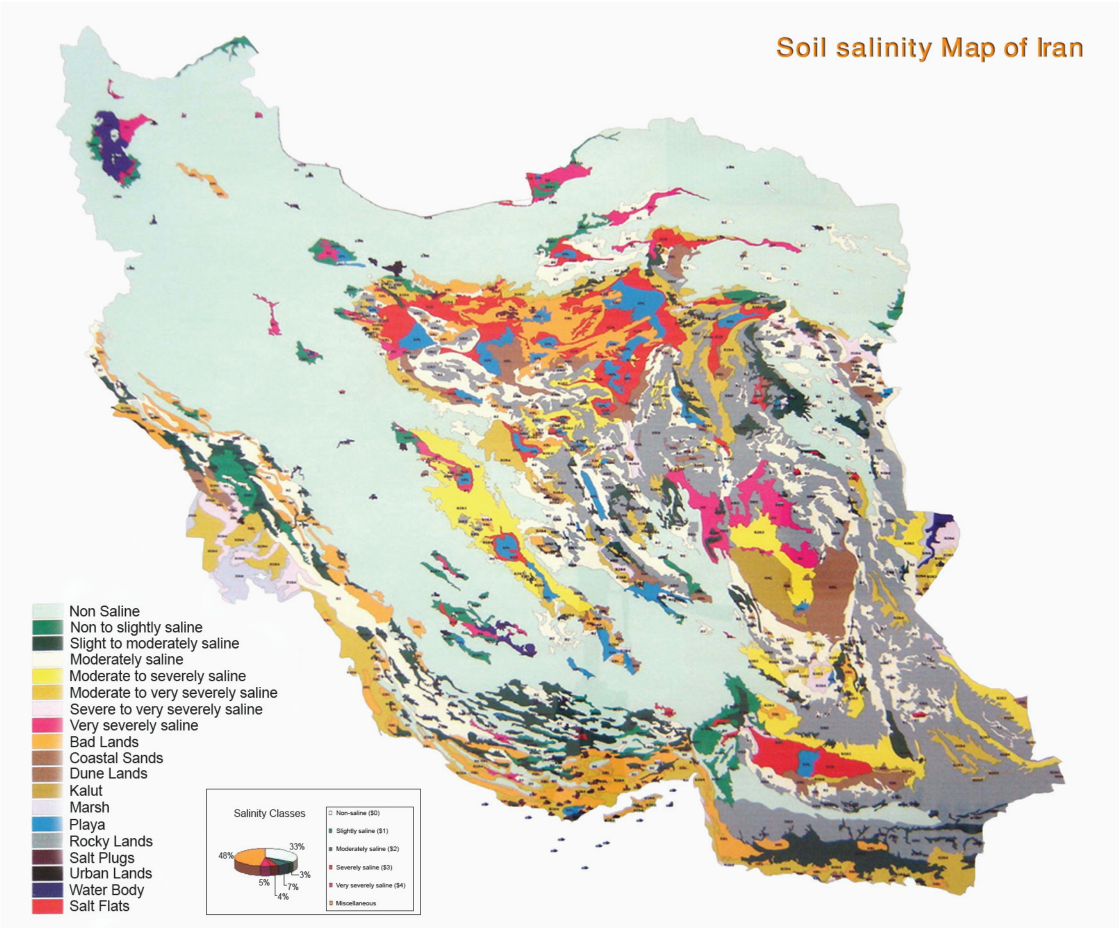
The salinization of land and water resources in Iran has been the consequence of both the naturally occurring phenomena †primary or fossil salinity and/or sodicity, and the anthropogenic activities †secondary salinity and/or sodicity (FAO 2000) (Figure 1). The following factors have contributed to primary salinity and/or sodicity of land and water resources in Iran.

- Geological composition of the parent material of the soils. Iran is rich in the distribution of naturally occurring materials such as halite (NaCl) and gypsum ($CaSO_4$) forming layers with marls, which were deposited in many parts of the country. The best known deposits are in the Zagros and Persian Gulf region and in the central part of Iran.
- In-stream salinity, mainly due to natural conditions, is one of the main causes of salt accumulation in the soils of the Central Plateau.
- Wind-borne salinity resulting from strong winds, blowing most of the year in the Central Plateau, contributes to the expansion of soil salinity by distributing the salts accumulated at the soil surface over a wider area.
- Seawater intrusion, which occurs mostly in coastal areas where saline seawater enters the inland channels or inundates coastal lowlands due to tidal waves. Seawater intrusion into the shallow groundwater in the coastal areas has also led to salinization of soils along the Caspian Coastal Plain, and in Khuzestan and the Southern Coastal Plains located in southwestern part of Iran.
- Low rainfall and high potential evapotranspiration as a consequence of extreme temperatures. In some cases such as the Zabol Irrigation Project in the Sistan Province, the average annual rainfall is 55 mm whilst the potential evaporation is about 4800 mm.

Human-induced salinization has occurred mostly in unique topographic conditions of semi-closed or closed intermountain basins, where irrigated agriculture has been practiced for centuries. There are several factors contributing to the secondary salinization of land and water resources in the country, including:

- irrigation with saline and/or sodic waters in areas of extreme water scarcity without adequate management practices;
- lack of suitable drainage infrastructure, which is the key to appropriate disposal and re-use of agricultural drainage water;
- unsustainable pumping of groundwater resources by over-exploitation and tapping of saline aquifers;
- poor irrigation management with freshwater, such as over-irrigation;
- overgrazing of the pastures and other vegetation resulting in exposure of soils to greater risks of salinization; and
- inadequate water quality monitoring programs to collect data from areas with potential for secondary salinization. These monitoring programs act as warning systems for larger areas predisposed to potential damage.

Figure 1. Soil map of Iran indicating area under non-saline soils and different categories of salt-affected soils (Banie 2001).



Various combinations of these factors have caused large-scale salinization of land and water resources in Iran. Development of secondary salinization in the Khuzestan, Sistan, Moghan, Zarrineh-Rud, Doroudzan, Saveh, and Zayandeh-Rud irrigation projects are important examples (Ghassemi *et al*. 1995).

SALT-PRONE LAND AND WATER RESOURCES IN IRAN—SOCIO-ECONOMIC IMPLICATIONS

It is extremely difficult to quantify the social and economic costs of salt-prone land and water resources. Salinization causes occupational or geographic shifting of the farming communities relying on these resources. In addition, it impacts on aggregate national income. Based on the global income losses from degraded lands (Dregne et al. 1991) and the estimates of the extent of salt-prone soils under irrigated agriculture in Iran, the annual economic losses in Iran due to the presence of these soils could be more than US$ 1 billion (Table 1). This economic loss is about 9 percent of the global value resulting from salt related land degradation (Ghassemi et al. 1995).

Although no hard data exist, it is generally recognized that a large proportion of salt-affected soils occur on land belonging to smallholder farmers, who rely on that land for their livelihoods. Generally, the worst situations of salinity impacts in Iran occur where the farming communities

Table 1. Estimates of the annual income loss as a consequence of salt-related land degradation under irrigated agriculture in Iran.

Year of estimation	Salt-affected area under irrigated	Estimated loss (US$ ha^{-1}) agriculture ($\times 10^6$ ha)	Annual income loss (US$ million)
1989	1.72[1]	250[2]	430
1995	2.20[3]	250	550
2004	4.05[4]	250	1013

[1] Based on irrigated area as reported by FAO (1989).
[3] Based on the income loss values per unit area of land degradation as reported by Dregne *et al.* (1991).
[3] Based on salt-affected area under irrigated agriculture as reported by Ghassemi *et al.* (1995).
[4] Calculated from the estimates of the Cheraghi (2004) considering 50 percent of irrigated area as salt-affected.

are relatively poor and face economic difficulties. Therefore, they are unable, even reluctant, to employ new technologies without financial help from the government. The livelihoods of the affected communities remain at stake in Iran, warranting sustainable development programs addressing the problems caused by the salinity of soil and water resources.

EXTENT AND CHARACTERIZATION OF SALT-PRONE SOILS

Despite widespread salinization of land resources in Iran, no comprehensive study has been undertaken regarding the extent of salinity and sodicity. However, scattered publications do provide insight into the extent and characteristics of salt-affected soils (Dewan and Famouri 1964; Abtahi 1977; Mahjoory 1979; Abtahi et al. 1979; Matsumoto and Cho 1985; Hajrasuliha et al. 1991). Earlier estimates reveal a figure of 15.5 million ha of salt-affected soils, almost 10 percent of surface area of Iran (Dewan and Famouri 1964). More recent estimates suggest that the area affected by salinity varies between 16 to 23 million ha (Siadat et al. 1997). These figures include both cultivated and barren lands and 7 million ha of salt marsh in Dasht-e-Kavir and Dasht-e-Lut. The more recent estimates reveal that about 25 million ha of the Iranian land are saline and/or sodic (Sayyari and Mahmoodi 2002). Recent estimates reveal that the magnitude of the salt-affected areas is much larger than that originally estimated (Table 2). According to the data extracted from the Soil Map of Iran (in digital format), slightly to moderately salt-affected soils cover about 25.5 million ha and soils having severe salinity occupy 8.5 million ha (FAO 2000).

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 predominate in the Central Plateau, the Khuzestan and Southern Coastal Plains, and the Caspian Coastal Plain. Saline and sodic soils cover about 17 percent of the area of the Khuzestan province, and 16.5 percent area of the Central province. The Gilan, Kordestan, and Bakhtaran provinces have the smallest percentage of salt-affected soil areas (Koocheki and Moghaddam 2004).

There are large differences in terms of temporal reporting of the extent of salt-affected area under irrigated agriculture (Table 3). This is due to the changes in area under irrigation as well as that under salt-affected soils within the irrigation commands. However, there have always been indications that the area under irrigated salt-affected soils is at least 30 percent of the area under irrigation at any point of time (ICID 1977; FAO 1989; Ghassemi et al. 1995). In recent years, reports on the extent of salt-affected soils suggest that these soils occupy about 50-75 percent of

Table 2. Extent of salt-affected soils in Iran.

Source	Total salt-affected area (× 10^6 ha)	Share of salt-affected area from total land area (%)
Dewan and Famouri (1964)	15.5	9.4
Soil and Water Research Institute (1987)	18.0	10.9
Dent et al. (1992)	21.1	12.8
Siadat et al. (1997)	16–23[1]	9.7–13.9
Pazira and Sadeghzadeh (1998)	24.0	14.6
Sayyari and Mahmoodi (2002)	25.0	15.2
Le Houerou (1993)	27.0	16.4
FAO (1994)	32.7	19.8
FAO (2000)	34.0[2]	20.6

[1] Reporting an approximate range.
[2] Based on the digital soil map of Iran, the area under salt-affected soils includes highly salt-affected soils (8.5 × 10^6 ha) and slightly and moderately salt-affected soils (25.5 × 10^6 ha).

Table 3. Extent of salt-affected soils under irrigated agriculture in Iran.

Source	Irrigated area (× 10^6 ha)	Salt-affected area under irrigated agriculture (× 10^6 ha)	Share of salt-affected area to total irrigated area (%)
ICID (1977)	4.00	1.50	38
FAO (1989)	5.74[1]	1.72	30
Ghassemi et al. (1995)	5.74[2]	2.20	38
ICID (2002)	8.10[3]	4.05[4]	50[5]

[1] FAO (1989) estimates based on the datasets for 1987.
[2] Irrigated area was considered the same as reported by FAO (1989).
[3] Based on the datasets for 2002.
[4] Calculated from the extent of irrigated area as reported by ICID and the percentage of salt-affected area under irrigated agriculture as reported by the Cheraghi (2004).
[5] Based on the estimates of Cheraghi (2004) considering 50 percent of irrigated area affected by salinity and sodicity.

the irrigated land in Iran (Cheraghi 2004). The lower limit of this range (50 percent) has been used in this report as the most recent assessment of salt-affected soils under irrigation.

Studies carried out to characterize salt-affected soils in Iran reveal soils having various degrees of salinity, alkalinity, and/or waterlogging on a range of landscape, including irrigated lands, dry farming areas and rangelands. These soils include: saline alluvial soils, solonchak soils (saline soils), solonetz soils (sodic soils), salt marsh soils, desert soils, and their combinations (Dewan and Famouri 1964; Mahjoory 1979; Hajrasuliha et al. 1991; Sayyari and Mahmoodi 2002; Moghaddam and Koocheki 2004).

While working on the characteristics of salt-affected soils representing arid and semi-arid regions of Iran, Mahjoory (1979) selected three soils from the alluvial plains of Karaj and Ghazvin, and Shiraz. The results of the laboratory analyses revealed that the soil samples contained elevated levels of salts, mainly carbonates and chlorides of calcium, magnesium, and sodium, indicating both the problems of salinity and sodicity (Table 4). The samples collected from different depths at these sites had pH values ranging from 8 to 10.2 and salinity levels expressed as EC_e in the range of 9 to 39 dS m^{-1}, Sodium Absorption Ratio (SAR) from 7 to 56, and Exchangeable Sodium Percentage (ESP) from 8 to 45.

Table 4. Characteristics of a pedon sampled from poorly drained area, about 25 km from Shiraz (modified from Mahjoory 1979).

Horizon depth (m)	pH	EC_e ($dS\ m^{-1}$)[1]	ESP[2]	SAR[3]
0.00-0.25	8.0	29.0	33	35
0.25-0.37	8.3	25.0	38	40
0.37-0.70	8.4	35.0	45	56
0.70-0.95	8.4	38.0	41	49
0.95-1.25	8.2	39.0	43	53
1.25-1.65	8.3	28.0	42	51

[1] Electrical conductivity of the saturated soil paste extract.
[2] Exchangeable sodium percentage of the soil.
[3] Sodium adsorption ratio of the soil.

Studies carried out by Matsumoto and Cho (1985) in the Shavour area—located about 70 km north of Ahwaz in Khuzestan province—revealed the effects of irrigation, shallow water table, and drainage on the distribution of salts in the profiles. The salts in the Shavour area are supplied from sedimentary rocks as well as irrigation water with EC levels of 1.35 $dS\ m^{-1}$. They investigated four groups of land resources: (1) uncultivated land not influenced by leakage from irrigation canals; (2) uncultivated land with a shallow water table due to leakage from irrigation canals; (3) irrigated land with tile drainage; and (4) irrigated land without drainage. The drained area had tile drains installed at 68 m intervals. The drainage water from the tile drains had salinity level of 5.2 $dS\ m^{-1}$ and was discharged to the Karkheh River.

Electrical conductivity and concentration of chloride (Cl^-) are two important criteria in the evaluation of soil salinity. Considering laboratory analysis of chloride and sodium expensive and time consuming, Hajrasuliha et al. (1991) investigated the relationship between EC and Cl^{-1} using 640 soil samples collected from irrigated and non-irrigated areas at 13 sites. These sites were selected in an approximately 200 km wide and 2400 km long strip, which ran from south to north-east Iran along Dasht-e-Kavir and Dasht-e-Lut. In order to qualify the relationship between chloride and salinity—expressed as EC_e l—for a broad range of soils, they developed linear and polynomial regression models. They concluded these models can be used for calibration of large-scale soil salinity surveys using electrical conductivity to categorize soil chloride concentrations.

In another assessment of soil salinity, Alavi-Panah and Zehtabian (2002) investigated salinity interaction with chloride and sodium concentrations in the deserts of Central Iran. They excavated 115 soil profiles and analyzed the physical and chemical properties of different horizons including a study on the accumulation of soluble salts in the soil profile. They concluded that salinity in the top soil layer (< 0.2 m) was very different from the salinity of the sub-soil (> 0.2 m). The upward movement of the soluble salts causes accumulation in the surface layer of the desert due to a long history of aridity. They also found a strong relationship between salinity, chloride and sodium in the study area, suggesting that a soil salinity map could be a good indicator of chloride and sodium. While considering the estimation of EC_e from $EC_{1:5}$ from the analytical datasets, they suggested that a higher accuracy would require a more detailed research. They found Landsat satellite images as valuable tool for characterization in desert regions.

Sayyari and Mahmoodi (2002) estimated salinity and sodicity in Dizbad region in Khorasan Province, using aerial photography. The study area was located 85 km southwest of Mashhad. Based on different physiographic units, 30 soil profiles were selected for detailed study. The micro-morphological observations showed accumulation of secondary gypsum and calcite in some pedons, forming gypsic and calcic horizons, respectively. The soils were classified according to United States Department of Agriculture (USDA) soil classification system. Most soils were sodic with SAR levels approaching 93 and ESP levels as high as 58. They also proposed a sub-group 'sodic torrifluvents' for the sodic soils of the region.

Akhavan-Ghalibaf (2002) carried out investigations on different types of salt-affected soils in relation to climatic and lithogenic micro-zones in Central Iran. Because of usual bedrock of older geologic periods, most soil parent materials contain lime, gypsum, and soluble salts such as sodium chloride. He developed relationships between different ionic compositions and SAR. The findings suggested that the salinity types changed with respect to the dominance of cations such as calcium and sodium, and anions such as chloride and carbonate. The role of anthropogenic agents caused the changes in different types of salinity.

The investigations on different types and characteristics of salt-affected soils reveal that all major types of these soils viz. saline, sodic and saline-sodic occur in Iran. This is applicable to both irrigated and non-irrigated conditions. Since most investigations have been carried out on selected soil profiles in some areas or on soil samples collected from potentially salt-affected soils, it is not possible to categorize these soils within Iran in terms of the relative distribution of their different types.

APPROACHES USED IN IRAN FOR THE IMPROVEMENT OF SALT-PRONE SOILS

In this section, a review of management practices used in the past for crop production and improvement of salt-prone soils is presented. Potential interventions proved successful elsewhere in the world and are pertinent to Iranian conditions are also proposed.

Leaching and drainage management approaches

Heavy textured, salt-affected soils (containing high percentages of clay) are difficult to ameliorate because of the problems associated with water movement through the soil profile. The soils containing a high percentage of clay are found in Tabrez flood plain. In some areas such as Rudasht region of Isfahan, hard pans also exist at different soil depths, restricting water movement (Akhavan-Ghalibaf et al. 1996). Karimi (1997) tested cultivation as an amelioration method for these soils through plowing at different depths. Plowing at shallow depth (0.25-0.30 m) did not result in efficient soil desalinization. By plowing at 0.45-0.50 m depth, more than 50 percent of the salts was removed from the soil. By sub-soiling at a depth of 0.75-0.80m, the salinity levels in the soil were decreased to levels suitable for plant growth.

In addition to high clay content, reclamation of salt-prone soils through leaching is complicated if the clay fraction is dominated by swelling type clay mineral such as monmorillnite. When water is applied for leaching, the clay minerals swell rapidly and destroy macro pores, which in turn reduce hydraulic conductivity of the soil. Naseri and Reycroft (2002) have shown that extensive swelling occurred when low salinity water (EC = 0.5 dS m^{-1}, SAR = 0.6) was used. Increasing Ca^{++} concentration in the leaching water not only reduced swelling during the leaching process, but also controlled the dispersion and migration of clay particles.

The Marvdasht Plain in south-central Iran has been the scene of irrigated agriculture for centuries. Salinity of land resources and waterlogging are two major constraints to optimal utilization of natural resources in the region. In the 1960s and 1970s, the Soil Institute of Iran carried out field experiments to evaluate different methods of improving these soils. Various techniques coupled with the establishment of an open drainage system substantially changed the salinity status of the soils. Moameni and Stein (2002) monitored spatio-temporal changes in soil salinity and waterlogging on about 0.18 million ha. They marked the sample areas for which past and present values for soil salinity and depth of groundwater were available. They compared the pre-intervention and post-intervention conditions using spatial interpolation of changes in soil salinity and depth of water table. Both datasets were geo-statistically analyzed to determine the significance of spatio-temporal changes in the area.

A summary of the changes in soil salinity in the study area is presented in Table 5. In 1972, all the sample locations had salinity levels greater than 4 dS m^{-1}. In about 95 percent locations of the study area, the salinity levels ranged from 8 to 32 dS m^{-1}. In contrast, the area covered by the locations with salinity levels less than 4 dS m^{-1} was 89 percent of the total study area, indicating that only 11 percent of the area had salinity levels greater than 4 dS m^{-1}. From what depths were these samples taken?

Table 5. Geo-statistically analyzed spatio-temporal changes in soil salinity in Marvdasht Plain in Iran as a result of different amelioration approaches introduced in the area (modified from Moameni and Stein, 2002).

Salinity range	1972		1996		Changes (1972 to 1996)	
(dS m^{-1})	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
0-2	0	0.0	293	49.5	+293	+49.5
2-4	0	0.0	233	39.4	+233	+39.5
4-8	25	4.2	64	10.8	+39	+6.6
8-16	323	54.6	2	0.3	–321	–54.2
16-32	238	40.2	0	0.0	–238	–40.2
> 32	6	1.0	0	0.0	–6	–1.0
Total	592	100	592	100	0	0.0

Khosgoftarmanesh and Shariatmadarih (2002) carried out a field experiment to investigate the leaching effects on bare saline soils for barley production in Qom province. The treatments were: L0 (conventional irrigation practice; control), L1 (two pre-planting excess irrigations), L2 (one pre-planting excess irrigation), L3 (one post-planting excess irrigation), and L4 (two post-planting excess irrigations). Groundwater from a well, which had an EC of 12 dS m^{-1}, was used for leaching the excess salts from the soil profile. The same water was used for irrigation. The initial soil salinity in all treatments was 67 dS m^{-1} and 55 dS m^{-1} in surface and sub-surface layers, respectively.

The salinity levels in all treatments decreased to that of the irrigation water at both soil depths. After one year, the final salinity levels in soil surface in all treatments, except control treatment, were even below the irrigation water. This was due to rainfall in winter and spring, as well as snow melt that removed salts from the root zone. Visual observations in all treatments at early growth stages of barley revealed signs of salinity impacts such as delayed germination with necrosis and burning of the leaf margins. The injuries were severe in the control treatment. The crop yield obtained from the treatment with two pre-planting excess irrigations (2675 kg ha^{-1}) was close to the average yield of barley from non-saline soils in Qom province (3000 kg ha^{-1}) (Table 6). This yield improvement was due to adequate salt leaching during early growth stages.

Table 6. Grain and straw yields of barley on a saline soil as affected by different leaching treatments in Qom province (modified from Khosgoftarmanesh and Shariatmadarih, 2002).

Treatment	Grain yield[1] (kg ha^{-1})	Straw yield (kg ha^{-1})
L0: Conventional irrigation practice (control)	121	276
L1: Two pre-planting excess irrigations	2675	5320
L2: One pre-planting excess irrigation	1271	2503
L3: One post-planting excess irrigation	445	883
L3: One post-planting excess irrigation	825	1631

[1] Average grain yield of barley from non-saline soils in Qom province = 3000 kg ha^{-1}

Mohajer-Milani and Javaheri (1998) summarized the results of a series of experiments carried out by the Soil and Water Research Institute (SWRI) on leaching behavior of soils from several provinces of the country, viz. Azerbaijan (East and West), Esfahan, Boushehr, Khorasan, Khuzestan (North and South), Semnan, Fars, Ghazvin, Kerman, Kermanshah, Gorgan, and Mazandran. They found that on the average 54 percent of the salts present in a specific depth of soil were leached when the same depth of water (quantity) was applied for leaching.

The results of above studies reveal that most of the salt-prone soils in Iran can be reclaimed if proper leaching is provided with an adequate drainage. The management of salt-prone soils in Marvdasht Plain is a pertinent example of combined effects of leaching and drainage intervention (Moameni and Stein 2002). Prathapar and Qureshi (1999a), through a modeling study, have shown that breaking the hydraulic connectivity of capillary up-flow by cultivating abandoned soil prior to heavy rainfall or leaching would lead to reclamation of saline soils. For leaching of salts, good quality irrigation water should be used because excessive leaching with low quality water needs extensive drainage systems to flush out salts from the system (Sarwar and Bastiaanssen, 2001). However, before deciding about options, it is very important to do economic and environmental analysis to evaluate trade-offs between risks and costs. In Iran, like in many other areas, salinity management and drainage control measures are adopted when soil salinity and groundwater levels have reached alarming levels. However, for sustainable management of irrigated lands, drainage should be considered as a complementary activity to irrigation. On-time installation of suitable drainage infrastructure in irrigated areas will help in delaying or even eliminating the onset of drainage and associated soil salinity and sodicity problems.

Crop-based management approaches

Crop-based management options for reclaiming saline soils have also been investigated in some studies in Iran. Guiti (1996) studied the effects of different types of re-vegetation on soil salinity management. He found *Tamarix* and *Atriplex* plantations as effective species in decreasing the salinity of surface soil. Djavanshir et al. (1996) carried out ecological characterization of different plant species for different types of constraints in Iranian deserts, including soil salinity, particle-size distribution, water table and climate. They used *Haloxylon aphyllum*, *Haloxylon persicum*, *Petropyrum euphratica*, and *Tamarix aphylla* in their studies. In a review on the use of halophyte species for animal feed and for combating desertification in Iran, Koocheki (1996) concluded that although halophyte species constitute a substantial proportion of the total flora of Iran, little has been done regarding their potential use in saline environments. In another review, Koocheki (2000) evaluated the potential of *Atriplex* as a fodder shrub in the arid lands of Iran. Tork Nejad and Koocheki (2000) evaluated the economics of *Atriplex* as a forage source for meat production in Iran. They estimated the total investment over a period of 10 years as US$200 ha^{-1}. They projected that the net annual income from *Atriplex* plantations could be as high as US$200 ha^{-1}.

Halophytes are predominant in rangeland communities in saline areas. Although a close relationship has been established between livestock herds and halophytic communities as a fodder source, this relationship has not been adequately exploited on a large scale. However, at the local level, the use of halophytic species for different purposes such as feed and industrial and domestic uses have been well established in salt-affected areas. There are 16 major halophytic plant families known in Iran. These species encompass about 92 percent of the halophytic species identified. The ranking order of halophytic families with respect to the number of species is: Chenopodiaceae > Poaceae > Asteraceae > Brassucaceae > Plumbaginaceae > Cyperaceae > Tamaricaceae > Zygophyllaceae > Polygonaceae > other families (Moghaddam and Koocheki 2004).

In addition to studies on halophytes, several studies have been carried out on different crop genotypes to evaluate their response to different levels of salinity. Most of these studies have been carried out under controlled conditions or on a small scale. Although these studies did provide insight into the mechanisms of salt tolerance in different crops, there is limited work done in Iran on large-scale development and use of salt-tolerant germplasm for saline soils. Table 7 provides information on different varieties of wheat, barley, alfalfa, and sorghum, which have been released for salt-affected environments (Cheraghi 2004).

Table 7. Different varieties of wheat, barley, alfalfa, and sorghum bred for salinity tolerance in Iran (modified from Cheraghi, 2004).

Crop	Variety name	Yield (t ha^{-1})	Water salinity[1] (dS m^{-1})
Wheat	Roshan	4.25	8.51
Wheat	Mahdavi	4.50	8.51
Wheat	Alvand	4.03	8.51
Wheat	Kavir	4.695	9.04
Barley	Afzel	5.14	14.17
Fodder Sorghum	Jambo	52.67	9.08
Alfalfa	Yazdi	13.84	8.40

[1] Based on salinity of irrigation water as the average root zone salinity levels were not available.

Although crop-based management of salt-prone soils has been in practice for decades in Iran and in other parts of the world, there has been a renewed interest in this approach because in addition to soil amelioration there are economic incentives from the crops in terms of their market demand or farm level utilization (Marcar et al. 2003; Dagar et al. 2004; Qadir and Oster 2004). Additional benefits from crop-based interventions include improved nutrient availability status (Qadir et al. 2001) and carbon storage (Kaur et al. 2002) in the post-plantation soil. Various field scale evaluations reveal such benefits through crop-based management of salt-prone soils (Farrington and Salama 1996; Garg 1998; Mishra and Sharma 2003). A number of field crops, forage shrubs and grasses, aromatic and medicinal species, and fruit tree and agroforestry systems have been found to be successful on a variety of salt-prone environments (Kumar 1998; Dagar et al. 2006).

Crop diversification and production systems based on salt-tolerant plant species are likely to be the key of future agricultural and economic growth and social wealth in those areas in Iran where salt-prone soils exist, saline drainage waters are generated, and/or saline aquifers are pumped for agriculture. Koochecki (1996) has also concluded that there is a need to exploit full potential of Halophytic and other salt-tolerant plant species in Iran. However, to increase the performance of plant species used for the management of salt-prone soils, involvement of local communities and stakeholders such as industry and traders is of paramount importance. In addition, markets for the products produced from salt-prone soils need to be established and strengthened to make it a profitable business for farmers.

Chemical amendments for reclaiming sodic soils

Despite the existence of large regions of sodic and saline-sodic soils in Iran, research on the amelioration of these soils has been done on a much smaller scale (Cheraghi 2004). This is the reason that no comprehensive plan is in place for the reclamation of these soils containing elevated levels of Na^+. In a field study, Ardakani and Zahrinia (2006) investigated the effects of gypsum application on erosion and runoff in unstable sodic soils. The results show that application of gypsum significantly reduces runoff (40 percent) and sediment yield (35 percent). The gypsum application also had a significant effect on soil salinity.

Mosavi-Khansari (1991) studied different physical and chemical characteristics of saline and sodic soils during the process of amelioration in the plains of Saveh in the Central province of Iran. Studies have also been carried out on the amelioration of sodic and saline-sodic soils by acidification through the application of sulfuric acid and sulfur powder enriched by *Thiobacillus* bacteria (FAO 2000). These studies have also shown beneficial effects of applying chemical amendments to saline-sodic and sodic soils where sodicity levels could not be decreased by routine irrigation and leaching practices.

Amelioration of sodic and saline-sodic soils with high clay content, particularly where montmorillonite is the dominant clay mineral, is technically difficult and expensive. When water is applied for leaching, the clay swells rapidly, destroying the macro-pores, which provide the primary drainage pathways. The hydraulic conductivity of the fully saturated soil is usually very low and drainage cannot be provided at economic spacing. Physical manipulation of the soil into smaller aggregates by intensive mechanical sub-soiling can increase drainage by increasing the hydraulic conductivity. Naseri and Rycroft (2002) used special permeameters and measured the effect of leaching water quality on the properties of saline-sodic soils during leaching. They found that extensive swelling occurred when low salinity water (EC = 0.5 dS m^{-1}, SAR = 0.6) was used. The swelling for a particular initial soil sodicity level increased as the salinity of the leachate decreased. Increasing calcium concentration in the leaching water not only reduced swelling during the leaching process, but also controlled the dispersion and migration of clay particles.

Increasing infiltration rates in the sodic soils through mechanical plowing is a temporary solution. For medium and long-term increases in infiltration rates, replacement of Na^+ by Ca^{2+} or Mg^{2+} is required. Jayawardene et al. (1994) developed “slotting technique” for the reclamation of sodic soils. With slotting, soil is disturbed to a required depth (usually 60-80 cm) in narrow, parallel and vertical bands (10-15 cm wide and 1-2 meters apart) leaving the rest of the soil undisturbed. Gypsum is mixed with the loosened soil and bands are filled with this soil. Row crops are planted along these slots. With the development of the crop, beneficial effects of gypsum are extended to the entire soil, which in turn improve the soil health. Prathapar et al. (2005b) has demonstrated the feasibility of this technique for the reclamation of highly sodic soils in the Pakistani Punjab.

The use of balanced fertilizers is crucial in various crop production systems on salt-affected soils. The split application of nitrogen fertilizers, mostly ammonium sulfate, at a higher rate than that applied to conventional agriculture on good soils improved yield. In Qom region, the application of nitrogen at 225 kg ha^{-1} and potassium at 120 kg ha^{-1} resulted in wheat grain yields as high as 5600 kg ha^{-1} (FAO 2000).

In the Khuzestan Province southwest of Iran, more integrated approaches have been used to address the problems of rising salinity and waterlogging. The sugarcane plantation in this area started some 1200 years ago but was halted in the beginning of last year due to the inability of farmers to cope with salinity and high watertbale problems. In 1950, sugarcane plantation was with the establishment of sugarcane estates at Haft-Tappeh (12,000 ha) in 1950, at Karun (20,000 ha) in 1965, and recently at Mian-Ab (10,000 ha). Khuzestan has started growing sugarcane again under the Sugarcane and By-Products Development Project (SBDP). Some 84,000 ha of uncultivated land is being reclaimed for the large-scale agro-industrial sugarcane units. The climate is arid with an annual rainfall of only 250 mm, mostly occurring in the winter, while the soils are fine-textured.

The prevailing high soil salinity and sodicity, and the presence of highly saline groundwater at shallow depth (salinity up to 63 g L^{-1}), have been the major constraints on the development of the project. Drainage problems of this area were solved by installing a composite type of pipe drainage network on a 12,000 ha. Drainage water from this area is pumped into open drains for further disposal into the Kuran River. The main environmental concern is the disposal of the large volume of saline drainage water, which is estimated at 250 million m^3 per year for Amir Kabir and the neighboring Mirza Kouchek Khan units. The drainage water from these two units is intended to be reused to grow salt-tolerant crops such as Eucalyptus and the remaining water will be disposed of in evaporation ponds. Accordingly, the “Eucalyptus and By-Products Development Project” is in place on an 18,000 ha downstream area (Shiati and Azari 1999).

Another example of the integrated project is the Moghan Irrigation Project located on the Iran-Azerbaijan border and covers about 0.3 million ha. The climate of the area is arid with average annual rainfall of 300 mm. In spite of the availability of water from Aras (Araks) river, irrigation in this area was not practiced until 1950s and farmers were totally dependent on rain-fed agriculture. The first big canal with a discharge of 17 m^3 s^{-1} was built in 1959 to irrigate 18,000 ha. Aras Dam was completed in 1970 and open drains were constructed to collect drainage water for disposal into Aras Dam at the northern end of the area. The EC of Aras river water is about 1.0 dS m^{-1} while groundwater salinity ranges from 3-10 dS m^{-1} in deep watertable areas and 10-40 dS m^{-1} in shallow watertable areas. With the introduction of irrigation systems, problems of salinity were reduced in deep watertable areas due to leaching however this was not the case in shallow watertable areas where these problems were intensified (Ghassemi et al. 1995).

The contrasting performance with respect to large scale salinity and groundwater table management reveal the need of integrated strategies for the management of salt-prone soils and saline waters. Salinity and drainage problems can be addressed by drainage provisions and re-use of drainage water for salt-tolerant crops (Stenhouse and Kijne 2006). In addition, drainage waters can also be used for the promotion of aquaculture especially in those areas which are abandoned for conventional agricultural production systems. In Iran, lots of such areas exist where sources of farm income can be diversified by exploiting unutilized resources and contributing to the remediation of waterlogging problems by removing excess water from the soil. This has already been adopted in many developing countries, particularly in Nile Delta Valley. This has provided an excellent opportunity for the farming community to increase their income base.

EXTENT AND CHARACTERIZATION OF SALT-PRONE WATER RESOURCES

The assessment of water resources in arid and semi-arid climates is crucial because of the implications of their use for land and water degradation. This is particularly important in Iranian conditions, where there is insufficient rainfall in most irrigated areas to leach salts that accumulate as a consequence of evapotranspiration of water applied in irrigation. The process of salinization of the surface water resources of Iran is mainly due to natural conditions, and to a lesser extent, to the discharge of drainage water into the river systems (Ghassemi et al. 1995). As reported by Shiati (1991), about 6.7 $km^3$of brackish water resources flow annually through 12 major rivers of the country. The improvement in the quality of these water resources has the potential to have a beneficial significant effect on the agricultural development in Iran.

Iran has large reserves of saline water resources having different levels of salinity. The temporal variation of salt content is partially constrained as a result of soil stratification. Reservoirs, therefore, can buffer the salinity of brackish surface water and be used as a management tool. Among the saline water resources in Iran, the Persian Gulf and Gulf of Oman Basins contribute 70 percent. It is followed by 14.2 percent in the Central Platuea, 8.8 percent in the Caspian Sea and Mazandaram Basin, and 6.6 percent in the Lake Urumie Basin (Shiati 1998). In case of Lake Hamoun and Kara-Kum Basin, there are no saline water resources in Hamoun; all saline water resources are in Kara-Kum. The distribution of saline water resources in different water basins of Iran is presented in Table 8.

Table 8. Distribution of saline water resources in major basins of Iran (modified from Shiati, 1998).

Basin	Total area (km^2)	Number of saline water resources	Percentage of total number of resources
Central Plateau	832,000	1,526	14.2
Persian Gulf and Gulf of Oman	431,000	7,536	70.1
Caspian Sea and Mazandaran	178,000	932	8.8
Lake Hamoun and Kara-Kum	150,000	82[1]	0.8
Lake Orumie	57,000	658	6.1
Total	1,648,000	10,734	100

[1] No saline water resources in Hamoun Basin; all saline water resources are in Kara-Kum Basin.

In addition to basin level studies on the assessment of saline water resources, few studies have been carried out on the quality of river waters (Valles et al. 1990; Shiati 1998). The Jaj-Rud (Djajerud) River Basin is located on the southern slopes of the Elburz Mountains, to the east of Tehran, and covers an area of 2,900 km^2. Snowmelt and rainfall are the two sources of water in the Jaj-Rud River. Owing to the diversity of water resources and the geological heterogeneity of the basin, there are marked changes in the chemical composition of the river water. Valles et al. (1990) carried out an investigation on the chemical composition of the river water at 9 stations within the basin. There was a clear trend of water quality deterioration as the water moved from upstream to downstream areas. The water quality deterioration had a major effect on the development of salinity and sodicity in the irrigated land located in the lower reaches of the basin. Seasonal fluctuations of water supply also impacted water quality. For example, the salinity levels in water increased to 14 dS m^{-1} in summer when the water flow was at its minimum. The snowfall and rainfall in winter and subsequent snowmelt in early spring resulted in an increased flow of water in the river, thereby diluting salinity levels in the range of 0.3 to 2 dS m^{-1}.

In the southern part of Iran, the Shapur-Dalaki River Basin has a catchment area of 10 000 km^2 with an annual flow of 1 km^3. The river discharges into the Persian Gulf. Shiati (1991) carried out an investigation on the origin and management of salinity in the basin. The water quality at the upstream was found to be good with salinity levels in the range of 0.35 to 0.50 dS m^{-1}. The water quality gradually deteriorated within a distance of 200 km as a consequence of the confluence of saline springs and passage of the river through high-salt materials such as evaporites and salt domes. The water quality at the lower reaches deteriorated to the extent that the salinity levels of river water reached between 4 to 8 dS m^{-1}. The salt load carried by the river was about 2.3 million tons per year.

With a storage capacity of 0.7 km^3 and height of 102 m, the Rais Ali Delvari Storage Dam is on the brackish Shapur River in the southern part of Iran to irrigate about 25,000 ha. The average monthly river salinity prior to dam construction was in the range of 1.8 to 3.6 g L^{-1}, as simulated by a dynamic reservoir simulation model (Shiati 1998). The reduction in salinity after construction of the dam was in the range of 1.8 to 2.5 g L^{-1}, an improvement potential of ~ 1 g L^{-1} in salinity with a significant beneficial effect on the soil, water and crop yield in the command area. The characteristics of saline water reservoirs in Iran are provided in Table 9.

Table 9. Characteristics of saline water reservoirs in Iran (modified from Shiati, 1998).

Dam	River	Total storage ($\times 10^6$ m^3)	Measured river water salinity (g L^{-1})
Voshmgir	Gorgan-Rud	113	0.40-1.67
Saveh	Ghareh Chai	290	0.45-1.90
Nomel	Ghareh Sou	7.5	0.40-1.62
Khordad	Ghom Rud	200	0.55-2.56
Alagol	Off stream of Atrak	75	0.98-4.00
Shahid Yaghobi	Kalsalar	70	0.52-1.42
Rais Ali Delvari	Shapur	700	0.180-3.27
Jamgardalan	Konjancham	96	0.45-1.56
Shahid Madani	Aji Chai	550	1.62-12.18
Garkaz	Gorgan-Rud	85	1.50

The discharge of drainage water to river systems is a common practice in Iran. For example, discharge of drainage water from irrigation systems back into the river is repeated several times along the rivers in Khuzhestan. This practice seriously decreases the quality of irrigation water to be used by the farmers at the lower reaches of the river system. Use of saline water in the absence of appropriate management has damaged the environment by increasing the levels of salinity and sodicity in soils with subsequent decline in agricultural production.

Jalali (2002) evaluated groundwater quality in Hamadan, the western part of Iran where the climate is semi-arid. In the study area, most water used for drinking and irrigation is supplied from groundwater. The major crops are wheat, potato and barley. The soils have been formed from calcareous parent material and are classified in the soil order 'Aridisols'. A total of 131 water samples were collected from wells and analyzed for salinity as well as concentrations of cations and anions. The salinity levels in water samples ranged between 0.2 to 9 dS m^{-1}. About 8 percent of the samples had conductivities higher than 3 dS m^{-1} (Table 10). In terms of sodicity, about 22 percent of the samples had SAR values greater than 9. Most water samples (about 85 percent) had levels of bicarbonate ions in the range of 1.5 to 8.5 $mmol_c$ L^{-1}, and 8 percent samples had bicarbonate levels in excess of 8.5 $mmol_c$ L^{-1}, suggesting that persistent use of these waters will tend to precipitate calcium ions as calcium carbonate. Consequently, there will be potential for the increase in sodium levels within the irrigated soils, requiring careful management practices.

Table 10. Quality of groundwater used for irrigation in western part of Iran (Developed from the databases of Jalali, 2002)[1].

Parameter	Value	Frequency (% of total samples)[2]
EC (dS m^{-1})	< 0.7	35
EC (dS m^{-1})	0.7-3.0	57
EC (dS m^{-1})	> 3.0	8
SAR_{adj}	< 3.0	51
SAR_{adj}	3.0-9.0	26
SAR_{adj}	> 9.0	23
HCO_3^- ($mmol_c$ L^{-1})	< 1.5	08
HCO_3^- ($mmol_c$ L^{-1})	1.5-8.5	85
HCO_3^- ($mmol_c$ L^{-1})	> 8.5	7

[1] Based on 131 groundwater samples collected from wells in Hamadan, the western part of Iran.
[2] Frequency distribution as percent of total samples is based on each parameter such as EC, SAR, and HCO_3^-.

APPROACHES USED IN IRAN FOR THE MANAGEMENT OF SALT-PRONE WATER RESOURCES

The dry and harsh climate and scarcity of freshwater resources in most parts of Iran have prompted the Iranian farmers and researchers to develop special methods of irrigation with saline water. The prevalent method of supplying water is through '*Qanats*', which is a long-standing traditional practice in Iran. Researchers consider that '*Qanats*' are an innovation by the Iranians almost 3000 years ago. A '*Qanat*' starts as a well dug in a mountain side to draw on water stored in the rocks from rainfall, which has fallen on the mountain ranges over time. Some of the main wells of the '*Qanat*' systems in eastern Iran are more than 400 m deep. About 75 percent of the water in Iran is supplied by '*Qanats*'. All '*Qanats*' do not provide freshwater. There are thousands of '*Qanats*' that provide highly saline water and are still effectively used for irrigation (Alizadeh et al. 2004). Since many '*Qanats*' or streams have saline water, the farmers have found that they need to irrigate more frequently to leach salts that accumulate with saline water irrigation. Therefore, in case of saline water irrigation the irrigation intervals are shorter, almost half (5-6 days instead of 12-14 days) than traditional irrigation with freshwater.

Research and large-scale development projects have been carried out on the management of saline and sodic water resources in Iran. Dordipour et al. (2004) investigated the impact of irrigation, using Caspian Sea water mixed with well water, on barley growth and yield and soil characteristics. The three irrigation regimes consisted of: (1) Well water with an EC of 0.8 dS m^{-1}; (2) Caspian Sea water with an EC of 21.5 dS m^{-1}, diluted with the well water at a 1:1 ratio and used at the stem elongation stage; and (3) same as Caspian Sea water treatment with respect to composition, but used at the ear formation. Irrigation with a 1:1 mixture of seawater and well water at the stem elongation stage adversely affected the barley yield, aerial biomass and the root growth in comparison to irrigation with well water alone. However, irrigation with the same quality water at the ear formation stage, had less effect on grain yield and aerial biomass, and most importantly, did not cause an economic reduction in yield compared to the well water treatment.

They suggested that the use of "seawater" for supplemental irrigation could substantially reduce the pressure on limited groundwater resources. However, increased soil salinity will result in problems for future germination and seedling growth when the plants are more susceptible to salinity. If leaching of excess salt from the root zone is possible, particularly at early stages of growth, this should increase yield. Supplementary irrigation can therefore be applied at the last stages of barley growth when water resources are limited, provided that freshwater, low saline water or precipitation can be applied to control the soil salinity at the early stages of growth of the next crop.

The Zarrineh-Rud Irrigation Project is located southeast of Lake Orumieh and covers an area of 1025 km^2 with an average annual rainfall of 350 mm. With good-quality water, two rivers, Zarrineh-Rud and Simineh-Rud, flow in the region. The Zarrineh-Rud plain underlain by a multilayered aquifer system, which is less than 160 m thick, is recharged by the rivers and discharges into the marsh lands of Lake Orumieh. A dam has also been constructed along with a gradual development of a drainage system. Water quality of the aquifer is good in the eastern side with salinity levels less than 0.55 dS m^{-1}, but it deteriorates towards the north-west and reaches levels as high as 10 g L^{-1}. Although the water table was shallow in the early 1960s and signs of salinization existed in the region, excessive use of surface water through the irrigation network has caused further rises in water table, resulting in widespread salinity and waterlogging problems in the area.

The Zayandeh-Rud Basin has an area of about 4 million ha. The Zayandeh-Rud Irrigation Project covers part of the Esfahan Plain, which is formed by the alluvial deposits of the Zarrineh-Rud. The region is arid and the rainfall decreases from about 300 mm in the west to less than 100 mm in the east. The Zayandeh-Rud is the major river of the area. The river water contains a natural load of salts. A reservoir with a capacity of 1.1 billion m^3 was constructed on the river in late 1960s and the irrigation project was completed in 1978. The project consisted of two diversion dams, 90 000 ha of irrigated land, 164 km of main canals, 129 km of secondary canals, and 235 km of surface drains. In 1995, the project had 95 000 ha of modern irrigation system with lined channels and automated gates for operation, 30 000 ha of traditional irrigation system, 4 main canals, 290 km of irrigation canals, and 256 km of drains. The water table is shallow and groundwater flows towards the river, which acts as the main drain of the aquifer. In spring and summer during the period of irrigation, the water table rises to only 0.6-0.7 below the land surface.

A drainage system collects drainage effluent and discharges it to the river to be used by downstream farmers.. Thus, water quality deteriorates downstream of the diversion dam. A part of the drainage effluent is also used by the local farming systems. The main crops in the area include wheat, barley, rice, sugar beet, vegetables, and orchards (Ghassemi et al. 1995). In situations like Zayandeh-Rud Basin and in many countries like Iran, uniform water allocations per unit area would be an important step in the reallocation of water from over-using upstream areas where groundwater is also relatively fresh and abundant, to the water-short and salt-abundant downstream areas. Therefore there is a need to restrict excessive use of fresh water resources at the upstream of irrigation systems to make sufficient water available for the downstream users. The government has started introducing volumetric delivery of irrigation water and charging the fee according to the actual use in some of the irrigation systems (Keshaverz et al. 2003). However, prices of water are still very low and efficiency of volumetric water delivery is still needs to be evaluated.

The Zabol Irrigation Project is located in the Sistan Province. The average annual rainfall is 55 mm against the potential evaporation of about 4800 mm, which is 87 times greater than the rainfall. The Sistan Plain is formed by alluvial material. The Sistan River, one of the tributaries of the Hirmand River, is the major source of irrigation water supply in the Zabol Irrigation Project. The Sistan Diversion Dam has been constructed on the river to distribute water through two main canals and a number of secondary canals. With salinity levels of 0.5 g L^{-1}, water from the Sistan River is suitable for irrigation. Groundwater in the area is not suitable because of its high salt concentration. The irrigation project covers an area of about 0.1 million ha. Wheat and barley are the major crops of the area.

The water and land-use management practices based on traditional methods have caused damage to the land and water resources with the aggravation of the problems of salinity, sodicity and waterlogging. Estimates in 1987 suggest that 80 percent of the land has been affected by varying levels of salinity and sodicity. In addition, strong winds blowing in summer contributed to the expansion of soil salinity in the area. Moreover, the farmers in the salt-affected area used to remove the top 0.1-0.2 m of top soil and collect it at the edges of the fields. The fields are then flooded with water for leaching of salts. The contaminated topsoil is another source for widespread distribution of salts by strong winds. As no comprehensive plans exist for periodic monitoring of soil salinity, field observations of patchy crop stand, retarded growth, leaf burns (where sprinklers are used with low quality water) are used as evidence for the aggravation of salinity problems (Siadat et al. 1997). For water salinity, taste of well water is considered as evidence for changing levels of salinity. Although the primary irrigation canals are lined, secondary canals and distributors are unlined and managed by the farmers relying on traditional methods of water management. Therefore, seepage from these canals is significant and contributes to water table rise. Farmers' salinity management practices include leaching, crop choice, cultural practices and application of chemical amendments. However, these practices have not proved very successful because they are done randomly without having much knowledge of the effective ways of reclamation.

The Dorudzan-Korbal Irrigation Project is located in Fars Province about 65 km north-east of Shiraz, which is the capital of the province. The Dorudzan-Korbal Plain has an elevation of 1560-1620 m. The major rivers in the plain are Kor, Maeen, and Seivand. Limestone formations surrounding the plain recharge the alluvial aquifer. Groundwater salinity at the margins of the plain is less than 1 dS m^{-1}, with increasing salinity from the north-west towards the south-west, where salinity levels greater than 5 dS m^{-1} are found. Of the annual groundwater extraction, almost all (98 percent) is used in irrigation. The salinity levels in different sources range considerably for wells (0.5-8.0 dS m^{-1}), *Qanats* (0.4-12 dS m^{-1}), and springs (0.5-1.5 dS m^{-1}). Water losses from irrigation canals are high, with an average value of 40 percent. Losses from irrigation canals and irrigation fields are considered the major reasons for high water table, which is shallower than 2 m over most of the plain. In some area, it is even less than 1 m. The soils in the area are highly salinised because the salts in groundwater reach to the root zone as a result of capillary action from the shallow water table. Although several drains have been designed to control water table levels and rootzone salinity, the problem has not been resolved as the drainage remains inadequate. The Dorudzan-Korbal Plain is suitable for the development of modern irrigation systems. A project to upgrade traditional diversion structures has been completed with concrete lining of the irrigation canals along with drainage facilities.

The Jarrahi River in Khuzestan Province is formed from the confluence of the Marun and Allah Rivers. The main crops consist of wheat, barley, and vegetables. The annual water use is about 85 million m^3 with an efficiency of 34 percent. Groundwater levels fluctuate with high levels in March-April due to rainfall and irrigation, and low levels in October-November. Salinity, alkalinity, and waterlogging are the major problems in the area due to the combined effects of a number of factors: climatic conditions, fine-textured soils, shallow water table, high salt concentration in the groundwater, irrigation with highly saline water, inadequate drainage facilities, excessive and uncontrolled irrigation practices, windborne salt and destruction of the native vegetation cover. The management plans to overcome the problems of salinity, alkalinity, and waterlogging include the control of flooding via the construction of diversion dam and diversion canal to divert the flood water to the lower end of the area, and the development of modern irrigation and drainage networks. The work on these plans is in progress and it is expected that timely completion of these projects will help in solving the problems to a large extent.

The drainage water from irrigated agriculture carries a salt load. Therefore adequate disposal or reuse of drainage effluent is important for long-term sustainability of irrigated agriculture in arid and semi-arid regions of Iran. Keshavarz and Brown (1998) investigated the drainage problems in the Amir Kabir Sugarcane Research Project in Ahwaz. They found that inadequate drainage along with rainfall and irrigation in excess of crop water requirements are the major factors that impact control over groundwater levels. Their findings suggested that high water table and silt-loam soil texture were the main problem for poor natural drainage of the area. Therefore, there is a need to develop extensive plans for the re-use of saline and drainage water and the safe disposal of saline brine through the provision of artificial drainage systems if irrigated agriculture has to be sustained in Iran. This is especially important because Iran is planning to invest huge money on the development of new irrigation schemes in future. If these aspects are not taken care, it will be difficult to achieve the desired outcomes.

DISCUSSION AND FUTURE PERSPECTIVES

Iran faces enormous challenges of widespread land and water resources degradation as a consequence of salinity and sodicity of these resources. In addition, rising water tables resulting from the inadequate management of irrigation practices have caused waterlogging problems in many areas. Despite these challenges, no national strategic plan is available to direct research on the true assessment and management of salinity and waterlogging problems. There are fragmented databases on the quantification of salt-prone land and water resources in the country. In addition, there are considerable differences in the quantification done by several studies, even questioning data reliability and reproducibility.

There is no single solution to the complex problems of salt-prone soil and water resources in Iran. The approaches addressing the management of these resources need to be multidimensional and must take into account the biophysical and environmental conditions of the target area as well as livelihood aspects of the associated.

The review of past research reveals that there is no established network for the monitoring of spatial and temporal changes in soil and water salinity. Therefore there is a need to develop a national strategic plan to integrate management of salt-prone land and water resources in the country. Detailed investigations should be carried out to prepare an extensive database and soil salinity and water quality maps to select representative sites for in-depth analysis of land and water degradation issues. These representative sites should be established as pilot projects to demonstrate the sustainable methods of managing salt-affected soils and saline waters. Latest approaches using GIS, remote sensing and satellite measurement techniques can help a great deal in spatio-temporal analysis of salt-prone land and water resources. These techniques are now widely used for this type of analysis and have proved to be accurate, less-expensive and effective in overcoming data limitation problems (Bastiaanssen and Ali. 2003).

The analysis of collected information shows that despite difficulties, farmers are continuing their efforts for the management of salt-prone land and water resources. Their efforts are based on their indigenous knowledge which include physical, chemical and biological interventions. However, they are not familiar with newly developed improved farm management practices. This is mainly due to the fact that research conducted to advice farmers was confined to local field scale experiments. The results of these studies were therefore regarded as local solutions and could not get the attention of the larger farming community. Furthermore, no serious attempts were made to generalize the results of these studies for wide scale dissemination to the farming community through extension services. Therefore, the farming communities should be involved in the planning and execution of amelioration and management of salt-prone land and water resources. This will increase their confidence and build capacity for wider adaptability. Without farmers' participation, true benefits of research could not be achieved.

In Iran where off-farm income generation activities are very limited due to lack of industries, using abandoned soils for biomass production would be a viable option. Many tree species capable of growth and production in highly saline conditions are now available and are being used in Australia, Pakistan, India and other Central Asian and Arabian countries (ICBA 2003). IWMI together with the national partners has also successfully tested the growth of a large number of halophytic species in Uzbekistan and Kazakhastan under their ADB funded Bright Spots Project (Noble et al. 2005). Noble et al. (2006), through their global analysis of the impact of "Bright Spots" on crop production have found that their significant positive benefits to individuals and communities and may help in eradication of poverty within communities. They have concluded that although global land degradation trends are still a major concern, improvements in the life of communities is possible through these localized resource conservation strategies.

Despite the shortage of water, there is a general tendency of over-irrigation in Iranian farmers, whereas the opposite should be accomplished. Due unlined canals (except for few newly constructed irrigation schemes), poor land leveling of fields and use of basin/flooding method of irrigation, water use efficiencies are around 30 percent (Keshaverz et al. 2003). Un-even distribution of water due to poor land leveling produces patches of low and high infiltration rates, which in turn produce patches of low and high salinity within the same field. Therefore farmers should be educated through extension services to level their fields and adopt water conservation measures to increase water use efficiency. Studies have shown that in water deficit environments such as Iran, water conservation strategies can save up to 25 percent of the irrigation water without compromising the crop yields (Prathapar and Qureshi 1999b; Sarwar and Bastiaanssen 2001).

Improved cultural practices such as precision land leveling, zero tillage and bed and furrow-bed methods of planting have shown water savings of up to 40 percent of the irrigation water and reduced levels of salinity development (Qureshi et al. 2003; Ahmad et al. 2007). These resource conservation techniques are now widely used in arid and semi-arid areas in growing wheat, cotton and other variety of crops. In southern parts of Iran where water shortage is more prevalent, these technologies can be of great value.

The use of saline water in Iran, to a large extent, is still confined to growing salt resistant grasses for fodder, bushes and trees such as Eucalyptus (Cheraghi 2004). Due to very limited economic benefits, farmers are not very interested to adopt these practices and prefer to leave their lands and look for off-farm income employment. Due to increasing dependence of irrigated agriculture on saline water in Iran, it is very important to dvelop strategies to use different quality irrigation water for agriculture. Stenhouse and Kijne (2006) have shown the technical feasibility of using saline water and land for irrigated agricultural production in the mixed farming systems of West Asia and North Africa (WANA) region. With practical examples from Egypt, Syria and

Tunisia, they have shown the efficacy of using saline and drainage water for conventional crops. The agro-climatic conditions in Iran are very similar to those in these countries. Therefore there is a good potential for adopting these practices. This will increase economic benefits to farmers and help in keeping their spirits high to work on these troubled lands.

One of the major bottle-necks in persuading farmers to use saline water for agricultural production is the lack of proper guidelines for farmers on mixing ratios of different quality water, irrigation amounts and frequencies, and cultural practices that can be instrumental in avoiding salt accumulation in the root zone. Considerable amount of work has been done to develop strategies for conjunctive use of different quality waters for irrigation under different climatic and crop conditions (Rhoades 1990; Rhoades et al. 1992; Qadir and Oster 2004; Qureshi et al. 2004a; Qureshi et al. 2004b). However, these findings need to be refined and tested for local climatic, soil and crop conditions. Therefore, there is a need to develop plans for targeted research in this area.

Finally, farmers alone can not tackle this huge task of rehabilitating degraded land and water resources. Therefore, governments should take lead in preparing strategic plans to improve the quality of research and extension services. This goal can be achieved by opening a dialogue with farming communities and policy makers to improve their understanding of the problem and its future implications at local, regional and national scale. The management options for salt-prone land and water resources built on the accumulated wisdom of relevant stakeholders will assist in the adoption of conservation measures at the community level. Such participatory approaches create a sense of ownership among the farmers. Furthermore, community-based management would help in strengthening linkages among researchers, farm advisors and farmers.

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