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Water Productivity Improvement Under Salinity Conditions: Case Study of the Saline Areas of Lower Karkheh River Basin, Iran

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Abstract

Soil salinity and low drainage capacity are major factors limiting crop yield and low agricultural water productivity (WP) in the Lower Karkheh River Basin (L-KRB) in the southwest to south of Iran. The objective of this chapter is to provide and elaborate cost-effective and adaptive solutions and measures for the amelioration of the situation and for enhancing WP in this area. The suggested approaches and measures are based on field experiments conducted both under farmer's field and research station. The main cultivated crop in the region is wheat. For the first step, WPs of wheat were determined under some farmer's fields. Based on results, WP of wheat in the area varied between 0.24 and 0.77 kg/m³. The study aimed to provide simple measures and management practices for reducing salinity and water-logging hazards and ultimately improving crop WP in the studied area. The focus of experiments was on the methods of land preparation for irrigation, sowing methods by the different adapted machines, and seeding rates. Changing of traditional basin irrigation to a modern mixed system of border-basin irrigation method could improve irrigation performance and will reduce applied water greatly and hence could improve WP. Construction and provision of fixed and low-cost water intake structures on farm ditches could have more impacts on the improvement of irrigation performance as well. Optimum (modern) border irrigation and optimum basin treatments had higher WPs (1.36 and 1.04 kg/m³, respectively) than the traditional irrigation practiced by the farmers (0.61 kg/m³). Although the WP of optimum border was highest, the basin irrigation method is suggested because this method is more adaptive and sustainable in terms of acceptance by the local farmers.

Keywords: water, salinity, productivity, basin, border, crop, improvement, Karkheh

1. Introduction

Agriculture plays an important role in Iran's economy. It accounts for 18% of gross domestic product (GDP), 25% of employment, 85% of food requirements, 25% of non-oil exports, and 90% of input materials for the local industries [1].

The climate of Iran is very diverse, and great extremes are common features of it due to its geographic location and highly varied topography. The major area of the country (almost 90%) could be classified as arid to semiarid. Of the characteristic

of such a climate are hot summers with the temperatures reaching up to 55°C in the interior and southern parts. Evaporation demand is much higher than precipitation in most areas of the country. Consequently, water resource management under these conditions is an important issue and a great challenge especially in the agricultural sector.

Despite reliance of the country on agriculture, especially irrigated agriculture, water resources required for agricultural production are limited but provide a vital input to agricultural production in Iran. Currently more than 93% of water consumption (84 billion cubic meter; BCM) is used to irrigate 8.2 million hectares (Mha) of lands. Considering the growing demand for water in industrial and municipal sectors, combined with the environmental concerns, in the near future, there will be lesser freshwater resources available for agriculture in the country.

The latest agricultural statistics reveal that Iran produced 77 million tons of agricultural products from 84 BCM of water consumed. Therefore, currently the average water productivity (WP) in agriculture is almost 0.92 kg/m³. This value is quite low and necessitates the use of appropriate approaches for its improvement [2].

Studies conducted on farmers' fields in five regions in the country (Kerman, Hamedan, Moghan, Golestan, and Khuzestan provinces) revealed that WP for the irrigated wheat varies in the range of 0.56–1.46, sugar beet (0.59–1.28), sugarcane (0.31), potato (1.45–3.0), silage corn (6.46), cotton (0.73), alfalfa (1.48), barley (0.56), and chickpea (0.18) kg/m³ [3, 4]. Based on the review of 84 references on values of WP during the past 25 years, it was found out that the average WPs of wheat are about 1.09 kg/m³ [5].

However, there is no information available or accessible that addresses assessment of WP in the Lower Karkheh River Basin (L-KRB). Preliminary estimates that are based on farmers' field visits and questionnaire on crop yield and applied water suggest WP of irrigated wheat to be about 0.6 kg/m³ in this region.

Soil and water salinity are major threats and barriers to the optimal crop production systems in most parts of the world, especially in arid and semiarid regions, including Iran [6, 7]. The salinization of land and water resources has been the main consequence of two factors including naturally occurring phenomena and anthropogenic activities. The first factor has caused primary fossil salinity and/or sodicity, while the second factor, which is more prominent, has caused human-induced or secondary salinity and/or sodicity [8].

Soil and water resource salinities are the major threats to the crop production and sustainability of natural resources, especially in irrigated agriculture based on groundwater resources in Iran. Salt-affected soils are the major features of many parts of the country, particularly in the Central Plateau, which is surrounded by two main ranges of high mountains along with the northwest to northeast (Alborz range) and northwest to southern parts and southeast (Zagros range).

Irrigated agriculture is the main cropping system in the country, while out of which at least 4.1 Mha of 8.2 Mha of total irrigated lands (nearly 50%) suffer from different levels of salinity and sodicity [9]. This is under conditions that irrigated agriculture is the main focus of government plans for increasing agricultural products and food security, especially in the recent decades.

Irrigated agriculture with low irrigation efficiencies has been one of the causes of human-induced salinization of land and water resources. This phenomenon has occurred mostly in unique topographic conditions of semi-closed or closed intermountain basins where irrigated agriculture has been practiced for many years. Distribution of land salinity in Iran is diverse. The extent and characteristics of salt-affected soils in Iran have been investigated and are reported by several

researches [10–14]. Overall, the slight to moderate salt-affected soils are mostly formed on the piedmonts at the foot of the Elburz Mountains in the northern part of the country, while the lands with severe to extreme degrees of salinity are mostly located in the Central Plateau, Khuzestan province plains, Southern Coastal Plains, and some parts of the Caspian Coastal Plains (mainly in Golestan province in the northeast) [7].

Average yields of the common crops vary highly depending on the climatic and soil and water conditions. However, because of many limiting factors, mainly water and salinity stresses, the achieved yields are generally suboptimal. Average crop yield losses due to salinity stress are estimated to be up to 50% in areas where salinity is present [15].

Large areas of Iran suffer from salinity and sodicity hazards. Wide distribution of such areas in the country reflects the fact that many factors are contribution to this phenomenon. Indeed, the causes of soil salinity could be divided into natural or primary causes and secondary or man-made causes. The natural causes include geological and physiographic conditions, climatic conditions, and salt loads by water. The man-made causes are mainly because of improper irrigation management followed by waterlogging problems. Waterlogging is mostly occurring in the irrigation networks developed under regulated waters, e.g., dams. Because of water scarcity, especially in recent decades, the increased use of marginal brackish waters for irrigation without required management also has worsened this problem and is sparking the soil's secondary salinization. Overall, the man-made causes of soil salinity in Iran could be nominated as poor water management, use of saline groundwater, over exploitation of groundwater, poor land preparation, fallowing and overgrazing of lands, improper cropping pattern, and sea-water intrusion into coastal areas.

Because of the importance of facing with salinity in agriculture of Iran, many research projects are conducted specifically on salinity issues in the country till date. These research projects cover some provinces or regions in the country facing with soil and water salinity hazard, e.g., Yazd, Golestan, Fars, Khurasan, Khuzestan, Markazi, Hormozgan (Bushehr), Moghan, Azerbaijan, Esfahan, and Qom. Very roughly it could be stated that till now the majority of research projects conducted in the country cover mainly the following areas including the extent of salt-affected soils, characteristics of salt-affected soils, methods of reclamation of salt-affected soils, crop fertility and productivity potentials of salt-affected soils, productivity of saline water used in different parts of the country, amount and distribution of saline water resources (as drainage water and groundwater resources), and quality of saline waters in regard to the salts and other contaminants. However, very limited salinity research projects have been conducted on the aspects of evaluation and improvement of WP under salinity conditions in the country in general and in the L-KRB in specific.

Karkheh River Basin (KRB) is a typical and important basin in Iran regarding the supply of water resources for the fertile plains and favorite climatic conditions for productive agriculture in the downstream basin, mainly located in the Khuzestan province. The other important characteristic of the KRB is that both dryland and irrigated agricultural production systems exist in the basin. Water in KRB is becoming scarcer because of climate change together with the population growth. Therefore water demand, especially for the irrigated areas on the downstream basin which are under intensive development, is increasing. The productivity of rainfed agriculture is low, conventional irrigation management is poor, cropping systems are suboptimal, and policies and institutions are weak [16]. Considering these inefficiencies, improvement of water productivity in agricultural sector is a recent and important policy of the country especially in KRB.

In the upper KRB, the dryland agriculture prevails. The challenges for the rural households in such areas are similar to the ones in other dryland areas, i.e., agricultural options are limited, and wheat, barely, and pulses are dominant cropping patterns in the landscape. Agricultural outputs are usually low and unstable, due mainly to the resource degradation, drought spells, and climate change impacts [16]. Irregular rainfall on poorly vegetated hill slopes results in severe soil erosion, downstream flooding, and sedimentation. Consequently, the lifetime of the Karkheh Reservoir Dam in the downstream basin is dwindling rapidly. These environmental constraints combined with their economic problems make this southwest corner of Iran one of the poor areas of the country with a high out-migration rate [16].

KRB had been selected as one of the nine benchmark basins of the CGIAR Challenge Program on Water and Food (CPWF¹). One of the CPWF Phase 1 projects focuses on interventions for the improvement of on-farm agricultural WP in KRB. This project was carried out jointly by the International Center for Agricultural Research in the Dry Areas (ICARDA) and Agricultural Research, Education and Extension Organization (AREEO) of Iran. The objectives of the project were to develop biophysical interventions to improve the farm and basin level of WP and sustainable management of the natural resources and to develop appropriate policies and institutions supporting the project interventions to help the poor communities for the improvement of their income and livelihoods. Moreover, the project aimed at strengthening and enhancing the capacity of the National Agricultural Research and Extension Systems (NARES) of Iran.

KRB is becoming a water-scarce area, and droughts and climate change are becoming permanent features of this region. Because of water scarcity and degradation of land and water resources, livelihoods of rural communities are at stake. With the current rate of deterioration of natural resources if no remediation is taken, the situation will worsen in the near future. However, there are great potentials for the improvement of land and water productivities in the KRB. Therefore KRB was well adapted to be a pilot area for the development-oriented research activities to be implemented under Phase 1 of CGIAR Challenge Program on Water and Food (CPWF). KRB situation provided a unique opportunity for the CPWF to make an impact through improvements in land and water productivities, which in turn will improve the livelihoods of rural poor living in this basin. The issues of KRB have a great similarity with other basins located in the similar hydrological conditions, e.g., West Asia and North Africa (WANA) region.

This chapter provides an overview of the soil and water potential of the L-KRB and the salinity and waterlogging constraints to agricultural production and agricultural WP improvement under saline areas of L-KRB. The findings are mostly based on the research results conducted during the CPWF Phase 1 comprehensive project in KRB.

¹ The Challenge Program on Water and Food (CPWF) is one of the pilot programs designed to reinvent the business model for the CGIAR. The CPWF was launched in 2002 as a reform initiative of the CGIAR, the Consultative Group on International Agricultural Research. CPWF aims to increase the resilience of social and ecological systems through better water management for food production (crops, fisheries, and livestock). CPWF does this through an innovative research and development approach that brings together a broad range of scientists, development specialists, policymakers, and communities to address the challenges of food security, poverty, and water scarcity. CPWF Phase 1 worked in nine river basins globally: Andean system of basins, Indo-Gangetic, Limpopo, Mekong, Nile River, Yellow River, Sao Francisco, Volta, and Karkheh River Basin.

2. Karkheh River Basin characteristics

KRB is located in the west to southwest of Zagros ranges in Iran (**Figure 1**). It is located between $56^{\circ}, 34' - 58^{\circ}, 30'$ north latitude and $46^{\circ}, 06' - 49^{\circ}, 10'$ longitude. The area of the basin (inside Iran) is 50,764 square kilometers (km^2). Out of which 27,645 km^2 are mountains and 23,119 km^2 are plains and hills. The mountainous areas of KRB are mostly in the eastern and central parts. The plains are mostly in the northern and southern parts and cover almost 45% of the basin area. Hypsometric studies indicate that 75% of the basin is located in altitudes of 1000–2000 and 0.6% of the basin is above 2500 m altitude.

The Karkheh River arises from the confluence of numerous large and small tributaries including the three large rivers, namely, Gamasiyab, Ghareh-So, and Kashkan. The Karkheh River has various names along its route and is locally best known as the Saymareh River at the point where the Gamasiyab and Ghareh-So Rivers combine, and later the point where the Kashkan River flows into the main waterway is known as the Karkheh River. When approaching to the Khuzestan province hypsometric and slope of the basin decrees and gently the river ultimately flows into the Hawr-al-Azim (HAA) wetland at the basin outlet. Therefore KRB could be classified as a closed basin.

Based on general hydrological classification of basins in Iran, the KRB is considered as one of the sub-basins of the Persian Gulf Great Basin.

The pattern of precipitation in KRB is affected by Mediterranean regime. It means that the dry season is coinciding with summer and rainy season match with cold months. The rainfall distribution in the basin is very scatter, but most of the rain falls in winter and autumn seasons. The annual precipitation of the basin is 219 mm in Hamidieh (in L-KRB) to 765 mm in the northern dryland farming areas (in upper KRB).

Based on climatic maps, the hottest areas of the basin are located in its southern parts (L-KRB) and are surrounded by the 25°C iso-temperature (isohyets) contours. The coldest areas of the basin are located in altitude higher than 3000 m and are mostly located in the north and northeast of the basin and are surrounded by the 5°C isohyets' contour map.

Evaporation in KRB varies between 1800 and 3600 mm depending on the altitude. For example, it is around 3561 mm in Abdul-Khan Station in an altitude of 40 m in L-KRB. Almost 79% of annual evaporation occurs from May to September.

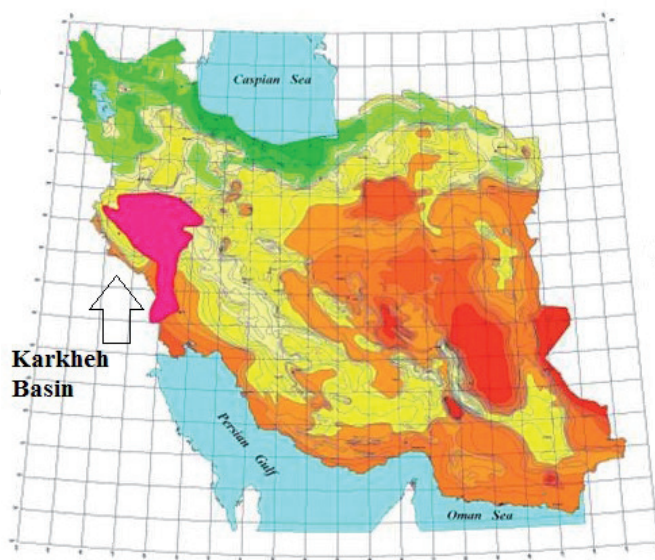


Figure 1.
Geographical location and boundaries of KRB.

In KRB both surface and groundwater resources are used. Based on data, in 1994, the share of total agricultural water uses from both resources was 3.92 BCM. The agricultural water consumption till completion of the ongoing water works could be increased to 7.43 BCM (90% increase).

The water resources of the basin in general have a good quality. However, the quality of groundwater in the Southern plains deteriorates to some extent. The potential of surface water resources of KRB is 7.4 BCM. In wet years it can be doubled, and in dry years, it can be reduced to half. Agricultural water withdrawn in KRB is 3.96 BCM (in year 1994). Out of which 36.8% is supplied from groundwater and 63.2% is supplied from surface water resources.

Plains of L-KRB are the highest consumer of surface water resources. Based on year 1994 statistics, out of different plains of KRB, Azadegan plain (Dasht-e Azadegan, DA) with 662 MCM water consumption is the greatest consumer of water in the basin. This plain also is the greatest consumer (660.2 MCM) of surface water in the basin.

Based on year 1994 statistics, out of 4157.4 MCM consumed water resources, 2504.6 MCM (60.2%) were from surface water, and 1653 MCM (39.8%) from groundwater resources. Out of the total consumption, share of rural, urban, industry and mining, and fishery consumptions was 1.23, 3.93, 0.32, and 0.35 BCM, respectively. The share of agricultural water uses this year was 94.2%. The share of agricultural water consumption in the basin is the highest. The sums of industrial and mining consumptions are very low and just consist 0.32% of total water consumptions. Therefore, from the aspects of water resources' uses, the KRB could be defined as an agricultural basin.

Two major agricultural production systems prevail in the KRB. The dryland system prevails in the upstream areas (upper KRB), while the fully irrigated areas are located in some part of upstream and mainly in downstream of the KRB (L-KRB). The dryland areas are well established and cover most of the basin agricultural lands, occupying 894,125 ha, whereas irrigated lands occupy 578,862 ha but are expected to expand up to 340,000 ha following the completion of irrigation and drainage networks under Karkheh reservoir Dam [16].

Owing to the different flowing rivers, abundant water resources, fertile lands, and sufficient extraterrestrial energy, Khuzestan province in the southwest Iran is one of the potentially most suitable regions for agricultural production. However, salinization of land and water resources has become a serious threat to the efficient use of agricultural lands. 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 conjunctive problems of soil salinization and waterlogging [16].

The next agricultural production system in the KRB is irrigated agriculture. It is estimated that about 1 Mha of land are irrigable in KRB. Out of which about 380,000 ha are currently under cultivation [16]. About 340,000 ha of additional available arable lands will be brought under irrigation following the completion of irrigation and drainage networks under Karkheh Reservoir in L-KRB [16].

The drainage outlet of the KRB is the HAA wetland along with the Iran-Iraq border (**Figure 2**). At present, there are very limited modern irrigation and drainage networks under operation within the L-KRB. However, the networks are under completion, and irrigated agriculture is developing gradually [17]. The government has started construction of irrigation and drainage networks, especially on the tertiary canal level, with the goal of improving on-farm water management and modernization of traditional irrigation networks. The focuses of these activities are the arable lands under the Karkheh Reservoir and in pilot projects such as DA plains in the southern parts of the L-KRB (**Figure 2**).

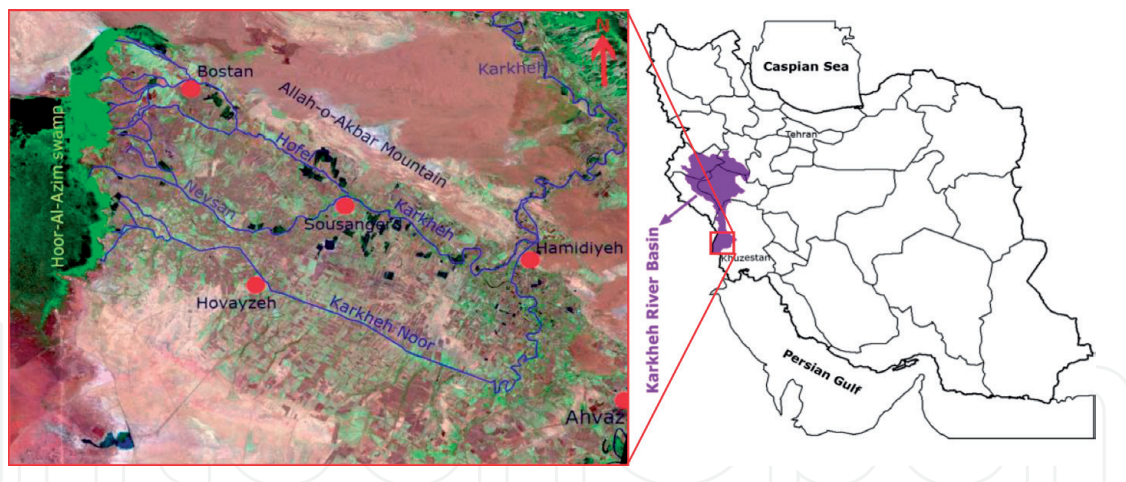


Figure 2.
 Karkheh River Basin (KRB) and Dasht-e-Azadegan (DA) region in the L-KRB.

In the L-KRB because of the differences in factors affecting agricultural WP in the northern and southern parts, two distinct regions can be identified. In the northern part, there are no serious limiting factors in regard to soil and water quality. In this part improving farmer's skills and use of appropriate farming systems can improve WP sufficiently. Shortfalls in water supply and excess irrigation water losses, mainly in earthen canals, cause low WPs of cultivated crops in this area. Extension of new farming systems, e.g., pressurized irrigation and land preparation methods (e.g., raised-bed and double-row cropping systems, etc.), could be some useful approaches for improving WP in the area. Overall in this part, successful introduction and implementation of new farming systems and technologies in accordance with other agricultural services could be effective ways for crop WP improvement.

In the southern parts of L-KRB, heavy soil texture and subsurface water recharge from upstream areas cause natural condition for waterlogging. This situation is more induced by deep percolation losses resulting from low irrigation efficiencies of irrigated lands in the area.

The available soil data indicate that the majority of arable lands in L-KRB possess with various degrees of limitations. However, soil salinity, waterlogging, lack of soil organic matter, soil structural deterioration, intrinsic low permeability, and low infiltration rate caused by soil compaction are the main factors limiting economic and sustainable crop production of the irrigated lands in this area [16].

Waterlogging and soil salinity are the main causes of inefficiencies in achieving high WPs and are threats to sustainable agricultural production in the L-KRB. Major factors causing soil salinization in the L-KRB could be classified as follows [18–20]: shallow water table, existence of salt containing soil layers, inadequate natural drainage, inadequate artificial drainage networks, high evaporation demand of the climate, salt intrusions by wind, and salty sediment transport during flood periods.

In the southern parts of L-KRB, mainly DA plain, available data and surveys show that the problem of soil salinity is intensified because of deficiencies in farmers' knowledge and skills and lack of new and improved farming practices.

In general, the main cause of soil salinity in the L-KRB is high water table which is often less than below 2.0 m from soil surface and usually varies between 1.2 and 3.0 m below the soil surface. If sufficient developments of drainage networks are not provided, the problem will be worsened considering the coming development plans with the aim of expansion of new irrigation networks.

The total rainfall in Susangerd and Bostan towns' climatological stations are 180 and 200 millimeter, respectively. The agricultural service centers also are equipped with rain gauges.

Current crops in Azadegan Plain in southern L-KRB include cereals (such as wheat, barely, rice), vegetables (such as melon, watermelon, tomato, cucumber, eggplant, okra, lettuce, cabbage, carrot, radish, onion, etc.), grains such as beans, and fodder crops (such as alfalfa, barely, maize, and sorghum). More than 78% of agricultural production in Azadegan Plain is dominated by grains, mainly wheat and barley [16, 21]. This is because of soil salinity and sodicity with high toxic elements which makes serious limitation for cultivation of other crops. Currently water supply limitations, agriculture economy (guaranteed purchase of with by the government), and security problems in the region (wheat need less labor, less irrigation, and in overall less need for the stay of farmer in his land) are some other reasons for the farmers' higher interests on wheat cultivation.

The main challenge of agriculture in this region is waterlogging and soil salinity. Waterlogging and secondary soil salinization occur in a certain period of the year. For example, early November is planting date of wheat cultivation system in DA. Late November is the first irrigation for land preparation, and the harvest time is in late May. Deep percolation losses of irrigation during this period cause rises in water table. The peak of water table rise is in February. The salinity [Electrical conductivity (EC)] of shallow groundwater and EC of irrigation water in this area are about 6–9 and 3 dS/m, respectively. The highest depth of water table depth is between 0 and 1.2 m. Operation of main drains has started in recent decade (in 2003), and their outlet is HAA Wetland in the border of Iran-Iraq [16].

3. Amelioration and management approaches for improving WP in the saline areas of lower KRB

There is no doubt that one of the most important requirements for the reclamation of lands in the L-KRB is installation of adequate drainage network for the entire irrigated area. Installation of drainage network is a fundamental solution to improve the quality of salt-affected soils in the L-KRB. Drainage system will reduce the adverse effects of shallow water table and waterlogging issues in the agricultural lands. Hence it will contribute to the improvement of crop production and crop WP. Promising efforts have been initiated by the government in this regard, but still the progress is low and very costly.

To avoid further salinization of agricultural lands and to ameliorate the current situation, the communities and agricultural agencies are called to apply sound management practices until adequate drainage systems are installed.

One of the most important prerequisites to enable sustainable crop production in the area is the development of a monitoring network for observing the effect of different management practices on the salt content of groundwater as well as the salt and water balance of the crop's root zone. The regular monitoring and data acquisition will provide the database required for providing the best measures to prevent restoration of soil and water salinity and secondary salinization of the crop root zone. Moreover, water and salt balance studies at the watershed level will increase the capability to predict the role of any hydrological impacts on the fate and behavior of catchments' salinity.

Salinity and depth to shallow water table in DA were monitored in observation wells during November 2003 to April 2004 [18, 19]. There was a large variation in salinity of groundwater ranging between 4 and 100 dS/m. No trend of salinity changes throughout the study area was found. However, trend of groundwater salinity changes may partly be explained in regard to the soil texture variation in a manner that was lower in light-textured soils than that of heavier textured ones.

Also salinity was lower in the vicinity of the river tributary than those further away from the river. The depth to water table was lowest in April as a result of deep percolation from winter rains, excess irrigation of fields, river floods, and seepage from earthen channels. The depth to water table reaches its maximum in September due to high evaporation during the hot dry summer. This pattern seems to repeat itself throughout the years resulting in accumulation of salt in the top surface soil layer.

Generally saying, the agricultural cropping systems and practices in the area are suboptimal. But there are great scopes and opportunities for their improvement. At present, the crop varieties used by the farmers are not adapted to the prevailing soil conditions, and significant improvements in crop production could be realized by introducing or applying of salt-tolerant crop varieties and species. As already noted the majority of the cultivated areas (almost 90%) are allocated to the winter wheat. The average yields of its two cultivated varieties grown, i.e., Chamran and Verinak, are low and about 2 tons/ha. Introducing and testing of high-yielding varieties to the area available in the country may respond well and be promising. Some salt-tolerant varieties such as Kavir, Bam, and Sistan were tested as part of the CPWF projects for improving WP in the area, and the results were promising.

Appropriate irrigation schedules based on soil moisture depletion or climatic data, and improvement of irrigation efficiency, would prevent excess losses of irrigation water into the subsoil or groundwater. Land leveling could improve water distribution in the field and prevent waterlogging problems. More attention should be paid to the irrigation systems. Efficiency of irrigation water application should be increased, and water should be applied more uniformly along the field [18, 19]. Some of these measures are tested in the field as part of the CPWF project, and the obtained results are given and elaborated in the next sections.

Another important issue limiting crop production in the area is the accumulation of salt in the top soil. This phenomenon mainly occurs during the fallow period, when the soil is uncultivated and the farm is left for the next cropping season. Conducting soil leaching activities prior to the sowing and land preparation activities could reduce the soil surface salinity. Therefore, it will ameliorate the adverse effects of salt stress on crop establishment especially in the early stages of crop growth. Other suitable practices are mulching with crop residues, adding organic matters to the soil, selection of suitable crop rotations, and implementation of proper cropping patterns [18, 19].

4. Determination and evaluation of water productivity

As improvement of WP and identification of its sources of inefficiencies are set as one of the top priorities in Iran, especially in KRB, some studies were conducted in the downstream areas of L-KRB located in the DA plain in the Khuzestan province (**Figure 3**).

The main objectives of these studies were to determine and evaluate WP of irrigated wheat, as a major cultivated crop in DA. Moreover some recommendations and simply applicable management approaches for the better management of irrigation practices and the amelioration of salinity-waterlogging hazards on crop yield and WP were suggested.

The researches were conducted in seven farmers' fields, typical of the farms in the region and during cropping season of 2006–2007. In **Figure 3** location of the selected fields is demonstrated.

The measured parameters were irrigation water inflows and runoffs; soil texture; soil and water salinity; soil and water pHs; soil organic matter; the P, K, Fe, Mn, Zn, and Cu elements of the soil profile; depth and quality (EC) of groundwater during growth season; and finally crop yield.

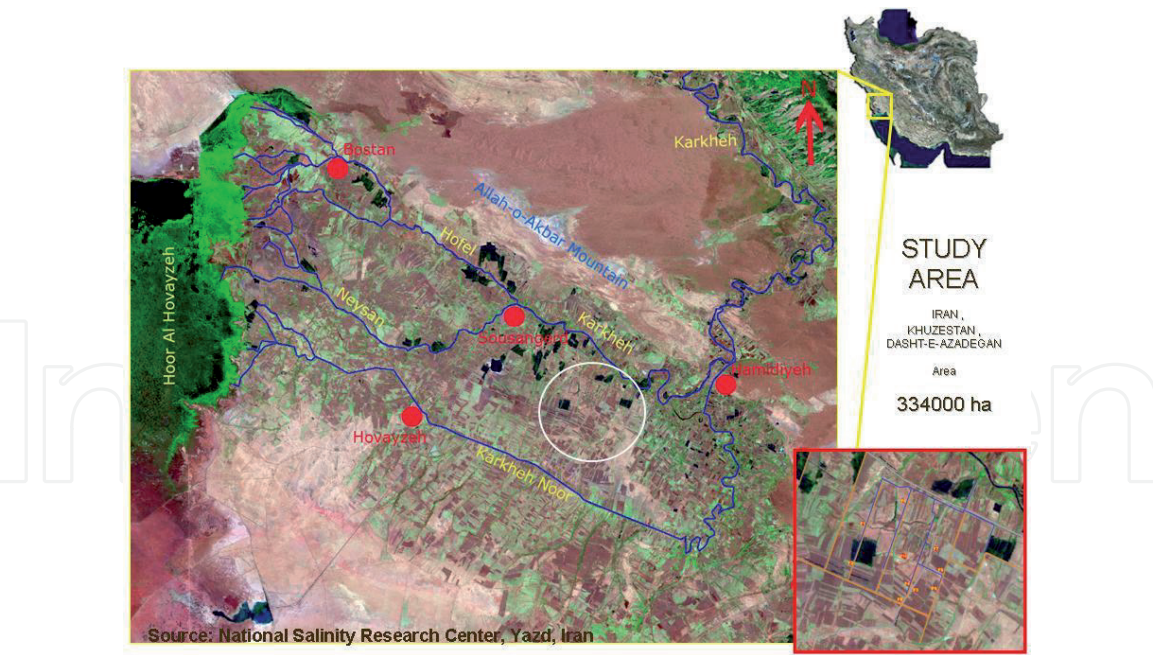


Figure 3.
The study area and location of the selected fields.

Table 1 shows some soil and water characteristics of the studied farms measured prior to the planting stage. Crop yield and yield components were measured through 20 field samples before harvest. The amount of applied irrigation water was measured by using Washington State College flume (WSC) flumes of different types. The irrigation intervals were the same as practiced by the farmers in the selected area.

WPs of wheat crop were calculated using the measured total applied waters and measured crop yields. The results are shown in **Table 2**.

The range of WP in the country is generally wide, and for the wheat crop, it is between 0.56 and 1.46 kg/m³ [3, 4]. Analysis of measured WPs in the DA area also indicates that the range of WP values is relatively high and varies between 0.24 and 0.86 kg/m³ (**Table 2**).

Results indicated that in general by increasing the farm sizes the amount of water consumed per hectare increases. This fact indicates the higher problems associated with irrigation water management in larger field sizes. The lack of required equipment and facilities, lack of farmer’s skills, and shortfalls in proper land leveling have led to higher water losses and hence higher water applications (even three times more) in the larger farm sizes.

Farm code	Area (ha)	Soil texture	EC (dS/m) (30 cm depth)	Depth of water table (cm)	EC of ground water (dS/m)
F1	1.05	SiL	26.4	105	8.8
F2	1.47	SiCL	10	205	39
F3	4.49	CL	52.6	180	71.5
F4	3.44	C	17	195	31
F5	1.73	C	21.5	182	48
F6	0.46	SiC	21.3	173	46
F7	5.24	C	10.5	213	8.7

Table 1.
Some soil and water characteristics of the selected fields.

Farm code	Water applied (m ³ /ha)	ET (mm)	Yield (kg/ha)	WUE (kg/m ³)
F1	3109	517	2392	0.77
F2	3460	522	1022	0.30
F3	2062	477	1336	0.65
F4	3792	505	1453	0.38
F5	3527	553	3032	0.86
F6	2311	553	4851	2.09
F7	5933	517	1431	0.24

Table 2.
Applied waters, crop yields, and WPs of wheat in different fields.

Evaluation of the relationships between WP and applied water, yield, initial soil salinity, initial groundwater salinity, groundwater depth, and farm sizes of the selected fields indicated that there was no clear and distinct correlation between WP and these factors in all cases. In other words, a combination of these factors is affecting WP, and meanwhile managerial factors are more prominent than the basic physical factors. Consequently, sources of inefficiencies and the limiting factors affecting WP in southern part of L-KRB are complex and can be categorized into four main factors as follows:

- Sociocultural problems governing the area and causing low motivation for investment in irrigation management and on-farm improvement activities by the farmers
- Hindering factors that are out of the farmer’s management control and authority (e.g., irrigation intervals and rationing) and shortage of agricultural inputs (e.g., fertilizers, other agrochemicals, equipment and machineries, etc.)
- Infrastructure limitations and lack of technical supports (e.g., inadequate drainage, no reclamation activities, and incomplete irrigation and drainage networks) that need extensive planning and investments and should be supported more by the government
- Managerial issues and limitations whose solutions are simple and do not need much investments and could be accomplished easily

The results indicated that the issues and challenges hindering improvement of WP in all the selected fields are not the same and vary depending on the farmer’s characteristics, the farmer’s management, and the location of the farms. Some of these limitations and issues are elaborated below:

Traditional common irrigation practice in the area is a combination of border-basin irrigation methods. It consists of the long borders (till 400 m) which are divided into different basins (12–15 in wide). Every basin receives its own water from the previous basin. The applied water remains for a long time in the first basins before flowing into the next one (**Figure 4**). This causes stagnation of water in the basin for a long period and stuffiness of the cultivated seeds. As usual the inflow rates to the plots are too high, and there are soil erosions, soil movements, and washing off of the cultivated seeds.

As there is not enough control on irrigation cutoff time, large amounts of outflows concentrate in the lower parts of the plots and create surface

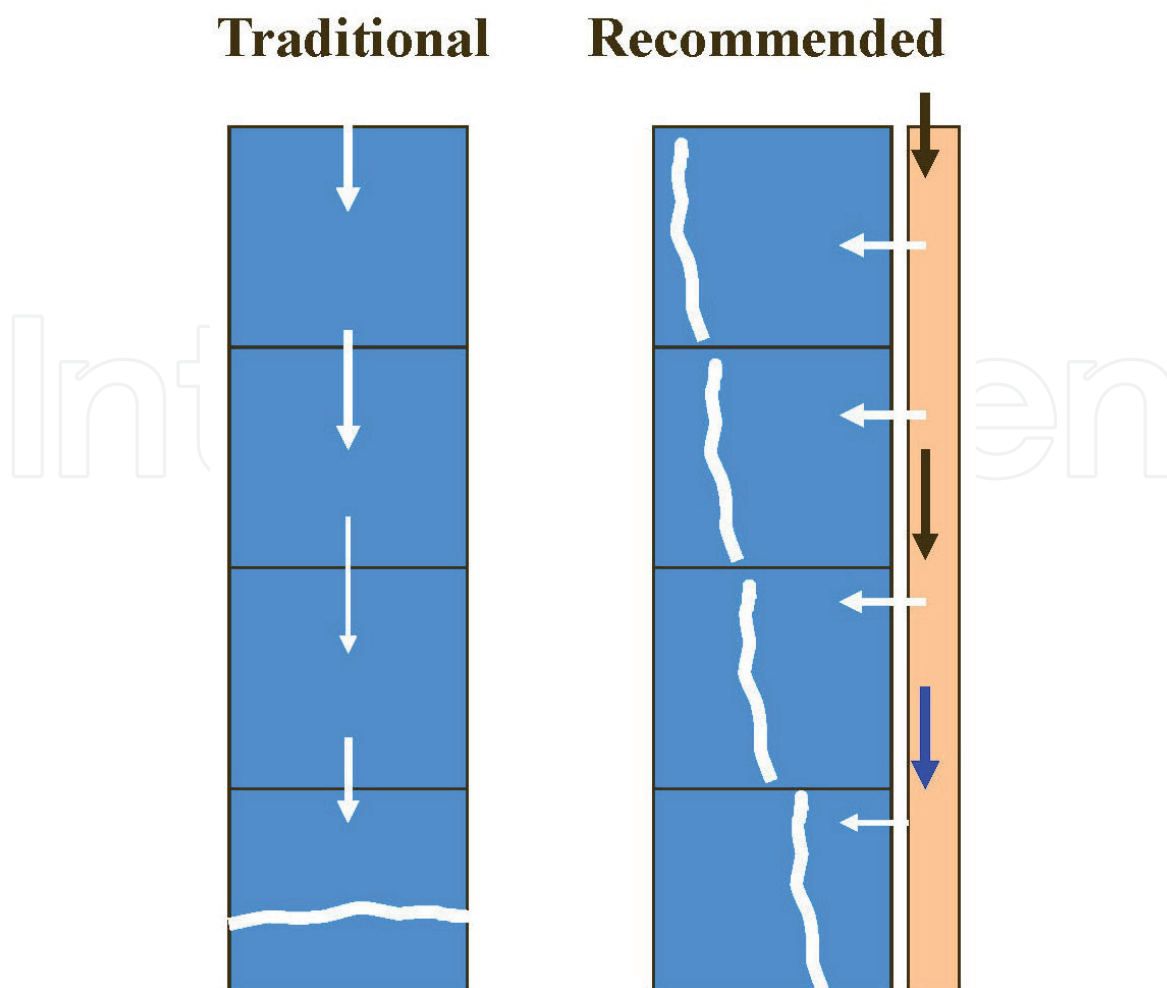


Figure 4.
The traditional (left) and recommended optimum border-basin irrigation (right) methods.

waterlogging problems. Recommend that by using a farm ditch alongside the border and construction of proper intakes, each basin to receive its inflow water individually (**Figure 4**).

Water intake and proper conduct of water into the irrigation plots is another issue. Farmers should pay high efforts to control the inflow, and this makes waste of the irrigation time. Consequently it causes poor water management and waste of water. Recommend that by construction of temporary and low-cost intake structures (gates), water intake and hence water management to be facilitated and improved.

Improper shaping of the plots in accordance with the land slope causes uneven water distribution in the basins.

Improper land preparation and agronomic practices (weed control, planting date, etc.) are some inefficiencies and shortfalls in regard to the crop production and improvement of WP in the studied area.

Considering the above limitations and issues, the following solutions and measures are recommended for improving WP in the saline areas of L-KRB:

- Conversion of traditional common irrigation practices to proper modern basin-border irrigation methods
- Construction of fixed and low-cost water intake structures on farm ditches
- Proper land leveling and bedding according to the farm slope

- Application of on-farm management improvement instructions provided by the rural extension services
- Conduct of training programs for the farmers and supervision of the farms by irrigation experts in order to provide required guidance for the upgrading of irrigation management and performances
- Provision of the required structures and enabling conditions for the volumetric allocation of water to the farmers and implementation of proper cropping patterns

5. Evaluation of the best management practices for improving WP in the salt-prone areas of lower KRB

The main objective of this section is to find out cost-effective and short-term solutions for enhancing WP under salinity conditions. According to this necessity, the following targets were identified for the saline areas of L-KRB:

- Identification of simple management practices for reducing soil salinity stress and improving agricultural WP
- Determination and comparison of WP values under different irrigation managements, i.e., traditional vs. improved border-basin irrigation methods (**Figure 4**)
- Recognition of the effects of different cultivation/sowing methods on wheat's WP in the area

The experiments were conducted during cropping season of 2006–2007 in DA plain in L-KRB. The experimental area was located between 47° 55' to 48° 30' E longitude and 31° 15' to 31° 45' N latitude, and it is about 3–12 m above the mean sea level. Soil texture was silty clay loam (SCL) to clay loam (CL). Soil's average pH was 7.8, and average soil salinity at the depth of 0–90 cm was 10.5 dS/m. Sowing was done in November and the crop was harvested in May.

The source of irrigation water was Karkheh River. The EC of groundwater and irrigation waters were 11.3 and 1.4 dS/m, respectively.

Groundwater depth at the early stages of the growth season (in winter) and before the start of rainfalls and irrigation season was at the depth of 2.4 m. It was gradually raised by the start of irrigation events and changed from 35 to 98 cm from soil surface during the growth season.

The experimental treatments were as follows [19]:

- T₁ = Border irrigation + sowing by centrifugal broadcaster + one pass disk.
- T₂ = Border irrigation + sowing by seed drill (Taka type).
- T₃ = Border irrigation + sowing by three-row bed seeder (Barzegar-e Hamedani type).
- T₄ = Basin irrigation + sowing by centrifugal broadcaster + one pass disk.
- T₅ = Basin irrigation + sowing by seed drill machine (Taka type).
- T₆ = Basin irrigation + sowing by three-row bed seeder (Barzegar-e Hamedani type).
- T_c = Traditional irrigation and sowing method by farmer (as control).

Dimensions of plots for the T₁, T₂, treatments (border irrigation) were 160 m x 10 m, while the plot dimensions of plots for the T₄, T₅, treatments (basin irrigation) were 40 m x 10 m. The selected dimensions were optimal sizes and were selected based on US Soil Conservation Service (SCS) criteria.

The control treatment, i.e., traditional irrigation method, was a combination of basin-border irrigation method practices by the local farmers (**Figure 4**). Local farmers choose the farm borders' length according to their farm dimensions which are usually between 100 and 400 m. The border's width usually ranges between 5 and 14 m. The farmers divide borders to several small basins with 30–70 m length, depending on their farm topography (**Figure 4**). In every irrigation event, they fill the first basin and then water transfers to the next one, and this process continues until filling of the last basin and completion of the irrigation in the irrigation border (**Figure 4**).

All the treatments were sown by the Chamran wheat seed variety. In treatments T₁ and T₄, the seeds were sown by centrifugal broadcaster machine, and the seeding rate was 240 kg/ha. In other treatments (T₂, T₃, T₅, T₆), two seeding machine types, i.e., seed drill machine (Taka type) sowed the seeds for the T₂ and T₅, and the three-row bed seeder (Barzegar-e Hamedani type) sowed the seed for the T₃ and T₆ treatments. The seeding rate for these treatments was 180 kg/ha. In the control treatment (T_c), which was sown by centrifugal broadcaster and managed by the farmer, the seed rate was 350 kg/ha.

In all treatments except control, the optimized irrigation management (**Figure 4**) was practiced. Other farming practices were the same for all the treatments.

In **Table 3** and **Figure 5**, some soil chemical characteristics measured prior to the planting date and fluctuations of water table depths (average of three points) during the cropping season are presented, respectively.

Crop yield and yield components were measured through sampling methods. Prior to harvest 20 soil samples were taken from the field. Volume of applied irrigation water was measured using WSC flumes. Interval and the number of irrigation events for the farmer's managed and optimum irrigation management treatments (**Figure 4**) were the same. In fact, the difference was in how to manage irrigation water and the methods of water application, which directly affected volume of consumed water.

The results indicated that the border irrigation with centrifugal sowing method (T₁) provided the highest WP (1.6 kg/m³) (**Table 4**).

The optimum border irrigation had the maximum WP (1.36 kg/m³), while the control treatment (traditional border-basin irrigation method under centrifugal sowing with 350 kg seed used) provided the minimum one, i.e., WP equal to 0.61 kg/m³ (**Table 4**).

There was no significant difference ($\alpha = 0.05$) in yields between the treatments with the control. Although the consumption of seed used in both Taka and Barzegar-e Hamedani sowing methods was 50% less than the centrifugal broadcasting method, the seed germination percentage was more in these sowing methods (**Table 5**).

Either “improved basin” or “border irrigation” methods could be recommended for the improvements of water management and WP in the L-KRB area. However, the basin irrigation method (**Figure 4**) is more adaptive and sustainable in terms of acceptance by the local farmers for the following reasons:

Soil depth (cm)	EC (dS/m)	pH	OC (%)	P (ppm)	K (ppm)	Fe (ppm)	Zn (ppm)	Cu (ppm)	Mg (ppm)
0–30	11.1	7.7	0.4	5.1	166	3.8	1.3	0.6	5.2
30–60	9	7.9	0.1	2.2	88.7	2.5	0.1	0.4	1.2
60–90	11.4	7.9	0.1	1.8	59	3.2	0.1	0.5	1.5

Table 3.
Some soil chemical characteristics measured prior to the planting date.

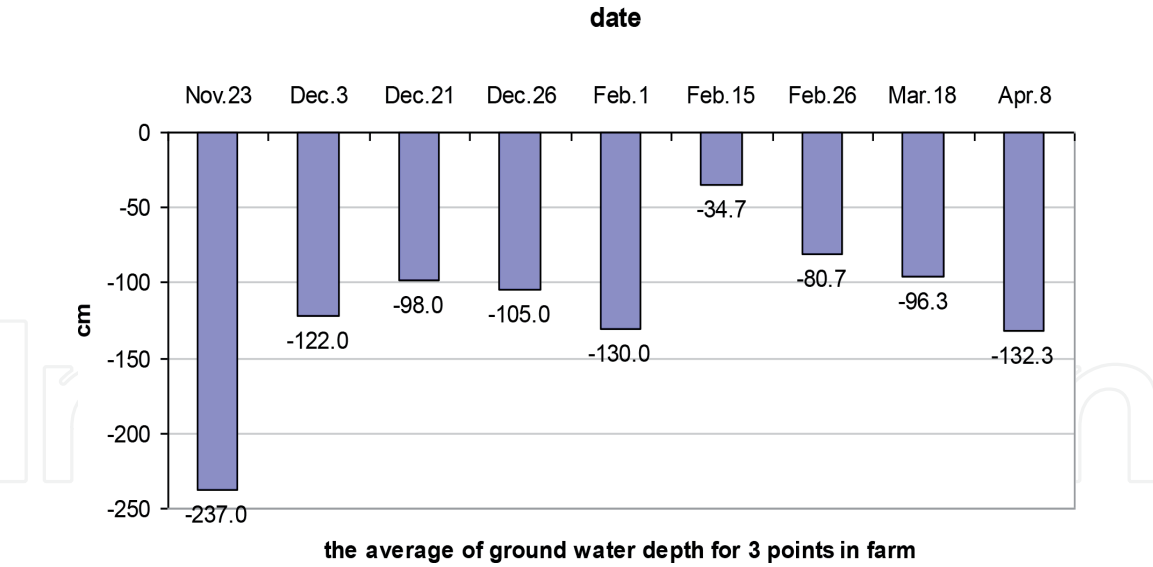


Figure 5.
Variation of the groundwater depth during growth season.

Irrigation method	Sowing method	Yield (kg/ha)	Applied water (m ³ /ha)	WP (kg/m ³)	WP (avg. of irrigation treatments) (kg/m ³)
Basin-border (farmer)	Centrifugal (350 kg seed/ha)	1953	3205	0.61	0.61
Optimum border	Centrifugal (250 kg seed/ha)	2590	1618	1.60	1.36
	Taka (180 kg/ha)	2434	1774	1.37	
	Barzegar-e Hamedani (180 kg/ha)	1901	1729	1.10	
Optimum basin	Centrifugal (250 kg seed/ha)	2730	2394	1.14	1.04
	Taka (180 kg seed/ha)	2521	2417	1.04	
	Barzegar-e Hamedani (180 kg seed/ha)	2198	2344	0.94	

Table 4.
Yield, water applied, and WP of the selected treatments [19].

- Basin irrigation method requires low levels of land leveling and uniform slope along the irrigation dimensions of plots for the T1, T2.
- Basin irrigation method is more adaptive to the farm micro relief caused by common cultivation practices.
- Basin irrigation method is more adaptive to the sociocultural conditions of the area.
- Basin irrigation method requires less labor (considering shortages in agricultural labor in the area).
- Considering shortfalls and/or lack of land leveling and low levels of on-farm improvement activities in the area at present situation, the basin irrigation method is the most adapted method to this condition.

Irrigation method	Sowing method	Seed consumption rate (kg/ha)	Number of shrub in m ²	Sprouting percentage (%)	Yield (kg/ha)
Basin-border (farmer)	Centrifugal (350 kg/ha)	350	247	34	1953
Optimum border	Centrifugal (250 kg/ha)	250	341	56	2308
	Taka (180 kg/ha)	180	262	60	
	Barzegar-e Hamedani (180 kg/ha)	180	286	65	
Optimum basin	Centrifugal (250 kg/ha)	250	387	63	2483
	Taka (180 kg/ha)	180	332	75	
	Barzegar-e Hamedani (180 kg/ha)	180	353	80	

Table 5.
Seed consumption, number of shrub, and sprouting percentage of the treatments [19].

- Basin irrigation method requires less control on flow considering high rate of variation in channel discharges and high rate of flow control requirements.
- Basin irrigation method has the advantage of providing pre-cultivation leaching opportunities, considering high levels of salinity and its variation in the wheat farms of the area.

Because of 50% reduction in seed consumption, the high rate of seed germination, and better flow of water, the use of seed drill machine (Taka type) or the three-row bed seeder (Barzegar-e Hamedani type) is recommended.

6. Summary and conclusions

Soil and water salinization are the most serious hindering factors on the improvement of WP, enhancement of agricultural production, and sustainability of natural resources in Iran and especially in L-KRB. The existence of vast areas with saline sodic conditions in various parts of the country especially in L-KRB reflects the fact that there are many factors affecting this phenomenon, and it should pay enough attention.

The soil texture in the area is mainly heavy textured and with low hydraulic conductivity. Natural drainage is very low, and the potentials for soil waterlogging followed by salinity hazard are high. Consequently agricultural production is suboptimal and crop WPs are low. Under these conditions installation of drainage networks may seem as a rapid solution for the removal of salinity and waterlogging problems, but simple and cost-effective water and crop managerial measures also have their own importance and merits.

The government’s huge investments in the expansion of irrigation networks in the L-KRB and future increase on applied water for agricultural activities will cause extreme changes in the surface and groundwater hydrology and in overall climatic parameters of the region. It is expected that without consideration of required arrangements, e.g., development of drainage networks and on-farm improvements activities, the problems of land salinity and waterlogging will be intensified in the future.

However, the trend of previous activities in this regard indicates that the rate of expansion of drainage networks is low. Therefore immediate actions are required for the mitigation of salinity and waterlogging hazards and for the improvement of crop WP in the L-KRB. At current condition this could be tackled by soil, water, and crop management activities such as assessment of current WP values, recognition of sources of inefficiencies on improvement of crop WPs, improvement of irrigation efficiencies, more use of salt-tolerant crop varieties, land leveling, changing of irrigation methods, changes in cropping patterns, and other on-farm improvement activities.

Waterlogging and soil salinity are the major threats to WP and sustainable agricultural production in the L-KRB. These problems are somehow because of physical characteristics of the region (heavy soil texture, high evaporation demand, low soil hydraulic gradient, etc.) but are mainly man-made problems. These challenging issues could be managed by proper measures and approaches including infrastructure activities (hardware) and to a greater extent by proper on-farm water management (software) measures.

Hardware measures may include completion of drainage networks and completion of farm canals (tertiary-level networks). The Ministry of Energy recently has emphasized this critical need in the government body in an attempt to obtain enough authority and resources to complete the irrigation and drainage networks in the country and in parallel to the Ministry of Agriculture.

Software measures include application of new approaches and tools such as the use of proper models relevant to the study of the issues at plant, farm, system, and basin levels, preparation and implementation of comprehensive plans at the basin level, conducting detailed or semi-detailed studies at the basin level and development of well-defined strategies and policies for water management in the Khuzestan province, and especially in the L-KRB, where two thirds of the country's water recourses flows at this province.

Recently the government has received the importance of water users and basin stakeholder participation in better management of water. Hence Water User Association (WUA) is developing irrigation networks, and the work is in process. However, the levels of their success to achieve their goals and their effects on WP improvement and performance of the irrigation networks vary much and need more research and evaluations in this regard.

Water scarcity and soil and water salinities in the arid regions such as L-KRB and all of the aforementioned issues suggest that the water in the agricultural sector should be consumed efficiently. The most important way to achieve this objective, especially in the L-KRB, is the improvement of agricultural WP index.

Research studies related to water table management, soil salinity control, irrigation water management, selection of suitable crop varieties, and improved agronomic practices will help to improve agricultural WP and farmer's livelihoods in the L-KRB. Waterlogging and resource salinity are major threats to WP enhancement and sustainable agricultural production in the L-KRB. Therefore sound and adaptive measures and solutions are required for this region. The KRB reflects in many aspects the problems and challenges associated with the water management and crop production in other arid to semiarid regions of the world. Therefore, it was intended by the CPWF to link the work studies in KRB with the Euphrates and Amu Darya river basins, which have been postponed to the next phase of the CGIAR Challenge Program on Water and Food (CPWF).

Overall, soil salinity and waterlogging, in addition to the other sources of inefficiencies in agricultural WP improvements, are the major limiting factors in the L-KRB. The causes to these hindering factors are somewhat because of physical characteristics of the region, but they are mainly man-made problems which could

be managed easily with low costs using proper measures and approaches including infrastructure activities (hardware) and to a greater extent by the water and crop management (software) measures.

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